Silent Spring

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RACHEL CARSON

Author of THE SEA AROUND US

SILENT SPRING, winner of 8 awards*, is the history making bestseller that stunned the world with its terrifying revelation about our contaminated planet. No science-fiction nightmare can equal the power of this authentic and chilling portrait of the un-seen destroyers which have already begun to change the shape of life as we know it.

"Silent Spring is a devastating attack on human carelessness, greed and irresponsibility. It should be read by every American who does not want it to be the epitaph of a world not very far beyond us in time."

--- *Saturday Review*

*Awards received by Rachel Carson for SILENT SPRING:

- The Schweitzer Medal (Animal Welfare Institute)
- The Constance Lindsay Skinner Achievement Award for merit in the realm of books (Women's National Book Association)
- Award for Distinguished Service (New England Outdoor Writers Association)
- Conservation Award for 1962 (Rod and Gun Editors of Metropolitan Manhattan)
- Conservationist of the Year (National Wildlife Federation)
- 1963 Achievement Award (Albert Einstein College of Medicine --- Women's Division)
- Annual Founders Award (Isaak Walton League)
- Citation (International and U.S. Councils of Women)

Silent Spring

(By Rachel Carson)

- “I recommend SILENT SPRING above all other books.” --- N. J. Berrill author of MAN’S EMERGING MIND
- "Certain to be history-making in its influence upon thought and public policy all over the world." --Book-of-the-Month Club News
- "Miss Carson is a scientist and is not given to tossing serious charges around carelessly. When she warns us, as she does with such a profound sense of urgency, we ought to take heed. SILENT SPRING may well be one of the great and lowering books of our time. This book is must reading for every responsible citizen." --Chicago Daily
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- "It should come as no surprise that the gifted author of THE SEA AROUN US can take another branch of science ... and bring it so sharply into focus that any intelligent layman can understand what she is talking about. Understand, yes, and shudder, for she has drawn a living portrait of what is happening to this balance of nature as decreed in the science of life --- and what man is doing (and has done) to destroy it and create a science of death." -Virginia Kirkus Bulletin

Silent Spring

By Rachel Carson

(ONE SINGLE BOOK WHICH BROUGHT THE ISSUE OF PESTICIDES CENTERSTAGE. WITH MASS SCALE POISONING OF THE LAND WITH PESTICIDES AND WITH THOUSANDS OF FARMERS COMMITTING SUICIDE THIS BOOK IS ESSENTIAL FOR PUBLIC RESEARCH IN INDIA.)

A CREST REPRINT

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To Albert Schweitzer

who said

“Man has lost the capacity to foresee

and to forestall. He will end by

destroying the earth.”

Contents

8. And No Birds Sing

OVER INCREASINGLY large areas of the United States, spring now comes unheralded by the return of the birds, and the early mornings are strangely silent where once they were filled with the beauty of bird song. This sudden silencing of the song of birds, this obliteration of the color and beauty and interest they lend to our world have come about swiftly, insidiously, and unnoticed by those whose communities are as yet unaffected. From the town of Hinsdale, Illinois, a housewife wrote in despair to one of the world's leading ornithologists, Robert Cushman Murphy, Curator Emeritus of Birds at the American Museum of Natural History.

Here in our village the elm trees have been sprayed for several years [she wrote in 1958]. When we moved here six years ago, there was a wealth of bird life; I put up a feeder and had a steady stream of cardinals, chickadees, downies and nuthatches all winter, and the cardinals and chickadees brought their young ones in the summer. After several years of DDT spray, the town is almost devoid of robins and starlings; chickadees have not been on my shelf for two years, and this year the cardinals are gone too; the nesting population in the neighborhood seems to consist of one dove pair and perhaps one catbird family.

It is hard to explain to the children that the birds have been killed off, when they have learned in school that a Federal law protects the birds from killing or capture. 'Will they ever come back?' they ask, and I do not have the answer. The elms are still dying, and so are the birds. *Is* anything being done? *Can* anything be done? Can *I* do anything? A year after the federal government had launched a massive spraying program against the fire ant, an Alabama woman wrote: 'Our place has been a veritable bird sanctuary for over half a century. Last July we all remarked, "There are more birds than ever." Then, suddenly, in the second week of August, they all disappeared. I was accustomed to rising early to care for my favorite mare that had a young filly. There was not a sound of the song of a bird. It was eerie, terrifying. What was man doing to our perfect and beautiful world? Finally, five months later a blue jay appeared and a wren.' The autumn months to which she referred brought other somber reports from the deep South, where in Mississippi, Louisiana, and Alabama the *Field Notes* published quarterly by the National Audubon Society and the United States Fish and Wildlife Service noted the striking phenomenon of 'blank spots weirdly empty of virtually *all* bird life'. The *Field Notes* are a compilation of the reports of seasoned observers who have spent many years afield in their particular areas and have unparalleled knowledge of the normal bird life of the region. One such observer reported that in driving about southern Mississippi that fall she saw 'no land birds at all for long distances'. Another in Baton Rouge reported that the contents of her feeders had lain untouched 'for weeks on end', while fruiting shrubs in her yard, that ordinarily would be stripped clean by that time, still were laden with berries. Still another reported that his picture window, 'which often used to frame a scene splashed with the red of 40 or 50 cardinals and crowded with other species, seldom permitted a view of as many as a bird or two at a time.' Professor Maurice Brooks of the University of West Virginia, an authority on the birds of the Appalachian region, reported that the West Virginia bird population had undergone 'an incredible reduction'. One story might serve as the tragic symbol of the fate of the birds—a fate that has already overtaken some species, and that threatens all. It is the story of the robin,

the bird known to everyone. To millions of Americans, the season's first robin means that the grip of winter is broken. Its coming is an event reported in newspapers and told eagerly at the breakfast table. And as the number of migrants grows and the first mists of green appear in the woodlands, thousands of people listen for the first dawn chorus of the robins throbbing in the early morning light. But now all is changed, and not even the return of the birds may be taken for granted. The survival of the robin, and indeed of many other species as well, seems fatefully linked with the American elm, a tree that is part of the history of thousands of towns from the Atlantic to the Rockies, gracing their streets and their village squares and college campuses with majestic archways of green. Now the elms are stricken with a disease that afflicts them throughout their range, a disease so serious that many experts believe all efforts to save the elms will in the end be futile. It would be tragic to lose the elms, but it would be doubly tragic if, in vain efforts to save them, we plunge vast segments of our bird populations into the night of extinction. Yet this is precisely what is threatened. The so-called Dutch elm disease entered the United States from Europe about 1930 in elm burl logs imported for the veneer industry. It is a fungus disease; the organism invades the water-conducting vessels of the tree, spreads by spores carried by the flow of sap, and by its poisonous secretions as well as by mechanical clogging causes the branches to wilt and the tree to die. The disease is spread from diseased to healthy trees by elm bark beetles. The galleries which the insects have tunneled out under the bark of dead trees become contaminated with spores of the invading fungus, and the spores adhere to the insect body and are carried wherever the beetle flies. Efforts to control the fungus disease of the elms have been directed largely toward control of the carrier insect. In community after community, especially throughout the strongholds of the American elm, the Midwest and New England, intensive spraying has become a routine procedure.

What this spraying could mean to bird life, and especially to the robin, was first made clear by the work of two ornithologists at Michigan State University, Professor George Wallace and one of his graduate students, John Mehner. When Mr. Mehner began work for the doctorate in 1954, he chose a research project that had to do with robin populations. This was quite by chance, for at that time no one suspected that the robins were in danger. But even as he undertook the work, events occurred that were to change its character and indeed to deprive him of his material. Spraying for Dutch elm disease began in a small way on the university campus in 1954. The following year the city of East Lansing (where the university is located) joined in, spraying on the campus was expanded, and, with local programs for gypsy moth and mosquito control also under way, the rain of chemicals increased to a downpour. During 1954, the year of the first light spraying, all seemed well. The following spring the migrating robins began to return to the campus as usual. Like the bluebells in Tomlinson's haunting essay 'The Lost Wood', they were 'expecting no evil' as they reoccupied their familiar territories. But soon it became evident that something was wrong. Dead and dying robins began to appear in the campus. Few birds were seen in their normal foraging activities or assembling in their usual roosts. Few nests were built; few young appeared. The pattern was repeated with monotonous regularity in succeeding springs. The sprayed area had become a lethal trap in which each wave of migrating robins would be eliminated in about a week. Then new arrivals would come in, only to add to the numbers of doomed birds seen on the campus in the agonized tremors that precede death. 'The campus is serving as a graveyard for most of the robins that attempt to take up residence in the spring,' said Dr. Wallace. But why? At first he suspected some disease

of the nervous system, but soon it became evident that 'in spite of the assurances of the insecticide people that their sprays were "harmless to birds" the robins were really dying of insecticidal poisoning; they exhibited the well-known symptoms of loss of balance, followed by tremors, convulsions, and death.'

