PESTICIDES: A HAZARD TO NATURE'S EQUILIBRIUM

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MY ASSIGNMENT is to deal with pesticides as a threat to nature's equilibrium. Others have told what is good about pesticides, and I shall not try to defend them further. Neither shall I consider the unfortunate side effects of pesticides on esthetic grounds, nor the poisoning of man, domestic animals, and game. These effects could, at least in theory, be prevented by careful and responsible use and by more thorough advance testing of these preparations than is now the practice. I wish instead to consider the more fundamental problems that arise from the broadcasting of toxic substances over the habitable and arable parts of the earth. I shall not try to promote the concept that nature is actually steady, in a state of equilibrium or balance, but I will suggest that there is stability in the composition and functioning of natural biotic communities, and that man is capable of disrupting this stability.

Man is doing many things that thoughtful biologists find disturbing; the widespread use of pesticides is only one of these, and certainly not the most important. By all odds the most serious biological threat today is the unregulated growth of the human population. There is, however, an intimate relationship between population growth and the use of pesticides, and we must consider this briefly if we are to see the problems in proper perspective.

The human population of the world now stands at 3.1 billion and is growing at 1.7 per cent per year—a rate sufficient to double it every 40 years. This cannot continue. Today there are 48,000 square meters of land area for each person on earth. Simple calculation shows that if the present trend should continue it would take a mere 550 years for the land area to amount to less than one square meter per person; our descendants would literally have standing room only, and at that they would be standing all over Antarctica, Greenland, and the Sahara Desert.

This farfetched computation actually underestimates the urgency of the problem. Mankind today requires as food about 1 per cent of all the solar energy trapped and bound into organic matter by all the earth's plant life (Cole, 1958). This energy represents all of the food there is for heterotrophic organisms such as animals. In a mere 250 years, at the present rate of population increase, man's food needs would demand two-thirds of the energy total. We should have to become strictly vegetarian and exterminate the animals competing with us for plant food. We should have to eliminate other heterotrophic organisms, such as the bacteria and fungi of the soil. We should have to harvest the phytoplankton from seas and lakes and to find replacements for most of our cultivated plants; we could not afford species that tie up the calories of solar energy in such inedible forms as straw and wood.

These computations may seem frivolous because none of us expects that these drastic things really will happen. Population growth must stop, and soon, and this can only come about through a balance of births and deaths. There is no solution through interplanetary emigration, which right now would mean launching 145,000 persons into space each day to keep the population from growing. I do not know how many calories it takes to put a man in space, but I am confident that it is more than he would consume in a lifetime of eating, so this process would yield a net loss to the planet.

My reason for mentioning the population problem in broaching the problem of pesticides is simply this: until we get national and international leaders with the courage to face the elementary fact that a continuously growing population simply cannot be provided for, policies are going to be influenced by persons who—for selfish reasons or humanitarian ones—insist that we try to provide for all mankind. These futile efforts will mean expanding agriculture, bringing more submarginal land under cultivation, and wringing the last measure of productivity from our arable lands. Anything that competes with crop plants for space or sunlight will be in danger of being defined as a "pest" and so, of course, will anything that competes with man for the harvest.

This process is already under way, in the spreading of nonselective toxins that tend to destroy all animals living in croplands. The desideratum is huge acreages virtually devoid of animal life, and under the continuous cover of a single variety of plant. Our agriculturists seem to have forgotten, or they ignore, what my prairie farmer grandfather taught me long ago; namely, that different parts of his farm had very different potentialities, and required different treatments, depending upon whether the land originally supported prairie grasses, or oaks and hickories. Today, airplanes and other machines apply the same treatments to former marshes and swamps, to former grasslands, and to lands which originally were covered with coniferous and deciduous forests. This does not seem like sound practice to ecologists—but I shall have space here for only the most superficial presentation of our reservations.

In undisturbed natural situations, plants and animals are assembled into biotic communities. The most complex of such communities to be found on land are unquestionably the tropical rain forests, which have always impressed naturalists with their diversity of species; early botanists and prospectors for wood often noted that they had to travel miles to find two trees of the same species. Regions rich in rain forest characteristically are well endowed with species of plants and animals. Frogs and toads occur from the Equator to the Arctic, but British Guiana, the size of Kansas, has more species than the United States and Canada combined. Little Costa Rica, smaller than West Virginia, has more species of birds than the United States. Similarly, a century ago, the naturalist Bates collected 700 species of butterflies within a radius of an hour's walk of his headquarters in Brazil, though only 400 species were known for the entire continent of Europe; tabulations, today, for other groups of insects would undoubtedly give the same order of result.

