A BULLETIN Dialogue

CRITIQUE

PAUL R. EHRLICH and JOHN P. HOLDREN

One of the most widely discussed books on the environmental dilemma is "The Closing Circle" by Barry Commoner, director of the Center for Biology and Natural Systems at Washington University, St. Louis. Shortly after its publication (Knopf, 1971), a critique of the book was issued by Paul R. Ehrlich, professor of biological sciences at Stanford University, and John P. Holdren, a physicist at the Environmental Quality Laboratory, California Institute of Technology. Professor Ehrlich, also author of a widely discussed book, "The Population Bomb" (Ballantine, 1968, 1971), and Dr. Holdren state in part that "in fixing the blame for environmental deterioration on faulty technology alone, Commoner's position is uncomplicated, socially comfortable and, hence, seductive. But there is little point in deluding the public on these matters; the truth is that we must grapple simultaneously with overpopulation, excessive affluence and faulty technology." The Bulletin *herewith presents the Ehrlich-Holdren critique and Commoner's response.*

ONE-DIMENSIONAL ECOLOGY

In his recent book, Barry Commoner presents his views of the origins of man's environmental predicament. Commoner has gained great prominence as a spokesman on the environment and has made extensive contributions to debates on issues ranging from the dangers of atomic fallout to the ecological consequences of man's intervention in the nitrogen cycle. His book contains much interesting material on the misuse of technology by industrialized societies, and it is written in a powerful and appealing style. Certainly he summarizes the dilemma beautifully when he states: "We come, then, to a fundamental paradox of man's life on the earth: that human civilization involves a series of cyclically interdependent processes, most of which have a built-in tendency to grow, except one — the natural, irreplaceable, absolutely essential resources represented by the earth's minerals and the ecosphere" (p. 122). Nor will many students of these problems deny that "the lesson of the environmental crisis is. . . . If we are to survive, ecological considerations must guide economic ones" (p. 292).

It is especially unfortunate, then, that so prominent and articulate an advocate for the environment should have written a book as inexplicably inconsistent and dangerously misleading as "The Closing Circle" proves to be. The book's principal defects are three. First, Commoner implicitly assumes that environmental deterioration consists only of pollution; this oversimplification leads him to discuss the environmental crisis as if it had begun in the 1940s. Second, in his zeal to place the blame for pollution on faulty technology alone, he resorts to biased selection of data, unconventional definitions, numerical sleight of hand and bad ecology; only thus can he explain away the contributions of population growth and increased affluence. Finally his misconceptions concerning certain aspects of demography lead him to draw erroneous conclusions about the "self-regulation" of human populations and viable strategies for population limitation. Because of the importance of these issues — and especially the possibility that uncritical acceptance of Commoner's assertions will lead to public complacency concerning both population and affluence in the United States — we have documented the errors in "The Closing Circle" at some length.

Commoner writes, "So long as human beings held their place in the terrestrial ecosystem — consuming food produced by the soil and oxygen released by plants, returning organic wastes to the soil and carbon dioxide to the plants — they could do no serious ecological harm" (p. 126). Yet only a few lines later he cites erosion, deforestation and destruction of fisheries as serious ecological problems, apparently unaware that he is contradicting himself. Far from starting in the 1940s, as Commoner implies, serious ecological harm has accompanied man's activities ever since the agricultural revolution some 10,000 years ago. In fact, it may date from even earlier; in the period of intensive hunting and food gathering preceding the advent of agriculture, men may have contributed to a dramatic reduction in the number of species of large mammals inhabiting the earth.[1]

Preindustrial Man

Whatever doubt there may be about the impact of human activities prior to farming, man's ecological transformation of the planet since that time has long been recognized. The earth has been badly scarred by the results of ecocatastrophes which predated by centuries the faulty technologies that have attracted Commoner's attention. Perhaps the most

(Continued on page 18)

on "The Closing Circle"

RESPONSE

BARRY COMMONER

For most readers, the review of "The Closing Circle" by Paul Ehrlich and John Holdren must raise a number of puzzling questions: Is my analysis of the origin of the environmental crisis as grossly wrong as their criticism would suggest? What accounts for the vehemence of what ordinarily might be regarded as an academic dispute over the relative importance of the several factors that influence environmental degradation? What is the relevance of this dispute to the outlook of the concerned citizen — who wants to know how to act to resolve the environmental crisis?

These comments are intended to help answer these questions. However, it is useful, first, to place the Ehrlich and Holdren criticism of my work, and this response to it, in a historical context. I refer here not to history in its large sweep, but to the much more modest arena in which the development of Paul Ehrlich's views, and my own, has occurred over the last few years.

As readers of "The Closing Circle" will know, my concern with the environmental crisis dates from the nuclear issues of the early 1950s. Since then I have made an effort to study the nature of the crisis and, in keeping with my views regarding the scientist's responsibility to society, to share what I have learned with the general public. Until the late 1960s I was largely concerned with identifying instances of environmental degradation, and with analyzing the interactions among them which comprise the environmental crisis. Beginning with the writing of "Science and Survival," which appeared in 1966, I became particularly concerned with the role played by modern technology in the development of the crisis, and soon recognized the importance of a thorough analysis of how all the relevant factors interact to generate environmental degradation. This was intensified when I discovered, during Earth Week 1970, that many of the views about the origins of the environmental crisis held by different Earth Week participants were contradictory and that some lacked scientific support. In particular, I was struck with the sharp contrast between the unalloyed conviction of Ehrlich, Hardin and others that the numerous assaults on the environment "can be traced easily to **too many people**" (Ehrlich, "The Population Bomb," emphasis in the original), and the absence of any firm, especially numerical, supporting data for this conclusion.

In the last few years, together with a number of colleagues, I have tried to assemble and analyze the available data regarding the roles of the several factors — population size, affluence and technology — that might influence the way in which the productive system of the United States affects the environment. In the course of that work it became increasingly evident that changes in productive technology since World War II have played an important role in the development of the environmental crisis. I began to write and speak about some of the examples that we had studied: how the use of more nitrogen fertilizer on less land (the displacement of land by fertilizer) has intensified the environmental impact of agriculture; how the conversion of the prewar car into today's high-powered monsters transformed a means of transportation into a smog generator; how the substitution of detergents for soap has worsened environmental quality. I found that the numerical size of such technological changes (for example a more than tenfold increase in the annual use of inorganic nitrogen fertilizer since 1945) was much larger than the concurrent increase in population (about 42 per cent), and on these grounds suggested that it might be wrong to conclude that the environmental crisis is exclusively, or even chiefly, the result of population growth.

At about this time I had several conversations about these issues with Ehrlich and his followers. In each of these conversations it was conceded by them, in contrast with Ehrlich's initial position (as expressed in "The Population Bomb"), that population growth is not **alone** responsible for environmental impact, and that technological factors are also significant. I was gratified by this indication that they were prepared to modify their position on the basis of the new data. However, in each of these conversations, I was urged to give up any discussion in public of the relative importance of the several factors that influence environmental impact. Ehrlich and his followers proposed that we should agree that all the factors are important, and not discuss their relative weight in public. It was argued that any public disagreement between Ehrlich and me on this issue would "split the environmental movement" and reduce the chances of effective

(Continued on page 42)

EHRLICH and HOLDREN: *Critique*

(Continued from page 16)

frequently cited is the conversion to desert, or desertification, of the lush Tigris and Euphrates Valleys, a process that started more than two millennia before Christ and was completed before Columbus sailed.[2] The destruction of that rich, ancient granary was a direct result of problems with irrigation, a difficult and ecologically risky operation even under the best of conditions. Often irrigation involves a constant battle against silting and salinization (the accumulation of salts in the soil as water evaporates — a problem not present when the water is "distilled" as it is in normal rainfall). The battle was lost in Mesopotamia, and silting and salinization are growing problems today as population growth forces mankind to bring more and more land under irrigation. These difficulties are not confined to underdeveloped countries, as abandonment of large salinized areas in California's rich Imperial Valley clearly shows.

Faulty Practices

Another major aspect of environmental deterioration long recognized by ecologists is the desertification of vast areas of the world through overgrazing and, in some cases, faulty agricultural practices.[3] The Sahara still marches southward at a rate of a mile or more a year, thanks in part to pastoral peoples exceeding the carrying capacity of the range and to inadequate soil husbandry by farmers. Much of Europe, Asia and Africa has been deforested, overgrazed, overfarmed and subject to heavy soil erosion as a result of the activities of preindustrial men. Even in North America the environment has been degraded through the activities of pastoral peoples. Carl Sauer wrote: "The present desolate shifting-sand area that lies between the Hopi villages and the Colorado River was such good pasture land late in the eighteenth century that Father Escalante, returning from his Canyon exploration, rested his travel-worn animals there to regain flesh. The effects of Navaho sheepherding in little more than a century and mainly in the last sixty years are well documented."[4]

The destruction of the environment by preindustrial man is not limited to relatively arid regions. In tropical forest areas a shifting "slash-and-burn" or "milpa" agriculture is widely practiced. The success of this system is utterly dependent on restricting the size of the clearing and allowing a sufficient recovery period before an area is cut over again and planted. The relationship between population growth and environmental deterioration here is direct; increased population density produces extreme stress in a milpa agricultural system. When fields are made too large or farmed too frequently the soil becomes depleted and is eroded away. Yields per unit area drop, forcing even more frequent and extensive clearing in a vicious cycle. Such a trend is suspected as being at least in part responsible for the collapse of the classic Maya civilization as population densities increased around growing urban centers.[5] A trip to many tropical forest areas in the world today will reveal to the most casual observer the extent of destruction wrought by milpa agriculture and woodcutting in areas where the population density has exceeded the carrying capacity of the land. Furthermore, those who predict the facile transplantation of "modern" agricultural technologies to wet lowland tropics are simply unschooled in tropical ecology. Indeed, the very ecological imperatives that Commoner so often invokes indicate that stabilizing population is a necessary prerequisite for avoiding an irreversible lowering of the human carrying capacity of the tropics.

Commoner's preoccupation with pollution almost to the exclusion of other forms of environmental deterioration leads him to give but scant attention to the general problem of ecosystem simplification. While clearly recognizing that the integrity of the ecosystems of the planet must be preserved, he does not seem aware that the reduction of the diversity of life and thus of the complexity of those systems may pose the most lethal threat of all. It is the complexity of the natural ecosystems that is primarily responsible for their stability.[6] Ecosystems are simplified by the extinction of populations and, more irreversibly, by the extinction of species. The very practice of agriculture on a large scale with its substitution of monocultures (stands of single crops) for natural communities rich in species is a potent force towards the destabilization of the global ecosystem. Because of its dependence on faulty technologies (such as the ritualized application of persistent biocides), modern agriculture has become an even more powerful **simplifying** force. Although this point supports Commoner's central argument, he largely neglects it.

Crop Monocultures

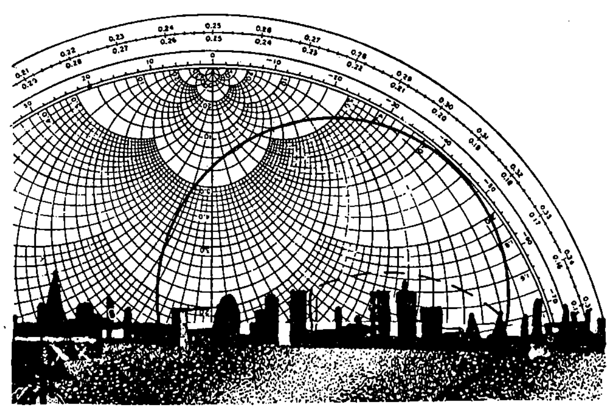
Of course, man paid the price of the creation of large unstable monocultures long before the first DDT molecule was manufactured. The Irish potato famine is the best known example of an ecocatastrophe entirely traceable to ecosystem simplification (and with no "faulty technology" component a la Commoner). When the potato monoculture in Ireland collapsed under the onslaught of the fungus **Phytophthora infestans** "in four years, 1,500,000 people had died, over one sixth of the population. A million had emigrated, and millions more were to emigrate over the coming decades until Ireland's population was cut in half. The Irish countryside was never the same again; the old customs and pleasures that had lightened the traditional poverty of the Irish peasant withered away."[7] Clearly, the Irish did serious harm to their environment even though they were living within the rules set down by Commoner (quoted at the beginning of this section).

Curiously, one of the most serious aspects of environmental deterioration is a "faulty technology" that has nothing to do with pollution. The continuance of high-yield agriculture is dependent on man's ability to select strains of plants that not only produce the desired yields but are resistant to the attacks of their enemies. That is, it depends on a genetic technology. There is no such thing as a strain that is permanently resistant to a pest or disease, because the plants and the organisms that attack them make up co-evolving systems. Unless the plant breeder has available to him the requisite genetic variability to use in producing new resistant strains when the biochemical or mechanical defenses of the old strains are breached (as they inevitably are), the whole basis of modern agriculture could be destroyed.

It is ironic that the very success of programs to develop extremely productive crops to feed mankind's burgeoning numbers is now threatening the diversity in the gene pools of some of the most nutritionally important plants. "Miracle" crops are now rapidly replacing large numbers of traditional strains as the high yield varieties are eagerly adopted by farmers. The genetic treasurehouse is being rapidly depleted, and not nearly enough is being done to arrest the process. To the extent that success in plant breeding leads to loss of variability, the genetic technology can be described as "faulty." This leads to the ultimate in ecosystem simplification; not only does greater uniformity increase the vulnerability of crop monocultures to widespread disaster, it also reduces the chances of recovering from disaster.

The foregoing are by no means all of the serious forms of environmental disruption having their origins long before World War II. Another is the injection of dust and smoke into the atmosphere in connection with agricultural burning and the removal of protective plant cover by cultivation or overgrazing. The latter aspects of the problem are especially severe when food producing activities are extended to marginal land, as population pressure makes inevitable. Agricultural hazes are already an important climatic perturbation in parts of Africa and Asia, and man's contribution to the global atmospheric dust burden is rising steadily.[8] (J. Murray Mitchell points out that man's dust contribution is presently small compared to the 120-year average figure for dust of volcanic origin, but is already large compared to the natural "baseline" figure between major eruptions.) Measurable effects on global climate are thought to be possible within 30 years if this long-established trend continues. A major reason for concern here is that global agriculture is dependent on crops highly adapted to present climatic conditions. Because global climate is determined by a balance of many opposing factors, it is possible that a destabilizing input by man at some leverage point in this rather poorly understood system could cause a sudden change rather than a gradual one — with disastrous consequences for food productivity. Carbon dioxide from the combustion of fossil fuels and heat dissipated when man uses energy of any kind are also potential influences on climate on a large scale.

Another serious form of environmental impact with a long history is the disruption of salt marshes and estuaries that serve as "nurseries" for much of the life in the sea. Salt marshes are continually being lost to landfill operations, and the salinity and temperature of estuaries are affected by irrigation projects upstream. Most of the productivity of the sea occurs on the continental shelves or in areas of upwelling relatively near the shore.[9] The long standing threats to the estuaries and salt marshes sheltering many of the creatures at the base of these food chains, combined with the more recent hazards of industrial and agricultural pollutants and overfishing, jeopardize one of mankind's principal sources of protein.



