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SILENT SPRING—II

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Illustration by Emiliano Ponzi

As man proceeds toward his announced goal of the conquest of nature, he is writing a depressing record of destruction—destruction of the earth he inhabits and destruction of the life that shares it with him. The history of recent centuries has its black passages—the slaughter of the buffalo on the Western plains, the massacre of the shore birds by the market gunners, the near extermination of the egrets for their plumage. Now to these, and others like them, we are adding a new chapter—the killing of birds, mammals, fishes, and, indeed, every form of wildlife by chemical insecticides indiscriminately sprayed on the land. Opinions on the effect of this spraying differ. On the one hand, conservationists and many wildlife biologists assert that the losses have been severe, and in some cases catastrophic. On the other hand, the insect-control specialists tend to deny that such losses have occurred, or that they are of any importance if they have. When we try to decide which view to accept, the credibility of the witness is of the first importance. The biologist on the scene is certainly well qualified to discover and interpret the loss of wildlife. The control specialist, even if he is an entomologist, is not so well qualified by training, and besides he is not psychologically disposed to look for undesirable side effects. Like the priest and the Levite in the biblical story, the control men in the state and federal governments and, of course, the chemical manufacturers—choose to pass by on the other side and to see nothing.

It is sometimes argued that the destruction of wildlife through spraying is only temporary and that the populations soon reëstablish themselves. Even in the occasional situations where this has happened, an injustice has been done. The bird watcher, the suburbanite who derives joy from birds in his garden, the hunter, the fisherman, and the explorer of wild regions have been deprived of pleasure to which they have a legitimate right. Such reëstablishment, however, is unlikely to occur, for spraying is ordinarily a repetitive process, and the environment becomes a trap, in which not only the resident wildlife populations succumb but those who come in as migrants as well. Now, in a decade marked by government insect-control programs in which many thousands, even millions, of acres are sprayed as a unit, a decade in which private and community spraying has also surged steadily upward, an extensive record of destruction and death of American wildlife has accumulated.

During the fall of 1959, about twenty-seven thousand acres in southeastern Michigan, including some of the suburbs of Detroit, were heavily dusted from the air with clay pellets containing one of the most poisonous of all the insecticides—a chemical called aldrin. Like the better-known DDT, aldrin is one of a group of synthetic chemicals called the chlorinated hydrocarbons, which have been in wide and growing use as pesticides since the end of the Second World War. The Michigan program was conducted by the state Department of Agriculture, with the coöperation of the United States Department of Agriculture; its announced purpose was control of the Japanese beetle. This beetle was first discovered in New Jersey in 1916, when a few shiny insects of a metallic-green color were seen in a nursery near Riverton. The beetles, at first unrecognized, were finally identified as a common inhabitant of the main islands of Japan. Apparently, they had entered the United States on nursery stock imported before 1912—the year when restrictions were established on such imports. From its original point of entrance, the Japanese beetle has spread rather widely through many of the states east of the Mississippi, where conditions of temperature and rainfall are suitable for it, and some outward movement beyond the existing boundaries of its distribution usually takes place each year. For a time, it was a troublesome destroyer of crops and ornamental plants, but then, in many of the eastern areas, ways were devised to keep its populations at relatively low levels—without large-scale spraying. Yet despite this record of reasonable control in eastern areas, the Midwestern states have launched an attack worthy of the most deadly enemy upon an only moderately destructive insect. At the time of the Michigan spraying, Walter P. Nickell, one of the best-known and best-informed naturalists in the state, declared, "For more than thirty years, to my direct knowledge, the Japanese beetle has been present in the city of Detroit in small numbers. The numbers have not shown any appreciable increase in all this lapse of years. . . . I have not yet been able to obtain any information whatsoever to the effect that they have increased in numbers." An official release by the state agency merely declared that the beetle had "put in its appearance," and the program was launched, with the state providing some of the manpower and supervising the operation, the federal government providing equipment and additional men, and the communities paying for the insecticide.

The Michigan spraying was one of the first large-scale attacks on the Japanese beetle from the air. The choice of aldrin was not arrived at by any inquiry into its suitability for Japanese-beetle control but simply by the wish to save money; aldrin was cheaper than the other poisons considered. While the state acknowledged in an official release to the press that aldrin is a "poison," it implied that no harm could come to human beings, and the official answer to the query "What precautions should I take?" was "For you, none." An official of the Detroit Department of Parks and Recreation was quoted in the press as saying that the dust was "harmless to humans and will not hurt plants or pets," and the Federal Aviation Agency's safety officer for the area was quoted as saying, "This is a safe operation." One must assume that none of these officials had consulted the published and readily available reports of the Public Health Service or the Fish and Wildlife Service, or any of the other evidence of the extremely poisonous nature of aldrin.

Acting under the Michigan Insect Pest and Plant Disease Act, which allows the state to spray and dust indiscriminately without gaining the permission of individual landowners or even notifying them, the planes began to fly over the Detroit area, at extremely low altitudes. The city authorities and the Federal Aviation Agency were immediately besieged by calls from worried citizens. After receiving nearly eight hundred calls in a single hour, the police begged radio and television stations and newspapers, in the words of the Detroit *News*, to "tell the watchers what they were seeing and advise them it was safe." The Federal Aviation Agency assured the public that "the planes are carefully supervised" and "authorized to fly low." As the planes went about their work, the pellets of aldrin and clay fell on beetles and human beings alike. The granules looked like snow, and housewives swept them from porches and sidewalks. A few days after the spraying, the Detroit Audubon Society began receiving calls about the birds. The Society's secretary, Mrs. Ann Boyes, has noted, "The first indication that the people were concerned about the spray was a call I received on Sunday morning from a woman who reported that coming home from church she saw an alarming number of dead and dying birds. The spraying there had been done on Thursday. She said there were no birds at all flying in the area . . . she had found at least a dozen [dead] in her back yard." Birds picked up in a dying condition showed the typical symptoms of insecticide poisoning—trembling, loss of the ability to fly, paralysis, and convulsions. Nor were birds the only form of life immediately affected. A local veterinarian reported that his office was full of clients with dogs and cats. The cats, so meticulous about grooming their coats and licking their paws, seemed to be the more seriously affected. Their illness took the form of severe diarrhea, vomiting, and convulsions. The only advice the veterinarian could give his clients was not to let the animals out unnecessarily, and to wash their paws as soon as possible if they did go out. But it has been demonstrated that aldrin, like the other chlorinated hydrocarbons, cannot be washed away, so little protection could be expected from this measure. The City-County Health Commissioner insisted that the birds must have been killed by "some other kind of spraying," and when an outbreak of human throat and chest irritations occurred after the dusting, he declared that it must have been due to "something else." Nevertheless, the local Health Department received many complaints, and a prominent Detroit internist was called upon to treat four of his patients within an hour after they had stood outdoors watching the planes at work. All four had similar symptoms: nausea, vomiting, chills, fever, extreme fatigue, and coughing.