In the rain forest, with its great diversity of species, outbreaks in which one species erupts to astronomical numbers do not occur. Further, it is virtually impossible to name an exotic species that has invaded the virgin tropical rain forest and successfully established itself in it. The African malarial mosquito, Anopheles gambiae, did spread 200 miles up the rivers of Brazil, between 1929 and 1939, but it was confined to areas disturbed by man, and, fortunately, was totally eradicated—a feat that would probably have been impossible if it had actually become established within the rain forest.

It is not very difficult to comprehend some of the major reasons for the stability of the rain forest and its resistance to invasion. In the first place, plants of one species are scattered, so that an animal especially associated with a particular plant will face hazards to dispersal in the rain forest. In the second place, many animal species are competing for the produce of the forest, and there is virtually no way of making a living there that is not already being exploited. Consequently, an invader can succeed only if it can displace, at least partially, an established species, one that is likely to be highly specialized in its adaptations to the rain forest biotic community.

A further important point has to do with the influence of predators. We know, from theory, and from studies in the field and laboratory, that an ecological system consisting of one species of predator and one species of prey is unstable. The predators starve when food is scarce, but prey species can normally outbreed their predators, and, once they get a head start, the predators cannot overtake them until something else slows population growth. The instability of simple predator-prey systems becomes most evident when no part of the prey population has a safe refuge and the predator has no alternative food. For example, in 1938, a ladybird beetle, Chilocorus, was taken from Cuba to Puerto Rico in an attempt to control scale insects on papayas and coconuts. This predator was so successful that, by 1943, it had exhausted its food supply and starved itself out. Twelve years later the scale insects returned with a heavy infestation (Wolcott, 1958).

For a predator to exercise effective and continuing control over populations of prey, it must have alternative foods to maintain its numbers during times of prey scarcity. This is why the farmer subsidizes the cats in his barn by feeding them. A sizable cat population can prevent mice from increasing, but a population adequate for this purpose could never be maintained if the cats had to depend on mice for food. In this principle we undoubtedly see one of the sources of stability of the biota of the rain forest. Predators there may have dozens or hundreds of alternative food species, and when one of these starts to increase it immediately becomes subject to increased attack, by a variety of predators.

Parasites and communicable diseases normally are able to increase more rapidly than their hosts, so they play a role somewhat different from that of predators. When host populations increase in density, parasites spread more readily and increase more rapidly, thus providing a negative feedback mechanism, which has a greater restraining effect as the host population becomes larger. The parasitic species, in turn, are similarly restrained by hyperparasites, so that no elements in the system tend to a runaway increase. We know less than we should about the roles of parasitism and disease in the biology of the rain forest, but each species certainly is attacked by parasites that are capable of spreading to adjacent species if they show a tendency to increase. Pathogenic fungi and parasitoid insects in particular often can attack a wide range of hosts.

It is these biological factors, combined with a minimum of seasonal fluctuations in the physical environment, that are primarily responsible for the stability of rain forest communities.

Now let us take a big jump to the North, to the east central United States. Here, the original vegetation, over tremendous areas, consisted of mixed hardwood forests. These contained many species of trees but usually each was dominated by one or two types, so that we speak of the beech-maple type, the oak-hickory type, and oak-chestnut type forest. These forests also harbored hundreds of species of smaller flowering plants, and thousands of species of animals, but the variety in such a community was nothing like that in the rain forest. It would have been no trick to collect in one of them a large series of specimens of a single species of plant or animal.

It is possible, today, to find earthworms, beetles, centipedes, and plants of European origin in virgin beech-maple forests in the United States—though these invaders make up an infinitesimal fraction of the total number of species present, and changes in number of plants and animals, indigenous and exotic, usually are inconspicuous from year to year. Nevertheless, these communities are obviously less stable and less resistant to invasion than the rain forest. As an example of this vulnerability, there is the chestnut blight, which took less than the first half of this century completely to eliminate one of the major dominant forest trees from a biotic community type that covered millions of acres.

Another northward jump brings us to the coniferous forests of eastern Canada, where huge acreages may be covered by almost pure stands of a single species of tree. The major insect pest here is the spruce budworm, which is actually a defoliator of the balsam fir rather than spruce. Unlike so many of our agricultural pests, this is a native American insect, which long has been at work killing fir trees. The situation has become worse in recent years, however, because the moth concentrates its attack on mature trees, and man, in reforestation planting, has provided many stands of firs of uniform age, whose trees all become subject to budworm defoliation at about the same time: when they reach the age of forty or so years (Morris, et al., 1958).