Obviously there is no basis whatever on which to conclude, as Commoner does, that man was only an innocuous environmental force prior to 1940. The sorts of human activity being carried on even then were steadily and probably irreversibly eroding the capacity of the planet to support human life. That the world now supports a considerably larger population than it did in 1940 is hardly proof that the environmental impact of this population, or even the 1940 population, could long be sustained. As zoologists know well, animal populations often considerably overshoot the carrying capacity of their environment — a phenomenon invariably followed by a population crash.

Having assumed that man's adverse impact on his environment was negligible before 1940, Commoner then alleges that "pollution levels" increased by an explosive 200 to 2,000 per cent between 1946 and 1968, and that neither population growth nor rising affluence had much to do with it. His argumentation purporting to prove this hypothesis is a house of cards supported by the flimsiest of props: the misleading use of percentages, data and definitions tailored to fit the foregone conclusion, and stubborn refusal to confront the mechanisms by which population growth can cause disproportionate increases in environmental impact.

Consider first the matter of percentages. Commoner admits that the factors contributing to environmental impact are multiplicative rather than additive; he offers (in a footnote to pp. 211-12) the equation,

pollution = (population) × (production/capita) × (pollution emission/production).

Here the second factor on the right, production per capita, is in some sense a measure of affluence, and the last factor, pollution per unit of production, is a measure of the relative environmental impact of the technology that provides the affluence. For compactness, let us rewrite this equation

$$I = P \times A \times T \qquad (1)$$

or, in terms of initial values and the subsequent changes over a specified period of time

$$I + \Delta I = (P + \Delta P) \times (A + \Delta A) \times (T + \Delta T). \qquad (2)$$

Here I is for impact (a better word than "pollution" for reasons already explained), P is for population, A for affluence, and T for technology. Let us also assume for a moment that the variables P, A and T are independent; i.e., that a change in P does not cause changes in A or T, and vice versa. We shall find later that this is not true, but it is the simplest assumption and the one most favorable to Commoner's hypothesis.

It is immediately obvious from equation (2), of course, that the actual magnitude of the environmental deterioration engendered by an adverse change in technology depends strongly both on the initial levels of population and affluence and on such changes in these levels as may occur simultaneously with the change in technology. A corollary is that population and affluence would be important factors in environmental degradation even if they were not growing. A change for the worse in the technology of production is more serious environmentally if it occurs in a populous, affluent society than if it occurs in small, poor ones.

In reality, population and affluence in the United States have both grown substantially in the postwar period on which Commoner concentrates. To see how his use of percentages has obscured the importance of the growth of these factors, we rewrite the impact equation to express all quantities as multiples of their initial values:

$$1 + \frac{\Delta I}{I} = (1 + \frac{\Delta P}{P}) \times \qquad (3)$$
$$(1 + \frac{\Delta A}{A}) \times (1 + \frac{\Delta T}{T}).$$

Then $(\Delta I/I)$ times 100 is the percentage increase in environmental impact, $(\Delta P/P)$ times 100 is the percentage change in population, and so on. (Note that an increase of 100 per cent means a doubling of the initial quantity, an increase of 200 per cent a tripling, etc.) Now let us put some typical numbers into the equation and see what happens. Population increased 42 per cent between 1946 and 1968, so $\Delta P/P = .42$ and the population factor in equation (3) is 1.42.[10] Let us assume that the affluence factor in this hypothetical example — say, per capita consumption of a commodity whose production entails significant environmental impact — has increased at the same rate as GNP per capita, or 59 per cent between 1946 and 1968, corrected for inflation. Then $\Delta A/A = .59$, and the affluence factor in equation (3) becomes 1.59. Suppose, finally, that a change in technology has led to a 33 per cent increase in environmental impact per unit of production, i.e., $\Delta T/T = .33$, so the technology factor in equation (3) is 1.33. Then the equation gives

$$1 + \frac{\Delta I}{I} = 1.42 \times 1.59 \times 1.33 = 3.00,$$

or a 200 per cent increase in environmental impact. In this hypothetical example, none of the causative factors is unimportant, and no single one accounts for a large fraction of the increase. It is the **multiplicative effect** of the three moderate increases occurring simultaneously that yields a dramatic increase in the total.

Yet, of the four relevant figures, Commoner invariably presents only two: the total increase in some index of impact and the increase in population. If he were reporting the example just given, he would cite 200 per cent and 42 per cent as the relevant numbers, leading the casual reader to believe that population was a minor factor. Nor is the deception less when the role of factors other than population is larger. Consider a case where total impact of some kind can be shown to have increased 400 per cent while population increased 42 per cent. Are the other factors then ten times as important as population, as Commoner repeatedly asserts? Hardly. The simple algebra of equation (3) shows that an actual increase of 400 per cent would have been only 252 per cent if population had stayed constant. That is, the product of the technology and affluence factors is 3.52:

$$\Delta I/I = 4.00$$
$$1 + \Delta I/I = 5.00 = 1.42 \times 3.52.$$

If, in this hypothetical example, we again assumed that the affluence factor increased in proportion to GNP per capita, we would find that the combination of the population and affluence factors was of equal importance to the technology factor:

$$1 + \Delta I/I = 5.00 = \underbrace{\overset{P}{1.42} \times \overset{A}{1.59}}_{2.26} \times \overset{T}{2.22}.$$

These somewhat tedious arguments have been based on nothing but elementary algebra and arithmetic; we have as yet invoked no cause-and-effect relationships between population size and the nature of the technology needed to support it, nor questioned the validity of the indices Commoner chooses to describe "pollution." Examination of the basic mathematics alone, irrespective of the definitions and analysis behind the numbers Commoner presents, shows that the relationships are not what he claims.

Next to the misleading use of percentages, one of the cornerstones of Commoner's argument is his dismissal of the role of affluence. Like most students of these problems, he is not happy with the strict use of GNP per capita as a measure of affluence. In one sense GNP includes too much (e.g., the costs of war and crime), in another sense too little (e.g., it omits part of the "cost" of our decaying cities, a cost paid not in dollars but in misery by those who must live and work in them). Unfortunately, Commoner's indicators of affluence are, if anything, more superficial than GNP.

First, he confines his attention almost entirely to production of goods, thereby omitting services (many of which surely are part of affluence and almost all of which generate environmental impact through the use of energy). He does mention a dramatic increase in passenger miles of automobile travel per person and on page 176 ascribes it to affluence. With this exception, Commoner apparently would have us believe that affluence in the United States has not risen appreciably since 1946. He supports this view by dividing affluence into "necessities" (food, shelter, clothing) and "amenities" (everything else). He notes that per capita availability of calories fell 4 per cent between 1946 and 1968; grams of protein per capita fell by a smaller amount; pounds of fiber per person, representing clothing, rose 9 per cent (figures for 1950-68 only); and housing units per capita rose 10 per cent. (For some reason, Commoner used the 1966 rather than the 1968 housing figure, leading him to compute a slightly smaller increase.)

Having thus "proven" that affluence as measured by necessities has not changed much in the postwar period, Commoner deals with amenities mainly by ignoring them. He concedes that "if affluence is measured in terms of certain household amenities, such as television sets, radios, and electric can-openers and corn-poppers, and in leisure items such as snowmobiles and boats, then there have been certain striking increases," but he adds, "again, these items are simply too small a part of the nation's over-all production to account for the observed increase in pollution level" (p. 139). This is precisely the reductionist pitfall that Commoner solemnly deplores several times in his book, but that he cannot himself avoid. No single factor can explain all of the increase of all of the indicators of environmental impact, but the rising per capita availability of amenities plays an important (and multiplicative) role in explaining part of the increase of some of them.

Commoner's general conclusions later in the book are clearly based on a redefinition of affluence that excludes amenities altogether (see, e.g., p. 176). Yet, curiously, he does not mind fattening his list of dramatically increasing kinds of production (p. 143) with items that are obviously affluence-related amenities (air conditioner compressor units, up 2,850 per cent between 1946 and 1968; electric housewares, up 1,040 per cent). Apparently, Commoner thinks he can offer affluence of some kinds as a symptom without admitting affluence of any kind as a cause.

TABLE 1
AMENITIES AND AFFLUENCE IN THE POSTWAR UNITED STATES

Item	Initial value	Final value	Per cent Increase
1. Automobiles in use p.c.[a]	.208 (1940)	.416 (1968)	100%
2. Telephones in use p.c.	.165 (1940)	.540 (1968)	227
3. Automatic heating units in use p.c.	.042 (1946)	.133 (1960)	217
4. Ranges in use p.c.	.242 (1951)	.305 (1960)	26
5. Water heaters in use p.c.	.122 (1950)	.177 (1960)	45
6. Percentage of households with air conditioners	0.2% (1948)	13.6% (1960)	6,700
7. Refrigerators in use p.c.	.145 (1946)	.277 (1960)	91
8. Clothes dryers p.c.	.0013 (1949)	.053 (1960)	4,000

Source: Items 1 and 2, "Statistical Abstract of the United States, 1970"; all other items, "Resources in America's Future," 1963.

[a] Abbreviation "p.c." stands for "per capita."

He cannot have it both ways.

Even if one accepts Commoner's narrow view of affluence, however, his conclusions do not follow. The statistics he has used for clothing and housing per capita are utterly inappropriate to an assessment of changing affluence. Specifically, his figures for housing units per capita are taken from the "Statistical Abstract of the United States," which uses the following definition: "A 'household' comprises all persons who occupy a 'housing unit,' that is, a house, an apartment or other group of rooms, or a room that constitutes 'separate living quarters.'" Obviously, the most important aspects of affluence in housing — namely, the type of housing people have and its quality — are not reflected in the statistic quoted by Commoner at all. By his measure, a country whose population all resided in one-room flats would be judged as affluent as one where each family lived in an 8-room ranch house — as long as the number of people per "household" were the same in each country. In the postwar United States, growing affluence manifested itself as a steady increase in expenditures per capita on housing (from $149 per person in 1946 to $235 in 1960, corrected for inflation) and in the fraction of the population dwelling in houses as opposed to apartments (most new dwelling units built since the war have been single-family houses, although this trend seems to have ended, or been temporarily interrupted, in the early 1960s).[11] This affluence in housing, in turn, was translated into environmental impact in the form of increased resource consumption (wood, metals, plastics), the overrunning of fertile farmlands by sprawling suburbs, and the increasing use of automobiles attendant upon spreading out the population.

A somewhat different set of defects underlies Commoner's discussion of clothing per capita. He has used the statistics for pounds of fiber produced per capita as a measure of supplies of clothing, in the face of three good reasons not to do so: First, a great deal of fiber is used for nonclothing purposes such as carpeting, furniture and tire cord. Second, statistics for the production of clothing itself are readily at hand in the same source. Third, the United States is increasingly a net importer of raw textiles and clothing (admitted by Commoner in a footnote), so consumption considerably exceeds production. According to the actual figures, just the production of apparel per capita increased 23.5 per cent between 1950 and 1968, versus the 9 per cent claimed by Commoner. Imports of clothing per capita jumped 2.5-fold between 1960 and 1968 alone.

Evidently, Commoner has appreciably understated the growth of "affluence" in postwar America, even within the confines of his unconventional definition of the term. But if one includes in the accounting the amenities that most Americans surely regard as part of their affluence, the magnitude of Commoner's underestimate grows even larger. In Table 1 we present the figures for a few of these items. The reader may now judge for himself whether Commoner is misleading his public when he writes, "The economy has grown enough to give the United States population about the same amount of basic goods, per capita, as it did in 1946" (p. 177).

The Postwar Growth Items

Commoner's selection of indicators of environmental impact is no more objective than his treatment of affluence. He has simply taken from the industrial statistics for the United States over the past 25 years a "representative" list of items, and ranked them according to percentage increase in production during this period. Table 2 gives the first 18 items on Commoner's list on page 143 of "The Closing Circle." Several questions must be asked concerning this tabulation: Are the top items — those that grew more than 500 per cent — sufficiently representative of the sources of environmental impact to justify Commoner's repeated assertions that "pollution" in the postwar United States grew 10 times as much as population or, indeed, 10 times as much as GNP? What important indicators of environmental impact are missing? Of those on the list, what part of the increases must be attributed to affluence, what part of population, and what part to those changes in technology which were a direct result of rising population and affluence?

TABLE 2
COMMONER'S SELECTION OF POSTWAR "GROWTH" ITEMS[a]

Item	Percentage Increase Quoted
1. Nonreturnable soda bottles	53,000%
2. Synthetic fibers	5,980
3. Mercury used in chlorine production	3,930
4. Mercury used in mildew-resistant paint	3,120
5. Air conditioner compressor units	2,850
6. Plastics	1,960
7. Fertilizer nitrogen	1,050
8. Electric housewares	1,040
9. Synthetic organic chemicals	950
10. Aluminum	680
11. Chlorine gas	600
12. Electric power	530
13. Pesticides	390
14. Wood pulp	313
15. Truck freight	222
16. Consumer electronics	217
17. Motor fuel consumption	190
18. Cement	150

[a] "The Closing Circle," p. 143.

The first item on the list, nonreturnable soda bottles, is a good example of the misleading use of numbers. Obviously, a dramatic percentage increase in production of an item does not necessarily mean that present production is enormous in absolute terms; it may only mean that initial production was very small. Nor does a large increase — or even a large absolute level of production — automatically mean that an item is an important index of environmental impact. Nonreturnable soda bottles illustrate both points: while they almost certainly represent a waste of energy, they are neither a major fraction of U.S. glass production nor an ecologically significant pollutant.

The second thing one notices is that several of the items on Commoner's list are closely related to each other; he tabulates separately synthetic organic chemicals, pesticides (the most dangerous of which are a subset of the synthetic organics), chlorine (the principal use of which is the manufacture of synthetic organics), and the mercury used in the production of the chlorine. There is no doubt that these items support, in this instance, Commoner's notion of "the technological flaw" — i.e., that considerable environmental impact has resulted from changes for the worse in technology. The interesting point here is that Commoner has padded his list of dramatic increases with four different aspects of essentially the same flaw. Since few sources of pollution have really increased enough to justify Commoner's general conclusions, he apparently intends to get maximum mileage out of those that have.