The Detroit experience has been repeated in many other communities trying to combat the Japanese beetle with chemicals. Perhaps no community has suffered more for the sake of a beetleless world than Sheldon, in eastern Illinois, and adjacent areas of Iroquois County, in which Sheldon is situated. In 1954, the United States Department of

Agriculture and the Illinois Department of Agriculture began a program to eradicate the Japanese beetle along the line of its advance into Illinois, holding out the hope—indeed, the assurance—that intensive spraying would destroy the invading beetle population. The first "eradication" took place in the spring of that year, when dieldrin—a chemical closely related to aldrin—was sprayed on fourteen hundred acres. Twenty-six hundred additional acres were similarly treated in 1955, and the task was presumed complete. But more and more chemical treatments were called for, and by the end of 1961 some hundred and thirty-one thousand acres had been covered. Even in the first years of the program, it was apparent that heavy losses were occurring among wildlife and domestic animals, yet neither the United States Fish and Wildlife Service nor the Illinois Game Management Division appears to have been consulted about the matter. (In the spring of 1960, officials of the Department of Agriculture appeared before a congressional committee in opposition to a bill that would require just such prior consultation. They declared that the bill was unnecessary, because coöperation and consultation were "usual." These officials were quite unable to recall situations where coöperation had not taken place "at the Washington level." In the same hearings, they clearly stated that they were unwilling to consult with state fish and game departments.) Although funds for chemical control came in never-ending streams, the biologists of the Illinois Natural History Survey, in Urbana, who attempted to measure the damage to wildlife, had to operate on a financial shoestring. A mere eleven hundred dollars was available for the employment of a field assistant in 1954, and no special funds were provided in 1955. Nevertheless, the biologists assembled facts that collectively paint a picture of almost unparalleled wildlife destruction. Conditions were made to order for poisoning insect-eating birds, with regard to both the poisons used and the events set in motion by their application. In the early programs at Sheldon, dieldrin was used at the rate of three pounds to the acre. In laboratory experiments on quail, it has proved to be about fifty times as poisonous as DDT, which is popularly considered safe in the ratio of one pound to an acre. The poison spread over the landscape at Sheldon was therefore roughly equivalent to a hundred and fifty pounds of DDT per acre. As dieldrin penetrated the soil, the poisoned beetle grubs crawled out on the surface of the ground, where they attracted insectivorous birds. Dead and dying insects of various species were conspicuous for about two weeks after the treatment. The effect on the bird populations could easily have been foretold. Brown thrashers, starlings, meadowlarks, grackles, and pheasants were virtually annihilated, and so were robins. Dead earthworms had been seen in numbers after a gentle rain; probably the robins had fed on them. For other birds, too, the once beneficial rain had been changed into an agent of destruction. Birds that sought out puddles left by rain a few days after the spraying were doomed, whether they drank the water or merely bathed in it. The birds that survived may have been rendered sterile. Although some nests were later found in the treated area, a few of them with eggs, none ever contained young birds.

Ground squirrels were almost wiped out in the Sheldon region; their bodies were found in attitudes characteristic of violent death by poisoning. The fox squirrel had been a relatively common animal in the town; after the spraying, it was gone. Dead muskrats and dead rabbits were found. And it was a rare farm in the Sheldon region that was blessed by the presence of a cat after the war on beetles was begun. Ninety per cent of all the farm cats fell victims to the dieldrin during the first season of spraying. Cats are extremely sensitive to all insecticides, and especially, it seems, to dieldrin. In west Java, in the course of an anti-malarial program carried out by the World Health Organization, many cats were reported to have died. In central Java, so many died that the price of a cat more than doubled. Livestock, too, were affected in Sheldon. The Natural History Survey report describes one episode as follows: "The sheep . . . were driven into a small, untreated bluegrass pasture across a gravel road from a field which had been treated with dieldrin spray on May 6. Evidently some spray had drifted across the road into the pasture, for the sheep began to show symptoms of intoxication almost at once. . . . They lost interest in food and displayed extreme restlessness, following the pasture fence around and around apparently searching for a way out. . . . [They] refused to be driven, bleated almost continuously, and stood with their heads lowered; they were finally carried from the pasture. . . . They displayed great desire for water. Two of the sheep were found dead in the stream passing through the pasture, and the remaining sheep were repeatedly driven out of the stream, several having to be dragged forcibly from the water."

In spite of the havoc that had been wrought in the name of Japanese-beetle eradication, the treatment of more than a hundred thousand acres in Iroquois County over an eight-year period seems to have resulted in an only temporary suppression of the insect, which is still making its way westward. If the communities that have endured chemical drenchings had been familiar with the earlier history of the Japanese beetle in the United States, they would surely have been less acquiescent. The Eastern states, which had the good fortune to face their beetle invasion in the days before DDT, aldrin, and the other synthetic insecticides were invented, have brought the insect under reasonable control, chiefly by means that represented no threat whatever to other forms of life. During the first dozen years after its entry into the United States, the beetle increased rapidly numbers, free of the restraints that had held it in check in its native land. By 1955, however, it had become a pest of only minor importance throughout much of the territory over which it had spread. Between 1920 and 1933, as result of diligent searching in the Orient, some thirty-four species of insects hostile to the beetle—either predatory or parasitic—were imported into the United States. Of these, five have become well established in the East. The most effective and widely distributed is a parasitic wasp, *Tiphia vernalis*, from Korea and China. The female tiphia, finding a beetle grub in the soil, injects it with a paralyzing fluid and attaches a single egg to its under-surface. The young wasp, hatching as a larva, feeds on the paralyzed grub and destroys it. In the course of some twenty-five years, colonies of tiphia were introduced into fourteen Eastern states in a coöperative program involving state and federal agencies. An even more important role than that of the imported insects has been played by a bacterial disease that affects beetles of the family to which the Japanese beetle belongs—the scarabaeids. The bacterium involved, *Bacillus popilliae*, attacks no other type of insect, and is harmless to earthworms, warm-blooded animals, and plants. The spores of the disease occur in soil. When a foraging beetle grub ingests them, they develop into bacteria that multiply prodigiously in its blood, causing it to turn white. Hence the disease has acquired the popular name "milky disease." Milky disease was discovered in New Jersey in 1933. By 1938, it was rather widely prevalent in the older areas of Japanese beetle infestation. In 1939, the Department of Agriculture launched a program to speed up the spread of the disease. Infected grubs were ground up, dried, and combined with chalk; in the standard mixture a gram of this dust contained a hundred million spores. The spores remain viable in the soil for years, and therefore become to all intents and purposes permanently established; moreover, their effectiveness increases, for they are steadily being spread by natural agencies. Between 1939 and 1953, some ninety-four thousand acres in fourteen Eastern states and the District of Columbia were treated in a coöperative federal-state program. Private organizations and individuals also undertook to introduce the spores into areas of unknown but large extent. By 1945, milky disease was raging among the beetle populations of Connecticut, New York, New Jersey, Delaware, and Maryland. In some test areas, as many as ninety-four grubs out of every hundred were infected. In 1953, the government discontinued its program, but production of the dust was taken over by a private laboratory, which supplies it to individuals, garden clubs, and citizens' associations. And an extensive program of research is currently under way in the United States Department of Agriculture laboratory at Peoria, Illinois, to find a means of growing the organism of milky disease in an artificial culture—a method that would greatly reduce its cost and should encourage its more extensive use. After years of work, some success has now been reported.