Several facts suggested that the robins were being poisoned, not so much by direct contact with the insecticides as indirectly, by eating earthworms. Campus earthworms had been fed inadvertently to crayfish in a research project and all the crayfish had promptly died. A snake kept in a laboratory cage had gone into violent tremors after being fed such worms. And earthworms are the principal food of robins in the spring. A key piece in the jigsaw puzzle of the doomed robins was soon to be supplied by Dr. Roy Barker of the Illinois Natural History Survey at Urbana. Dr. Barker's work, published in 1958, traced the intricate cycle of events by which the robins' fate is linked to the elm trees by way of the earthworms. The trees are sprayed in the spring (usually at the rate of 2 to 5 pounds of DDT per 50-foot tree, which may be the equivalent of as much as *23 pounds per acre* where elms are numerous) and often again in July, at about half this concentration. Powerful sprayers direct a stream of poison to all parts of the tallest trees, killing directly not only the target organism, the bark beetle, but other insects, including pollinating species and predatory spiders and beetles. The poison forms a tenacious film over the leaves and bark. Rains do not wash it away. In the autumn the leaves fall to the ground, accumulate in sodden layers, and begin the slow process of becoming one with the soil. In this they are aided by the toil of the earthworms, who feed in the leaf litter, for elm leaves are among their favorite foods. In feeding on the leaves the worms also swallow the insecticide, accumulating and concentrating it in their bodies. Dr. Barker found deposits of DDT throughout the digestive tracts of the worms, their blood vessels, nerves, and body wall. Undoubtedly some of the earthworms themselves succumb, but others survive to become 'biological magnifiers' of the poison. In the spring the robins return to provide another link in the cycle. As few as 11 large earthworms can transfer a lethal dose of DDT to a robin. And 11 worms form a small part of a day's rations to a bird that eats 10 to 12 earthworms in as many minutes.

Not all robins receive a lethal dose, but another consequence may lead to the extinction of their kind as surely as fatal poisoning. The shadow of sterility lies over all the bird studies and indeed lengthens to include all living things within its potential range. There are now only two or three dozen robins to be found each spring on the entire 185-acre campus of Michigan State University, compared with a conservatively estimated 370 adults in this area before spraying. In 1954 every robin nest under observation by Mehner produced young. Toward the end of June, 1957, when at least 370 young birds (the normal replacement of the adult population) would have been foraging over the campus in the years before spraying began, Mehner could find *only one young robin*. A year later Dr. Wallace was to report: 'At no time during the spring or summer [of 1958] did I see a fledgling robin anywhere on the main campus, and so far I have failed to find anyone else who has seen one there.'

Part of this failure to produce young is due, of course, to the fact that one or more of a pair of robins dies before the nesting cycle is completed. But Wallace has significant records which point to something more sinister—the actual destruction of the birds' capacity to reproduce. He has, for example, 'records of robins and other birds building nests but laying no eggs, and others laying eggs and incubating them but not hatching them. We have one record of a robin that sat on its eggs faithfully for 21 days and they did not hatch. The normal incubation period

is 13 days...Our analyses are showing high concentrations of DDT in the testes and ovaries of breeding birds,' he told a congressional committee in 1960. 'Ten males had amounts ranging from 30 to 109 parts per million in the testes, and two females had 151 and 211 parts per million respectively in the egg follicles in their ovaries.' Soon studies in other areas began to develop findings equally dismal. Professor Joseph Hickey and his students at the University of Wisconsin, after careful comparative studies of sprayed and unsprayed areas, reported the robin mortality to be at least 86 to 88 per cent. The Cranbrook Institute of Science at Bloomfield Hills, Michigan, in an effort to assess the extent of bird loss caused by the spraying of the elms, asked in 1956 that all birds thought to be victims of DDT poisoning be turned in to the institute for examination. The request had a response beyond all expectations. Within a few weeks the deep-freeze facilities of the institute were taxed to capacity, so that other specimens had to be refused. By 1959 a thousand poisoned birds from this single community had been turned in or reported. Although the robin was the chief victim (one woman calling the institute reported 12 robins lying dead on her lawn as she spoke), 63 different species were included among the specimens examined at the institute. The robins, then, are only one part of the chain of devastation linked to the spraying of the elms, even as the elm program is only one of the multitudinous spray programs that cover our land with poisons. Heavy mortality has occurred among about 90 species of birds, including those most familiar to suburbanites and amateur naturalists. The populations of nesting birds in general have declined as much as 90 per cent in some of the sprayed towns. As we shall see, all the various types of birds are affected—ground feeders, treetop feeders, bark feeders, predators. It is only reasonable to suppose that all birds and mammals heavily dependent on earthworms or other soil organisms for food are threatened by the robins' fate. Some 45 species of birds include earthworms in their diet. Among them is the woodcock, a species that winters in southern areas recently heavily sprayed with heptachlor. Two significant discoveries have now been made about the woodcock. Production of young birds on the New Brunswick breeding grounds is definitely reduced, and adult birds that have been analyzed contain large residues of DDT and heptachlor. Already there are disturbing records of heavy mortality among more than 20 other species of ground-feeding birds whose food—worms, ants, grubs, or other soil organisms—has been poisoned. These include three of the thrushes whose songs are among the most exquisite of bird voices, the olive-backed, the wood, and the hermit. And the sparrows that flit through the shrubby understory of the woodlands and forage with rustling sounds amid the fallen leaves—the song sparrow and the white-throat—these, too, have been found among the victims of the elm sprays. Mammals, also, may easily be involved in the cycle, directly or indirectly. Earthworms are important among the various foods of the raccoon, and are eaten in the spring and fall by opossums. Such subterranean tunnelers as shrews and moles capture them in numbers, and then perhaps pass on the poison to predators such as screech owls and barn owls.

Several dying screech owls were picked up in Wisconsin following heavy rains in spring, perhaps poisoned by feeding on earthworms. Hawks and owls have been found in convulsions—great horned owls, screech owls, red-shouldered hawks, sparrow hawks, marsh hawks. These may be cases of secondary poisoning, caused by eating birds or mice that have accumulated insecticides in their livers or other organs. Nor is it only the creatures that forage on the ground or those who prey on them that are endangered by the foliar spraying of the elms. All of the treetop feeders, the birds that glean their insect food from the leaves, have disappeared from

heavily sprayed areas, among them those woodland sprites the kinglets, both ruby-crowned and golden-crowned, the tiny gnatcatchers, and many of the warblers, whose migrating hordes flow through the trees in spring in a multicolored tide of life. In 1956, a late spring delayed spraying so that it coincided with the arrival of an exceptionally heavy wave of warbler migration. Nearly all species of warblers present in the area were represented in the heavy kill that followed. In Whitefish Bay, Wisconsin, at least a thousand myrtle warblers could be seen in migration during former years; in 1958, after the spraying of the elms, observers could find only two. So, with additions from other communities, the list grows, and the warblers killed by the spray include those that most charm and fascinate all who are aware of them: the black-and-white, the yellow, the magnolia, and the Cape May; the ovenbird, whose call throbs in the Maytime woods; the Blackburnian, whose wings are touched with flame; the chestnut-sided, the Canadian, and the black-throated green. These treetop feeders are affected either directly by eating poisoned insects or indirectly by a shortage of food.

The loss of food has also struck hard at the swallows that cruise the skies, straining out the aerial insects as herring strain the plankton of the sea. A Wisconsin naturalist reported: 'Swallows have been hard hit. Everyone complains of how few they have compared to four or five years ago. Our sky overhead was full of them only four years ago. Now we seldom see any...This could be both lack of insects because of spray, or poisoned insects.' Of other birds this same observer wrote: 'Another striking loss is the phoebe. Flycatchers are scarce everywhere but the early hardy common phoebe is no more. I've seen one this spring and only one last spring. Other birders in Wisconsin make the same complaint. I have had five or six pair of cardinals in the past, none now. Wrens, robins, catbirds and screech owls have nested each year in our garden. There are none now. Summer mornings are without bird song. Only pest birds, pigeons, starlings and English sparrows remain. It is tragic and I can't bear it.'