Mercury Consumption

The figures for mercury deserve closer examination. Commoner has cited two particular uses of mercury that have increased dramatically, without noting that total consumption of mercury has changed relatively little. U.S. mercury consumption between 1930 and 1970 was 63,000 metric tons, or an average of 1,575 tons per year; the 1968 figure was 1,827 tons, only 16 per cent above the 40-year average.[12] Furthermore, there is good reason to believe that other sources of environmental mercury may be more important than industrial production of the metal. Mercury occurs throughout the earth's crust and is released continuously by outgassing. The global rate for this process, which is accelerated when man disturbs the earth's surface by mining, agriculture and urbanization, has recently been estimated as at least 25,000 metric tons per year. For comparison, world industrial production of mercury in 1968 was 8,800 metric tons, and degassing during the roasting of sulfide ores contributes perhaps an additional 2,000 metric tons of mercury globally per year. The input from burning fossil fuels may be as much as 20,000 metric tons annually. (Some authors have obtained a much smaller figure by using an older value for the mercury content of coal and assuming that 90 per cent of the mercury in the fuel is trapped in bottom ash and does not reach the environment. However, no mercury is reclaimed in connection with the use of fossil fuels, so it seems prudent to assume that all of it reaches the environment by one pathway or another, e.g., leaching from ash piles by rainwater.) It is apparent, then, that the numbers presented by Commoner have little relevance as indicators of the overall level of mercury pollution or its rate of increase since World War II. The major sources have been increasing far more slowly than those he cites, and are rather well explained, it seems, in terms of increases in population and affluence (as measured by total fossil fuel consumption and, possibly, disruption of the land). It is not our intention, of course, to disparage the importance of chlor-alkali plants and paint manufacturing as local sources of mercury — such sources should be controlled wherever possible. However, the evidence simply does not support the use of mercury as an example of pollution increasing many times faster than population or affluence.

What of the other items on Commoner's list? Air-conditioner compressors and electric housewares represent affluence by any definition but Commoner's, so these figures do not support his case. Also, with air conditioners, as with nonrefillable bottles, the percentage increase is so dramatic largely because the initial production was so small. Synthetic fibers, plastics and aluminum also rose from small initial values, and they are now produced in quantities that are significant in absolute terms. (By "synthetic" fibers, Commoner means only the noncellulosic manmade fibers such as nylon. Rayon and acetate, by contrast, are manmade as fibers but they are cellulose based.) Since these commodities are at least plausible indices of environmental impact — the fibers and plastics because they are not easily degraded in nature, the aluminum as a major consumer of electric power — we should examine the relevant data more closely. First, all three commodities grew by replacing or supplementing more conventional ones: plastics for wood and steel; aluminum for wood, steel and copper; synthetic fibers for cotton and wool. To this extent, the evidence supports the proposition (with which few would disagree) that technology has often dramatically changed the way man meets established wants and needs, sometimes with serious side-effects. What Commoner has failed to prove, however, is that such changes are not stimulated by the demands of a growing population or by perceived advantages of the new technology over the old, aside from cheapness.

Consider the fibers. The relevant data are presented in Table 3, in a form somewhat more enlightening than Commoner's percentages. It is apparent that providing today's total demand for fiber without the man-made ones would amount to nearly a doubling of the 1945 consumption of both cotton and wool. What would have been the cost of doing it this way in terms of pounds of pesticides and fertilizer applied to cotton fields, the fossil fuels burned in cultivation, planting, harvesting and ginning, the side effects of irrigation projects, the extra land devoted to monoculture, the overgrazing and subsequent erosion of grassland? Has the environmental cost of meeting the increased demand with synthetics been greater? This is the real issue: not whether the environmental impact of noncellulosic fibers in 1968 is 70 times their impact in 1945, but whether the impact of alternate means to provide the 1968 number of people with the 1968 level of affluence would have been any less. Commoner admits he does not know (see his footnote to page 160), but the uncertainty is forgotten when he draws his conclusions.

A Popular Misconception

Consider aluminum. It is a popular misconception that most aluminum goes into beer cans. Actually, containers of all kinds account for 10 per cent of aluminum consumption, while the building and construction industry uses 23 per cent, the transportation industry uses 20 per cent, and the electrical industry uses 13 per cent.[13] In the building industry, aluminum is replacing wood for siding, window frames, awnings and other applications, not simply because it is cheap, but because it is durable and maintenance free. Many people believe low maintenance is part of affluence. Aluminum is costly in energy, but meeting the demands of a growing population for better housing with wood alone would put an additional demand on forests already being too intensely exploited. (Need we remind Dr. Commoner that "there is no such thing as a free lunch?") In transportation, aluminum replaces iron in automobile engines and steel in aircraft. Aluminum is about 5 times as costly in energy as steel to produce, but lighter cars and aircraft burn less fuel. In the electrical industry, abundant aluminum is replacing scarce copper as a conductor of electricity. This is not coincidence or technological frivolity: it is the classic example of the sort of substitution that is inevitable when a growing, affluent population presses on a finite resource base.

Plastics have replaced wood in some applications, such as furniture, and steel in others. Often they are more durable than wood and need less maintenance (affluence again), and their production requires only about a fourth as much energy per ton as steel.[14] Their persistence as a pollutant is a liability. Again, however, Commoner can offer no comparison of the environmental impact of the observed increase in production of plastics since 1946 with the impact of producing from other materials the same goods for the same number of people. It is clear, then, that population growth and rising affluence can stimulate qualitative changes in the technologies of production, and that mere comparison of percentage increases in the new technologies with those of population and GNP does not clarify the relationship.

Another mechanism by which population and affluence generate environmental impact far out of proportion to their own percentage increases is diminishing returns. This term refers to a situation in which the additional output resulting from each

TABLE 3
CONSUMPTION OF FIBERS IN U.S. MILLS, 1945-1968
(MILLIONS OF POUNDS)

Year	Cotton	Wool	Man-made: Rayon & Acetate	Man-made: Non-cellulosic
1945	4,516	645	795	50
1955	4,382	414	1,455	448
1968	4,147	330	1,711	3,585

additional unit of input is becoming less and less. Here "output" refers to a desired good such as food or metal, and "input" refers to what we must supply — say, fertilizer, energy, raw ore or labor — to obtain the output. If diminishing returns prevail, the per capita consumption of inputs needed to provide the fixed per capita level of outputs will increase. Since environmental impact is generated by the inputs as well as by the outputs, per capita impact will also increase.

Consider the problem of providing nonrenewable resources such as minerals and fossil fuels to a growing population, even at fixed levels of per capita consumption. More people mean more demand, and thus more rapid depletion of resources. As the richest supplies of these resources and those nearest to centers of use are consumed, it becomes necessary to use lower-grade ores, drill deeper and extend supply networks. All these activities increase the **per capita** use of energy, and hence the **per capita** impact on the environment. In the case of partly renewable resources such as water (which is effectively nonrenewable when groundwater supplies are mined at rates far exceeding natural recharge), per capita costs and environmental impact escalate enormously when the human population demands more than is locally available. Here the loss of free-flowing rivers and other economic, aesthetic and ecological costs of massive water-movement projects represent increased per capita diseconomies directly stimulated by population growth. These effects would, of course, also eventually overtake a stable population that demands more than the environment can supply on a perpetual basis; growth simply speeds the process and allows less time to deal with the problems created.

Commoner implicitly acknowledges the possibility of diminishing returns (p. 133), but declares that this phenomenon cannot explain the increases in environmental impact that have occurred. As we have already noted, no **single** factor can explain **all** of the increases, but Commoner's rejection of diminishing returns as a significant contributing factor is based on his evident misunderstanding of the term's economic meaning. Specifically, he restricts attention to productivity, or "value produced per unit of labor used in the process" (p. 134); since this quantity has **increased** since 1956, he argues, diminishing returns have not been important. Actually, the only justifiable conclusion from this datum is that diminishing returns **with respect to labor** have not been important. The reason, of course, is that the rampant technology that Commoner deplores has reduced the importance of labor in comparison with other inputs, such as energy, machinery and raw ore. It is with respect to these nonlabor inputs that diminishing returns have occurred. (The phenomenon has become sufficiently dramatic to show up in the very coarse index, energy consumption per dollar of GNP, corrected for inflation, which has been increasing since 1965.) And, of course, it is the nonlabor inputs which generate the sorts of environmental impact with which Commoner concerns himself.

Perhaps the best known example of diminishing returns is the use of nitrogen fertilizer in food production — a situation which Commoner himself describes with admirable clarity on page 85. The essence of the matter is that feeding an extra increment of population from a fixed or dwindling amount of good quality land requires inputs of fertilizer far out of proportion to the increase in yield. That the amount of agricultural land is dwindling is of course partly a consequence of other demands being made on the land by a growing and affluent population — freeways, subdivisions, airports, reservoirs, and so on. It is ironic, then, that one of the centerpieces of Commoner's argument — the dramatic postwar increase in the production of nitrogen fertilizer — is so revealing as an illustration of what he has overlooked: namely, that there are striking cause-and-effect connections between the size of a population and the nature of the technology needed to support it.

There are far more aspects of the causal relation among population size, affluence and per capita impact on the environment than we have space to describe here.[15] However, those we have mentioned should suffice to show that such connections are important factors in man's rising environmental impact, and that they cannot be defined or wished away.

Having considered the items which are on Commoner's list, we turn to an examination of some that are missing. Probably the most accurate indices of a society's impact on its environment are the production and consumption (production plus imports minus exports) of energy. Commoner discusses electricity, which has grown much more rapidly than energy consumption as a whole (partly by replacing direct uses of fossil fuels in home heating, cooking and industry). He also treats motor fuel consumption, one of the few increases he is willing to attribute partly to affluence. He says almost nothing about energy production or consumption as a whole, however; perhaps because it would damage his case to do so.

Of course, no single statistic now kept by society is designed to measure environmental impact, but the figures on energy at least tend to average out substitutions. Thus they are not subject to the limitations of measures such as aluminum or plastic production, as already discussed. Using energy production or consumption also avoids the pitfall of redundancy into which Commoner has fallen in the case of synthetic organics. Most important, all of man's environmental impacts involve his production and consumption of energy, and virtually all the energy he commands, except that which drives his own body, is accounted for in the statistics. (At least in the United States and other industrial nations where relatively accurate statistics are recorded.)

Our judgment that the energy figures are appropriate indices of environmental impact is confirmed by the prestigious MIT-sponsored Study of Critical Environmental Problems ("Man's Impact on the Global Environment"). Of the five global environmental problems given most attention by the study — oil in the oceans, carbon dioxide and particulate matter in the atmosphere, heavy metals, euthophication and pesticides — the first three are directly related to energy production (the relationship of the heavy metal, mercury, to energy production is discussed above).

U.S. energy production in 1969 was 2.4 times that in 1940. Population increased 53 per cent in this period, and energy production per capita increased 57 per cent ($1.53 \times 1.57 = 2.40$). Thus, in purely arithmetic terms, population growth and increased production per capita accounted for almost identical shares of the total increase. U.S. energy consumption increased 2.75-fold between 1940 and 1969, corresponding to an 80 per cent increase in consumption per capita ($1.53 \times 1.80 = 2.75$). Again, even ignoring the interdependence of the factors, the contribution of population growth is hardly unimportant.

Another spectacular omission from Commoner's "representative" list of indices of postwar production is the number of automobiles manufactured. (Discussions of some of the individual impacts of the automobile are scattered through "The Closing Circle," but identifying automobile production as an informative index of resource wastage and environmental degradation does not suit Commoner's purpose.) Between 1940 and 1968 the production of automobiles increased 2.37-fold while population grew 1.52-fold. Per capita production rose 1.56-fold ($1.52 \times 1.56 = 2.37$). Population growth thus "caused" about half of the increase while **affluence** (as reflected in the increased number of cars per person) "caused" the rest.

Commuting Syndrome

Commoner argues that "in a sense, the increase in automobile travel during the last 25 years is also a counterecological consequence of a technological change — in the distribution of residences and places of work" (p. 170). We will leave for the reader to decide whether the commuting syndrome is best described as a "technological mistake" or as a complex situation resulting partly from increases in population concentration, which are highly correlated with population growth, and from increased affluence. After all, increased affluence is what permits flight to the suburbs.

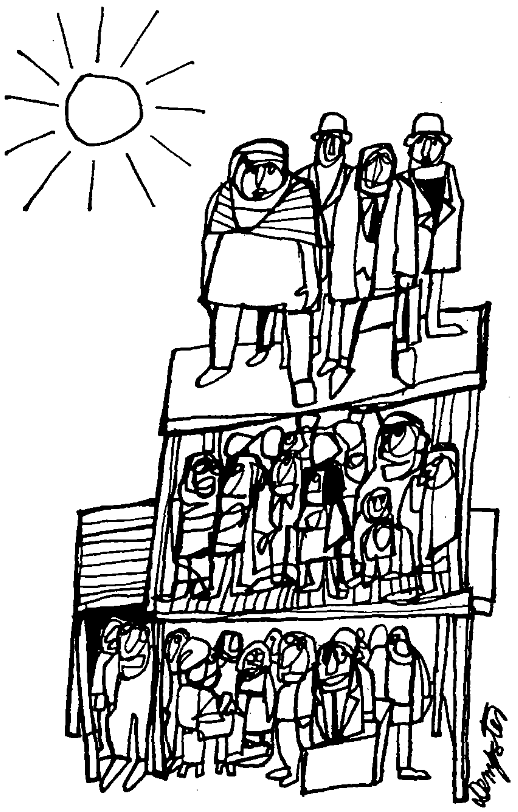
Commoner correctly points out that one of the major impacts from the automobile, the production of nitrogen oxides, has increased since 1946 because of a technological mistake. That mistake was raising compression ratios, which increased average emissions of oxides of nitrogen in the exhaust from 500 parts per million to 1,200 parts per million (a 2.4-fold increase) between 1946 and 1968. Commoner notes further that total nitrogen oxide emissions increased 7-fold in the same period. Application of the simple mathematics of impact to these figures shows that the combination of population growth and affluence accounts for a larger portion of the nitrogen oxide problem than does the technological "error":

$$P \times A = 2.9;\ T = 2.4;$$
$$I = 2.9 \times 2.4 = 7.0.$$

Commoner also neglects to point out an obvious trade-off. The error of raising compression ratios had an effect beyond increasing nitrogen oxides: it reduced the emissions of hydrocarbons, dangerous pollutants implicated in causing cancer.

Here, as in many other places in "The Closing Circle," Commoner seems to have forgotten what he calls The Fourth Law of Ecology: there is no such thing as a free lunch. Many of the technological flaws we all deplore will not be easily corrected, for the alternatives, too, are full of defects. Switching from today's automobiles to electric vehicles would simply shift part of the environmental burden of personal transportation from the air over highways to the air over electric power stations. Changing from fossil fuel to nuclear fission electricity generation replaces the problems of strip mining, oil spills and air pollution with an accident hazard of indeterminate magnitude and a burden of radioactive wastes to be stored virtually in perpetuity. Regulating trash burning to minimize air pollution maximizes the burden of solid wastes. The sad fact is that most attempts to eliminate man's impact on his environment only shift and redistribute it. Obviously, some technologies are better than others, and approaches that promise to minimize environmental impact should be vigorously pursued. It is well to admit, however, that barring a repeal of the laws of thermodynamics, no technology can reduce the impact of population and affluence to zero.

On page 237 Commoner points out that the demographic transition is a tendency for population growth to "level off" as a natural social response to prosperity. On page 242 we are told that population growth in the developing nations should be "brought into balance by the same means that have already succeeded elsewhere — improvement of living conditions, urgent efforts to reduce infant mortality, social security measures and the resultant effects on de-



sired family size, together with personal, voluntary contraceptive practice." He then states, "It is this view with which I wish to associate myself."