Why, with this impressive record in the East, was the same procedure not used in the Midwestern states? We are told that inoculation with milky disease is "too expensive," although no one found it so in the fourteen Eastern states in the nineteen-forties. And, in any case, by what sort of accounting was it determined that the method was too expensive? Certainly not by any that assessed the true cost of the total destruction wrought by programs like the Sheldon spraying. This kind of accounting must also have ignored the fact that inoculation with the spores need be done only once; the first cost is the only cost. We are told, further, that milky disease cannot be used on the periphery of the beetle's range, because it can be established only where a large grub population is already present in the soil. Like many other statements in support of spraying, this one needs to be questioned. The bacterium that causes milky disease has been found to infect at least forty other species of beetles, which, collectively, have quite a wide distribution, and these would in all probability serve to establish the disease even where the Japanese-beetle population is very small, or nonexistent. Moreover, the long viability of the spores in soil insures the practicability of introducing them in the complete absence of grubs—that is, on the fringes of the present beetle infestation—for they can simply await the advancing population.

Those who want immediate results, at whatever cost, will doubtless continue to use chemicals against the beetle. So will those who favor the modern principle of built-in obsolescence, for chemical control demands frequent and costly repetition. On the other hand, those who are willing to wait a season or two in order to obtain really lasting results will turn to milky disease; they will be rewarded with a form of control that becomes more, rather than less, effective with the passage of time.

Over increasingly large areas of the United States, spring now comes unheralded by the return of the birds, and the early mornings, once filled with the beauty of bird song, are strangely silent. This sudden silencing of the song of the birds, this obliteration of the color and beauty and interest they lend to our world, has come about swiftly and insidiously, and has gone unnoticed by those whose communities are as yet unaffected. From the town of Hinsdale, in northeastern Illinois, in 1958, a housewife wrote in despair to one of the world's leading ornithologists, Robert Cushman Murphy, Lamont Curator Emeritus of Birds at the American Museum of Natural History: "Here in our village the elm trees have been sprayed for several years. 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."

One story might serve as a tragic symbol of the fate of the birds—a fate that has already overtaken some species and 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 described eagerly at the breakfast table. And as the number of arrivals grows and the first mists of green appear in the woodlands, thousands of people listen for the 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 fate of the robin, and indeed of many other species as well, seems linked with that of the American elm, a tree that is part of the history of thousands of towns within its native range, from the Atlantic to the Rockies, gracing their streets, their village squares, and their college campuses with majestic archways of green. Today, the elms are subject to 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. The so-called Dutch elm disease entered the United States from Europe in 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 in the flow of sap, and, by mechanical clogging and also by poisons it secretes, causes the branches to wilt and the tree to die. The disease is spread from diseased trees to healthy ones by elm-bark beetles. The insects tunnel out galleries under the bark, and these become a favorable habitat for the invading fungus. As the insects move through the galleries, they pick up the spores, and later carry them wherever they fly. Efforts to control the disease have concentrated on achieving control of the carrier insect, and in community after community, especially throughout the strongholds of the American elm, the Middle West and New England, intensive spraying with DDT 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. In 1954, when Mr. Mehner began work toward his doctorate, he chose a research project that had to do with robin populations. This came about entirely 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 that very year. In 1955, the city of East Lansing, where the university is situated, joined in; spraying on the campus was expanded; and, with local programs for control of the gypsy moth and the mosquito also under way, the chemical rain increased to a down pour. In 1954, the year of the first, light spraying, all seemed to be well. The following spring, the migrating robins returned to the campus as usual. Like the bluebells in H. M. Tomlinson's haunting essay "The Lost Wood," they were "expecting no evil" as they reoccupied their familiar territory. But soon it became evident that something was wrong. Dead and dying robins began to appear on the campus. Few birds were seen engaging in their normal foraging activities or assembling in their customary roosts. Few nests were built; few young appeared. The pattern was repeated with monotonous regularity in succeeding springs. In the sprayed area, 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 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," Dr. Wallace noted. 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 invariably exhibited the well-known symptoms of loss of balance, followed by tremors, convulsions, and death." Several circumstances suggested that the robins were being poisoned not so much by direct contact with the insecticides as indirectly, by eating poisoned earthworms. Campus earthworms had been fed to crayfish in a research project, and all the crayfish had quickly 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 presently supplied by Dr. Roy Barker, of the Illinois Natural History Survey. 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 or early summer and often again a few months later. Powerful sprayers direct a stream of poison toward 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 on 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, which feed in the leaf litter, for elm leaves are among their favorite foods. In feeding on the leaves, the worms, of course, also swallow the insecticide. Dr. Barker found deposits of DDT throughout the digestive tracts of the worms, and in their blood vessels, nerves, and body wall. Undoubtedly some of the earthworms themselves succumb, but those that survive become "biological magnifiers" of the poison—that is, the concentration of insecticide builds up in their bodies. Then, in the spring, the robins return. As few as eleven large earthworms can transfer a lethal dose of DDT to a robin. And eleven worms form a small part of a robin's daily ration; in fact, a robin may easily eat eleven earthworms in as many minutes.

Not all robins receive a lethal dose, but another consequence of poisoning may lead as surely to the extinction of their kind. The shadow of sterility lies over all the bird studies—and, indeed, lengthens to include all living things. There are now only two or three dozen robins to be found each spring on the entire hundred-and-eighty-five-acre campus of Michigan State University, compared with a conservatively estimated three hundred and seventy adults before spraying. In 1954, every robin nest under observation by Mehner produced young. In 1957, Mehner could find only one young robin. Part of this failure to produce young is due, of course, to the death of one or both of a pair of robins before the nesting cycle is completed. But Dr. Wallace has significant records that point toward something more sinister—the actual destruction of the birds' ability 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." In 1960, he told a congressional committee that was holding hearings on a bill for better coördination of spraying programs, "We have one record of a robin that sat on its eggs faithfully for twenty-one days and they did not hatch. The normal incubation period is thirteen days. . . . Our analyses are showing high concentrations of DDT in the testes and ovaries of breeding birds."

