The Hysteria Against the Case

Recently Stanford physicist Dr. Sidney Liebes, Jr. proposed an interesting exhibit for the next Earth Day — a graphic display to illustrate the course of evolution. He suggested [1] that the display be 5001 feet long, just under one mile. The starting point would be labelled 5000 feet from the present, representing the formation of the Earth, 5 billion years in the past. Each foot of the display would then represent one million years. The first 4000 feet would represent the eons when no multicellular organisms existed. The age of the dinosaurs would stretch from 200 to 60 feet from the present. Within 6 feet the first "men" would appear. The agricultural revolution would occur about one-tenth of an inch from the present; the year 2000 would be only five ten-thousandths of an inch in the future.

To quote Dr. Liebes, "A human population curve might be plotted, scaled at one vertical foot per 100 million human beings. One million years ago (one foot into the past) the population curve would be one-hundredth of an inch high. Ten thousand years ago (0.1 inch into the past) the curve would be half an inch high. At the time of Christ, 0.02 inch into the past, it would be two feet high. In April 1971 it would be 37 feet high and climbing vertically at a rate of some 37 feet for each horizontal one-half of a thousandth of an inch."

Just one more way to dramatize the unique situation in which *Homo sapiens* finds itself? Perhaps. But I think it also contains a clue to a problem which has concerned my colleagues and me a great deal lately. Attempts to focus public attention on the seriousness of the environmental crisis has aroused a heavy "backlash" from certain politicians, labor unions, industries, a wide variety of scientists and technologists employed by government and industry. Their motives may be less than noble but at least they are understandable. Interestingly enough, however, some of the most ill-informed and vituperative opposition has originated among those who have no clear pecuniary motive in promoting environmental deterioration. In particular, biochemists,[2] physicists,[3] demographers,[4] chemists,[5] and economists [6] have stepped forward to condemn ecologists for "exaggerating" mankind's peril. The whole backlash is typified by a blithering unsigned editorial in *Nature*, entitled "The Case Against Hysteria".[7]

It would be simple to write off their attacks as being simply a function of jealousy at the attention suddenly showered on ecologists, since this is obviously involved in several cases. But I cannot believe that otherwise competent scientists would publish pronouncements in areas so clearly outside their competence *unless they actually felt that they understood what they were writing about.* Few people are anxious to appear foolish in print. The hypothesis that these colleagues don't realize that they are out of their depth is further supported by a characteristic of their writings: rarely is there any sign that their statements have been reviewed prior to publication by anyone even remotely familiar with the technical literature of ecology (which I define broadly here to include evolutionary biology, biosystematics, and so forth).

Which brings me back to the Liebes display. Dr. Liebes clearly possesses something universally absent from the spokesmen of what I will call the *scientific backlash.* He has an evolutionary perspective. Putting man's present behavior into the context of evolutionary time in itself should be enough to bring most of these spokesmen to a reconsideration of their views. Can they really view with equanimity a human population explosion occupying only one-tenth of an inch on a 4000 foot scale of life? Can they fail to appreciate the significance of the rise, in a mere instant of evolutionary time, of just one among perhaps 5 million animal species to a position of dominance in the biosphere? Can they, for instance, remain undisturbed while that species exhausts the Earth's entire store of liquid petroleum in less than one thousandth of an inch?

The answer is, sadly, that they probably can, and we evolutionary biologists must share a large part of the blame. We have consistently failed to develop a broad evolutionary perspective among scientists in general; indeed among biologists in general. This has permitted many scientists to view the population-environment crisis as a phenomenon that sprang *de novo* from the ruins of World War II.[8] This narrow perspective helps generate the belief that rather minor changes in human behavior can get us through the crisis. Install a smog control device here, a breeder reactor there, farm the Amazon Basin, pass out contraceptives — but never promote a revolutionary change in the behavior of an entire species.

Along with this lack of perspective three sources of misunderstanding seem to be at the root of most of the scientific backlash. The first is a confusion of pollution with environmental deterioration. This is closely linked with ignorance of the critical role of agriculture in the latter. The second is a series of misapprehensions about the so-called "demographic transition". And, finally, there is a lack of grasp of the consequences of exponential growth itself.