Although many species of plants and animals are present in the coniferous forests, the relative instability of this community is noteworthy. Not only does the budworm do its damage during infrequent outbreaks, but the birds and mammals undergo spectacular fluctuations in numbers from year to year. Rodent and hare populations reach plague proportions, and then crash to very low levels. Predators, including owls and fur-bearers like the lynx, have no important alternative foods, and so exhibit spectacular increases and declines along with their prey—a phenomenon that was most disconcerting to the early fur traders. Man has not caused these fluctuations; they are inherent in a relatively simple biotic community where many species are largely dependent on one or a very few other particular species.

One final jump to the North brings us to the arctic tundra, which is just about the simplest type of terrestrial biotic community of any significant extent to be found on earth. One can get the impression from books that the tundra vegetation consists only of a few species of mosses and lichens, but it really is not this simple; the United States Atomic Energy Commission recently released a report (Weichold, 1962) of a survey of the life in an Alaskan valley 100 miles north of the Arctic Circle, where they are contemplating the use of nuclear explosions to excavate a channel. Here, on permafrost 1,000 feet thick, where only the top foot or so of soil thaws, for about two months each year, they found 75 species of lichens, 100 species of mosses and liverworts, and 300 species of vascular plants. Thus the variety of life is tremendous, compared to that of cultivated land. Nevertheless, the tundra community is famous for its instability. The so-called migrations of the lemmings have become legend, and the great annual fluctuations in populations of the voles, or field mice, and of the arctic hares and arctic foxes have long intrigued biologists.

A brief survey like this suggests very compellingly that stability in a biotic community is to an important extent a function of the number of species present (cf., Elton, 1958). Also, we have many theoretical reasons for expecting diversity of species to promote community stability, and I have already touched upon some of the processes involved. It is important to note that stability is not a direct consequence of the character of the nonliving part of the environment; stability is lost when man clears the rain forest for agriculture. A quarter of a century ago, entomologists in Sumatra learned that plantations of the gambier plant were subject to severe damage by a moth if they were grown in locations remote from the virgin forest, but that in the proximity of the rain forest they were protected by insect parasites of the moth (Schneider, 1939).

Modern agricultural practice strives to produce pure stands of a single plant spread over large areas. Clean cultivation eliminates other species, whether they are detrimental to the crop or not. The modern trend also is toward the elimination of hedgerows between fields; the killing of roadside brush; and the elimination of many species from such woodlands as may be allowed to persist. All these practices make for biotic communities with less diversity of species than occurs in nature. Such communities are necessarily unstable, and predisposed to outbreaks of "pests"—by which are meant weeds, rodents, insects, mites, snails, nematodes, fungi, and anything else that might exploit the crop plant. To practice this type of agriculture successfully, man is going to have to intervene, at least occasionally, to halt incipient or full-fledged outbreaks of pests. I want to emphasize this because much of the current controversy over the best ways of controlling pests impresses me as irrelevant. If a pest species is rendered impotent by breeding a resistant strain of plant, by importing parasites, predators, and diseases, by tricking the pest into laying infertile eggs or by killing it with toxic chemicals, we shall still be left with an inherently unstable biotic community, in which outbreaks of some new pest are to be expected.

Data are now available to document this conclusion ad nauseum. When I was a boy the codling moth was the pest of apples, and we expected some of them to be wormy. Now, as long as one changes insecticides as fast as the moth develops resistance to them, it can be controlled. But the sprayed orchard is a very unstable community and control of the codling moth has brought to orchards everywhere outbreaks of various mites that damage the trees. These, in turn, have inspired an almost frantic development of miticides. In my section of New York State, around Ithaca, spring weather is damp, and orchards must have a thick covering of sod to support the heavy spraying equipment for chemical treatment of the trees. This sod provides an ideal habitat for our local field mouse, which is a prodigous girdler of apple trees. So, a colleague of mine finds himself deeply involved with problems of applying rodenticides to the orchards (Eadie, 1963). I will not venture to guess what will be the next major pest of apples to break out of control, but I am confident that there will be a succession of them in the so-simplified biotic community that the apple orchard has come to be.

The cottony cushion scale insect from Australia once threatened to wipe out the California citrus industry. A predator, a ladybird beetle from Australia, was imported and properly subsidized by laboratory breeding, and, by 1890, the cottony cushion scale was forgotten as a pest of citrus (DeBach, 1958). But, of course, this was not the end of the pest problems. More and more treatments were applied to control other pests, and, with the advent of DDT, the friendly ladybird was hit harder than the scale. Cottony cushion scale is again a major citrus pest in California.