The dormant sprays applied to the elms in the fall, sending the poison into every little crevice in the bark, are probably responsible for the severe reduction observed in the number of chickadees, nuthatches, titmice, woodpeckers, and brown creepers. During the winter of 1957-58, Dr. Wallace saw no chickadees or nuthatches at his home feeding station for the first time in many years. Three nuthatches he found later provided a sorry little step-by-step lesson in cause and effect: one was feeding on an elm, another was found dying of typical DDT symptoms, the third was dead. The dying nuthatch was later found to have 226 parts per million of DDT in its tissues. The feeding habits of all these birds not only make them especially vulnerable to insect sprays but also make their loss a deplorable one for economic as well as less tangible reasons. The summer food of the white-breasted nuthatch and the brown creeper, for example, includes the eggs, larvae, and adults of a very large number of insects injurious to trees. About three quarters of the food of the chickadee is animal, including all stages of the life cycle of many insects. The chickadee's method of feeding is described in Bent's monumental *Life Histories* of North American birds: 'As the flock moves along each bird examines minutely bark, twigs, and branches, searching for tiny bits of food (spiders' eggs, cocoons, or other dormant insect life).' Various scientific studies have established the critical role of birds in insect control in various situations. Thus, woodpeckers are the primary control of the Engelmann spruce beetle, reducing its populations from 45 to 98 per cent and are important in the control of the codling moth in apple orchards. Chickadees and other winter-resident birds can protect orchards against the cankerworm.

But what happens in nature is not allowed to happen in the modern, chemical-drenched world, where spraying destroys not only the insects but their principal enemy, the birds. When later there is a resurgence of the insect population, as almost always happens, the birds are not there to keep their numbers in check. As the Curator of Birds at the Milwaukee Public Museum, Owen J. Gromme, wrote to the Milwaukee *Journal*: 'The greatest enemy of insect life is other predatory insects, birds, and some small mammals, but DDT kills indiscriminately, including nature's own safeguards or policemen... In the name of progress are we to become victims of our own diabolical means of insect control to provide temporary comfort, only to lose out to destroying insects later on? By what means will we control new pests, which will attack remaining tree species after the elms are gone, when nature's safeguards (the birds) have been wiped out by poison?'

Mr. Gromme reported that calls and letters about dead and dying birds had been increasing steadily during the years since spraying began in Wisconsin. Questioning always revealed that spraying or fogging had been done in the area where the birds were dying.

Mr. Gromme's experience has been shared by ornithologists and conservationists at most of the research centers of the Midwest such as the Cranbrook Institute in Michigan, the Illinois Natural History Survey, and the University of Wisconsin. A glance at the Letters-from-Readers column of newspapers almost anywhere that spraying is being done makes clear the fact that citizens are not only becoming aroused and indignant but that often they show a keener understanding of the dangers and inconsistencies of spraying than do the officials who order it done. 'I am dreading the days to come soon now when many beautiful birds will be dying in our back yard,' wrote a Milwaukee woman. 'This is a pitiful, heartbreaking experience... It is, moreover, frustrating and exasperating, for it evidently does not serve the purpose this slaughter was intended to serve... Taking a long look, can you save trees without also saving birds? Do they not, in the economy of nature, save each other? Isn't it possible to help the balance of nature without destroying it?' The idea that the elms, majestic shade trees though they are, are not 'sacred cows' and do not justify an 'open end' campaign of destruction against all other forms of life is expressed in other letters. 'I have always loved our elm trees which seemed like trademarks on our landscape,' wrote another Wisconsin woman. 'But there are many kinds of trees...We must save our birds, too. Can anyone imagine anything so cheerless and dreary as a springtime without a robin's song?' To the public the choice may easily appear to be one of stark black-or-white simplicity: Shall we have birds or shall we have elms? But it is not as simple as that, and by one of the ironies that abound throughout the field of chemical control we may very well end by having neither if we continue on our present, well-traveled road. Spraying is killing the birds but it is not saving the elms. The illusion that salvation of the elms lies at the end of a spray nozzle is a dangerous will-o'- the-wisp that is leading one community after another into a morass of heavy expenditures, without producing lasting results. Greenwich, Connecticut sprayed regularly for ten years. Then a drought year brought conditions especially favorable to the beetle and the mortality of elms went up 1000 per cent. In Urbana, Illinois, where the University of Illinois is located, Dutch elm disease first appeared in 1951. Spraying was undertaken in 1953. By 1959, in spite of six years' spraying, the university campus had lost 86 per cent of its elms, half of them victims of Dutch elm disease. In Toledo, Ohio, a similar experience caused the Superintendent of Forestry, Joseph A. Sweeney, to take a realistic look at the results of spraying. Spraying was begun there in 1953 and continued

through 1959. Meanwhile, however, Mr. Sweeney had noticed that a city-wide infestation of the cottony maple scale was worse after the spraying recommended by 'the books and the authorities' than it had been before. He decided to review the results of spraying for Dutch elm disease for himself. His findings shocked him. In the city of Toledo, he found, 'the only areas under any control were the areas where we used some promptness in removing the diseased or brood trees. Where we depended on spraying the disease was out of control. In the country where nothing has been done the disease has not spread as fast as it has in the city. This indicates that spraying destroys any natural enemies. 'We are abandoning spraying for the Dutch elm disease. This has brought me into conflict with the people who back any recommendations by the United States Department of Agriculture but I have the facts and will stick with them.' It is difficult to understand why these midwestern towns, to which the elm disease spread only rather recently, have so unquestioningly embarked on ambitious and expensive spraying programs, apparently without waiting to inquire into the experience of other areas that have had longer acquaintance with the problem. New York State, for example, has certainly had the longest history of continuous experience with Dutch elm disease, for it was via the Port of New York that diseased elm wood is thought to have entered the United States about 1930. And New York State today has a most impressive record of containing and suppressing the disease. Yet it has not relied upon spraying. In fact, its agricultural extension service does not recommend spraying as a community method of control.

How, then, has New York achieved its fine record? From the early years of the battle for the elms to the present time, it has relied upon rigorous sanitation, or the prompt removal and destruction of all diseased or infected wood. In the beginning some of the results were disappointing, but this was because it was not at first understood that not only diseased trees but all elm wood in which the beetles might breed must be destroyed. Infected elm wood, after being cut and stored for firewood, will release a crop of fungus-carrying beetles unless burned before spring. It is the adult beetles, emerging from hibernation to feed in late April and May, that transmit Dutch elm disease. New York entomologists have learned by experience what kinds of beetle-breeding material have real importance in the spread of the disease. By concentrating on this dangerous material, it has been possible not only to get good results, but to keep the cost of the sanitation program within reasonable limits. By 1950 the incidence of Dutch elm disease in New York City had been reduced to of 1 per cent of the city's 55,000 elms. A sanitation program was launched in Westchester County in 1942.

During the next 14 years the average annual loss of elms was only of 1 per cent a year. Buffalo, with 185,000 elms, has an excellent record of containing the disease by sanitation, with recent annual losses amounting to only of 1 per cent. In other words, at this rate of loss it would take about 300 years to eliminate Buffalo's elms. What has happened in Syracuse is especially impressive. There no effective program was in operation before 1957. Between 1951 and 1956 Syracuse lost nearly 3000 elms. Then, under the direction of Howard C. Miller of the New York State University College of Forestry, an intensive drive was made to remove all diseased elm trees and all possible sources of beetle-breeding elm wood. The rate of loss is now well below 1 per cent a year. The economy of the sanitation method is stressed by New York experts in Dutch elm disease control. 'In most cases the actual expense is small compared with the probable saving,' says J. G. Matthysse of the New York State College of Agriculture. 'If it is a case of a dead or broken limb, the limb would have to be removed eventually, as a precaution

against possible property damage or personal injury. If it is a fuel-wood pile, the wood can be used before spring, the bark can be peeled from the wood, or the wood can be stored in a dry place. In the case of dying or dead elm trees, the expense of prompt removal to prevent Dutch elm disease spread is usually no greater than would be necessary later, for most dead trees in urban regions must be removed eventually.' The situation with regard to Dutch elm disease is therefore not entirely hopeless provided informed and intelligent measures are taken. While it cannot be eradicated by any means now known, once it has become established in a community, it can be suppressed and contained within reasonable bounds by sanitation, and without the use of methods that are not only futile but involve tragic destruction of bird life. Other possibilities lie within the field of forest genetics, where experiments offer hope of developing a hybrid elm resistant to Dutch elm disease. The European elm is highly resistant, and many of them have been planted in Washington, D.C. Even during a period when a high percentage of the city's elms were affected, no cases of Dutch elm disease were found among these trees. Replanting through an immediate tree nursery and forestry program is being urged in communities that are losing large numbers of elms. This is important, and although such programs might well include the resistant European elms, they should aim at a variety of species so that no future epidemic could deprive a community of its trees. The key to a healthy plant or animal community lies in what the British ecologist Charles Elton calls 'the conservation of variety'. What is happening now is in large part a result of the biological unsophistication of past generations. Even a generation ago no one knew that to fill large areas with a single species of tree was to invite disaster. And so whole towns lined their streets and dotted their parks with elms, and today the elms die and so do the birds. . . .