The robins are only one element in the complex pattern of devastation arising from the spraying of the elms, even as the elm program is only one of the multitudinous spray programs that spread poison over our land. Heavy mortality has occurred among about ninety species of birds, including those most familiar to amateur naturalists, and in some of the sprayed towns the populations of nesting birds in general have declined as much as ninety per cent. All the various types of birds are affected—ground feeders, treetop feeders, bark feeders, predators. Among them is the woodcock, which includes earthworms in its diet and which winters in southern areas that have recently been heavily sprayed with chemicals. Two significant discoveries have now been made about the woodcock. The numbers of young birds in New Brunswick, where many woodcocks breed, have definitely been reduced, and adult birds that have been analyzed contain heavy residues of both DDT and a chlorinated hydrocarbon called heptachlor. Already there are disturbing records of mortality among more than twenty other species of ground-feeding birds, including 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 whitethroat—have also been found among the victims of the sprays.

All the treetop feeders—the birds that glean their insect food from the leaves—have disappeared from heavily sprayed areas, including 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 Whitefish Bay, Wisconsin, in the years before 1958, at least a thousand myrtle warblers could be seen in migration; after the spraying of the elms in that year, 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 Canada, and the black-throated green. These treetop feeders are affected either directly, by the eating of poisoned insects, or indirectly, by a shortage of food.

The loss of food has also struck hard at the swallows, which cruise the skies straining out the aerial insects as herring strain out the plankton of the sea. A Wisconsin naturalist has 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 observer wrote, "Another striking loss is the phoebe. Flycatchers are scarce everywhere, but the early 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."

The sprays applied to the elms in the fall, sending the poison into every little crevice in the bark, are probably responsible for severe reductions observed in the numbers of bark feeders—chickadees, nuthatches, titmice, woodpeckers, and brown creepers. During the winter of 1957-58, Dr. Wallace for the first time in many years saw no chickadees or nuthatches at his home feeding station. Three nuthatches that he came upon later provided a sorry little step-by-step lesson in cause and effect: one was feeding on an elm, another was found dying, and the third was dead. The loss of all these birds is deplorable for economic reasons as well as for less tangible ones. 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 insect species 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 Arthur Cleveland Bent's "Life Histories of North American Jays, Crows, and Titmice": "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 a variety of situations. Thus, woodpeckers are the primary factor in the control of the Engelmann spruce beetle, reducing its populations by a minimum of forty-five per cent and a maximum of ninety-eight per cent, and are also 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, as almost always happens, there is a resurgence of the insect population, the birds are not there to keep their numbers in check.

To the public, the choice may easily appear to be one of stark 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. Spraying is killing the birds but is not saving the elms. The theory that the survival of the elms lies in spraying is a dangerous illusion, 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 a thousand per cent. In Toledo, Ohio, a similar experience caused the city's Superintendent of Forestry, Joseph A. Sweeney, to take a realistic look at the results of spraying. Spraying of elms was begun there in 1953 and continued through 1959. Meanwhile, however, Mr. Sweeney had noticed that a citywide 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 for himself the results of spraying for Dutch elm disease. 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 county, 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 Midwestern towns have so unquestioningly embarked on ambitious and expensive spraying programs, apparently without inquiring into the experience of other areas, which have had a longer acquaintance with the problem. New York State has almost certainly had the longest history of continuous experience with Dutch elm disease of any state in the Union, for, according to the best evidence, it was via the Port of New York that diseased elm wood first entered the United States, about 1930. And New York State today has probably the most impressive record of containing and suppressing the disease. It has not relied on spraying, however; 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 insisted upon rigorous sanitation; that is, the prompt removal and destruction of all diseased or infected wood. In the beginning, the results were sometimes 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 cut and stored for firewood, for example, will release a crop of fungus-carrying beetles in the spring, unless it is burned before then. It is the adult beetles, emerging from hibernation to feed in late April and May, that transmit Dutch elm disease. And as facts like these became understood, the results became good. By 1950, the incidence of Dutch elm disease in New York City had been restricted to two-tenths of one per cent of the city's fifty-five thousand elms. A sanitation program was launched in Westchester County in 1942. During the next fourteen years, the average annual loss of elms was only two-tenths of one per cent. Buffalo, with a hundred and eighty-five thousand elms has an excellent record of containing the disease by sanitation, with recent losses amounting to only three-tenths of one per cent a year. At this rate of loss, it would take about three hundred years to eliminate Buffalo's elms, even if none were replaced. What has happened in Syracuse is especially impressive. Until 1957, no effective program was in operation there, and between 1951 and 1956 the city lost nearly three thousand elms. Then, under the direction of Howard C. Miller, of the State University College of Forestry, an intensive drive was launched to remove all diseased elm trees and all possible sources of beetle-breeding elm wood. The rate of loss is now well below one per cent a year. The economy of the sanitation method is stressed by New York experts in the control of Dutch elm disease. "In most cases the actual expense is small compared with the probable saving," J. G. Matthysse, of the New York State College of Agriculture, has said. "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. . . . In the case of dying or dead elm trees, the expense of prompt removal to prevent the spread of Dutch elm disease 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. Once it has become established in a community, to be sure, it cannot be eradicated by any means now known, but it can be contained within reasonable bounds by sanitation. Other possibilities lie within the field of forest genetics, where experiments offer some hope that a hybrid elm resistant to Dutch elm disease can be developed. The European elm is highly resistant, and many such elms have been planted in Washington, D.C. During a period when a large percentage of the city's elms were infected with Dutch elm disease, no cases of the disease were found among these trees. Replanting, through an immediate tree-nursery and forestry program, is being urged on communities that are losing large numbers of elms. This is important, and while such programs might well include the resistant European elm, they should aim at a variety of species, so that no future epidemic can 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 one generation ago, no one knew that to fill vast areas with a single species of tree was to invite disaster. And so whole towns lined their streets and dotted their parks with elms. Today, in consequence, the elms die and so do the birds.