Environmental Deterioration

The confusion between pollution and environmental deterioration is perhaps best illustrated by the backlasher's "London Smog Defense". The argument is made that ecological disaster can be avoided by the kind of steps which have made the air in London less opaque since the great smog disaster of 1952. John Maddox makes this point.[9] He points to lower levels of particulates and sulfur dioxide in some urban environments in 1969 and 1970 than were present in 1962 and 1959. He then concludes: "what these and other statistics imply is that pollution and other assaults on the natural environment are not nearly as novel as those who have recently discovered them pretend." Needless to say, ecologists are only too aware as Maddox apparently is not, that serious environmental deterioration dates at least back to the agricultural revolution.[10]

Furthermore, the relatively novel elements of air pollution are neither particulates nor sulfur dioxide but nitrogen oxides and hydrocarbons (the sources of photochemical smog), radioactive materials and a wide variety of molecules synthesized by man which are truly novel in the sense that organisms have no previous evolutionary experience with them. And, from the point of view of global ecology, urban pollution may not be as important as the general dust load, especially from agriculture, which may ultimately have a serious effect on climate if population growth continues. But, more important, air pollution is by its nature the most readily reversed of pollution problems. In a sense we must continue to expend energy to keep the pollution airborne. If we stop pouring wastes into the atmosphere, most air pollution will settle out and convert itself automatically into soil and water pollution. From the point of view of man's long term tenure on Earth, air pollution may prove to be a trivial matter compared to, say, the reduction of organic diversity — unless a catastrophic climatic change or reduction in the ozone screen is triggered.[11]

What the producers of the scientific backlash fail to grasp is that man depends on natural ecosystems for the operation of the chemical cycles which support our food production, for the control of most potential pests of our crops, for the maintenance of the quality of the atmosphere, and for the storage of the genetic information from which all new strains of crops, biological pest controls, and antibiotics (among other indispensables) must come. We depend on those systems for virtually the entire commercial fisheries yield — the source of a substantial proportion of mankind's desperately needed supply of high quality protein. And one of the major factors in the stability and thus continued functioning of those systems is their complexity.

Unfortunately a vast spectrum of human activities, rapidly increasing in scale, has led directly and indirectly to the reduction in size or extinction of populations of many organisms, and to the extinction of some species. The loss of diversity has reduced the complexity of natural ecosystems and thus also reduced their stability. More and more energy is being diverted from the maintenance of complex networks involving millions of other kinds of organisms to the exclusive support of *Homo sapiens*. A side effect of this is a general repatterning of our life support systems so that, increasingly, energy is flowing through the simple food webs of decay rather than through the complex and relatively stable herbivore-carnivore webs. As George Woodwell [12] put it, "the longterm trend of evolution toward building complex, integral, stable ecosystems is being reversed". Simultaneously, man also has been further simplifying the artificial ecosystems which he has created in the course of practicing agriculture. In addition, all current trends indicate a pattern of rapidly accelerating simplification. The consequences of this can only be predicted in a general way — a lowering of the carrying capacity of the Earth for human life.

Agriculture itself is central to the problem of ecosystem simplification. As the human population has grown, more and more land has been brought under cultivation. Generally this has meant the replacement of relatively complex and stable forest and grassland ecosystems with stands of one or a few kinds of plants, or the replacing of a balanced community of herbivores and predators with herds of domestic animals. Very often the instability of these systems has resulted in their collapse. Sometimes the collapse was followed by at least partial restoration of diversity. For instance, tropical forests partially reclaimed overworked milpa systems when the classic Maya civilization disappeared. Sometimes the complexity is not restored, as when faulty irrigation resulted in the desertification of the Tigris and Euphrates valleys.