Like the robin, another American bird seems to be on the verge of extinction. This is the national symbol, the eagle. Its populations have dwindled alarmingly within the past decade. The facts suggest that something is at work in the eagle's environment which has virtually destroyed its ability to reproduce. What this may be is not yet definitely known, but there is some evidence that insecticides are responsible.

The most intensively studied eagles in North America have been those nesting along a stretch of coast from Tampa to Fort Myers on the western coast of Florida. There a retired banker from Winnipeg, Charles Broley, achieved ornithological fame by banding more than 1,000 young bald eagles during the years 1939-49. (Only 166 eagles had been banded in all the earlier history of birdbanding.) Mr. Broley banded eagles as young birds during the winter months before they had left their nests. Later recoveries of banded birds showed that these Florida-born eagles range northward along the coast into Canada as far as Prince Edward Island, although they had previously been considered nonmigratory. In the fall they return to the South, their migration being observed at such famous vantage points as Hawk Mountain in eastern Pennsylvania. During the early years of his banding, Mr. Broley used to find 125 active nests a year on the stretch of coast he had chosen for his work. The number of young banded each year was about 150. In 1947 the production of young birds began to decline. Some nests contained no eggs; others contained eggs that failed to hatch. Between 1952 and 1957, about 80 per cent of the nests failed to produce young. In the last year of this period only 43 nests were occupied. Seven of them produced young (8 eaglets); 23 contained eggs that failed to hatch; 13 were used merely as feeding stations by adult eagles and contained no eggs. In 1958 Mr. Broley ranged over 100 miles of coast before finding and banding one eaglet. Adult eagles, which had been

seen at 43 nests in 1957, were so scarce that he observed them at only 10 nests. Although Mr. Broley's death in 1959 terminated this valuable series of uninterrupted observations, reports by the Florida Audubon Society, as well as from New Jersey and Pennsylvania, confirm the trend that may well make it necessary for us to find a new national emblem. The reports of Maurice Broun, curator of the Hawk Mountain Sanctuary, are especially significant. Hawk Mountain is a picturesque mountaintop in southeastern Pennsylvania, where the easternmost ridges of the Appalachians form a last barrier to the westerly winds before dropping away toward the coastal plain. Winds striking the mountains are deflected upward so that on many autumn days there is a continuous updraft on which the broad-winged hawks and eagles ride without effort, covering many miles of their southward migration in a day. At Hawk Mountain the ridges converge and so do the aerial highways. The result is that from a widespread territory to the north birds pass through this traffic bottleneck. In his more than a score of years as custodian of the sanctuary there, Maurice Broun has observed and actually tabulated more hawks and eagles than any other American. The peak of the bald eagle migration comes in late August and early September. These are assumed to be Florida birds, returning to home territory after a summer in the North. (Later in the fall and early winter a few larger eagles drift through. These are thought to belong to a northern race, bound for an unknown wintering ground.) During the first years after the sanctuary was established, from 1935 to 1939, 40 per cent of the eagles observed were yearlings, easily identified by their uniformly dark plumage. But in recent years these immature birds have become a rarity. Between 1955 and 1959, they made up only 20 per cent of the total count, and in one year (1957) there was only one young eagle for every 32 adults. Observations at Hawk Mountain are in line with findings elsewhere. One such report comes from Elton Fawks, an official of the Natural Resources Council of Illinois. Eagles—probably northern nesters—winter along the Mississippi and Illinois Rivers. In 1958 Mr. Fawks reported that a recent count of 59 eagles had included only one immature bird. Similar indications of the dying out of the race come from the world's only sanctuary for eagles alone, Mount Johnson Island in the Susquehanna River. The island, although only 8 miles above Conowingo Dam and about half a mile out from the Lancaster County shore, retains its primitive wildness. Since 1934 its single eagle nest has been under observation by Professor Herbert H. Beck, an ornithologist of Lancaster and custodian of the sanctuary. Between 1935 and 1947 use of the nest was regular and uniformly successful. Since 1947, although the adults have occupied the nest and there is evidence of egg laying, no young eagles have been produced. On Mount Johnson Island as well as in Florida, then, the same situation prevails—there is some occupancy of nests by adults, some production of eggs, but few or no young birds. In seeking an explanation, only one appears to fit all the facts. This is that the reproductive capacity of the birds has been so lowered by some environmental agent that there are now almost no annual additions of young to maintain the race.

Exactly this sort of situation has been produced artificially in other birds by various experimenters, notably Dr. James DeWitt of the United States Fish and Wildlife Service. Dr. DeWitt's now classic experiments on the effect of a series of insecticides on quail and pheasants have established the fact that exposure to DDT or related chemicals, even when doing no observable harm to the parent birds, may seriously affect reproduction. The way the effect is exerted may vary, but the end result is always the same. For example, quail into whose diet DDT was introduced throughout the breeding season survived and even produced normal

numbers of fertile eggs. But few of the eggs hatched. 'Many embryos appeared to develop normally during the early stages of incubation, but died during the hatching period,' Dr. DeWitt said. Of those that did hatch, more than half died within 5 days. In other tests in which both pheasants and quail were the subjects, the adults produced no eggs whatever if they had been fed insecticide-contaminated diets throughout the year. And at the University of California, Dr. Robert Rudd and Dr. Richard Genelly reported similar findings. When pheasants received dieldrin in their diets, 'egg production was markedly lowered and chick survival was poor.' According to these authors, the delayed but lethal effect on the young birds follows from storage of dieldrin in the yolk of the egg, from which it is gradually assimilated during incubation and after hatching. This suggestion is strongly supported by recent studies by Dr. Wallace and a graduate student, Richard F. Bernard, who found high concentrations of DDT in robins on the Michigan State University campus. They found the poison in all of the testes of male robins examined, in developing egg follicles, in the ovaries of females, in completed but unlaid eggs, in the oviducts, in unhatched eggs from deserted nests, in embryos within the eggs, and in a newly hatched, dead nestling. These important studies establish the fact that the insecticidal poison affects a generation once removed from initial contact with it. Storage of poison in the egg, in the yolk material that nourishes the developing embryo, is a virtual death warrant and explains why so many of DeWitt's birds died in the egg or a few days after hatching.

Laboratory application of these studies to eagles presents difficulties that are nearly insuperable, but field studies are now under way in Florida, New Jersey, and elsewhere in the hope of acquiring definite evidence as to what has caused the apparent sterility of much of the eagle population. Meanwhile, the available circumstantial evidence points to insecticides. In localities where fish are abundant they make up a large part of the eagle's diet (about 65 per cent in Alaska; about 52 per cent in the Chesapeake Bay area). Almost unquestionably the eagles so long studied by Mr. Broley were predominantly fish eaters. Since 1945 this particular coastal area has been subjected to repeated sprayings with DDT dissolved in fuel oil. The principal target of the aerial spraying was the salt-marsh mosquito, which inhabits the marshes and coastal areas that are typical foraging areas for the eagles. Fishes and crabs were killed in enormous numbers. Laboratory analyses of their tissues revealed high concentrations of DDT—as much as 46 parts per million. Like the grebes of Clear Lake, which accumulated heavy concentrations of insecticide residues from eating the fish of the lake, the eagles have almost certainly been storing up the DDT in the tissues of their bodies. And like the grebes, the pheasants, the quail, and the robins, they are less and less able to produce young and to preserve the continuity of their race. . . .