In the spraying of the elms, the birds are the incidental victims of an attack directed at an insect, but in other situations they are now becoming a direct target of poisons. There is a growing trend toward aerial applications of deadly poisons, like parathion, a member of the family of organic-phosphate insecticides, for the purpose of "controlling" concentrations of birds distasteful to farmers. The Fish and Wildlife Service has expressed 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 joined forces in the summer of 1959 to engage a spray plane to treat an area of river-bottom land with parathion. The area was a favored roosting site of thousands of blackbirds, which were feeding in nearby cornfields. The problem could have been solved easily by a slight change in agricultural practice—a shift to a variety of corn with deep-set ears, inaccessible to the birds—but the farmers had been persuaded of the merits of killing by poison, and so they sent in the plane. The results probably gratified them, for the casualty list included some sixty-five thousand red-winged blackbirds and starlings. The question of other wildlife deaths that may have occurred was not considered. Parathion is not a specific for blackbirds; it is a universal killer. But such rabbits or raccoons or opossums as roamed those bottom lands, and perhaps never visited the farmers' cornfields, were doomed by a judge and jury who neither knew nor cared about their existence. And what of human beings? In orchards sprayed with this same parathion, workers handling foliage that had been treated a month earlier have collapsed and gone into shock, escaping severe injury only by a small margin, thanks to skilled medical attention. Does Indiana still raise boys who roam the woods and fields, and might even explore the margins of a river? If so, who guarded the poisoned area to keep out any boys who might wander in? Who kept watch to tell the innocent stroller that the fields he was about to enter were deadly, their vegetation coated with a lethal film? No one. Yet it was at so fearful a risk that the farmers waged their war on blackbirds.

Over the last decade or so, our attitude toward poisons has undergone a subtle change. Once, they were kept in containers marked with skull and crossbones; on the infrequent occasions of their use, the utmost care was taken that they should come in contact with the target and with nothing else. Then, with the development of the new insecticides during the Second World War and the abundance of surplus planes after it was over, all this was forgotten by the great majority. Not only the target insect but anything—human or non-human—within range of the chemical fallout may know the touch of poison. In the circumstances, it is not surprising that a good many people now have misgivings about the aerial distribution of lethal chemicals over millions of acres. Two mass-spraying campaigns undertaken in the late nineteen-fifties have done much to strengthen these doubts—one against the gypsy moth in the Northeastern states and the other against the fire ant in the South. Neither is a native insect, but both had been in this country for many years without creating a situation that called for desperate measures.

The gypsy moth, a native of Eurasia, became established in the United States nearly a hundred years ago. In 1869, a French scientist, Léopold Trouvelot, accidentally allowed a few of these moths to escape from a laboratory in Medford, Massachusetts, where he was attempting to cross them with silkworms. Little by little, the gypsy moth has since spread throughout New England. The primary means of its progressive spread is the wind; in the larval, or caterpillar, stage, it is extremely light and can be carried to considerable heights and over great distances. Another means is the shipment of plants carrying the egg masses, the form in which the species exists over the winter. The gypsy moth, which in its larval stage attacks the foliage of oak trees, a few other hardwoods, and some evergreens for a few weeks each spring, now occurs in all the New England states. It also occurs sporadically in New Jersey, where it was introduced in 1911 on a shipment of spruce trees from Holland, and in Pennsylvania and New York, to which it was carried by the New England hurricane of 1938, but the Adirondacks, being forested with species that are not attractive to it, have served in general as a barrier to its westward advance. However, by a method of entry that is still unknown, it has appeared in Michigan.

The task of containing the gypsy moth has been accomplished by a variety of methods, and in the ninety-odd years since its arrival on this continent the fear that it would invade the great hardwood forests of the southern Appalachians has not been justified. Between 1907 and 1931, ten parasites and predators were imported from abroad and successfully established in New England. This natural control, plus quarantine measures and local spraying, achieved what the United States Department of Agriculture, in 1955, described as "outstanding restriction of distribution and damage." Yet only a year after the department had thus expressed its satisfaction with the state of affairs, its Plant Pest Control Division initiated a federal-state program of blanket spraying, with the announced intention of eventually "eradicating" the gypsy moth. (As successive programs have failed, the department has sometimes found it necessary to speak of second or third "eradications" of the same species in the same area.) The all-out chemical war on the gypsy moth began on an ambitious scale. In 1956, nearly a million acres were sprayed in Pennsylvania, New Jersey, Michigan, and New York. Many complaints of damage were made by people in the sprayed areas. Conservationists became disturbed as the pattern of spraying huge areas began to establish itself. When plans were announced for spraying approximately three million acres in 1957, opposition became even stronger, but state and federal officials shrugged off individual complaints as unimportant. In that year, the sprayers were paid by the gallon, rather than by the acre, and many properties were sprayed not once but several times The area included part of Nassau County and all of Suffolk County, on Long Island, which consists chiefly of heavily populated towns and suburbs, plus some coastal areas with bordering salt marsh. As for Nassau County, it is the most densely settled county in New York outside of New York City. In what seems the height of absurdity, the "threat of infestation of the New York City metropolitan area" was cited as a justification for the program. The gypsy moth is a forest insect, and is certainly not an inhabitant of cities. Nor does it live in meadows, cultivated fields, gardens, or marshes. Nevertheless, in 1957 planes hired by the United States Department of Agriculture and the New York State Department of Agriculture and Markets impartially showered down the prescribed DDT, mixed with fuel oil. They sprayed truck gardens and dairy farms, fishponds and salt marshes. They sprayed the quarter-acre lots of suburbia, drenching a housewife as she was making a desperate effort to cover her garden before the roaring plane could reach her, and showering insecticide over children at play and commuters at railway stations. At Setauket, a fine quarter horse drank from a trough in a field that the planes had sprayed; ten hours later it was dead. Automobiles were spotted with the oily mixture; flowers and shrubs were ruined. Birds, fish, crabs, and useful insects were killed. A group of Long Island citizens led by Robert Cushman Murphy had sought a court injunction against the 1957 spraying. Denied a preliminary injunction, the citizens had to suffer the drenching with DDT, but thereafter they persisted in their efforts to obtain a permanent injunction. But because the act had already been performed the courts held that their petition was "moot." The case was carried all the way to the Supreme Court, which declined to hear it. Justice William O. Douglas, in a dissenting opinion, held that "the alarms that many expert and responsible officials have raised about the perils of DDT underline the public importance of this case." The suit brought by the Long Island citizens at least served to focus public attention on the power and inclination of the control agencies to disregard supposedly inviolate property rights of private citizens.

The contamination of milk and of farm produce that occurred in the course of the gypsy-moth spraying came as an unpleasant surprise to many people. What happened on one two-hundred-acre farm in northern Westchester was revealing. Its owner, Mrs. Thomas Waller, had specifically requested officials not to spray her property, because if the woodlands were sprayed, it would be impossible to avoid spraying the pastures as well, and the pastures supported a herd of purebred Guernsey cows. She offered to have the land checked for gypsy moths and to have any infestation destroyed by spot spraying. Although she was assured that no farms would be sprayed, her property received two direct sprayings and, in addition, was twice subjected to drifting spray. Forage samples from fields where the cows had grazed were, of course, contaminated, and milk samples taken forty-eight hours later contained DDT in the amount of fourteen parts per million. The Food and Drug Administration permits no residues of pesticides in milk, but its restrictions apply only to interstate shipments. State and county laws are seldom as strict as the federal, and as far as Mrs. Waller could determine, neither the New York State Department of Health nor the Westchester County Department of Health made any effort after the gypsy-moth spraying to prevent the sale of contaminated milk, or even to discover whether milk had been contaminated.