But, in any case, man tends to pay a price when he is not successful at maintaining the stability of his simple ecosystems. Consider the results of an early "Green Revolution", the introduction of the potato to Ireland. The productivity of the potato provided the basis for an increase in the Irish population from about 3 million to 8 million people.[13] Unfortunately, as has frequently occurred, expansion of food supplies did not result in a general rise in the standard of living. Population increased along with food supply, and improvement in per capita supplies was limited. Then in 1845–48 the inevitable happened: the unstable potato ecosystem collapsed. A fungal blight invaded the fields and destroyed most of the crop, producing one of history's great disasters — the Irish Potato Famine. In a four year period about 1.5 million Irish men, women, and children starved to death. An additional million or so were forced to emigrate, and millions of others underwent great suffering and deprivation. The entire horror could be traced to the inherent instability of a simple ecosystem.[14]

Man is forced to pour large amounts of energy into modern high yield agricultural ecosystems in order to stabilize them. This energy is provided mostly as fossil fuels used to manufacture and transport pesticides and fertilizers, to construct and operate irrigation systems, and to cultivate the crops. The productivity of modern agricultural systems is, of course, based on the success of plant breeders at producing genetic strains which, given the proper "inputs" to the agricultural system, produce very high yields per acre. Under the related pressures of economics and population growth, a relatively few high-yield strains of crops are now rapidly replacing a rich diversity of more traditional strains. This is resulting in a further simplification of ecosystems, through the loss of genetic diversity in crops.[15] Should enough of that diversity be lost, man could well be out of business of high-yield agriculture forever. There is, of course, no such thing as a strain of plants permanently "resistant" to all the organisms which attack it. Plants, like other organisms, are involved in a continual "coevolutionary race" [16] with their parasites and predators. Unless the genetic variability necessary for natural selection to occur is maintained, new defenses cannot be evolved to meet new attacks. The race is lost and extinction results.

This rather important point is lost on those ignorant of evolutionary ecology. For instance, Maddox writes,[17] "In any case, damaging though plant diseases can be to harvests, there is no more reason to fear that they need go uncontrolled than there is to fear that infectious diseases that sweep the human population like medieval plagues will again be a hazard to human survival." If Maddox understood more of ecology, genetics, and epidemiology, he would know that there is ample reason to fear both.

The Demographic Transition

In fairness to those creating the scientific backlash it must be noted that most realize that human population growth must stop eventually. And, of course, the demographers in the group know very well how far off that "eventually" is likely to be if a halt is to be achieved by reduction in birth rates rather than a rise in death rates (their complacency about the current state of affairs seems rooted purely in their misunderstanding of the physical and biological world). But a major source of misapprehension among technologists relates to ideas about automatic (and relatively rapid) control of population. A typical view is that expressed by that most un-ecological of gentlemen, Buckminster Fuller, in a poem he sent to Senator Edmund Muskie: [18]

> "As world industrialization will be completed
> By twentieth-century's end
> The ever-diminishing birth rate
> Of the industrial countries
> Will bring about world population stabilization
> By 2000 A.D."

Skipping the small point that world industrialization by the year 2000 is clearly not possible (indeed it may never be), it must be pointed out that even if reproduction around the world dropped to the replacement level *now*, population growth will continue until nearly the middle of the next century! Although few of the other backlashers can be accused of making statements quite that absurd, some of them have come pretty close. Maddox writes,[19] ". . . in any case there are already signs that the most rapidly growing populations in the world will in the next few decades be held in check by natural social forces — not just the machinery of contraception — which have in the past century given Western Europe and North America a measure of demographic stability." His general confusion about elementary demography is further illuminated by the incredible statement,[20] "Just what is meant by demographic stability? The slogan 'Zero Population Growth' is not much help, as can be told from what is now happening in Western Europe. The number of births each year is for practical purposes the same, but the population continues to grow." Maddox follows this with a discussion which shows that he does not know the difference between a stable population (one with a stable age distribution), a stationary population (one where crude birth rates and death rates are in balance, producing ZPG), and a population with a net reproductive rate (NRR) equal to one (where each generation of women is just replacing itself). He also makes the most elementary error of discussion reductions in the numbers of births without simultaneously analyzing trends in death rates, and even then carefully selects his data. Thus from his table showing "Decreasing numbers of births in selected countries", a naive reader might assume that the population explosion in Africa was about over, when in fact anticipated declines in death rates there may result in annual growth rates in the vicinity of 4% in the not too distant future.