Pest problems in such artificial biotic communities are too familiar to require elaboration here. Outbreaks and severe damage may come from native pests such as grasshoppers and Colorado potato beetles, or from any number of invaders, many of which are named for their regions of origin; we are all too familiar with the English sparrow, Japanese beetle, Mediterranean fruit fly, Hessian fly, European corn borer, Russian thistle, Dutch elm disease, and a virtually interminable list of others.

The principal practical conclusion that we can draw from a consideration of diversity in biotic communities is that those persons who would make toxic chemicals a constant part of the environment are clearly on the wrong track. Many have proposed the routine chemical treatment of seeds; the incorporation of residual insecticides into soils; and routine spraying of crops, annually or more often. Such measures will only produce inherently unstable communities growing in altered environments. One can be confident that there will be outbreaks of pest organisms resistant to the toxins; these may or may not be the same pests for which the control measures were designed.

Chemical pesticides represent some of our most potent weapons for suppressing incipient outbreaks of pests before they become disastrous. The food needs of the human population now, and increasingly in the future, will demand advanced agricultural technology and there is no doubt in my mind that pesticides will continue to play an important role in this technology. But the problem of regulating population size by any means is basically ecological, and until now the ecology of the situation has been largely ignored. (There is even a tendency to forget that most flowering plants—and this includes most of our agricultural plants other than those of the grass family—are largely dependent on insects for pollination. It is difficult to imagine any greater disaster that could overtake agriculture than the total extermination of insects.)

Even this brief survey of community dynamics will, I hope, indicate the direction in which we should be moving to put pest control on an ecologically sound basis. We should try to decide what level of infestation of crops with weeds and herbivores is economically tolerable, and then should seek to maintain that level, instead of trying for total eradication. A few farsighted entomologists have recognized this (Smith and DeBach, 1953) and, in California, they are actually experimenting with the laboratory-rearing of pests for planting in the field during periods of scarcity, so that populations of parasites and predators can be sustained.

We should try in every way to increase diversity. Boundaries where different community types meet are especially rich in plant and animal species, and practical use can be made of this "edge effect" to increase diversity and provide refuge for beneficial insects. Hedgerows and roadside brush should be encouraged and managed as little as possible. Undisturbed woodlands, even small patches, are desirable and should be allowed to remain. Crop rotation and variation of crops on adjacent fields are preferable to immense acreages of one crop; they, too, should be encouraged.

These practices cannot be expected to provide absolute protection from pest outbreaks, but they can reduce the frequency and severity of such occurrences. When the outbreaks do occur man will have to intervene, but he will be wise to try to do this in a selective manner, without devastating the entire community. When the problem involves a particular pest which is indigenous to a given region, the ideal solution probably lies in the breeding of resistant plants. Occasionally, it may be possible to devise ingenious tricks, such as the use of sex attractants as lures, or the release of sterile males—which has so effectively controlled the screwworn fly in Florida (Bushland, 1960). Dr. Frank Egler, a very competent plant ecologist, who probably knows more than anyone else about the control of roadside brush, has argued very convincingly that the selective spraying of individual plants of the relatively few species that are troublesome to highway engineers and utility companies is ultimately more effective and more economical than mass spraying, which is now all too often the practice (cf., Egler, 1958).

We should intensify the search for selective toxins; I have a feeling that we have actually retrogressed in this area, perhaps not in the herbicide field but insofar as animal control is concerned. Red squill was quite a specific rat killer, but it seems to have lost out to cheaper—but more deadly—synthetics that are poisonous to a great variety of animals. Pyrethrum is not toxic to vertebrates, but it, too, has had to yield ground to things that the chemists know how to manufacture. Before DDT touched off the boom in cheap synthetic insecticides, a sharp distinction was made between stomach poisons and contact poisons and efforts were made to select the appropriate type for a particular problem. Now, I am sorry to say, the insecticide is likely to be selected without any effort being made to analyze the pest problem at hand.

Studies of the ecology of potential pest species, and of the species to be protected, could pay big dividends. The casual exterminator would neither notice nor recognize the significance of the fact that, in parts of California, while parasites fail to control the purple scale insect, 90 per cent of these pests are confined, by micrometeorological conditions, to the northern halves of the trees (DeBach, 1958). Thus, there is present a chance for selective treatment to eliminate the bulk of the pest population, with a minimum risk of destroying community diversity through broadcast exterminating procedures.

Finally, I should like to note a threat to the welfare of life on earth which cannot be assessed by me, nor by the chemists, because the necessary data do not exist. A physician could easily discover with his basal metabolism rate apparatus that soils take in oxygen and give off carbon dioxide, as do animals. I have estimated the metabolic rates of soils in various communities by very simple but fairly accurate means. For example, the amount of humus in the soil of a mature deciduous forest remains essentially constant year after year, despite the annual fall on each acre of some seven tons of leaves, containing 19 or 20 million kilocalories of stored energy, which must be metabolized annually. Other biotic community types give similar results, and suggest soil metabolic rates equivalent to a human population averaging, say, half a dozen persons per acre.