If it only were that simple. A casual look at the statistics would reveal the most fundamental flaw in Commoner's thesis: even after the completion of the demographic transition the developed countries still have high growth rates.[16] Contrary to Commoner's beliefs, the reduction in birth rates associated with the demographic transition was not adequate to compensate for the even more dramatic fall in death rates that preceded it.

Technically, the demographic transition is the change from a high death rate-high birth rate regime to a low death rate-low birth rate regime — such as has occurred historically in the developed countries, where the transition was essentially over by 1940.[17] Indeed, most of these countries have had low birth and death rates since the 1920s, yet their birth rates are still well above their death rates. For instance, in 1971 Northern Europe had a birth rate of 16 per thousand and a death rate of 11; the birth rate of North America was 18 and the death rate was 9. (Incidentally, that is below the 10 to 12 per thousand Commoner describes as the "minimal death rate" on page 238. In 1971, more than 50 nations had death rates below the Commoner "minimum," and some, such as Singapore and Taiwan, were as low as 5 per thousand.)

To varying degrees, this situation is a result of the age composition of the population as well as of excess fertility. Nonetheless, an examination of net reproductive rates from the 1920s to today in the industrialized nations gives little reason to assume that there is an automatic process of population regulation leading to stationary populations. (Net reproductive rate, NRR, is a measure of whether a population will be growing, stationary or shrinking, when and if the age composition stabilizes and if age specific vital rates remain constant.) Indeed, it seems at least as likely, assuming death rates do not rise, that industrial nations could fluctuate over the long term at growth rates of about 0.5 to 1.0 per cent annually, thus doubling their populations every century or so.

Let's examine, however, what would happen if demographic transitions started immediately in underdeveloped countries (in most cases there is little or no sign of such an event) and followed a pattern similar to that experienced by the developed countries (DCs) in the past. It would be perhaps 80 years before one could expect growth rates in underdeveloped countries (UDCs) to be in the relatively low range now found in developed countries.[18] To see even more clearly that such a demographic transition in the UDCs cannot solve the problem in time, it is only necessary to examine a much more optimistic projection. Demographer Nathan Keyfitz has recently calculated the possible results of a population control miracle (which we might call a "super demographic transition").[19] He calculated, in essence, what would happen if family size dropped precipitously in UDCs so that reproduction reached the replacement level around the year 2000. If that should occur, the size of the population of a typical UDC would be 2.5 times its present size when it eventually stopped growing. (Achievement of replacement reproduction, that is, NRR = 1, does not lead to a stationary population until many decades later if the age distribution is not a stable one. Even in the United States there are so many more young people who will soon be breeding than old people who will soon be dying that achieving and maintaining replacement reproduction would not stabilize our population until well into the next century.) This phenomenon means that, even under wildly optimistic assumptions about population control, the eventual population of India would be some 1.4 billion people; China, perhaps 1.7 billion; Brazil, 240 million; Indonesia, 310 million, and so on. Since most underdeveloped nations are in the tropics, one need only mesh this information with a little knowledge of the ecology of the tropics to see why Commoner's invocation of the demographic transition as a "cure" is a tragic mistake.

Unfortunately, he also perpetuates the myth that population control can be achieved in part by dropping infant mortality rates (page 236, and elsewhere). Laudable as the goal of reducing such rates is on grounds of compassion, it would in many cases result in temporarily rising growth rates, since the projected declines in birth rate will not compensate for the lowered death rates. (This conclusion is supported by recent computer simulation work by Donella Meadows at M.I.T., based on data from Indian villages.) There is virtually no evidence that depressing infant mortality rates anywhere would result in drops in growth rate until at least a generation had passed.

It is, of course, not at all clear that UDCs would undergo a classic demographic transition, even if they should be industrialized. The social and economic conditions are so different in those countries today in comparison to those in the now developed countries in the last century that prediction is difficult.

One-Dimensional Approach

Commoner's "optimistic outlook" (page 240) can only be based on his ignoring the rate and magnitude problems outlined above, combined with a misplaced faith in man's ability to industrialize instantly without environmental damage. An examination of statistics on the consumption of energy and materials needed to industrialize the underdeveloped countries reveals the difficulties of achieving even partial industrialization of the UDCs without vast damage to the ecosphere. Mankind's only chance for improving the lot of the poor significantly lies in diverting energy and other resources from extravagant affluence in the DCs to necessity-oriented uses in the UDCs.

Although Commoner gives perfunctory acknowledgment to some of the many deficiencies in his argument (mostly in footnotes), he manages to ignore these considerations completely in reaching his conclusions. Thus he writes on page 176 that "the increase of population accounts for from 12 to 20 per cent of the various increases in total pollutant output since 1946," the "affluence factor . . . accounts for 1 to 5 per cent," and the "technology factor . . . accounts for about 95 per cent" (except in the case of passenger car travel, when Commoner admits the contribution of affluence is larger and that of technology smaller). The charitable reader may wish to overlook the point that the lesser of these figures add up to 108 per cent of the problem. In no event is an allocation of "blame" remotely like the one Commoner gives justified by the data and arguments presented in his book.

Yet, as several glowing reviews of "The Closing Circle" bear witness, Commoner has produced a tract quite capable of persuading the naive that he has a calm, "scientific" view of the ecological crisis. In fixing the blame for environmental deterioration on faulty technology alone, Commoner's position is uncomplicated, socially comfortable and, hence, seductive. But there is little point in deluding the public on these matters; the truth is that we must grapple **simultaneously** with overpopulation, excessive affluence and faulty technology. Of course, facing honestly the need for population control and stabilized consumption exposes one to the painful criticism of being both anti-people and anti-poor, but the fact is that these unpopular measures offer mankind's only hope for averting unprecedented misery. It is better to tell the rich that they will have to share to survive, and to tell those who want large families that the price is mortgaging their children's future, than to offer false hopes of an easy way out.

The fallacy in Commoner's one-dimensional approach is perhaps best illustrated by his own, often repeated analogy that pressing for population control "is equivalent to attempting to save a leaking ship by lightening the load and forcing passengers overboard" (page 255 of "The Closing Circle" and, verbally, before several scientific and popular audiences). Needless to say, if a leaking ship were tied to a dock and passengers were still swarming up the gangplank, a competent captain would keep any more from boarding **while** he manned the pumps and attempted to repair the leak.[20]

REFERENCES

1. P. S. Martin and T. E. Wright, Jr., eds., "Pleistocene Extinctions: The Search for a Cause" (New Haven: Yale University Press, 1957).

2. Thorkild Jacobsen and Robert M. Adams, "Science," 128 (1958), 1251-58.

3. Carl O. Sauer, in "Man's Role in Changing the Face of the Earth," ed. by William L. Thomas (Chicago: The University of Chicago Press, 1956). See also many other papers in this volume, as well as "Arid Lands in Transition," Publication 90 (Washington, D. C.: AAAS, 1970).

4. Sauer, in "Man's Role in Changing the Face of the Earth."

5. Jeremy A. Sabloff, in "Patient Earth," ed. by John Harte and Robert Socolow (New York: Holt, Reinhart & Winston, 1971), pp. 16-27.

6. E. O. Wilson and W. A. Bossert, "A Primer of Population Biology" (Stamford, Conn.: Sinauer Assoc., 1971); and "Diversity and Stability in Ecological Systems," Brookhaven Symposia in Biology No. 22 (BNL 50175, c-56), 1969.

7. Allen H. Barton, "Communities in Disaster: A Sociological Analysis of Collective Stress Situations" (New York: Doubleday, 1969), p. 20.

8. Reid A. Bryson and Wayne M. Wendland, in "Global Effects of Environmental Pollution," ed. by S. F. Singer (New York: Springer Verlag, 1970); and J. Murray Mitchell, in "Global Effects."

9. John Ryther, "Science," 166 (1969), 72-76.

10. These figures and all subsequent demographic, economic and industrial statistics not otherwise attributed are from the "Statistical Abstract of the United States, 1970" (Washington, D. C.: U.S. Department of Commerce, 1970).

11. H. Landsberg, L. Fischman, and J. Fisher, "Resources in America's Future" (Baltimore: Johns Hopkins Press, 1963), p. 549; and Arnold B. Barach, "U.S.A. and Its Economic Future" (New York: MacMillan, 1964), p. 39.

12. The mercury discussion in this paragraph is based on information from "Man's Impact on the Global Environment" (Cambridge, Mass.: M.I.T. Press, 1970); Herbert V. Weiss, Minuro Koide, and Edward D. Goldberg, "Science," 174 (1971), 692; and O. I. Joensu, "Science," 171 (1971), 1027.

13. "Minerals Yearbook, 1968," Vols. I-II (Washington, D. C.: U.S. Department of the Interior, 1969), p. 155.

14. A. B. Makhijani and A. J. Lichtenberg, An Assessment of Energy and Materials Utilization in the U.S.A., in "Electronics Research Laboratory Memorandum ERL-M310" (Berkeley: University of California, 1971).

15. See, e.g., P. R. Ehrlich and J. P. Holdren, "Science," 171 (1971), 1212-17.

16. "1971 World Population Data Sheet" (Washington, D. C.: Population Reference Bureau); or any recent volume of the "U.N. Demographic Yearbook."

17. Ansley J. Coale, in "Fertility and Family Planning," ed. by S. J. Behrman, Leslie Corso, Jr., and Ronald Freedman (Ann Arbor: University of Michigan Press, 1969).

18. See, e.g., Donald J. Bogue, "Principles of Demography" (New York: John Wiley, 1969), p. 59.

19. Nathan Keyfitz, "Demography," 8 (1971), 71-80.

20. Many technical references to this article have been abbreviated or eliminated in the interests of space. Copies of the more fully documented version are available from the authors.

BARRY COMMONER:

Response

(Continued from page 17)

action toward environmental improvement.

I responded to these suggestions by expressing a position which I have long held: that is, if there is in fact a real and important difference between my views of the origins of the environmental crisis and Ehrlich's, then **both of us are obliged to express them openly;** otherwise the mechanism by which science generates the truth, open discussion, is thwarted and our obligation, as scientists, to inform the public, evaded. I expressed considerable shock at the proposition that two scientists should agree in private to withhold from the public their views, whether or not conflicting, on so vital a public issue.

Accordingly I continued to study the ways in which the several factors interact and to write and speak about what I had learned of their relative importance in the environmental crisis. I was particularly interested in working out a means of making **numerical** estimates of the effects of the several factors on environmental degradaiton in order to provide an objective means of assessing their influence.

Early in 1971, together with my colleagues Michael Corr and Paul Stamler, I wrote an article on this problem for "Environment" (April 1971). We began our considerations with a helpful statement published earlier by Ehrlich and Holdren. We said, "Dr. Paul Ehrlich provides the following statement regarding these several related factors:"

> Pollution can be said to be the result of multiplying three factors; population size, per capita consumption, and an "environmental impact" index that measures, in part, how wisely we apply the technology that goes with consumption.

We paraphrased this relationship as follows:

> Population size × per capita consumption × environmental impact per unit of production = level of pollution.

We then pointed out that:

> If we are to take effective action, we will need a more detailed guide than the equation offers. To begin with, we must know the relative importance of the three factors on the left side of the equation.

Our article then goes on to discuss the relative values of these factors in the United States since 1946 (as revealed in the available statistical tables) and to point out that the technology factor (environmental impact per unit of production) appears to have increased more than the other two factors.

The "Environment" article was followed by the preparation of a detailed paper scheduled for delivery at a symposium of Resources For the Future (RFF) on this same question. I was extremely interested in working out a way of actually using the relationship first proposed by Ehrlich and Holdren, that is, to find a way of entering the actual values for the several factors and thus computing, numerically, their relative importance. Following discussion with my colleagues, we succeeded in working out a mathematically valid way of carrying out this computation, which will be explained later on.

By these means it was possible to collect the necessary data for a series of pollutants (phosphate from cleaners, fertilizer nitrogen and pesticides from agriculture, nitrogen oxides and lead from automobiles, and bottles from beer consumption), and to compute from them the numerical contributions of the three factors. All of these computations were reported in the RFF paper; they all showed that technological changes contributed the major share of the increases in environmental impact since 1946. It was this data which provided the factual basis for my discussion of these issues in "The Closing Circle."

This now brings us to the Ehrlich and Holdren review of "The Closing Circle." I received several copies of this document in the mail, together with a duplicated letter from Ehrlich and Holdren which accompanied it, apparently in order to explain why the review was written. The text of this letter follows:

> The enclosed detailed review of Barry Commoner's "The Closing Circle" is not for publication, but you are welcome to use the information in it in any way you see fit. We have made several personal attempts to persuade Commoner to avoid a debate on which factor in the environmental crisis is "most important." We felt that such a debate would be counterproductive for the goals which we all share. Unhappily, however, he has persisted in carrying out a campaign, both in speeches and the popular media, to dismiss the roles of population growth and affluence, and place the blame entirely on "faulty technology." He has not argued his case in the refereed scientific literature (as for instance, by publishing a reply to our paper The Impact of Population Growth — "Science," 171: 1212-1217, 1971) but instead has presented it in a popular book.
>
> It is clear from the reviews that few laymen are in a position to deal critically with the arguments in "The Closing Circle." In discussing this problem with colleagues we decided that a comprehensive, well-documented review giving the pertinent data would be useful for circulation among those interested in environmental problems. Thus the enclosed. We intend to publish a version of this manuscript but thought you might have use for a preliminary copy. Comment or additions would be welcome.
>
> Paul R. Ehrlich
> John P. Holdren

One obvious error in this letter is the assertion that my analysis of the origins of the environmental crisis has not been published in "the refereed scientific literature." As already noted, the scientific material which forms the basis of my views on the relative importance of the several factors which influence environmental deterioration was first presented in an article which, together with two colleagues, Michael Corr and Paul Stamler, I submitted for publication in "Environment." It was published in the April 1971 issue of that journal following a review of the manuscript by the scientific advisers of "Environment"; indeed my records show that certain changes in the original manuscript were made in response to criticisms elicited in this review. The members of the "Environment" editorial review board are my peers in these matters, and I regard their review of the manuscript quite sufficient to qualify it as a publication in the "refereed scientific literature." My analysis of environmental impact has also been published in two journals — "The Monthly Labor Review" (a publication of the U.S. Department of Labor) and "Chemistry in Britain" (a publication of the Royal Institute of Chemistry) — both of which qualify, I believe, as refereed scientific literature. It is perhaps worth noting that Ehrlich first heard a detailed exposition of my analysis at a symposium at the December 1970 meeting of the American Association for the Advancement of Science; I organized the symposium for the purpose of eliciting debate on the subject, and Ehrlich participated at my invitation. It might be pertinent to note here, since Ehrlich and Holdren have raised the issue, that Ehrlich's "Population Bomb" was published well before he expressed his views in the refereed scientific literature.