From all over the world come echoes of the peril that faces birds in our modern world. The reports differ in detail, but always repeat the theme of death to wildlife in the wake of pesticides. Such are the stories of hundreds of small birds and partridges dying in France after vine stumps were treated with an arsenic-containing herbicide, or of partridge shoots in Belgium, once famous for the numbers of their birds, denuded of partridges after the spraying of nearby farmlands. In England the major problem seems to be a specialized one, linked with the growing practice of treating seed with insecticides before sowing. Seed treatment is not a wholly new thing, but in earlier years the chemicals principally used were fungicides. No effects on birds seem to have been noticed. Then about 1956 there was a change to dual-purpose

treatment; in addition to a fungicide, dieldrin, aldrin, or heptachlor was added to combat soil insects. Thereupon the situation changed for the worse.

In the spring of 1960 a deluge of reports of dead birds reached British wildlife authorities, including the British Trust for Ornithology, the Royal Society for the Protection of Birds, and the Game Birds Association. 'The place is like a battlefield,' a landowner in Norfolk wrote. 'My keeper has found innumerable corpses, including masses of small birds— Chaffinches, Greenfinches, Linnets, Hedge Sparrows, also House Sparrows...the destruction of wild life is quite pitiful.' A gamekeeper wrote: 'My Partridges have been wiped out with the dressed corn, also some Pheasants and all other birds, hundreds of birds have been killed... As a lifelong gamekeeper it has been a distressing experience for me. It is bad to see pairs of Partridges that have died together.' In a joint report, the British Trust for Ornithology and the Royal Society for the Protection of Birds described some 67 kills of birds—a far from complete listing of the destruction that took place in the spring of 1960. Of these 67, 59 were caused by seed dressings, 8 by toxic sprays. A new wave of poisoning set in the following year. The death of 600 birds on a single estate in Norfolk was reported to the House of Lords, and 100 pheasants died on a farm in North Essex. It soon became evident that more counties were involved than in 1960 (34 compared with 23). Lincolnshire, heavily agricultural, seemed to have suffered most, with reports of 10,000 birds dead. But destruction involved all of agricultural England, from Angus in the north to Cornwall in the south, from Anglesey in the west to Norfolk in the east.

In the spring of 1961 concern reached such a peak that a special committee of the House of Commons made an investigation of the matter, taking testimony from farmers, landowners, and representatives of the Ministry of Agriculture and of various governmental and non-governmental agencies concerned with wildlife. 'Pigeons are suddenly dropping out of the sky dead,' said one witness. 'You can drive a hundred or two hundred miles outside London and not see a single kestrel,' reported another. 'There has been no parallel in the present century, or at any time so far as I am aware, [this is] the biggest risk to wildlife and game that ever occurred in the country,' officials of the Nature Conservancy testified.

Facilities for chemical analysis of the victims were most inadequate to the task, with only two chemists in the country able to make the tests (one the government chemist, the other in the employ of the Royal Society for the Protection of Birds). Witnesses described huge bonfires on which the bodies of the birds were burned. But efforts were made to have carcasses collected for examination, and of the birds analyzed, all but one contained pesticide residues. The single exception was a snipe, which is not a seed-eating bird. Along with the birds, foxes also may have been affected, probably indirectly by eating poisoned mice or birds. England, plagued by rabbits, sorely needs the fox as a predator. But between November 1959 and April 1960 at least 1300 foxes died. Deaths were heaviest in the same counties from which sparrow hawks, kestrels, and other birds of prey virtually disappeared, suggesting that the poison was spreading through the food chain, reaching out from the seed eaters to the furred and feathered carnivores. The actions of the moribund foxes were those of animals poisoned by chlorinated hydrocarbon insecticides. They were seen wandering in circles, dazed and half blind, before dying in convulsions.

The hearings convinced the committee that the threat to wildlife was 'most alarming'; it accordingly recommended to the House of Commons that 'the Minister of Agriculture and the Secretary of State for Scotland should secure the immediate prohibition for the use as seed

dressings of compounds containing dieldrin, aldrin, or heptachlor, or chemicals of comparable toxicity.' The committee also recommended more adequate controls to ensure that chemicals were adequately tested under field as well as laboratory conditions before being put on the market. This, it is worth emphasizing, is one of the great blank spots in pesticide research everywhere. Manufacturers' tests on the common laboratory animals—rats, dogs, guinea pigs—include no wild species, no birds as a rule, no fishes, and are conducted under controlled and artificial conditions. Their application to wildlife in the field is anything but precise. England is by no means alone in its problem of protecting birds from treated seeds. Here in the United States the problem has been most troublesome in the rice-growing areas of California and the South. For a number of years California rice growers have been treating seed with DDT as protection against tadpole shrimp and scavenger beetles which sometimes damage seedling rice. California sportsmen have enjoyed excellent hunting because of the concentrations of waterfowl and pheasants in the rice fields. But for the past decade persistent reports of bird losses, especially among pheasants, ducks, and blackbirds, have come from the rice-growing counties. 'Pheasant sickness' became a well-known phenomenon: birds 'seek water, become paralyzed, and are found on the ditch banks and rice checks quivering,' according to one observer. The 'sickness' comes in the spring, at the time the rice fields are seeded. The concentration of DDT used is many times the amount that will kill an adult pheasant.

The passage of a few years and the development of even more poisonous insecticides served to increase the hazard from treated seed. Aldrin, which is 100 times as toxic as DDT to pheasants, is now widely used as a seed coating. In the rice fields of eastern Texas, this practice has seriously reduced the populations of the famous tree duck, a tawny-colored, gooselike duck of the Gulf Coast. Indeed, there is some reason to think that the rice growers, having found a way to reduce the populations of blackbirds, are using the insecticide for a dual purpose, with disastrous effects on several bird species of the rice fields. As the habit of killing grows—the resort to 'eradicating' any creature that may annoy or inconvenience us—birds are more and more finding themselves a direct target of poisons rather than an incidental one. There is a growing trend toward aerial applications of such deadly poisons as parathion to 'control' concentrations of birds distasteful to farmers. The Fish and Wildlife Service has found it necessary to express serious concern over this trend, pointing out that 'parathion treated areas constitute a potential hazard to humans, domestic animals, and wildlife.' In southern Indiana, for example, a group of farmers went together in the summer of 1959 to engage a spray plane to treat an area of river bottomland with parathion. The area was a favored roosting site for thousands of blackbirds that were feeding in nearby corn fields. The problem could have been solved easily by a slight change in agricultural practice shift to a variety of corn with deep-set ears not accessible to the birds—but the farmers had been persuaded of the merits of killing by poison, and so they sent in the planes on their mission of death.

The results probably gratified the farmers, for the casualty list included some 65,000 red-winged blackbirds and starlings. What other wildlife deaths may have gone unnoticed and unrecorded is not known. Parathion is not a specific for blackbirds: it is a universal killer. But such rabbits or raccoons or opossums as may have roamed those bottomlands and perhaps never visited the farmers' cornfields were doomed by a judge and jury who neither knew of their existence nor cared. And what of human beings? In California orchards sprayed with this

same parathion, workers handling foliage that had been treated a month earlier collapsed and went into shock, and escaped death only through skilled medical attention.

Does Indiana still raise any boys who roam through woods or fields and might even explore the margins of a river? If so, who guarded the poisoned area to keep out any who might wander in, in misguided search for unspoiled nature? Who kept vigilant watch to tell the innocent stroller that the fields he was about to enter were deadly—all their vegetation coated with a lethal film? Yet at so fearful a risk the farmers, with none to hinder them, waged their needless war on blackbirds. In each of these situations, one turns away to ponder the question: Who has made the decision that sets in motion these chains of poisonings, this ever-widening wave of death that spreads out, like ripples when a pebble is dropped into a still pond? Who has placed in one pan of the scales the leaves that might have been eaten by the beetles and in the other the pitiful heaps of many-hued feathers, the lifeless remains of the birds that fell before the unselective bludgeon of insecticidal poisons? Who has decided —who has the *right* to decide— for the countless legions of people who were not consulted that the supreme value is a world without insects, even though it be also a sterile world ungraced by the curving wing of a bird in flight? The decision is that of the authoritarian temporarily entrusted with power; he has made it during a moment of inattention by millions to whom beauty and the ordered world of nature still have a meaning that is deep and imperative.