Truck gardeners also suffered from the gypsy-moth spraying. Some leaf crops were so burned and spotted as to be unmarketable. Others carried heavy residues. For example, peas analyzed at Cornell University's New York State Agricultural Experiment Station contained between fourteen and twenty parts per million of DDT; the legal maximum for peas, as for most fruits and vegetables, is seven parts per million. Growers therefore had to sustain heavy losses or else find themselves in the position of selling produce that carried illegal residues. Some of them sought, and collected, damages. Beekeepers, too, were hard hit. One man, with four hundred colonies of bees, reported that a hundred per cent of the field force of bees—that is, the workers out gathering nectar and pollen for the hives—had been killed in forest areas, and that up to fifty per cent had been killed in farming areas sprayed less intensively. "It is a very distressful thing," he wrote, "to walk into a yard in May and not hear a bee buzz."

After the 1957 spraying, the program was abruptly and drastically curtailed, and vague statements were issued about "evaluating" previous work and testing alternative insecticides. From the three and a half million acres sprayed in 1957, the treated areas fell to half a million in 1958 and to about a hundred thousand in 1959, 1960, and 1961. Meanwhile, the Plant Pest Control officials must have found reports from Long Island disquieting. The gypsy moth had reappeared there in large numbers.

In 1957, the Department of Agriculture's Plant Pest Control men were also busy launching an even more ambitious program in the South. In this case, too, the word "eradication" came easily from the department's mimeograph machines, and this time it was applied to the fire ant. An insect named for its fiery sting, the fire ant seems to have entered the United States from South America by way of the port of Mobile, Alabama, where it was discovered shortly after the end of the First World War. By the late nineteen-fifties, it was to be found in most of the Southern states. During most of the forty-odd years since its arrival in the United States, the fire ant had apparently attracted little attention. The states where it was most abundant considered it a nuisance, chiefly because it built large nests or mounds, a foot or more high, which could hamper the operation of farm machinery, but only two listed it among the twenty most important insect pests, and these placed it near the bottom of the list. With the development of chemicals of broad lethal powers, however, there came a sudden change in the official attitude toward the fire ant, and in 1957 a mighty program was announced, in which the federal government, in coöperation with the afflicted states, would ultimately treat some twenty-two and a half million acres and spend more than a hundred million dollars. As set up, the program called for a three-way sharing of expenses by the federal government, the state governments, and the local communities or landowners. In practice, the federal government has borne a disproportionately large share of the cost. "United States pesticide makers appear to have tapped a sales bonanza in the increasing numbers of broad-scale pest-elimination programs conducted by the U.S. Department of Agriculture," one trade journal cheerfully reported in 1958.

Never has any pesticide program been so thoroughly damned by practically everyone except the beneficiaries of the "sales bonanza." The fire ant was pictured by the Department of Agriculture, in press releases and motion pictures, as a serious threat to farming through the destruction of crops and as a serious threat to wildlife through attacks on the young of ground-nesting birds, and its sting was said to make it a serious menace to human health. Just how sound were these claims? The "facts" presented by the department's witnesses who were seeking appropriations do not accord with those contained in its own publications. The 1961 edition of the yearly bulletin "Insecticide Recommendations for the Control of Insects Attacking Crops and Livestock" does not so much as mention the fire ant—an extraordinary omission if the department believes its own propaganda. Moreover, according to a careful study made by the Agricultural Experiment Station in Alabama, the state that has had the most intimate experience with this insect, "damage to plants in general is rare." At about the time the spraying began, Dr. F. S. Arant, the head of the department of zoology and entomology at Auburn University, in Auburn, Alabama, stated that his department "has not received a single report of damage to plants by ants in the past five years," and that "no damage to livestock has been observed." Men who had the ants under study in the field and in the laboratory say that the fire ants feed extensively on other insects, many of them considered harmful to man's interests—fire ants have been observed picking larvae of the boll weevil off cotton—and that their mound-building activities serve a useful purpose in aerating and draining the soil. And the Alabama studies have been substantiated by investigations at Mississippi State University.

The claim that the ant is a menace to human health and life also needs considerable modification. The Department of Agriculture sponsored a movie in which horror scenes were built around the fire ant's sting. Admittedly, this is painful, and one is well advised to avoid being stung, just as one ordinarily avoids being stung by a wasp or a bee. Severe reactions may occasionally occur in sensitive individuals, and medical literature records one death possibly, but not definitely, attributable to fire-ant venom. In contrast to this, the Office of Vital Statistics records thirty-three deaths in the United States in 1959 alone from the sting of bees and wasps. Yet no one seems to have proposed "eradicating" these insects. Again, local evidence is convincing. The Alabama State Health Officer declares that "there has never been recorded in Alabama a human death resulting from the bites of imported fire ants," and that he considers the medical cases resulting from the bites of fire ants "incidental." Mounds on lawns or playgrounds may create a situation in which children are likely to be stung, but such a situation can easily be handled by treatment of the individual mounds.

The Department of Agriculture also alleged that fire ants damage game birds. A man who is unquestionably well qualified to speak on this issue is the leader of the Wildlife Research Unit at Auburn, Dr. Maurice F. Baker, who has had many years' experience in the area. Dr. Baker's opinion is in direct conflict with the claims of the Agriculture Department. He declares, "In the almost forty years that south Alabama has had the fire ant, game populations have shown a steady and very substantial increase. Certainly, if the imported fire ant were a serious menace to wildlife, these conditions could not exist."

What would happen to wildlife as a result of the insecticide used against the ants was another matter. The chemicals to be used, dieldrin and heptachlor, were both relatively new, and no one knew what their effects would be. It was known, however, from tests on various birds, that each of the poisons was from four to fifty times as toxic as DDT, which had killed some birds and many fish even at a concentration of one pound per acre. But the dosage of dieldrin and heptachlor was heavier—two pounds to the acre under most conditions. The effect to be expected, therefore, would be that of from eight to a hundred pounds of DDT to the acre. Although local agricultural agencies and farmers supported the program, the conservation departments of most of the states concerned, national conservation agencies, and individual ecologists and entomologists called upon the then Secretary of Agriculture, Ezra Taft Benson, to delay action at least until some research had been done to determine the effects of heptachlor and dieldrin on wild and domestic animals and to establish the minimum amount that would control the ants. The protests were ignored and the program was launched in 1958, with the spraying of a million acres. It was clear that any research would be in the nature of a post-mortem.