In their letter, Ehrlich and Holdren report — as I have already indicated above — that they had earlier asked me to desist from public discussion of our differing views on the relative importance of the several factors which influence environmental impact, and they voice their regret that I have, nevertheless, "persisted." It would appear from this letter that Ehrlich's present attack on my views is a consequence of my refusal to accept his earlier proposition for joint silence on this issue.

Basic Mathematical Fault

However, if Ehrlich's criticism does not originate in wholly scientific considerations, it is, nevertheless largely — but not entirely — scientific in content. Hence, I propose to reply to it largely in scientific terms; offering comments outside the context of science only where the criticism in itself departs from that realm.

Central to Ehrlich and Holdren's scientific criticism of "The Closing Circle" is their claim that I have not used proper mathematical methods to analyze the relationships among the several factors which influence environmental impact. Specifically, Ehrlich and Holdren ascribe to me certain procedures (involving mathematical relationships between percentages) which they regard as an invalid means of expressing the relationships among the several factors that might give rise to environmental impact. They then develop an equation which, in apparent contrast to my treatment, is, in their view, valid.

Obviously if they are correct in this claim, there is little reason for anyone to pay attention to much of what I have written in "The Closing Circle." It becomes essential, then, to compare the validity of my analysis and of that put forward by Ehrlich and Holdren, for either my analysis or their criticism of it must be wrong. In order to permit the reader to choose between these alternatives, I propose (a) to describe the procedures which my colleagues and I used to establish numerical values for the effects of the several environmental factors, as they were presented in the RFF paper and later summarized in "The Closing Circle," and (b) to cast these results into a form which permits a direct mathematical comparison between my analytical procedure and equation (3) of the Ehrlich and Holdren review, which they regard — in contrast with my treatment — as mathematically valid. As will be shown below, it then becomes self-evident whether my analysis, or their criticism of it, is wrong.

As indicated earlier, my colleagues and I developed our approach from an equation proposed earlier by Ehrlich and Holdren. We began with the population factor (P), which is simply the size of the U.S. population in a given year. Then the affluence factor (A) was defined as the amount of goods produced (or consumed) per capita in that same year, and the technology factor (T) as the amount of pollutant emitted per unit of goods produced (or consumed) in that year. The overall amount of pollutant emitted in the year was defined as the environmental impact (I).

Once the several factors are defined in this way, the proper mathematical relationship among them is self-evident from the procedure called "dimensional analysis." (A very simple problem which can be solved by this procedure is the following: What is the proper mathematical realtionship between the length of a rectangle (L), its width (W), and its area (A), given that the area is expressed in square feet and the length and width in feet? Noting that $\text{ft} \times \text{ft} = \text{ft}^2$, it becomes evident that the only relationship which conforms with this requirement is: $L \times W = A$.) Thus, given the above definitions of the terms I, P, A, and T, it can be seen that the following relationship produces a mathematical identity, in which amount of pollution = amount of pollutant (i.e., $I = I$):

$$\text{Amount of Pollutant (I)} = \text{Population} \times \frac{\text{Production (or consumption)}}{\text{Population}} \times \frac{\text{Amount of Pollutant}}{\text{Production (or consumption)}}$$

Note that both population terms and both production terms cancel out, leaving the relationship: amount of pollutant = amount of pollutant. Since this relationship is obviously dimensionally correct, the entire equation is also dimensionally correct.

Our primary concern was to explain numerically the **increase** in the amount of pollutants emitted annually, for what characterizes the environmental crisis is the sharp rise in pollution levels in the years since World War II. Accordingly we needed to compute the **increases,** over a given span of years, of all four factors: I, P, A, and T. This was done by tabulating, for a variety of pollutants, the actual values of each of these factors for two years: usually 1946, or the earliest year for which the necessary statistics were available, and 1967 or 1968. Then, to show how the factors interacted to produce the **increase** in pollutants emitted over this period of time, the **ratios** of the 1946 and 1968 values of the factors were multiplied together. As an example, we present in the table the values for beer bottles for 1950 and 1967. This table illustrates an important feature of such computation, that is, they often involve the use of a figure for pollutant emissions (I) which is not the actual amount of the pollutants

BEER BOTTLES
ENVIRONMENTAL IMPACT INDEX

	Index Factors (a)	(b)	(c)	Total Index
	Population (1000's)	Beer Consumption / Population (Gallons/cap)	Beer Bottles / Beer Consumption (Bottles/gallon)	(a × b × c)[a] Beer Bottles (1000 Gross)
1950	151,868	24.99	.25	6,540
1967	197,859	26.27	1.26	45,476
1967:1950	1.30	1.05	5.08	6.95
% Increase 1950-1967	30	5	408	595

[a] This multiplication applies only to the first three lines, not to the per cent increase 1950 to 1967.

entering the environment but the best available indicator of that amount. In this instance, the number of beer bottles directly expresses the environmental impact of beer consumption on solid waste, but it is only indirectly related to the impact due to the air pollutants produced from fuel burned in the production, filling and distribution of the bottles. However, since Bruce Hannon ("Environment," March 1972) has now computed the latter values, once the number of bottles is known, the effects on air pollution can be computed.

Put into the form of an equation, the operation represented by the underscored line in the above table may be stated as follows:

$$(1 + \frac{\Delta P}{P}) \times (1 + \frac{\Delta A}{A}) \times (1 + \frac{\Delta T}{T}) = (1 + \frac{\Delta I}{I})$$

where I, P, A, and T represent respectively the 1950 values of impact, population size, goods per capita (affluence factor), and pollutant per unit goods (technology factor) and ΔI, ΔP, ΔA, and ΔT represent the increases between 1950 and 1967 in the corresponding values. Thus, for the example cited above we have:

$$(1 + \frac{45{,}991}{151{,}868}) \times (1 + \frac{1.28}{24.99}) \times (1 + \frac{1.01}{.25}) = (1 + \frac{38{,}936}{6{,}540})$$

or $1.30 \times 1.05 \times 5.08 = 6.95$.

This computation shows that whereas the technology factor has increased about fivefold since 1949, the affluence factor has increased only 1.05-fold (which means that people drink nearly the same amount of beer per capita, annually, as they used to), and the population only 1.30-fold. This leads to the conclusion that the technology factor makes by far the largest contribution to the approximately sevenfold change in beer bottle dissemination that occurred between 1950 and 1967. The table also provides an alternative way of expressing the very same relationships: that the 595 per cent increase in beer bottle dissemination arises from a 30 per cent increase in population, a 5 per cent increase in the affluence factor, and a 40 per cent increase in the technology factor. Note, however, that the operation of multiplication is not carried out on these percentages, but between the ratios, as required by the mathematics of the equation. Similar computations — for the impact of fertilizer and pesticides due to their use in agriculture, of lead and nitrogen oxides due to passenger car operation, and of phosphate due to the use of cleaners — are reported in the RFF paper and summarized in "The Closing Circle." All of them show that, as in the case of beer consumption, the largest contribution to the postwar increase in pollutant emissions is made by the technology factor.

This, then, is the basis for the position developed in "The Closing Circle." Ehrlich and Holdren's most serious criticism of this position is that it depends on a faulty mathematical procedure. In part this criticism is based on their claim that I use an analysis which involves a mathematically inadmissible procedure — the multiplication of percentages. However, as can be seen from the above account (and as shown in detail below), this description is false; nowhere in the procedure are percentages multiplied. Then, in order to validate their overall criticism of my mathematical procedures, Ehrlich and Holdren proceed to develop what they regard to be the proper mathematical procedure: their development culminates in the following statement:

> To examine more closely how Commoner's use of percentages has obscured the importance of the growth of these factors, we rewrite the impact equation to express all quantities as multiples of their initial values:
>
> $$1 + \frac{\Delta I}{I} = (1 + \frac{\Delta P}{P}) \times (1 + \frac{\Delta A}{A}) \times 1 + \frac{\Delta T}{T}).$$

Now it will be noted that this equation is precisely the one which my colleagues and I had developed earlier and which had been reported — with several examples of real data (as compared with the universally hypothetical ones put forward by Ehrlich and Holdren) — well before their critique: in April 1971 to the RFF symposium; in a keynote address which I delivered in July 1971 to the Conference of Parliamentary Public Health Specialists of the Parliament of Europe in Stockholm; in a report published in September 1971 by the U.S. Senate Committee on Interior and Insular Affairs ("Selected Readings on Economic Growth in Relation to Population Increase, Natural Resources Availability, Environmental Quality Control, and Energy Needs"); in abbreviated form in the November 1971 issue of "Monthly Labor Review," published by the U.S. Department of Labor. In "The Closing Circle" the material of the RFF paper was summarized without departing in any way from the original mathematical treatment (see below), and in the notes the reader is referred to the RFF paper for details.

Criticism Unfounded

In sum, with regard to this crucial "scientific" criticism of my analysis by Ehrlich and Holdren, the situation is this: With the help of several colleagues, basing our procedure on a simplified relationship among the several pollution-related factors first advanced by Ehrlich and Holdren (and giving credit to them), I refined their equation into a form that expressed changes in time as ratios of the values for two years. (In other words, the values for the later year are expressed as multiples of the corresponding values for the earlier year.) We then accumulated actual data for a number of pollutants, and computed, by means of this equation, the actual numerical relationship among the relevant factors. These computations of the actual data on postwar changes in the United States showed that, among the three relevant factors, technological change had the major effect on environmental impact. These results were reported in several places between April and November 1971 and were incorporated in "The Closing Circle," which was published in October 1971. Some time in December 1971, Ehrlich and Holdren prepared and distributed a review of the book in which they criticized my mathematical treatment of these relationships by contrasting it with a "proper" equation which they claim to have developed. **Their equation is identical to the one which I reported earlier, beginning with the RFF paper in April 1971, and which is the basis of treatment developed in "The Closing Circle."** Thus, Ehrlich and Holdren propose to correct my supposedly faulty mathematical analysis of the impact factors by offering in its place the very same equation which I had used. Obviously, on their own grounds my analytical method is correct and their criticism of it unfounded. In sum, Ehrlich and Holdren's basic criticism of my analysis of the relative effects of population size, "affluence" and productive technology on environmental impact is not only false, but absurdly so.

Given this background, it should come as no surprise that all of the specific criticisms made by Ehrlich and Holdren of my mathematical analysis of environmental impact turn out to be equally false. These are taken up in what follows.

Ehrlich and Holdren assert, regarding the basic equation:

> Within this framework, an objective discussion of the relative importance of the three factors on the right of equation (1) would attempt to assign numerical values to all of them, rendering the comparison self-evident. Commoner does not do this.

As already established, the first of these sentences repeats my own position on the use of the equation. The second sentence is simply false. What I have done in the RFF paper referred to above is precisely "to assign numerical values" to the three factors. Moreover, the results of this analysis were reported in "The Closing Circle," as follows.

Following a description of the equation, I state (p. 176) that:

> In the United States all three factors have changed since 1946. By comparing these changes with the concurrent increases in total pollutant output it is possible to assign to each of the three factors the fraction of the overall increase in pollutant output for which it is responsible. When this computation is carried out for the economic goods considered above . . . a rather clear picture emerges.

Reference to the notes for this part of the text informs the reader that these computations are to be found in the several papers already referred to. One might expect that, on noting these references, scientifically qualified commentators such as Ehrlich and Holdren would read them in order to determine whether I have or have not carried out the computations as claimed in the passage cited above. As already indicated, there they would find all the required computations set forth in a series of tables, one of which has already been provided as an example above.

At this point Ehrlich and Holdren make an additional and quite crucial statement about my computations. They state:

> Concentrating on the period from 1946 to 1968, he cites percentage increases of 200 per cent or more in various pollutants (claimed to be indications of the impact, I) and he notes that population in this period grew "only" 42 per cent. Thus the reader inexperienced in such calculations is left with the impression that population accounted for only a fifth or less of the increase in pollution (40 per cent/200 percent = 1/5), and that affluence and technology must have accounted for the other four-fifths. But this is not so because the causative factors are multiplicative.

If the foregoing statement is meant to refer to any statement made by me, it is false, for nowhere in "The Closing Circle," or in any other writings, have I presented a computation of the form cited above. What follows summarizes all the places in "The Closing Circle" in which the factors are introduced and arithmetic operations are performed.

One, on page 128 data are presented which show that annual emissions of a number of key pollutants have increased by about 200 to 2,000 per cent since 1946. Neither population, affluence, nor technology factors are mentioned here; neither comparisons nor arithmetic operations are made.

Two, on page 133 it is noted that the postwar U.S. population increased about 42 per cent and that this is insufficient, in itself, to account for the much larger concurrent increases in pollution emissions. (This assertion is obviously correct, since annual emissions increased by 200 to 2,000 per cent). No other numbers are mentioned here and no computations are made.

Three, on page 136 it is asserted that "the ratio between the amount of pollution generated in the United States and the size of the population has increased sharply since 1946." (The correctness of this statement is self-evident.) The statement continues, "This relationship can be converted to a mathematically equivalent but — as we shall see — highly misleading statement: that there has been a sharp increase in the amount of pollution produced per person [emphasis in original]. For example if pollution has increased tenfold while population has increased by 43 per cent, then pollution per person has increased about sevenfold ($1.43 \times 7 = 10$ approximately)." (Note that the term "pollution per capita" is the product of the "affluence" and "technology" terms in the basic equation.) Here for the first time a mathematical relationship between amount of pollution and the product of population $\times$ pollution per capita is put forward. Both the prose and the arithmetic are accurate and informative. Note for example that while the increase in population is referred to in per cent (43 per cent), in the arithmetic operation it is converted, as required, to the appropriate ratio or multiple (1.43). Thus, the reader is shown explicitly the proper relationship between the more common percentile expression and the multiple which must be used in the arithmetic operation.

Four, on page 140 the relationship among the three factors is stated as follows:

> While two factors frequently blamed for the environmental crisis, population and affluence, have intensified in that time (i.e., following World War II), these increases are much too small to account for the 200 to 2,000 per cent rise in pollution levels since 1946. The product of the two factors, which represents the total output of goods (total production equals population times production per capita), is also insufficient to account for the intensification of pollution. Total production — as measured by GNP (Gross National Product) — has increased 126 per cent since 1946, while most pollution levels have risen by at least several times that rate.

Again, the statements are accurate and wholly in keeping with the proper arithmetic relationships, as described in the basic equation.

Five, on pages 175 and 176 the necessary multiplicative relationship between all three factors is described as follows:

> It is useful, at this point, to return to a question asked earlier: What are the relative effects of the three factors that might be expected to influence the intensity of environmental pollution — population size, degree of affluence, and the tendency of the productive technology to pollute? A rather simple mathematical relationship connects the amount of pollutant emitted into the environment to these factors: pollutant emitted is equal to the product of the three factors — population times the amount of a given economic good per capita times output of pollutant per unit of the economic good produced.

As indicated earlier (and, in fact, as acknowledged by Ehrlich and Holdren) this is an accurate statement, in prose, of the basic relationship among the three factors.

Six, finally, on pages 211 and 212, an exercise involving the entire equation is proposed; the exercise is described in detail in the notes, where it is evident that the computations are governed by the equations given earlier.