15. Nature Fights Back

TO HAVE RISKED so much in our efforts to mold nature to our satisfaction and yet to have failed in achieving our goal would indeed be the final irony. Yet this, it seems, is our situation. The truth, seldom mentioned but there for anyone to see, is that nature is not so easily molded and that the insects are finding ways to circumvent our chemical attacks on them.

'The insect world is nature's most astonishing phenomenon,' said the Dutch biologist C. J. Briejèr. 'Nothing is impossible to it; the most improbable things commonly occur there. One who penetrates deeply into its mysteries is continually breathless with wonder. He knows that anything can happen, and that the completely impossible often does.' The 'impossible' is now happening on two broad fronts. By a process of genetic selection, the insects are developing strains resistant to chemicals. This will be discussed in the following chapter. But the broader problem, which we shall look at now, is the fact that our chemical attack is weakening the defenses inherent in the environment itself, defenses designed to keep the various species in check. Each time we breach these defenses a horde of insects pours through.

From all over the world come reports that make it clear we are in a serious predicament. At the end of a decade or more of intensive chemical control, entomologists were finding that problems they had considered solved a few years earlier had returned to plague them. And new problems had arisen as insects once present only in insignificant numbers had increased to the status of serious pests. By their very nature chemical controls are self-defeating, for they have been devised and applied without taking into account the complex biological systems against which they have been blindly hurled. The chemicals may have been pretested against a few individual species, but not against living communities. In some quarters nowadays it is fashionable to dismiss the balance of nature as a state of affairs that prevailed in an earlier, simpler world—a state that has now been so thoroughly upset that we might as well forget it. Some find this a convenient assumption, but as a chart for a course of action it is highly dangerous. The balance of nature is not the same today as in Pleistocene times, but it is still there: a complex, precise, and highly integrated system of relationships between living things which cannot safely be ignored any more than the law of gravity can be defied with impunity by a man perched on the edge of a cliff. The balance of nature is not a *status quo*; it is fluid, ever shifting, in a constant state of adjustment. Man, too, is part of this balance. Sometimes the balance is in his favor; sometimes—and all too often through his own activities—it is shifted to his disadvantage.

Two critically important facts have been overlooked in designing the modern insect control programs. The first is that the really effective control of insects is that applied by nature, not by man. Populations are kept in check by something the ecologists call the resistance of the environment, and this has been so since the first life was created. The amount of food available, conditions of weather and climate, the presence of competing or predatory species, all are critically important. 'The greatest single factor in preventing insects from overwhelming the rest of the world is the internecine warfare which they carry out among themselves,' said the entomologist Robert Metcalf. Yet most of the chemicals now used kill all insects, our friends and enemies alike.

The second neglected fact is the truly explosive power of a species to reproduce once the resistance of the environment has been weakened. The fecundity of many forms of life is almost beyond our power to imagine, though now and then we have suggestive glimpses. I remember from student days the miracle that could be wrought in a jar containing a simple mixture of hay and water merely by adding to it a few drops of material from a mature culture of protozoa. Within a few days the jar would contain a whole galaxy of whirling, darting life—uncountable trillions of the slipper animalcule, *Paramecium*, each small as a dust grain, all multiplying without restraint in their temporary Eden of favorable temperatures, abundant food, absence of enemies. Or I think of shore rocks white with barnacles as far as the eye can see, or of the spectacle of passing through an immense school of jellyfish, mile after mile, with seemingly no end to the pulsing, ghostly forms scarcely more substantial than the water itself.

We see the miracle of nature's control at work when the cod move through winter seas to their spawning grounds, where each female deposits several millions of eggs. The sea does not become a solid mass of cod as it would surely do if all the progeny of all the cod were to survive. The checks that exist in nature are such that out of the millions of young produced by each pair only enough, on the average, survive to adulthood to replace the parent fish.

Biologists used to entertain themselves by speculating as to what would happen if, through some unthinkable catastrophe, the natural restraints were thrown off and all the progeny of a single individual survived. Thus Thomas Huxley a century ago calculated that a single female aphis (which has the curious power of reproducing without mating) could produce progeny in a single year's time whose total weight would equal that of the inhabitants of the Chinese empire of his day. Fortunately for us such an extreme situation is only theoretical, but the dire results of upsetting nature's own arrangements are well known to students of animal populations. The stockman's zeal for eliminating the coyote has resulted in plagues of field mice, which the coyote formerly controlled. The oft repeated story of the Kaibab deer in Arizona is another case in point. At one time the deer population was in equilibrium with its environment. A number of predators—wolves, pumas, and coyotes—prevented the deer from outrunning their food supply. Then a campaign was begun to 'conserve' the deer by killing off their enemies. Once the predators were gone, the deer increased prodigiously and soon there was not enough food for them. The browse line on the trees went higher and higher as they sought food, and in time many more deer were dying of starvation than had formerly been killed by predators. The whole environment, moreover, was damaged by their desperate efforts to find food.

The predatory insects of field and forests play the same role as the wolves and coyotes of the Kaibab. Kill them off and the population of the prey insect surges upward. No one knows how many species of insects inhabit the earth because so many are yet to be identified. But more than 700,000 have already been described. This means that in terms of the number of species, 70 to 80 per cent of the earth's creatures are insects. The vast majority of these insects are held in check by natural forces, without any intervention by man. If this were not so, it is doubtful that any conceivable volume of chemicals —or any other methods—could possibly keep down their populations. The trouble is that we are seldom aware of the protection afforded by natural enemies until it fails. Most of us walk unseeing through the world, unaware alike of its beauties, its wonders, and the strange and sometimes terrible intensity of the lives that are being lived about us. So it is that the activities of the insect predators and parasites are known to few.

Perhaps we may have noticed an oddly shaped insect of ferocious mien on a bush in the garden and been dimly aware that the praying mantis lives at the expense of other insects. But we see with understanding eye only if we have walked in the garden at night and here and there with a flashlight have glimpsed the mantis stealthily creeping upon her prey. Then we sense something of the drama of the hunter and the hunted. Then we begin to feel something of that relentlessly pressing force by which nature controls her own. The predators—insects that kill and consume other insects—are of many kinds. Some are quick and with the speed of swallows snatch their prey from the air. Others plod methodically along a stem, plucking off and devouring sedentary insects like the aphids. The yellowjackets capture soft-bodied insects and feed the juices to their young. Muddauber wasps build columned nests of mud under the caves of houses and stock them with insects on which their young will feed. The horseguard wasp hovers above herds of grazing cattle, destroying the blood-sucking flies that torment them. The loudly buzzing syrphid fly, often mistaken for a bee, lays its eggs on leaves of aphis-infested plants; the hatching larvae then consume immense numbers of aphids. Ladybugs or lady beetles are among the most effective destroyers of aphids, scale insects, and other plant-eating insects. Literally hundreds of aphids are consumed by a single ladybug to stoke the little fires of energy which she requires to produce even a single batch of eggs.

Even more extraordinary in their habits are the parasitic insects. These do not kill their hosts outright. Instead, by a variety of adaptations they utilize their victims for the nurture of their own young. They may deposit their eggs within the larvae or eggs of their prey, so that their own developing young may find food by consuming the host. Some attach their eggs to a caterpillar by means of a sticky solution; on hatching, the larval parasite bores through the skin of the host. Others, led by an instinct that simulates foresight, merely lay their eggs on a leaf so that a browsing caterpillar will eat them inadvertently.

Everywhere, in field and hedgerow and garden and forest, the insect predators and parasites are at work. Here, above a pond, the dragonflies dart and the sun strikes fire from their wings. So their ancestors sped through swamps where huge reptiles lived. Now, as in those ancient times, the sharp-eyed capture mosquitoes in the air, scooping them in with basket-shaped legs. In the waters below, their young, the dragonfly nymphs, or naiads, prey on the aquatic stages of mosquitoes and other insects. Or there, almost invisible against a leaf, is the lacewing, with green gauze wings and golden eyes, shy and secretive, descendant of an ancient race that lived in Permian times. The adult lacewing feeds mostly on plant nectars and the honeydew of aphids, and in time she lays her eggs, each on the end of a long stalk which she fastens to a leaf. From these emerge her children—strange, bristled larvae called aphis lions, which live by preying on aphids, scales, or mites, which they capture and suck dry of fluid. Each may consume several hundred aphids before the ceaseless turning of the cycle of its life brings the time when it will spin a white silken cocoon in which to pass the pupa stage.