Maddox's discussion is capped by the statement [21] "Although the demographic transition has only just begun in large parts of the developing world, there is every reason to expect that it will produce demographic stability entirely comparable with that which now exists in Western Europe and elsewhere in the industrialized world." If it only were that simple! A casual look at the statistics [22] will reveal the most fundamental flaw in this thesis, as he could have found out. *Even after the completion of the demographic transition, the developed countries still have high growth rates.* 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. In the industrial areas of the world the transition was essentially over by 1940.[23] A quarter of a century later, birth rates in Europe, North America, the USSR, Australia, New Zealand and Japan were still, on the average, almost double the death rates. This is, to varying degrees, a result of the age composition of the population as well as of excess fertility. Nonetheless an examination of net reproductive rates [24] from the 1920s to today in the industrialized nations gives little reason to assume there is an automatic process of population regulation leading to stationary populations. Indeed it seems at least as likely, assuming death rates did not rise, that industrial nations could fluctuate over the long term at growth rates of about 0.5–1.0% annually, doubling their populations every century or so.

Let's examine, however, what *would* happen if demographic transitions started immediately in underdeveloped countries (UDCs) and followed a pattern similar to that experienced by the developed countries (DCs) in the past. It would be perhaps eighty years before one could expect growth rates in underdeveloped countries to be in the relatively low range now found in developed countries.[25] To see that such a demographic transition in the UDCs cannot stop population growth without a substantial delay, 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").[26] He calculated, in essence, what would happen if family size dropped precipitously in UDCs so that by around the year 2000 reproduction had reached replacement level. If that should occur (and no competent demographer thinks there is the remotest possibility of it occurring) the size of the population of a typical UDC would be 2.5 times its present size when it eventually stopped growing.[27] That means, for instance, that the population of India would be some 1.4 *billion* people, that of China perhaps 1.7 *billion*, Brazil's 240 million, Indonesia's 310 million, and so on. *Note that these are estimates based on wildly optimistic assumptions about population control.* Since most underdeveloped nations are in the tropics, one need only mesh this information on the momentum of population growth with some knowledge of the problems of agriculture in the tropics [28] to see that the invocation of the demographic transition as a "cure" is a tragic mistake.

Maddox is not alone in clinging to the demographic-transition-is-a-panacea view. Indeed he may have picked it up from Barry Commoner's book, *The Closing Circle*, which he strongly attacks. If so, it is poetic justice, since Commoner's treatment of the demographic transition is a low point in a volume not outstanding in its scientific competence. Commoner not only misinterprets the demographic transition, he also perpetuates the myth that population control soon can be achieved by, in part, dropping infant mortality rates. 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.[29] Moreover, there is virtually no evidence that depressing infant mortality rates anywhere would result in lower birth rates until at least a generation had passed.

In addition it is not at all clear that UDCs would undergo a classic demographic transition, even if they were 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.

Exponential Growth

Finally, there is the problem the backlashers have in coming to grips with exponential growth. They do not comprehend that in a sense the last million years or so of cumulative human population growth will, barring disaster, be duplicated in the next 35 years. When something is growing (or shrinking) exponentially, a constant percentage of its size at the beginning of each successive period is added (subtracted) during that period. When the exponential rate does not change, the growth can be characterized by the doubling time — the period required for the original quantity to double. Thus the human population, now growing at a rate of 2% a year, will have a doubling time of 35 years if that rate remains constant.

This bit of simple arithmetic leads to an important way of looking at various kinds of limits. Suppose that the human population continues to grow at a constant rate of 2% per annum, doubling every 35 years. Suppose also that somewhere there is a limit to this growth, determined by the carrying capacity of the Earth. That is, assume that there is some population size, which if reached in the future will overload the system and result in a catastrophic population crash. Such an assumption should be acceptable to most backlashers, who are willing to admit that population cannot grow forever. An important conclusion follows from these two assumptions. Whatever the overload size is, the population will be only one-half that size a mere 35 years before disaster strikes.