The foregoing is the **total** presentation of the arithmetic relationships among the several factors as given in "The Closing Circle." Nowhere can one find the relationship put forward by Ehrlich and Holdren as the supposed basis whereby "the reader inexperienced in such calculations is left with the impression that population accounted for only a fifth or less of the increase in pollution (40 per cent/200 per cent $= 1/5$) and that affluence and technology must have accounted for the other four-fifths." Hence, their statement is false.

The conclusion which Ehrlich and Holdren ascribe to me (i.e., that population increase accounts for one-fifth or less of the increases in pollution level) **is accurate.** What they have falsely described is the mathematical means by which I reached that conclusion. The method which I used is described in a general way in "The Closing Circle" and in detail in the indicated references. In both places, as already shown above, the computations developed **are identical in form to those put forward later by Ehrlich and Holdren** as a criticism of my methods.

Following the development of the basic analysis outlined above, Michael Corr and I became interested in finding a way to compare the several computations of different pollutants in order to arrive at possible generalizations about the relative effects of the three separate factors. By expressing the ratios of the impacts for two different years in logarithmic terms, it was possible to evaluate the contribution of the change in any one factor; for example, population (as given by the ratio of the populations in the two years) in terms of the fraction which the **logarithm** of that ratio represented of the **logarithm** of the corresponding ratio of the total impacts. Since in multiplication logarithms are **added**, it becomes possible by this means to compute a relative measure of the contribution of each of the three factors to the total impact. We found that for the several different pollutants, the logarithm of the population ratios was about 15 to 20 per cent of the logarithm of the total impact ratios. These further computations are the basis of the statement in "The Closing Circle" that:

> The increase in population accounts for from 12 to 20 per cent of the various increases in total pollutant output since 1946. The affluence factor (i.e., amount of economic good per capita), accounts for from 1 to 5 per cent of the total increase in pollutant output, except in the case of passenger travel, where the contribution rises to about 40 per cent of the total. . . . The technology factor — that is, the increased output of pollutants per unit production resulting from the introduction of new productive technologies since 1946 — accounts for about 95 per cent of the total output of pollutants, except in the case of passenger travel, where it accounts for about 40 per cent of the total.

Now there are, in fact, two errors in the passage quoted above. One of the figures, "about 95 per cent," is a typographical error; it should read "about 80 to 85 per cent." More important, the passage should have referred to the relationships among **logarithms** of the increases (as expressed by the ratios) rather than to the increases themselves. Thus, to be precise, the passage should have read: "The logarithm of the increase in population (as given by the ratios of the values for the two years) accounts for from 12 to 20 per cent of the logarithm of the various increases in total pollutant emitted annually since 1946 (again, as given by the ratios)." In other words, the logarithms of the ratios and not the ratios are being compared. While, in mathematical terms this permits the kind of comparison we sought, it is important to note that it does so on a logarithmic rather than on the more common linear scale. While such logarithmic comparisons have the disadvantage of not being readily incorporated into the context of everyday thinking, they do permit us to make the sought-for generalizations about the relative roles of the factors involved in environmental impact. The omission of the logarithmic term in the above passage is regrettable, but it in no way changes the actual relationships among the factors; it remains true that the largest effect is due to technology.

I proceed now to detailed comments on the other major points raised in the Ehrlich and Holdren review. I have tried to deal with all of the major criticisms; some of the others are simply too trivial or too patently peevish to warrant space in this already crowded statement.

The basic position taken by Ehrlich and Holdren regarding "The Closing Circle" appears to be that the overall argument of the book consists of "fixing the blame for environmental deterioration on faulty technology alone" and that "uncritical acceptance" of this argument will lead to "public complacency concerning both population and affluence," the other two important factors. They assert — and attempt to demonstrate — that my argument has three defects: it rests on the misuse of data and their mathematical relationships; it ignores environmental problems other than pollution; and it rests on mistakes about "certain aspects of demography."

Numerical Sleight-of-Hand

Ehrlich and Holdren assert that "[Commoner] resorts to biased selection of data, unconventional definitions, numerical sleight of hand, and bad ecology." A good part of this criticism is based on the supposed errors in my mathematical treatment of environmental impact. As already shown above, that criticism is not only false but absurd.

Another major charge is that my argument consists of "fixing the blame for environmental deterioration on faulty technology alone." This charge is patently false, for as already shown, a great deal of the effort in "The Closing Circle" (and in the more detailed studies on which it is based) was directed toward estimating the relative effects of **all three** factors which are involved in environmental impact. Indeed, to my knowledge, the computations presented in the book and in the background papers include the first numerical estimates of the effect of **population growth** on environmental impact; in no instance have I reported a zero effect, which would be the case if environmental impact were due to "technology alone." Nowhere in "The Closing Circle," or in any other of my writings, can there be found a statement which holds or implies that "faulty technology alone" is to "blame for environmental deterioration."

Ehrlich and Holdren claim that my analysis "resorts to biased selection of data." Presumably a prime instance of this supposed defect is what they call "Commoner's list" of sources of environmental degradation. Here a couple of parenthetical remarks are in order, to begin with.

First, as I shall show below, the list of supposed ecological offenders exists not in my writing but in the imaginations of Ehrlich's and Holdren. My list is one of **displacements** of one means of meeting human needs by another.

Now, let us examine the Ehrlich and Holdren exercise which purports to correct my "omission" of an important source of environmental degradation: "He [Commoner] says almost nothing about energy production or consumption as a whole, however, perhaps because it would damage his case to do so." They attempt to show that in this specific instance the technology factor is not as important a source of environmental impact as I believe. They point out that total U.S. energy production in 1969 was 2.4 times that in 1940; population increased 53 per cent, and energy production per capita increased by 57 per cent in that time. Hence they assert that these two factors contribute about equally to total energy production (since population $\times$ production/capita $=$ production, and $1.53 \times 1.57 = 2.40$). On these grounds Ehrlich and Holdren conclude that "the contribution of population growth is hardly unimportant." However (curiously in contrast with their exhortation elsewhere that all three factors must be related to environmental impact), Ehrlich and Holdren have here **omitted to enter the third factor: pollutant/economic good (the technology factor).**

It is illuminating to rectify this omission. What we need to know is the amount of pollutant emitted per unit of fuel used in 1940 and 1969. Unfortunately we have this information only for pollutants due to automotive use of energy, but a discussion of this aspect of the fuel problem is sufficient to illustrate where Ehrlich and Holdren have gone astray.

Missing Factor

What is required is to enter the missing technology factor into the equation and, thereby, compute the influence of all three factors on the overall environmental impact of automotive fuel consumption. This is, of course, precisely what I have done in my earlier papers and have reported in "The Closing Circle" (pp. 169-170) in the case of passenger cars for two major pollutants, lead and nitrogen oxides. The computations for nitrogen oxides, for example, are as follows for the period 1946-1967. The ratios of the 1967: 1946 values are for population, 1.41; for total fuel consumption, 2.85; for fuel consumption/population, 2.02; for vehicle-miles/population, 2.00; for nitrogen oxide emissions/vehicle mile, 2.58; and for total nitrogen oxide emission (impact), 7.3.

Now, given these data, if we follow the approach of Ehrlich and Holdren, it would be stated that since population increased by a factor of 1.41, fuel consumption per capita by a factor of 2.02, and total fuel consumption by a factor of 2.85, the relevant relationship is: $1.41 \times 2.02 = 2.85$. Since the overall impact is only a 2.85-fold increase, and the effect of population growth represents a 1.41-fold increase, it seems valid to conclude, as Ehrlich and Holdren do, that "the contribution of population growth is hardly unimportant."

My approach to these same data is different. First, I define the affluence factor not in terms of fuel consumption, but in terms of the actual good which it yields — in this case vehicle-miles/population. Then, whereas Ehrlich and Holdren deal with only the population and affluence factors, I introduce the third factor, technology, or in this case nitrogen oxides emitted per vehicle mile. Now the **whole** relationship becomes:

$$1.41 \times 2.00 \times 2.58 = 7.3$$

Note that, according to Ehrlich and Holdren, the contribution of population growth (1.43-fold) is compared to the increase in fuel consumption (2.85-fold), so that the contribution of the population factor does indeed seem relatively important. In contrast, if the missing technology factor is included, and the effect expressed in terms of a real **pollutant** (nitrogen oxides), the total impact increases 7.3-fold (rather than 2.85-fold), so the importance of the population factor has to be judged against that figure rather than against 2.85. The significance of the population effect relative to the other two factors is thereby diminished.

Thus, in violation of their own admonition — "an objective discussion of the relative importance of the three factors on the right of equation (1) would attempt to assign numerical values to **all of them** [emphasis mine]" — Ehrlich and Holdren have neglected to consider the third factor, technology. When the third factor **is** entered, as I have done above, the picture changes drastically, and the relative effect of population growth becomes smaller than Ehrlich and Holdren would have us believe.

This error is repeated in Ehrlich and Holdren's comments on automobile production. Here they consider the environmental impact of the number of cars produced (not used), dividing the effect between population and cars produced per capita. Obviously what is missing here is the technology factor, in this case pollutants emitted per car produced (i.e., environmental pollution due to car manufacturing). Complete data are lacking, but the effect of changes in the amount of electric power used in motor vehicle manufacturing — an important aspect of environmental degradation — gives us at least a partial answer.

In 1937 (the closest year to 1940 for which the necessary data are available to us) about 179 kilowatt-hours of electric power were used to manufacture each motor vehicle; by 1967 that figure was 708 kilowatt-hours per vehicle. Thus, the technology figure (pollution due to power used per vehicle) increased 3.95-fold between 1937 and 1967. During that time, population increased 1.54-fold and affluence, as measured by vehicles produced per capita, increased 1.22-fold. The full equation using the relevant ratios now becomes

$$1.54 \times 1.22 \times 3.95 = 7.43,$$

from which it can be seen that the effect of increased population on total impact is relatively small (i.e., 1.54-fold as compared with 7.43-fold) and that the technology factor has the largest effect (3.95-fold) of the three factors.

However, Ehrlich and Holdren compute the environmental impact of car production from the number of cars produced, and divide this effect between only two factors, population and cars per capita. Hence their relationship is

$$1.54 \times 1.22 = 1.88,$$

and now the effect of population growth (1.54-fold increase) is indeed significant because it is compared with an increase in total impact which is only 1.88-fold. Again we see that when the technology factor is omitted from the computation the population factor can be compared with a relatively small increment in total impact, and to that degree gains in apparent importance. However, this type of computation, which is used here by Ehrlich and Holdren, violates their earlier emphasis — with which I agree — on the necessity of considering all **three** factors.

Thus, in this feature of their criticism of "The Closing Circle," Ehrlich and Holdren exhibit a remarkable reversal of position. Whereas earlier they criticize me (falsely, as we have seen) for failing to undertake computations of environmental impact in which values for all three relevant factors are entered, here they do precisely what they accuse me of doing and, as a consequence, exaggerate the role of population growth in environmental impact.

Point Missed

Here Ehrlich and Holdren appear to reflect a serious fault in their understanding of the relationship of the three factors to environmental degradation. One of the ideas that I tried very hard to make clear in the book, because I have found it so essential to an effective understanding of this issue, is that when we attempt to assess the significance of a given level of pollution, it is essential that it be related to the **economic good** which results from the relevant production process. I have found it particularly important to separate carefully the actual good from its more superficial embodiments. Thus, I point out that when a bottle of beer is purchased the economic good which is received is chiefly the **beer** and not the container, an insight which tells us that the rising clutter of beer bottles is closely related to the introduction of a new technology, throwaway bottles. This relationship is particularly important to a consideration of the balance between the benefit of a technology and its environmental hazard — a judgment which is the necessary prelude to action on an environmental issue. Thus, if the benefit is defined as beer, then the ratio of benefit-hazard **falls** as delivery of the same pint of beer is shifted from a returnable bottle to a throwaway one, even though beer consumption per capita remains constant. Unfortunately, Ehrlich and Holdren have missed this point and, as a result, as shown above, are quite thoroughly mistaken in their analysis of the roles of the several factors in environmental degradation.

To take another example, Ehrlich and Holdren have failed to understand that fuel consumption is **not in itself** an **economic good** (which is the desired **transportation,** for example, as measured by passenger-miles), but is rather part of one **technological** factor which contributes to the environmental impact of car-driving. Fuel is the appropriate economic good in a computation regarding the relative effects of population increase, changes in "affluence," and technology only when it is the **final product** of the process under examination. For example, in the **production** of gasoline from crude petroleum it would be appropriate to compute the amount of gasoline produced per capita as a measure of affluence and to compute the amount of a pollutant, such as sulfur dioxide, released by the production process per gallon of gasoline as a measure of the technological factor. However, when fuel is **used** to generate some other economic good, fuel consumption is **not** the appropriate measure of economic good. Here, fuel consumption is an appropriate measure of the influence of the **technological** factor on the overall environmental impact, in the form: fuel consumed/goods produced.

The failure of Ehrlich and Holdren to understand these relationships — which derive directly from the three-factor equation that they so much admire — largely accounts for their complaints that I have ignored the environmental role of "affluence," as it is often defined — in terms of television sets and fancy cars. What the equation indicates, and what I have tried to express in my writings, is that regardless of the myth created by advertising propaganda and the consequent cultural attitudes, true affluence ought to be measured by the actual consumption of goods that in fact contribute to human welfare.

Ehrlich and Holdren's failure to understand these relationships is reflected in their Table 1, which is designed, apparently, to show that I have neglected to discuss such items of "affluence" as telephones and water heaters in my consideration of the origin of environmental impact. Here they report data on the numbers of these items **in use** per capita, Now these data reflect not the effect of **production** of these goods on environmental impact but their use. As already indicated, for the evaluation of the latter it is necessary to consider the environmental impact of the fuel used to operate these items. This is a rather complex problem which at the time of the writing of "The Closing Circle" had been insufficiently analyzed, in my opinion, to warrant inclusion in the book. Since then, thanks to a number of current studies of the energy problem we have learned a great deal more about this problem some of which was reported in my recent paper "Power Production and Human Welfare," presented at the annual meeting of the AAAS in Philadelphia in December 1971. It is pertinent to note that the results of this study support the conclusions reached in "The Closing Circle" quite well. For example, in the case of hot-water heaters, if affluence is measured in terms of the actual good (in this case, hot water) it becomes evident that the technology factor (pollution per unit hot water) has increased as electric heaters, which are relatively inefficient in their use of the fuel resource, have displaced the more efficient oil- or gas-fired heaters.

On Affluence

It is also pertinent to note that the discussion of affluence in "The Closing Circle" was specifically oriented toward environmental impact, and was in no sense intended to evaluate consumption levels for their own sake. In these terms, importation of items such as clothing is irrelevant to the computation of environmental impact **in the United States,** since the production took place elsewhere. Of course such imported clothing does involve an environmental impact in the country of origin, but what is at issue in this discussion is the explanation of the rising environmental impact in the United States, and that derives from productive operations **within** the United States. Similarly, Ehrlich and Holdren's comments about rising per capita expenditures for housing do not necessarily reflect a comparable increase in the contribution of affluence to the environmental impact due to housing. For example, housing costs are dependent on interest rates, which have certainly increased in the postwar years, but the resultant increase in per capita housing cost has nothing to do with environmental impact. Rather we need to know the environmental costs of the construction and maintenance of dwellings; and, again, the technology factor would appear to dominate as steel is displaced by aluminum and as inefficient electric space heating displaces fuel-fired systems.