Before long, the facts began to accumulate. In Hardin County, Texas, for example, opossums, armadillos, and an abundant raccoon population virtually disappeared. Even by the second autumn after treatment, these animals were scarce. The few raccoons then found in the area carried residues of the chemicals in their tissues. The only species of bird surviving in any numbers was the house sparrow, which in other areas, too, has given some evidence that it may be relatively immune. In Alabama, biologists of the Wildlife Research Unit conducted a preliminary census of the quail population in a thirty-six-hundred-acre area that was scheduled for treatment. Thirteen resident coveys—a hundred and twenty-one quail—ranged over the area. Two weeks after treatment, only dead quail could be found. And so it went, with variations in the statistics of death, all over the sprayed areas.

One of the most widely known and respected wildlife biologists in the country, Dr. Clarence Cottam, the director of the Welder Wildlife Foundation, at Sinton, Texas, called on some of the Alabama farmers whose property had been treated. Besides remarking that "all the little tree birds" seemed to have disappeared, most of these people reported losses of livestock, poultry, and household pets. One man was "irate against the control workers," Dr. Cottam reported, "as he said he burned or otherwise disposed of nineteen carcasses of his cows that had been killed by the poison." And Dr. Cottam added, "Calves died that had been given only milk since birth." One woman told him she had set several hens after the surrounding land had been treated, "and for reasons she did not understand very few young were hatched or survived." Another farmer "raises hogs and for fully nine months after the broadcast of poisons, he could raise no young pigs," Dr. Cottam noted, adding, "The litters were born dead or they died after birth."

The Department of Agriculture has consistently brushed aside all evidence of damage to livestock, poultry, pets, and wildlife. Yet when specimens of dead birds from the sprayed areas were sent to the Fish and Wildlife Service for analysis, a great majority of them were found to contain residues of the poisons. And a veterinarian in Bainbridge, Georgia, Dr. Otis L. Poitevint, who was called on to treat many affected animals, has summarized his reasons for attributing the deaths to the insecticide as follows: Within a period ranging from two weeks to several months after the fire-ant poison was applied, cattle, goats, horses, and chickens, as well as birds and other wildlife, began to suffer an often fatal disease of the nervous system. It affected only animals that had access to contaminated food or water. Stabled animals were not affected. The condition was seen only in areas treated for fire ants. Laboratory tests for disease were negative. The symptoms observed by Dr. Poitevint were the same ones given in authoritative texts for poisoning by dieldrin or heptachlor. Dr. Poitevint also described an interesting case involving a two-month-old calf that showed symptoms of poisoning by heptachlor. This was five months after the poison had been applied. The animal was subjected to exhaustive laboratory tests, and the only significant finding was the discovery of seventy-nine parts per million of heptachlor in its fat. Did the calf get the heptachlor directly from grazing or indirectly from its mother's milk, or even before birth? "If from the milk," asked Dr. Poitevint, "why were not special precautions taken to protect our children who drank milk from local dairies?"

Once again, then, the problem of contamination of milk arises. The area included in the fire-ant program is predominantly croplands and fields. What about the dairy cattle that graze in these fields? In treated fields, the grasses will inevitably carry residues of heptachlor or dieldrin, and if the residues are eaten by the cows, the poison will appear in the milk. This was demonstrated experimentally for heptachlor in 1955, and was reported for dieldrin in 1956—before the fire-ant program was launched. The Department of Agriculture's annual publications now list heptachlor and dieldrin among the chemicals whose presence makes forage plants unsuitable for feeding to dairy animals or to animals ready for slaughter, yet the control divisions of the department promote programs that spread heptachlor and dieldrin over substantial areas of grazing land. To be sure, the Department of Agriculture has advised farmers to keep milk cows out of treated pastures for thirty to ninety days, but given the small size of many of the farms involved and the large scale of the program, it is extremely doubtful whether this recommendation was followed, or could have been. Nor is the prescribed period adequate, in view of the persistent nature of the residues. The Food and Drug Administration has little authority in this situation, because in most of the Southern states the dairy industry is small and dairy products do not cross state lines. Protection of the milk supply is therefore left to the states themselves. In 1959, the health officers or other appropriate officials of Alabama, Louisiana, and Texas revealed that no tests had been made and that it simply was not known whether the milk was contaminated with pesticides. "It is perhaps a program we should undertake, but funds and personnel do not permit such a project at this time," an Alabama official said.

Meanwhile, some research into the peculiar nature of heptachlor was done. It might be more accurate to say that someone looked up research already published, for one basic fact had been discovered several years before. This was the fact that heptachlor, after a short period in the tissues of animals or plants or in the soil, assumes a considerably more toxic form, known as heptachlor epoxide. It had been known that this transformation could occur since 1952, when the Food and Drug Administration conducted a relevant experiment; two weeks after female rats were put on a diet containing thirty parts per million of heptachlor, they were found to have stored a hundred and sixty-five parts per million of the epoxide in their tissues. This fact was allowed to come out of the obscurity of biological literature in 1959, when the Food and Drug Administration took action that had the effect of banning any residues of heptachlor or its epoxide in food. The ruling put at least a temporary damper on the fire-ant program, for although the Department of Agriculture continued to request annual appropriations for the purpose, local agricultural agents became increasingly reluctant to advise farmers to use chemicals that would probably result in making crops legally unmarketable.

After a year of heavy dosages, the Department of Agriculture abruptly reduced the rate of application of heptachlor from two pounds to one and a quarter pounds per acre in 1959; later on, this was changed to half a pound per acre, applied in two treatments of a quarter of a pound each, three to six months apart. An official of the department explained that "an aggressive methods-improvement program showed the lower rate to be effective. Had this information been acquired before the program was launched, the taxpayers could have been saved a great deal of money, and, more important, a vast amount of irrecoverable damage could have been avoided. Moreover, effective and inexpensive methods of local control had been known for years. The mound-building habit of the fire ant makes the chemical treatment of individual colonies a simple matter. The cost of such treatment is about a dollar per acre. For situations in which mounds are numerous and mechanized methods are desirable, there is a cultivator, developed by Mississippi's Agricultural Experiment Station, that first levels the mounds and then applies a chemical directly to the earth used in their construction. Control of the ants by this method is between ninety and ninety-five per cent effective. Its cost is twenty-three cents per acre. The Department of Agriculture's mass-control program cost three dollars and fifty cents per acre—the most expensive, the most damaging, and the least effective program of all.