Soil metabolic activity is distributed among a myriad of kinds of organisms that are doing many useful things. Inert compounds such as lignin, cellulose, and chitin are being decomposed into simpler compounds that can be re-used by plants. The molecular nitrogen of the atmosphere is being fixed in usable form, and is being regenerated by the biological decomposition of inert compounds. Photosynthesis today proceeds at a rate that would exhaust the nitrogen in the atmosphere and bring an end to life on earth in less than a million years, if these processes should cease. At least a half dozen different types of organisms are absolutely essential for maintaining the integrity of the nitrogen cycle alone, and the same must be true for other essential chemical nutrients. It is really frightening to realize that ever-increasing areas are being treated with new chemicals, by persons who do not give a thought for the welfare of—and who are probably unaware of the existence of—the soil organisms on which the very continuation of life depends.

Fortunately, the soil biota is very versatile and the few studies that have been made (Boswell, 1952) indicate that crop plants are damaged before the soil is sterilized—which ought to tend to discourage the practice. However, there is nevertheless probably real danger in applying novel chemicals to soils. It has been learned, just recently, that the soil organisms apparently cannot degrade certain of the synthetic detergent molecules. So citizens of Long Island, and elsewhere, are complaining about suds in their drinking water. These suds are not biocides—but, why cannot we adopt a rational approach to the wholesale broadcasting of synthetic chemicals?

In the recent fire ant fiasco, something like a million acres of land were dusted with a concoction of heptachlor designed to remain effective in soil for at least three years. This program continued for over a year before it was revealed that weathering in soil transforms heptachlor to the very persistent and poisonous epoxide; the United States Food and Drug Administration then banned all heptachlor residues on crops (cf., Brown 1961). I consider it plain irresponsibility to subject the soil biota to hazards like this without intensive preliminary research.

My general conclusion, in summary, is that those persons who think they see something inherently good in the continuous expansion of government, industry, population, or the use of pesticides are likely to poison the goose with the golden ova. The antidote lies in adopting a sound scientific approach: making use of what we already know, and supporting research in areas where we are ignorant.

BIBLIOGRAPHY

Boswell, V. R. "Residues, Soils, and Plants." In Insects. USDA Yearbook of Agriculture. Washington, D. C.: Gov. Ptg. Office, 1952, pp. 284-297.

Brown, W. L., Jr. Mass Insect Control Programs: Four Case Histories. Psyche 68:75–111, 1961.

Bushland, R. C. "Male Sterilization for the Control of Insects." In Advances in Pest Control Research. New York, N. Y.: Interscience Publishers 3:1–25, 1960.

Cole, L. C. The Ecosphere. Scient. American 198:83–92, 1958.

DeBach, P. Application of Ecological Information to Control of Citrus Pests in California. Proc. Tenth Int. Cong. Ent. (1956) 3:187–194, 1958.

Eadie, W. R. (Personal communication, 1963.)

Egler, F. E. Science, Industry, and the Abuse of Rights of Way. Science 127:573–580, 1958.

Elton, C. S. The Ecology of Invasions by Animals and Plants. London, England: Methuen, 1958.

Morris, R. F.; Miller, C. A.; Greenbank, D. O.; and Mott, D. G. The Population Dynamics of the Spruce Budworm in Eastern Canada. Proc. Tenth Int. Cong. Ent. (1956) 4:137–149, 1958.

Schneider, F. Ein Vergleich von Urwald und Monokultur in Bezug auf ihre Gefährdung durch phytophage Insekten auf Grund einiger Beobachtungen an der Ostküste von Sumatra. Schweiz. Z. Forstw. 90:41–55 and 82–89, 1939.

Smith, H. S., and DeBach, P. Artificial Infestation of Plants with Pest Insects as an Aid in Biological Control. Proc. Seventh Pacific Sci. Cong. Zool. (1949) 4:255–259, 1953.

Sweetman, H. L. Principles of Biological Control. Dubuque, Iowa: Brown, 1958.

Weichold, B. (Ed.). Bioenvironmental Features of the Ogoturk Creek Area, Cape Thompson, Alaska. Plowshare Program, USAEC, 71D–17226, 1962.

Wolcott, G. N. The Evanescence of Perfect Biological Control. Proc. Tenth Int. Cong. Ent. (1956) 4: 511–513, 1958.

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