Apparently, my approach to the problem of affluence has been meaningful to some readers. Thus, in reviewing "The Closing Circle," Sir Eric Ashby comments:

> Pollution is compounded of people, their per capita consumption of goods and services, and the impact on the environment which these goods and service make. The run-of-the-mill Cassandra indicates population and consumption. Commoner maintains that per capita consumption has not risen alarmingly; what has risen alarmingly is the impact of modern, as opposed to traditional, goods and services on the environment. He supports his thesis with some interesting facts. Take beer, for instance. Between 1950 and 1967 the per capita consumption of beer in the United States increased by about 5 per cent. But over the same period the per capita consumption of nonreturnable beer containers increased by 595 per cent. The consumer is no more affluent: it is the beer he wants. ("Spectator," London, Feb. 5, 1972.)

Similarly, Rene Dubos's review of "The Closing Circle" states, regarding criticism of my definition of affluence:

> Indeed, his critics are probably right if affluence is to be measured in terms of two cars in every garage, color television sets, motor boats, snowmobiles, and a multiplicity of convenience foods and garments. However, these criteria are rapidly losing validity. Technological innovation and economic growth are no longer considered to be self-evident goals. Commoner has rendered a great service by providing a factual basis for an inquiry into the options which are available to men at the present stage of scientific technological development in their search for the good life and for a better form of society. ("Environment," January-February 1972.)

Obviously, Ehrlich and Holdren are less receptive to my view of affluence than are Dubos and Ashby. Ehrlich and Holdren may certainly disagree with me (and with Dubos and Ashby) and may offer a different, more conventional, definition of affluence if they like; but they repeatedly reveal that they have failed to understand my position.

Ehrlich and Holdren also seem to be particularly unable to grasp what I try to say in connection with the relative growth of the production of various goods, as described on page 143. They appear to regard this list as a roster of "indicators of environmental impact" and complain that for a variety of reasons certain of the items on the list are not suitable for this purpose. But the list was not composed for the purpose which Ehrlich and Holdren describe. Rather, as stated explicitly (p. 142), the list was a technique for describing "how the economy has grown." I describe the technique for computing the growth rates and then state "when this list is rearranged in decreasing order of growth rate, a picture of how the United States economy has grown since World War II begins to emerge." I then point out the most interesting feature of the list, that is, "what has changed drastically is the technology of production rather than overall output of the economic good."

Ecological Impact Inventory

Thus, the list deals with the relative rates of growth of different productive technologies, and not with the absolute sizes of the different activities. The list describes the displacement of one technology by another rather than the importance of the environmental impact generated by any given item. Ehrlich and Holdren clearly fail to understand this point. Thus they complain with respect to the high growth rate of nonreturnable bottles that the bottles are "neither a major fraction of United States glass production nor an ecologically significant pollutant." Nowhere do I claim that this is the case. Instead I point out from the high rate of growth in throwaway bottles that they have displaced returnable ones which are, after all, ecologically more sound, so that the benefit-hazard ratio involved in the consumption of soda and beer has been reduced.

Again, asserting the false claim that the list is designed as a roster of ecological guilt, Ehrlich and Holdren complain that "Commoner has padded his list of dramatic increases with four different aspects of essentially the same flaw," because I include in the list synthetic organic chemicals, pesticides, chlorine, and mercury used to manufacture chlorine. Here Ehrlich and Holdren have missed a vital aspect of the pollution problem to which many other environmentalists are now giving considerable attention: the great value of input-output analysis in explicating environmental impact. Such an analysis depicts the full extent of the environmental impact associated with the production of a particular good (e.g., pesticides) by showing how the manufacture of necessary raw materials (e.g., chlorine) also generates environmental impacts (e.g., mercury). To most environmentalists these interactions have become a fruitful source of new insights, and it seemed useful to provide a glimpse into them for the readers of "The Closing Circle." It is only in the imaginations of Ehrlich and Holdren that the list is a roster of ecological insults. That I have "padded" it is likewise a view which is peculiarly their own. Ehrlich and Holdren belabor the point that the rate of growth of the use of mercury for chloralkali production has "little relevance" as an indicator "of the overall level of mercury pollution" — still driven by the false notion that this is the purpose of my discussion. This item was included in the list, however, not as a measure of the overall use of mercury, but to illustrate how the displacement of natural substances by synthetic ones intensifies environmental impact, for example, in the manufacture of synthetics chlorine is used which results in the release of mercury to the environment.

What is noteworthy about all of these "defects" in my position is that they are such obvious ones — provided one accepts Ehrlich and Holdren's definition of the purpose of my displacement list. It is, after all, widely known that detergents, most pesticides and materials used to manufacture plastics and synthetic fibers are subsumed under the category "synthetic organic chemicals," so that my supposed "padding" of the list should be evident to almost anyone who, like Ehrlich and Holdren, misconstrued its purpose. It is perhaps worth noting here that among the 100 or so reviews of "The Closing Circle," many of which discuss in some detail the displacement list, there is not a single instance in which the reviewer interprets it as Ehrlich and Holdren do.

The Ehrlich and Holdren review treats us to a display of detailed concern about the elaborate considerations (including longevity and effects on energy use of substitute materials) which need to go into a full analysis of environmental impact. This is, of course, precisely the detailed accounting, an ecological impact inventory, that is called for on page 197 of "The Closing Circle":

> Such pollution price tage are needed for all major products. . . . The foregoing account shows how far we are from the goal and once again reminds us how blind we are about the environmental effects of modern technology.

Ehrlich and Holdren's observations about the environmental hazards associated with an effort to supply present fabric needs from natural sources illustrates this point quite well. We are, indeed, still largely ignorant about the most ecologically sound way to produce the needed fabrics: How cotton might be produced without the ecological insult of pesticides and fertilizers, or how wool could be produced without degrading the soil through overgrazing. What is at issue is that the basic process of producing cotton or wool is biological and, therefore, capable of successful integration into the biosphere, while the synthesis of nylon from petroleum, even with the best possible environmental controls, is nevertheless outside the ecosystem and therefore stresses it. On these matters Ehrlich and Holdren remind us that "Commoner admits he does not know (see his footnote to p. 160), but the uncertainty is forgotten when he draws his conclusions." In the absence of the relevant data, I regard the admission of uncertainty — of ignorance, if need be — as a virtue. Not so Ehrlich and Holdren, for they are quite content to conclude, following their recitation of the numerous needed parameters — but of no numbers to match them — that "it is clear, then, that population growth and rising affluence can stimulate qualitative changes in the technologies of production. . . ."

"The environmental crisis involves very grave and complex social problems that ought to be resolved by public decision and not determined by the force of private agreements among scientists . . ."

Diminishing Returns

Then there is the matter of "diminishing returns," which according to Ehrlich and Holdren are "another mechanism by which population and affluence generate environmental impact far out of proportion to their own percentage increases." They cite the use of nitrogen fertilizer as "the best known example" of this effect, asserting that "the essence of the matter is that feeding an extra increment of population from a fixed or dwindling amount of good quality land requires inputs of fertilizer far out of proportion to the increase in yield." Here Ehrlich and Holdren are promulgating a myth more often heard from "agrobusinessmen" and fertilizer salesmen than from environmentalists — that the intensity (i.e., high yields per acre) of U.S. agriculture is essential to provide food for the growing population, because of "a fixed or dwindling amount of good quality land." The fact is that land has been retired from agriculture in the United States not because it is of "poor quality," but because nonuse of land is economically advantageous: to the farmer because of Land Bank payments and the effects of controlled production on market prices, and to the fertilizer industry (and the farmer as well) because fertilizer is the cheapest way to increase yield per acre and thereby compensates for restricted acreage. Those familiar with actual farm operations know that the retired acreage varies from year to year and is not, on the average, significantly worse than the rest. According to one agricultural expert, the acreage held out of production "is suitable for regular cultivation with no additional investment" (J. C. Headley, Productivity of Agricultural Pesticides in "Symposium on Economic Research on Pesticides for Policy Decision Making." U.S. Department of Agriculture, Washington, D.C., April 27-29, 1970). Moreover, Ehrlich's use of such a concept of land "quality" is surprising in an ecologist. As pointed out in Chapter 12 of "The Closing Circle," this is an economic rather than ecological concept; while on economic grounds land which has a low intrinsic fertility is useless in agriculture (there is no reason to invest in its low return), on ecological grounds such land can certainly be put to productive use so long as the amount of crop extracted is limited to its natural rate of productivity. The reason why the U.S. farmer much prefers to use more fertilizer and less land to obtain a given overall output is quite simple: The economic gain per dollar invested in fertilizer is vastly greater (about fiftyfold or more) than that obtainable from the same investment in land. (See, for example, Headley, Estimating the Productivity of Agricultural Pesticides "Journal of Farm Economics," February 1968, pp. 13-23.) As I took pains to explain in Chapter 5, it is such economic factors, not the demand for food imposed by a growing population, that force the Illinois corn farmer to operate at levels of fertilization that are so high as to result in water pollution. Of course, all of the foregoing rebuttal is hardly needed to establish the weakness of Ehrlich and Holdren's argument that intense fertilization is forced by the need to increase production. Sufficient evidence is the simple fact that in order to maintain farm prices, production is limited by government fiat.

As to Ehrlich and Holdren's effort to involve "diminishing returns" in my discussion of labor productivity (p. 15), this is again a case in which they are unable to grant me the right to write my own book. They assert that I have done some kind of violence to the significance of "diminishing returns" by restricting "attention to productivity" and "since this quality has increased since 1956, he [Commoner] argues, diminishing returns have not been important."

A False Description

This is, again, a false description of my position, since I do not, in fact, anywhere in "The Closing Circle," discuss the general problem of "diminishing returns." Although this criticism is therefore irrelevant, it is perhaps worth taking this opportunity to note that Ehrlich and Holdren happen to be wrong about the effects of diminishing returns on environmental impact, or at least on that quite major part due to industry.

Ehrlich and Holdren assert that nonlabor (e.g., energy) aspects of productivity have in fact decreased (i.e., that goods produced per unit energy used have declined as production levels have risen), thereby establishing their notion of the effect of "diminishing returns." As it happens, since publication of "The Closing Circle" the relevant data (not cited by Ehrlich and Holdren) have now been computed (Commoner, "Power Production and Human Welfare," December 1971). They show that for all U.S. industry in 1947, about $5.40 of value was added per million British thermal units (BTUs) of fuel expanded (expressed in 1958 dollars), to industry as a whole; in 1967 about $7.30 of value was added per million BTUs of fuel expended. Clearly, despite the large increase in total production (value added increased by about 228 per cent from 1947 to 1967), the efficiency of use of fuel in industrial production has **not** declined but has **increased.** There is no sign of a "diminishing returns" problem here, and no evidence of the exacerbation of resource use which, Ehrlich believes, derives from high levels of production. Or consider the use of water by industry: in 1954 gross water use was about 21 billion gallons, the index of production was 86, and value added amounted to about $130 billion. In 1968 these figures were, respectively, about 36 billion gallons of water; index of production, 160; and $225 billion. Thus the efficiency of water use, measured as production index/water use was 4.1 in 1954 and 4.2 in 1968; the comparable measure, value added-water use, changed from 6.2 in 1954 to 6.3 in 1968. Again, there is no sign of "diminishing returns." Only in one aspect of industrial production — electric power — do we find a decline in efficiency of use: In 1946 U.S. industry produced $0.75 per kilowatt-hour of electricity used; in 1967 it produced $0.45 per kilowatt-hour. However, this is by no means evidence of "diminishing returns," for the drop in efficiency is clearly not associated with high levels of industrial production. Rather the decline in efficiency is due to the progressive displacement, since 1946, of power-thrifty industries (such as wood products) by power consumptive industries (such as aluminum production), and by the displacement of labor by power, resulting from increased automation.

In sum, the available evidence regarding U.S. industry, which is after all a major source of environmental deterioration, quite thoroughly invalidates the Ehrlich and Holdren notion that rising population and demand have led to decreased efficiency of resource use and therefore have exacerbated environmental impact through the mechanism of "diminishing returns."

Non-Pollution Aspects Neglected

Ehrlich and Holdren assert that "Commoner implicitly assumes that environmental deterioration consists only of pollution; this oversimplification leads him to discuss the environmental crisis as if it had begun in the 1940s."

This statement is incorrect, for I state (pp. 126-127):

> Certain human activities — agriculture, forestry, and fishing — directly exploit the productivity of a particular ecosystem. In these cases, a constituent of the ecosystem that has economic value — an agricultural crop, timber, or fish — is withdrawn from the ecosystem. This represents an external drain on the system that must be carefully adjusted to natural and man-made inputs to the ecosystem if collapse is to be avoided. A heavy drain may drive the system out of balance toward collapse.

> Examples include destructive erosion of agricultural or forest lands following overly intense exploitation or the incipient destruction of the whaling industry due to the extinction of whales.

In addition to the above, a detailed description is provided (pp. 33-39) of how environmental distress may be generated in natural processes by perturbations (for example, the fluctuation of the lynx and rabbit populations) that have nothing to do with pollution.

A Tour de Force

Thus, as in the previous matters, Ehrlich and Holdren have misstated my position. In this case, however, their technique of criticism is carried one step further. Having asserted that I equate environmental degradation with pollution, they then proceed to quote the above passage from "The Closing Circle" which belies that assertion, adding: [he is] apparently unaware that he is contradicting himself." One can almost admire this tour de force: A false statement is made, and then the evidence which shows that it is false is cited as proof of self-contradiction!

There follows a lengthy discussion of various instances of environmental damage resulting from human activities before the 1940s. All this is banging on an open door, for as indicated above, I am aware that overexploitation of agricultural or forest lands can indeed lead to environmental degradation.

In the course of this discussion, however, we are treated to the following: "he [Commoner] does not seem to be aware that the reduction of the diversity of life and then of the complexity of those systems may pose the most lethal threat of all." And Ehrlich and Holdren remind me that "it is the complexity of the natural ecosystems that is primarily responsible for their stability." Yet on page 38 of "The Closing Circle" one finds the following:

> The amount of stress which an ecosystem can absorb before it is driven to collapse is also a result of its various interconnections and their relative speeds of response. The more complex the ecosystem, the more successfully it can resist a stress. For example, in the rabbit-lynx system, if the lynx had an alternative source of food they might survive the sudden depletion of rabbits. In this way, branching — which establishes alternative pathways — increases the resistance of an ecosystem to stress. Most ecosystems are so complex that the cycles are not simple circular paths, but are crisscrossed with branches to form a network or a fabric of interconnections. Like a net, in which each knot is connected to others by several strands, such a fabric can resist collapse better than a simple unbranched circle of threads — which if cut anywhere breaks down as a whole. Environmental pollution is often a sign that ecological links have been cut and that the ecosystem has been artificially simplified and made more vulnerable to stress and to final collapse.