Exponential growth progresses towards limits at an accelerating rate: a long history of growth does not necessarily imply a long future. It is no surprise that many environmental problems are perceived by the naive as having materialized *de novo* in the past few decades. Many of these problems are simply manifestations of exponential growth processes interacting with a series of thresholds. Similarly, recent awareness of impending resource depletion in part reflects exponential shrinkages of reserves in response to exponential increases in demand. For instance, mankind now gathers somewhat over 60 million metric tons of fishes annually [30] from the "limitless" resources of the sea. Many fisheries biologists feel that, in the absence of overfishing and ecocatastrophe, the maximum sustainable yield would be some 100 million metric tons.[31] If that is the case and the human population continues to grow exponentially, per capita yields *must* decline around the year 2000 because another doubling of total catch will not be possible. Suppose, on the other hand, that a yield of 200 million metric tons can be sustained. If exponential population growth persists the decline is postponed a mere 35 years to around 2035. But, of course, it now appears that overfishing and oceanic pollution may prevent us even from approaching the lower figure.

The situation is especially frightening when one considers that recent estimates of the increase of environmental impact (or "ecological demand") are in the vicinity of 5% per annum [32] giving a doubling time of 14 years. If these estimates are correct, the ecosystems of the Earth will not have been stressed to half of their limit until only 14 years before they collapse. In an oversimplified view, if the symptoms of ecosystem malfunctioning of the first Earth Day in 1970 indicated that the systems were absorbing one-half of the impact they were capable of absorbing, then disaster is scheduled for 1984. If one wishes to make an ultra-optimistic assumption, that the systems can absorb more than 30 times as much punishment as they were receiving in 1970, then the ultimate disaster is deferred until 2040 — should ecological demand continue to grow at 5% per annum.

The seriousness of exponentially approaching limits is, of course, exacerbated by the momentum inherent in many current trends. The delays built into any reasonable program to halt population growth have already been mentioned. And apart from those intrinsic in the bottom-heavy age structure of rapidly growing populations, there are, of course, those resulting simply from the time lag which seems inevitably involved in public acceptance of new behavior patterns. The experience of the last few years also shows clearly that sounding of the ecological warning will not be followed by instant and drastic action to avert disaster (remember, a system stressed to only one-half the breaking point may seem in no danger whatever). Furthermore many ecological insults, such as persistent poisons, may do their greatest damage some time after they are released. And worse, many of their consequences may be irreversible. In short, when a system is careening towards ecological oblivion, it may not be possible to turn aside at the last minute, and the point of no return may be passed without being detected.

Conclusion

Whatever time is left, it is clear that our chances of survival will be enhanced if the effects of the scientific backlash can be minimized. On the bright side, numerous natural and social scientists untrained in ecology have educated themselves about the environmental situation and are working with ecologists in attempts to find solutions. The groundswell of informed opinion is impressive — the *SCEP* report, the report of the *Workshop on Global Ecological Problems*, the work of the Meadows' group summarized in *The Limits to Growth*, and the report of the Commission on Population and the American Future all indicate growing organized movement in the right direction.

Furthermore we have one substantial resource which remains largely untapped. I am referring to the thousands of biologists who have the training to understand the current situation. Many individual ecologists, evolutionists, systematists, and so on have been heavily involved in the fight for survival, but they do not make themselves felt *en masse*. All of us have seen numerous examples of pseudo-expertise, some even more blatant than Maddox's masquerade. Consider for a moment the reaction of the American Medical Association to quacks — political pressure, successful lobbying for laws to restrict practice, and so on. But the number of quacks claiming to be ecologists is now myriad, and hardly a murmur is raised. It is high time that population biologists began to speak out as a group, through their professional organizations. It will take time, energy, money, and the recognition that some "unscientific" activities such as public relations are required if a world in which scientific research can be pursued is to persist.

On its one hundredth anniversary it seems unlikely that the Arnold Arboretum will be around to host a bicentennial celebration. It is ironic that those most interested in its well-being are among those most capable of brightening its future. Or perhaps I should say that it is hopeful. Agriculture is moving to the center of the world stage, and plant scientists must move with it. Plant ecologists, geographers, taxonomists, evolutionists, must play key roles in the development of high yield agricultural systems which do not endanger the carrying capacity of the planet. Biologists must strive to find ways to inform the public about the problems of producing food and how these problems relate to the functions of the Earth's ecosystems. I can testify from wide personal experience that many if not most Americans now think their food materializes by magic in supermarkets. If that is still true a decade or so from now it means that institutions like the Arnold Arboretum will have failed when mankind needed them most.