And there are many wasps, and flies as well, whose very existence depends on the destruction of the eggs or larvae of other insects through parasitism. Some of the egg parasites are exceedingly minute wasps, yet by their numbers and their great activity they hold down the abundance of many crop-destroying species. All these small creatures are working—working in sun and rain, during the hours of darkness, even when winter's grip has damped down the fires of life to mere embers. Then this vital force is merely smoldering, awaiting the time to flare again into activity when spring awakens the insect world. Meanwhile, under the white blanket

of snow, below the frosthardened soil, in crevices in the bark of trees, and in sheltered caves, the parasites and the predators have found ways to tide themselves over the season of cold. The eggs of the mantis are secure in little cases of thin parchment attached to the branch of a shrub by the mother who lived her life span with the summer that is gone.

The female *Polistes* wasp, taking shelter in a forgotten corner of some attic, carries in her body the fertilized eggs, the heritage on which the whole future of her colony depends. She, the lone survivor, will start a small paper nest in the spring, lay a few eggs in its cells, and carefully rear a small force of workers. With their help she will then enlarge the nest and develop the colony. Then the workers, foraging ceaselessly through the hot days of summer, will destroy countless caterpillars. Thus, through the circumstances of their lives, and the nature of our own wants, all these have been our allies in keeping the balance of nature tilted in our favor. Yet we have turned our artillery against our friends. The terrible danger is that we have grossly underestimated their value in keeping at bay a dark tide of enemies that, without their help, can overrun us.

The prospect of a general and permanent lowering of environmental resistance becomes grimly and increasingly real with each passing year as the number, variety, and destructiveness of insecticides grows. With the passage of time we may expect progressively more serious outbreaks of insects, both disease-carrying and crop-destroying species, in excess of anything we have ever known. 'Yes, but isn't this all theoretical?' you may ask. 'Surely it won't really happen—not in my lifetime, anyway.' But it is happening, here and now. Scientific journals had already recorded some 50 species involved in violent dislocations of nature's balance by 1958. More examples are being found every year. A recent review of the subject contained references to 215 papers reporting or discussing unfavorable upsets in the balance of insect populations caused by pesticides.

Sometimes the result of chemical spraying has been a tremendous upsurge of the very insect the spraying was intended to control, as when blackflies in Ontario became 17 times more abundant after spraying than they had been before. Or when in England an enormous outbreak of the cabbage aphid—an outbreak that had no parallel on record—followed spraying with one of the organic phosphorus chemicals. At other times spraying, while reasonably effective against the target insect, has let loose a whole Pandora's box of destructive pests that had never previously been abundant enough to cause trouble. The spider mite, for example, has become practically a worldwide pest as DDT and other insecticides have killed off its enemies. The spider mite is not an insect. It is a barely visible eight-legged creature belonging to the group that includes spiders, scorpions, and ticks. It has mouth parts adapted for piercing and sucking, and a prodigious appetite for the chlorophyll that makes the world green. It inserts these minute and stiletto-sharp mouth parts into the outer cells of leaves and evergreen needles and extracts the chlorophyll. A mild infestation gives trees and shrubbery a mottled or salt-and-pepper appearance; with a heavy mite population, foliage turns yellow and falls.

This is what happened in some of the western national forests a few years ago, when in 1956 the United States Forest Service sprayed some 885,000 acres of forested lands with DDT. The intention was to control the spruce budworm, but the following summer it was discovered that a problem worse than the budworm damage had been created. In surveying the forests from the air, vast blighted areas could be seen where the magnificent Douglas firs were turning brown and dropping their needles. In the Helena National Forest and on the western slopes of

the Big Belt Mountains, then in other areas of Montana and down into Idaho the forests looked as though they had been scorched. It was evident that this summer of 1957 had brought the most extensive and spectacular infestation of spider mites in history. Almost all of the sprayed area was affected. Nowhere else was the damage evident. Searching for precedents, the foresters could remember other scourges of spider mites, though less dramatic than this one. There had been similar trouble along the Madison River in Yellowstone Park in 1929, in Colorado 20 years later, and then in New Mexico in 1956. *Each of these outbreaks had followed forest spraying with insecticides.* (The 1929 spraying, occurring before the DDT era, employed lead arsenate.)

Why does the spider mite appear to thrive on insecticides? Besides the obvious fact that it is relatively insensitive to them, there seem to be two other reasons. In nature it is kept in check by various predators such as ladybugs, a gall midge, predaceous mites and several pirate bugs, all of them extremely sensitive to insecticides. The third reason has to do with population pressure within the spider mite colonies. An undisturbed colony of mites is a densely settled community, huddled under a protective webbing for concealment from its enemies. When sprayed, the colonies disperse as the mites, irritated though not killed by the chemicals, scatter out in search of places where they will not be disturbed. In so doing they find a far greater abundance of space and food than was available in the former colonies. Their enemies are now dead so there is no need for the mites to spend their energy in secreting protective webbing. Instead, they pour all their energies into producing more mites. It is not uncommon for their egg production to be increased threefold—all through the beneficent effect of insecticides.

In the Shenandoah Valley of Virginia, a famous apple-growing region, hordes of a small insect called the red-banded leaf roller arose to plague the growers as soon as DDT began to replace arsenate of lead. Its depredations had never before been important; soon its toll rose to 50 per cent of the crop and it achieved the status of the most destructive pest of apples, not only in this region but throughout much of the East and Midwest, as the use of DDT increased. The situation abounds in ironies. In the apple orchards of Nova Scotia in the late 1940s the worst infestations of the codling moth (cause of 'wormy apples') were in the orchards regularly sprayed. In unsprayed orchards the moths were not abundant enough to cause real trouble.

Diligence in spraying had a similarly unsatisfactory reward in the eastern Sudan, where cotton growers had a bitter experience with DDT. Some 60,000 acres of cotton were being grown under irrigation in the Gash Delta. Early trials of DDT having given apparently good results, spraying was intensified. It was then that trouble began. One of the most destructive enemies of cotton is the bollworm. But the more cotton was sprayed, the more bollworms appeared. The unsprayed cotton suffered less damage to fruits and later to mature bolls than the sprayed, and in twice-sprayed fields the yield of seed cotton dropped significantly. Although some of the leaf-feeding insects were eliminated, any benefit that might thus have been gained was more than offset by bollworm damage. In the end the growers were faced with the unpleasant truth that their cotton yield would have been greater had they saved themselves the trouble and expense of spraying.

In the Belgian Congo and Uganda the results of heavy applications of DDT against an insect pest of the coffee bush were almost 'catastrophic'. The pest itself was found to be almost completely unaffected by the DDT, while its predator was extremely sensitive. In America, farmers have repeatedly traded one insect enemy for a worse one as spraying upsets the

population dynamics of the insect world. Two of the mass-spraying programs recently carried out have had precisely this effect. One was the fire ant eradication program in the South; the other was the spraying for the Japanese beetle in the Midwest. (*See Chapters 10 and 7.*)

When a wholesale application of heptachlor was made to the farmlands in Louisiana in 1957, the result was the unleashing of one of the worst enemies of the sugarcane crop—the sugarcane borer. Soon after the heptachlor treatment, damage by borers increased sharply. The chemical aimed at the fire ant had killed off the enemies of the borer. The crop was so severely damaged that farmers sought to bring suit against the state for negligence in not warning them that this might happen. The same bitter lesson was learned by Illinois farmers. After the devastating bath of dieldrin recently administered to the farmlands in eastern Illinois for the control of the Japanese beetle, farmers discovered that corn borers had increased enormously in the treated area. In fact, corn grown in fields within this area contained almost twice as many of the destructive larvae of this insect as did the corn grown outside. The farmers may not yet be aware of the biological basis of what has happened, but they need no scientists to tell them they have made a poor bargain. In trying to get rid of one insect, they have brought on a scourge of a much more destructive one. According to Department of Agriculture estimates, total damage by the Japanese beetle in the United States adds up to about 10 million dollars a year, while damage by the corn borer runs to about 85 million.

It is worth noting that natural forces had been heavily relied on for control of the corn borer. Within two years after this insect was accidentally introduced from Europe in 1917, the United States Government had mounted one of its most intensive programs for locating and importing parasites of an insect pest. Since that time 24 species of parasites of the corn borer have been brought in from Europe and the Orient at considerable expense. Of these, 5 are recognized as being of distinct value in control. Needless to say, the results of all this work are now jeopardized as the enemies of the corn borer are killed off by the sprays.