Ehrlich and Holdren then go to great lengths to attempt to establish that "far from starting in the 1940s, as Commoner implies, serious ecological harm has accompanied man's activities ever since the agricultural revolution of some 10,000 years ago." Nowhere in "The Closing Circle," or in any other writings, have I held that "serious ecological harm" has occurred only since 1940. The instances of man-made ecological disasters, such as the Mediterranean desert areas that Ehrlich cites, are, of course, well known, even to me. Why then have I failed to discuss these matters in "The Closing Circle?" Because, by design, it is **not** a treatise on ecological degradation in general. Rather, as directly stated in the opening chapter of the book, I was concerned with the meaning of "the environmental crisis," which I defined, as it was during Earth Week, as concern with the deteriorating quality of the present environment. And in characterizing the environmental crisis I did, indeed, concentrate on those aspects of deterioration represented by the accumulation of pollutants, rather than on overgrazing and similarly old-fashioned ecological sins, for I believed that these were the more relevant features of the crisis. In this I was not alone. Here is Ehrlich's own characterization of the environmental crisis: "Too many cars, too many factories, too much detergent, too much pesticide, multiplying controls, inadequate sewage treatment plants, too much carbon dioxide. . ." ("The Population Bomb").

Ehrlich and Holdren in their review continue: "Having assumed that man's adverse impact on his environment was negligible before 1940, Commoner then alleges that 'pollution levels' increased by an explosive 200 to 2,000 per cent between 1946 and 1968. . . ." This statement quite neatly reverses the actual logic of my position. An examination of "The Closing Circle" will show that there is no discussion of the time of origin of the environmental crisis until page 127. There I state:

> Our task, then, is to discover how human activities generate environmental impacts. . . . As a first step we might look at the history of the pollution problem in a highly industrialized country such as the United States . . . a rather striking picture does emerge from the data that are available: **most pollution problems made their first appearance, or became very much worse, in the years following World War II.** (Emphasis in original.)

There then follows a paragraph giving the actual numerical data which support this conclusion (for example that phosphate entering surface waters in the United States from municipal sewage somewhat more than doubled in the 30-year period 1910 to 1940 and increased sevenfold in the succeeding 30 years).

Their Own Invention

Thus, my discussion of the relative environmental impact of human activities before and after World War II did not — as Ehrlich and Holdren state — deal with "man's adverse impact on his environment," but only with "most pollution problems." Moreover, my "assumption" concerning the prewar condition did **not** precede — as they claim — my statement regarding the postwar rise in pollution levels. Indeed I make no assumption at all, but simply show from actual data that postwar pollution levels have indeed increased by 200 to 2,000 per cent — a factual assertion which Ehrlich and Holdren do not attempt to deny.

Thus Ehrlich and Holdren first complain that I have chosen to discuss the environmental crisis in terms of current pollution problems, rather than including other aspects

of man's overall impact on the environment (they neglect to point out that Ehrlich has himself done the same); they then falsify my actual position regarding pollution problems in the United States into precisely the position which they accuse me earlier of avoiding, asserting that I have "assumed that man's adverse impact on the environment was negligible before 1940. . . ." What they are criticizing here is their own invention.

Demographic Transition

Ehrlich and Holdren criticize my view that the demographic transition is a reasonable means by which improvements in living conditions can lead, by voluntary control of fertility, toward a balance between death rate and birthrate. They suggest that I am naive to regard the demographic transition as a realistic means of achieving a balanced population by voluntary action rather than by coercion. It should be noted here that the crucial difference between my view of population control and Ehrlich and Holdren's is precisely at this point — that is, the difference between self-made decisions to limit fertility which people reach because they have confidence in their future, and Ehrlich's often-expressed view that "persuasion" and ultimately coercion are needed.

There is a curious contrast between Ehrlich and Holdren's derogation of the demographic transition and the view expressed earlier in Population-Resources-Environment by Paul R. Ehrlich and Anne H. Ehrlich::

> . . . as the industrial revolution progressed, another significant trend appeared. Birthrates in Western countries began to decline . . . this was the start of the so-called "demographic transition" — a falling of birthrates which has characteristically followed industrialization. . . . By the 1930s, decreases in birthrates had in some countries outpaced decreases in death rates. By then the combined death rate of Denmark, Norway and Sweden had decreased to 12 per thousand, but the birthrate had dropped precipitously to 16. Populations in the industrial countries of Europe in the 1930s were in a demographic situation that, if continued, would have led to population declines. True birthrates were still above death rates, but they would not have stayed that way for long. . . . However, stimulated by improving economic conditions and World War II, birthrates rose again during the 1930s and 1950s. European growth rates have generally averaged between 0.5 and 1.0 per cent since the War.

This passage clearly presents the demographic transition as a basic, first-order phenomenon that is secondarily affected by fluctuations induced by a variety of social and economic factors. This is, of course, precisely my own position. (Despite Ehrlich and Holdren's derogation of "Commoner's beliefs" on this matter I am quite aware, as most people are, that birthrates in most developed countries are still somewhat in excess of death rates — a fact which is evident in all my writings, including "The Closing Circle.") As to the secondary fluctuations, it is now evident that there is in the United States a strong trend toward declining birthrates which has been underway for a decade or so and is continuing. Not even Ehrlich has argued, to my knowledge, that this decline is due to "persuasion" — since it began long before the recent public campaigns for "zero population growth." It would appear, then, that current social and economic trends are being translated, voluntarily, into a declining birthrate which is rapidly bringing the United States birthrate to the replacement level — that is, the level at which population will be constant. Of course, it is totally unrealistic to expect a zero growth rate to hold **at all times.** Given the complexities of the human condition, what can be expected is only a long-term zero growth rate with shorter-term fluctuations above and below that level.

In sum, my view of the nature and significance of the demographic transition is quite in keeping with the available data and, curiously enough, agrees with the view expressed elsewhere by Ehrlich himself.

The rest of the Ehrlich and Holdren criticism of my position on the population problem is only a recitation of unsupported assumptions about the means whereby underdeveloped countries might achieve population balance, and about my views on this matter. As to the former, they assume that a demographic transition would not "solve the problem in time," because it might take more than a generation; but they offer nothing to support their notion of how long a time we have to bring the world into approximate ecological balance without serious risks of large-scale catastrophe. In fact, elsewhere Ehrlich has indicated that it is already "too late." Thus, in the revised edition of "The Population Bomb," published in 1971, he asserts that "the battle to feed all humanity is over . . . at this late date nothing can prevent a substantial increase in the world death rate." And to make matters perfectly clear he was quoted in an interview as saying: "When you reach a point where you realize further efforts will be futile, you may as well look after yourself and your friends and enjoy what little time you have left. That point for me is 1972." ("Look," April 21, 1970.)

Catastrophe Inevitable?

In a way this statement provides the clearest expression of the gulf which separates Ehrlich's view of the global population problem and my own. He takes the position that ecological catastrophe is inevitable if the peoples of the developing countries — or, for that matter, of the industrialized ones — are left to regulate population growth by their own self-determined actions, following the course taken by the developed countries (as described by the demographic transition). These actions include "improvement of living conditions, urgent efforts to reduce infant mortality, social security measures, and the resultant effects on desired family size, together with personal, voluntary contraceptive practice" ("The Closing Circle"). According to Ehrlich, population growth is governed by the automatic mechanism made famous by Malthus — the inescapable clash between the self-accelerating rate of reproduction of the human population and the slower growth of the resources, especially food, needed to support it. Ehrlich believes, apparently, that human society is today in the grip of an automatic clash between population and resources, and that no self-motivated human effort (either to improve the availability of resources or voluntarily to restrict fertility) can possibly prevent catastrophe.

My view is different. I believe that population control is generated within a given society by a series of complex interactions in which improved well-being and social security motivate people to reduce fertility voluntarily and that, subject to short-term fluctuations, this phenomenon (demographic transition) can achieve long-term population stability. Ehrlich's view stresses the inevitable clash between two **biological** processes: growth of population and the slower increase of food supply. My view stresses the effects of **social action** to improve living conditions; such action can affect both personal motivation for reduced fertility and the availability of resources (For example by means of social action to eliminate exploitation of resources for private profit or to eliminate waste of resources even when it is 'cheaper" to waste them).

To put the difference between us more bluntly. This, after all being the year 1972, Ehrlich's advice is to "look after yourself and your friends and enjoy what little time you have left." While I believe that, today and into the future, human society (as distinct from "yourself and your friends") can be organized as a stable, ongoing, humane civilization — by powerful, sustained social action to remove the economic and political barriers that keep people and whole nations in poverty.

Relevance to Political Action

As I pointed out in "The Closing Circle," none of the foregoing positions are scientific estimates; rather, they are political judgments. I find it difficult to believe that the intensity of the conflict on scientific matters which is expressed in Ehrlich's and Holdren's review is accountable by a straightforward disagreement, on their part, with my scientific data and analyses. Surely, if there were nothing more to the conflict than their disagreements with my mathematical techniques and analytical procedures, it would have been fairly simple, as can be seen from the above discussion, to resolve nearly all of them by a reading of my RFF paper, or by a more careful reading of "The Closing Circle." Given the gross misconceptions of my analysis which encumber the Ehrlich and Holdren review, I must conclude that they failed to take this rudimentary step toward resolving the disagreement. Thus I am compelled toward the view that Ehrlich and Holdren are less concerned with resolving the scientific differences between us than they are with the possibility that "uncritical acceptance of Commoner's assertions will lead to public complacency regarding both population and affluence in the United States." Apparently, Ehrlich is so intent upon population control as to be unwilling to tolerate open discussion of data that might weaken the argument for it.

Open Debate

In this connection, the Ehrlich and Holdren covering letter raises an issue which I regard with the utmost seriousness. This relates to the notion which they advance that an honest, open scientific debate can be "counterproductive for the goals which we all share." My goal in environmental matters is to encourage strong, informed public action toward the improvement of environmental quality, by methods which — through appropriate political mechanisms — **are the choice of the American people.** This requires that the people of the United States become familiar with the basic facts about environmental deterioration, become aware of alternative interpretations of these facts (including the resultant uncertainty which attaches to them), and then undertake the difficult task of weighing this information (and its inadequacies and uncertainties) against their own ethical, social and political beliefs in order to determine what ought to be done. Given this goal, there is no conceivable way that a "debate on which factor in the environmental crisis is 'most important'" can be "counterproductive." Suppose, for the sake of argument, it turns out on examination, that no one factor is "most important"; surely an open debate between two scientists — one of whom is convinced, nevertheless, that some factor is indeed "most important," — can only illuminate the truth and increase public understanding of it.

What is so curious about Ehrlich's position is that, on the record, it is he, not I, who first took a public position as to which factor is "most important" in generating environmental degradation. It was, after all, Ehrlich who in 1968 — well before I undertook to analyze the relative significance of the several factors — in "The Population Bomb" asserted that "the causal chain of the deterioration [of the environment] is easily followed to its source . . . too many people." When, later on, I found from analysis that the technological factor played an important role in environmental deterioration, and said so openly, Ehrlich acknowledged that **both** factors are important, and indicated that he would be happy if we both agreed to keep to that position without raising any questions about the **relative** importance of the two factors.

In other words, so long as I refrained from questioning the necessity of population control in a campaign for environmental quality, Ehrlich was prepared to accept my position without debate. He urged silence only when I began to examine precisely this question, in the belief that the public needed to know the relative importance of the several factors in order to decide where an attack on environmental issues is best directed.

Two Alternatives

In my view, the environmental crisis involves very grave and complex social problems that ought to be resolved by public decision and not determined by the force of private agreements among scientists as to which issues are to be openly debated and which are to be hidden from public view. As I have pointed out in "The Closing Circle," these issues confront the American people with two alternative (but not mutually exclusive) paths toward a solution: a reduction in the population sufficient to render tolerable the environmental degradation due to ecologically faulty technology, or social action to correct counter-ecological technologies and to change the economic mechanisms which generate them. Population control (as distinct from voluntary, self-initiated control of fertility), no matter how disguised, involves some measure of political repression, and would burden the poor nations with the social cost of a situation — overpopulation — which is the current outcome of their previous exploitation, as colonies, by the wealthy nations. And as I have also taken pains to point out, the alternative means of resolving the environmental crisis by improvement of productive technology would require sweeping and basic changes in the private enterprise system in a nation such as the United States. Now, I know of no scientific principle which can tell us how much to rely on population control and how much on technological change (and the required economic controls) in order to reduce environmental impact. The choice between these alternative paths is clearly a political one, not a matter of science.

Like everyone else, I have the right as an individual to choose between these political alternatives. My own choice is, I believe, made clear in "The Closing Circle." But more important, I have shared with my readers the data and analyses which have enabled me to make that choice, and I have urged them to make their own. For in a democracy this decision belongs in the hands of every citizen, and ought not to be preempted by one or two scientists, or even a committee of them. Without the information that the scientist can provide, the citizen cannot make his own decision and becomes the ready victim of those who would decide for him. I regard all efforts to deprive the citizen of this right — whether by a government's rule of secrecy or by a scientist's proposition for silence — with equal abhorrence.

There is, of course, an important relationship between such political decisions and the relevant scientific information. Scientific evidence is essential to evaluate the consequences of the alternative decisions. Data are required to answer the questions: What are the relative influences of population size and defective technology on environmental impact? How much would population size, or the ecological impact of present technology need to be changed in order to accomplish a given reduction in environmental impact? What are the economic and social consequences of curtailing population as compared to the alternative of changing technology?

As I have often stated, scientists have a grave responsibility to help find the answers to these questions and to bring them before the public, so that, thus informed, **the public can make its own choice between the political alternatives.** "The Closing Circle," like most of my writing, is an effort to carry out this obligation. In it I offer to the public the knowledge that I have acquired about the origins of the environmental crisis, about the relative importance of the several factors, and about the economic and social consequences of efforts to control them. On scientific grounds, which — despite Ehrlich's and Holdren's intemperate onslaught — remain valid, I show that environmental degradation is far more responsive to technological improvement than to population control.

Right of the Public

Had I agreed to the urging of Ehrlich and his emissaries to refrain from a discussion of such scientific evidence on the relative importance of population growth and of technology, I might have escaped their critical wrath. But this act would have violated my duty to science and to the public. It would have eroded the only means by which the scientific community can approach the truth — open discussion. It would have eroded the only means, in a democracy, by which the public can exert its political will — to be informed. And need we be reminded, in the period of the Pentagon Papers, that when those in power wish to protect their policies from public judgment they cover them with a cloak woven out of private agreements to be silent lest "counterproductive debates" ensue.

In writing "The Closing Circle," I have chosen to speak out about the scientific evidence on the origins of the environmental crisis; the alternative courses of action that might resolve it; and the right of the public, rather than propagandists or scientists, to make that choice. This was my duty to science, to the people whom science must serve, and to the survival of a civilized society.