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Notes

1. *Stanford Daily*, April 12, 1972.
2. Philip Handler, President of the National Academy of Sciences,

a highly competent biochemist, has unfortunately attempted to minimize environmental problems. The quality of his thought on ecological matters can be gleaned from his statement (*Science*, vol. 171, p. 148) "The predicted death or blinding by parathion of dozens of Americans last summer must rest on the consciences of every car owner whose bumper sticker urged a total ban on DDT." It is a pity he has not bothered to learn a little more ecology so that he could evaluate pesticide risks not associated with acute toxicity, men with his intelligence are badly needed on the side of survival.

3. Physicist John Maddox has performed the service of presenting in a single book, *The Doomsday Syndrome* (Macmillan & Co., Ltd., London, 1972), numerous examples of the ignorance, sloppy thinking, selected data and outright error which characterizes the worst of the backlash.
4. Demographer Philip M. Hauser perhaps characterizes the best of the backlash among demographers. A distinguished scientist who has been in the forefront of warning about various consequences of the population explosion, he got beyond his area of recognized expertise when he decided that environmental problems were not as serious as ecologists thought they were. A good example of his exposition is "On population and environmental policy and problems" (In: Noel Hinricks, ed., *Population, Environment and People*, McGraw-Hill, 1971) in which he confuses pollution with environmental deterioration and then proceeds to do battle with a series of straw men.
5. The prize here must go to Sir Robert Robinson, Nobel Laureate organic chemist, for a classic blunder. In a letter to the *London Times* (Feb. 4, 1971) discounting the threat of leaded compounds to oceanic plankton, he began: "Neither our 'Prophets of Doom', nor the legislators who are so easily frightened by them, are particularly fond of arithmetic . . ." and then goes on to do some "simple arithmetic" (as he describes it) to show that the dilution of lead in the oceans will be so great that it will remain biologically negligible. Of course his whole exercise in "simple arithmetic" completely misses the point because of, among other things, the phenomenon of biological magnification — a process familiar to most undergraduate students in ecology. I often wonder when some physical scientists will learn that things are a bit more complex in the biological and behavioral sciences. As Garrett Hardin wrote in his brilliant new book, *Exploring New Ethics for Survival* (p. 31), "No great Chemist in the Sky stirs the ocean into one homogeneous soup. Lead enters the ocean in two ways: as fallout from the air, and as dissolved, suspended, and organism-bound matter in river water. River water is lighter than ocean water and tends to spread out on the surface — and it is here that *all* of the photosynthesis takes place. Below about 250 feet there is too little light for photosynthesis. We need to know how much lead there is in the first 250 feet of the ocean.

How much there is in the remaining 13,000 feet doesn't matter much. The 'window' through which lead enters is where the action takes place. The dynamic geometry of the earth system is quite different from that of a Waring Blender in the chemical lab."