If this seems absurd, consider the situation in the citrus groves of California, where the world's most famous and successful experiment in biological control was carried out in the 1880s. In 1872 a scale insect that feeds on the sap of citrus trees appeared in California and within the next 25 years developed into a pest so destructive that the fruit crop in many orchards was a complete loss. The young citrus industry was threatened with destruction. Many farmers gave up and pulled out their trees. Then a parasite of the scale insect was imported from Australia, a small lady beetle called the vedalia. Within only two years after the first shipment of the beetles, the scale was under complete control throughout the citrus-growing sections of California. From that time on one could search for days among the orange groves without finding a single scale insect.

Then in the 1940s the citrus growers began to experiment with glamorous new chemicals against other insects. With the advent of DDT and the even more toxic chemicals to follow, the populations of the vedalia in many sections of California were wiped out. Its importation had cost the government a mere $5000. Its activities had saved the fruit growers several millions of dollars a year, but in a moment of heedlessness the benefit was canceled out. Infestations of the scale insect quickly reappeared and damage exceeded anything that had been seen for fifty years. 'This possibly marked the end of an era,' said Dr. Paul DeBach of the Citrus Experiment Station in Riverside. Now control of the scale has become enormously complicated. The vedalia can be maintained only by repeated releases and by the most careful attention to spray

schedules, to minimize their contact with insecticides. And regardless of what the citrus growers do, they are more or less at the mercy of the owners of adjacent acreages, for severe damage has been done by insecticidal drift. . . .

All these examples concern insects that attack agricultural crops. What of those that carry disease? There have already been warnings. On Nissan Island in the South Pacific, for example, spraying had been carried on intensively during the Second World War, but was stopped when hostilities came to an end. Soon swarms of a malaria-carrying mosquito reinvaded the island. All of its predators had been killed off and there had not been time for new populations to become established. The way was therefore clear for a tremendous population explosion. Marshall Laird, who has described this incident, compares chemical control to a treadmill; once we have set foot on it we are unable to stop for fear of the consequences.

In some parts of the world disease can be linked with spraying in quite a different way. For some reason, snail-like mollusks seem to be almost immune to the effects of insecticides. This has been observed many times. In the general holocaust that followed the spraying of salt marshes in eastern Florida (*pages 115-116*), aquatic snails alone survived. The scene as described was a macabre picture—something that might have been created by a surrealist brush. The snails moved among the bodies of the dead fishes and the moribund crabs, devouring the victims of the death rain of poison. But why is this important? It is important because many aquatic snails serve as hosts of dangerous parasitic worms that spend part of their life cycle in a mollusk, part in a human being. Examples are the blood flukes, or schistosoma, that cause serious disease in man when they enter the body by way of drinking water or through the skin when people are bathing in infested waters. The flukes are released into the water by the host snails. Such diseases are especially prevalent in parts of Asia and Africa. Where they occur, insect control measures that favor a vast increase of snails are likely to be followed by grave consequences.

And of course man is not alone in being subject to snail-borne disease. Liver disease in cattle, sheep, goats, deer, elk, rabbits, and various other warm-blooded animals may be caused by liver flukes that spend part of their life cycles in fresh-water snails. Livers infested with these worms are unfit for use as human food and are routinely condemned. Such rejections cost American cattlemen about 3½ million dollars annually. Anything that acts to increase the number of snails can obviously make this problem an even more serious one. . . .

Over the past decade these problems have cast long shadows, but we have been slow to recognize them. Most of those best fitted to develop natural controls and assist in putting them into effect have been too busy laboring in the more exciting vineyards of chemical control. It was reported in 1960 that only 2 per cent of all the economic entomologists in the country were then working in the field of biological controls. A substantial number of the remaining 98 per cent were engaged in research on chemical insecticides.

Why should this be? The major chemical companies are pouring money into the universities to support research on insecticides. This creates attractive fellowships for graduate students and attractive staff positions. Biological-control studies, on the other hand, are never so endowed—for the simple reason that they do not promise anyone the fortunes that are to be made in the chemical industry. These are left to state and federal agencies, where the salaries paid are far less. This situation also explains the otherwise mystifying fact that certain outstanding entomologists are among the leading advocates of chemical control. Inquiry into the

background of some of these men reveals that their entire research program is supported by the chemical industry. Their professional prestige, sometimes their very jobs depend on the perpetuation of chemical methods. Can we then expect them to bite the hand that literally feeds them? But knowing their bias, how much credence can we give to their protests that insecticides are harmless? Amid the general acclaim for chemicals as the principal method of insect control, minority reports have occasionally been filed by those few entomologists who have not lost sight of the fact that they are neither chemists nor engineers, but biologists.

F. H. Jacob in England has declared that 'the activities of many so-called economic entomologists would make it appear that they operate in the belief that salvation lies at the end of a spray nozzle...that when they have created problems of resurgence or resistance or mammalian toxicity, the chemist will be ready with another pill. That view is not held here...Ultimately only the biologist will provide the answers to the basic problems of pest control.' 'Economic entomologists must realize,' wrote A. D. Pickett of Nova Scotia, 'that they are dealing with living things...their work must be more than simply insecticide testing or a quest for highly destructive chemicals.' Dr. Pickett himself was a pioneer in the field of working out sane methods of insect control that take full advantage of the predatory and parasitic species. The method which he and his associates evolved is today a shining model but one too little emulated. Only in the integrated control programs developed by some California entomologists do we find anything comparable in this country.

Dr. Pickett began his work some thirty-five years ago in the apple orchards of the Annapolis Valley in Nova Scotia, once one of the most concentrated fruit-growing areas in Canada. At that time it was believed that insecticides—then inorganic chemicals—would solve the problems of insect control, that the only task was to induce fruit growers to follow the recommended methods. But the rosy picture failed to materialize. Somehow the insects persisted. New chemicals were added, better spraying equipment was devised, and the zeal for spraying increased, but the insect problem did not get any better. Then DDT promised to 'obliterate the nightmare' of codling moth outbreaks. What actually resulted from its use was an unprecedented scourge of mites. 'We move from crisis to crisis, merely trading one problem for another,' said Dr. Pickett.

At this point, however, Dr. Pickett and his associates struck out on a new road instead of going along with other entomologists who continued to pursue the will-o'-the-wisp of the ever more toxic chemical. Recognizing that they had a strong ally in nature, they devised a program that makes maximum use of natural controls and minimum use of insecticides. Whenever insecticides are applied only minimum dosages are used—barely enough to control the pest without avoidable harm to beneficial species. Proper timing also enters in. Thus, if nicotine sulphate is applied before rather than after the apple blossoms turn pink one of the important predators is spared, probably because it is still in the egg stage.

Dr. Pickett uses special care to select chemicals that will do as little harm as possible to insect parasites and predators. 'When we reach the point of using DDT, parathion, chlordane, and other new insecticides as routine control measures in the same way we have used the inorganic chemicals in the past, entomologists interested in biological control may as well throw in the sponge,' he says. Instead of these highly toxic, broad-spectrum insecticides, he places chief reliance on ryania (derived from ground stems of a tropical plant), nicotine sulphate, and lead arsenate. In certain situations very weak concentrations of DDT or malathion are used (1 or 2

ounces per 100 gallons in contrast to the usual 1 or 2 pounds per 100 gallons). Although these two are the least toxic of the modern insecticides, Dr. Pickett hopes by further research to replace them with safer and more selective materials.

How well has this program worked? Nova Scotia orchardists who are following Dr. Pickett's modified spray program are producing as high a proportion of first-grade fruit as are those who are using intensive chemical applications. They are also getting as good production. They are getting these results, moreover, at a substantially lower cost. The outlay for insecticides in Nova Scotia apple orchards is only from 10 to 20 per cent of the amount spent in most other apple-growing areas. More important than even these excellent results is the fact that the modified program worked out by these Nova Scotian entomologists is not doing violence to nature's balance. It is well on the way to realizing the philosophy stated by the Canadian entomologist G. C. Ullyett a decade ago: 'We must change our philosophy, abandon our attitude of human superiority and admit that in many cases in natural environments we find ways and means of limiting populations of organisms in a more economical way than we can do it ourselves.'

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