6. "The Ecosystem Doom" by Theodore W. Schultz (*Science and Public Affairs, The Bulletin of the Atomic Scientists*, April 1972, pp. 12–17) shows that under some circumstances economists can be reduced to incoherence by the idea that their systems must operate within ecological constraints.
7. *Nature*, Jan. 14, 1972.
8. This view has been made explicit by plant physiologist Barry Commoner in his book, *The Closing Circle* (Knopf, 1971).
9. *Op. cit.*, p. 26.
10. Ehrlich, P. R. and J. P. Holdren, 1972. One-dimensional ecology. *Science and Public Affairs, Bulletin of the Atomic Scientists*, vol. 28 (May).
11. Ehrlich, P. R. and A. H. Ehrlich, 1972. *Population, Resources, Environment*, 2nd Edition, Freeman and Co., San Francisco; *Man's Impact on the Global Environment*, report of the Study of Critical Environmental Problems (SCEP), MIT Press, Cambridge, Mass., 1970.
12. Woodwell, George M., 1970. The energy cycle of the biosphere. In *The Biosphere*, W. H. Freeman & Co., San Francisco, p. 31.
13. Material on the Irish potato famine is from A. H. Barton, 1969, *Communities in Disaster*, Doubleday and Co., New York.
14. An excellent elementary discussion of the relationship between complexity and stability in ecosystems, including some exceptions to the rule, can be found in E. O. Wilson and W. A. Bossert, 1971, *A Primer of Population Biology*, Sinauer Associates, Stamford, Conn. A collection of papers indicating the intricacy of explaining the relationships will be found in *Diversity and Stability in Ecological Systems*. Brookhaven Symposia in Biology no. 22, BNL 50175 (C–56), 1969. Above all, it is well to remember that regardless of explanatory mechanisms the correlation of diversity and stability is well-established empirically.
15. Chedd, Graham, 1970. Hidden peril in the Green Revolution, *New Scientist*, 22 Oct.; O. H. Frankel and E. Bennett, eds., 1970, *Genetic Resources in Plants — Their Exploration and Conservation*. F. H. Davis Co., Philadelphia; H. Garrison Wilkes, 1971, Too little gene exchange. *Science*, vol. 171, p. 955.
16. Ehrlich, P. R. and P. H. Raven, 1965. Butterflies and plants; a study in coevolution. *Evolution*, vol. 18, pp. 586–608; P. R. Ehrlich, 1970, Coevolution and the biology of communities. *Proc. 29th Biology Colloquium*, Oregon State Univ. Press, Corvallis.
17. *Op. cit.*, p. 152.
18. *New York Times*, March 21, 1971.
19. *Op. cit.*, p. 30.
20. *Ibid.*, p. 49.
21. *Ibid.*, p. 55.

22. See either the Population Reference Bureau *1971 World Population Data Sheet,* available from the Bureau, 1755 Massachusetts Ave., N.W., Washington, D.C. or any recent annual volume of the *United Nations Demographic Yearbook.*
23. Coale, Ansley, J., 1969. The decline of fertility in Europe from the French Revolution to World War II. In S. J. Behrman and Leslie Corso, Jr., eds. *Fertility and Family Planning,* pp. 3–24. 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. Most of those countries have had low birth and death rates since the 1920's, and now have birth rates well above 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 in North America was 18 and the death rate was 9. Some demographers feel, even though there is no evidence for it, that somehow the demographic transition is an automatic process leading to a stationary population, and the older literature on animal population dynamics also is replete with such fanciful ideas. Even if this were the case, the obvious long lag-time would make depending on such processes a dangerous policy at best.
24. NRR is a measure of whether or not a population will be growing, stationary or shrinking — *when and if* the age composition stabilizes, and *if* age specific vital rates remain constant. See, for example, Nathan Keyfitz and Wilhelm Flieger, 1971, *Population Facts and Methods of Demography.* W. H. Freeman and Co., San Francisco, p. 55.
25. See, for example, Donald J. Bogue, 1969, *Principles of Demography,* Wiley, N.Y., fig. 3–4, p. 59.
26. On the momentum of population growth, *Demography,* vol. 8, pp. 71–80, 1971.
27. It is important to remember that in a young, growing population, achievement of replacement reproduction (NRR = 1) does not lead to a stationary population (ZPG) until many decades later. For instance, even if the U.S. reaches NRR-1 this year, it will be well into the next century before our growth stops. (See Tomas Frejka, 1968. Reflections on the demographic conditions needed to establish a U.S. stationary population growth. *Population Studies,* vol. 22, p. 379–397.)
28. A fine, concise treatment of the problems of tropical agriculture is "The unexploited tropics" by Daniel H. Janzen (*Bull. Ecological Soc. of America,* Sept. 1970, pp. 4–7.)
29. This conclusion has recently been confirmed by the computer simulation work of Donella Meadows at M.I.T. based on data from villages in India.
30. Food and Agricultural Organization of the United Nations (FAO), 1971. *The State of Food and Agriculture,* p. 8.
31. Ryther, J. H., 1969. Photosynthesis and fish production in the sea. *Science,* vol. 166, pp. 72–76.
32. *SCEP,* pp. 118–119.