In 1959, the department offered the chemicals free to Texas landowners who would sign a release absolving federal, state, and local governments of responsibility for damage. That same year, the State of Alabama refused to appropriate any further funds for the project. One of its officials characterized the whole program as "ill advised, hastily conceived, poorly planned, and a glaring example of riding roughshod over the responsibilities of other public and private agencies." (In 1961, however, the legislature was again persuaded to make a small appropriation.) Meanwhile, farmers in Louisiana showed increasing reluctance to sign up for the project, for it had become evident that use of chemicals against the fire ant was causing an upsurge of insects destructive to sugar cane. Moreover, the program was obviously accomplishing nothing. Its dismal state was tersely summarized in the spring of 1962 by Dr. L. D. Newsom, the director of entomology research at Louisiana State University's Agricultural Experiment Station: "The imported fire ant 'eradication' program which has been conducted by state and federal agencies is thus far a failure. There are more infested acres in Louisiana now than when the program began."

"The insect world is nature's most astonishing phenomenon," the Dutch biologist C. J. Briejèr has said. "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. By our chemical attack, we are weakening the defenses inherent in the environment itself—defenses designed to keep the species in check. Each time we breach these defenses, a horde of insects pours through. From all over the world come reports that make this predicament clear. At the end of a decade or more of intensive chemical control, entomologists have been finding that problems they had considered solved a few years earlier have returned to plague them, and also that new problems have arisen as insects once present in insignificant numbers have increased to the status of serious pests. By their very nature, chemical controls are self-defeating, for man has devised and applied them without taking into account the complex biological systems against which he has hurled them. The chemicals may sometimes have been pre-tested against a few individual species, but never 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 now so thoroughly upset that we might as well forget it. As a chart for a course of action, this assumption is highly dangerous. The balance of nature is not the same today as it was 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 ignored by a man perched on the edge of a cliff. The balance of nature has never been static; it is fluid, ever shifting, in a constant state of adjustment. Man himself 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 the formulation of the modern insect-control programs. The first is that the really effective control of insects is the control applied by nature. Populations are kept in check by something that the ecologists call the resistance of the environment, and this has been so since the first life was created. The amount of food available, the weather and climate, the presence of competing or predatory species—all play their part. "The greatest single factor in preventing insects from overwhelming the rest of the world is the internecine warfare which they carry out among themselves," the California entomologist Robert Metcalf has said. 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 are permitted suggestive glimpses of its scope. I remember from my student days the miracle that could be wrought in a jar containing a simple mixture of hay and water if one merely added 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 paramecia, the slipper animalcule, each as small as a dust grain, all multiplying without restraint in their temporary Eden of favorable temperature, abundant food, absence of enemies. And I remember shore rocks white with barnacles as far as the eye can see, or the spectacle of an immense school of jellyfish, mile after mile, with seemingly no end to the pulsing, ghostly forms, scarcely more substantial than the water itself. Biologists used to entertain themselves by speculating about what would happen if 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 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 familiar story of the deer inhabiting the Kaibab Plateau 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 growing too numerous in relation to 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, and there were many more deer dying of starvation at any one time than had formerly been killed by predators. The whole environment, moreover, had been damaged by the desperate efforts of the deer to find food.

The predatory insects of field and forest—the insects that kill and consume other insects—play the same role as the wolves and coyotes. Kill them off and the population of their prey surges upward. No one knows how many species of insects inhabit the earth, because so many are yet to be identified, but more than seven hundred thousand have already been described. This means that seventy to eighty per cent of the earth's species of living creatures are insects. The vast majority of these insects are held in check by natural forces, without any intervention by man. The trouble is that we are seldom aware of the protection afforded us by these natural enemies until it fails. Most of us walk unseeing through the world, unaware alike of its beauties and wonders and of 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 little known. Perhaps we may have noticed an odd-shaped insect of ferocious mien on a bush in the garden and been dimly aware that it was a praying mantis, which lives at the expense of other insects. But we see with an understanding eye only if we have walked in the garden at night and, here and there, with the aid of a flashlight, have glimpsed the mantis stealthily creeping up on its prey. Then we sense something of the drama of hunter and hunted. Then we begin to feel something of that relentless force by which nature controls her own. The predators 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 yellow jacket captures soft-bodied insects and feeds the juices to its young. The mud-dauber wasp builds a columned nest of mud under the eaves of houses and stocks it with insects on which its young will feed. The horse-guard wasp hovers above herds of grazing cattle, destroying the blood-sucking flies that torment them. The loudly buzzing syrphus fly, often mistaken for a bee, lays its eggs on the leaves of aphis-infested plants; the larvae, when they hatch, consume immense numbers of aphids. Ladybugs, or lady beetles, are among the most effective destroyers of aphids, and of scale insects and other plant-eating insects as well. Literally hundreds of aphids are consumed by a single ladybug to stoke the fires of energy that she requires to produce a single batch of eggs. Even more extraordinary in their habits are the parasitic insects. These do not kill their hosts outright. Instead, they utilize them for the nurture of their young. Some deposit their eggs within the larvae or the eggs of their prey, so that their own developing young can consume the host. Others attach their eggs to a caterpillar by means of a sticky solution; on hatching, the larval parasite bores through the skin of the host. Still others, led by an instinct akin to foresight, merely lay their eggs on a leaf, so that a browsing caterpillar will eat them.

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 the swamps where huge reptiles lived. Now, as in those ancient times, the sharp-eyed dragonflies 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. And there, almost invisible against a leaf, is the lacewing, with gauzy green wings and golden eyes, shy and secretive, descendant of a 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 secures to a leaf. From these emerge her children—strange, bristled larvae called aphis lions, which live by preying on aphids, scale insects, or mites, capturing them and sucking them 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 pupal stage. And there are many wasps and flies whose very existence depends on the destruction of the eggs or larvae of other insects. Some of the egg parasites are exceedingly minute, yet by their numbers and their great activity they hold down the abundance of many crop-destroying species. There is, for example, a tiny wasp of the genus Trichogramma, whose fragile body may be smaller than the eggs of her prey. She flies tirelessly through the cotton fields, seeking out the eggs of the bollworm and the leafworm, or through orchards, to find the eggs of the codling moth, or into the cane fields, where the sugarcane borer, a brown moth, deposits her eggs on the stalks of growing cane. What unerring instinct—what scent trail that man knows nothing about—leads her to these places? Finding the eggs of her prey, by whatever means, the wasp pierces them one by one, depositing one of her own eggs within each. The egg so invaded does not complete its own development but supplies nourishment for the infant parasite now developing within it; thus each parasitized egg becomes a Trojan horse from which will emerge an enemy of its kind.

All these small creatures are working—working in sun and rain, during the hours of darkness, even when winter has damped down the fires of life to mere embers, waiting to flare again into activity as soon as spring awakens the insect world. Under the white blanket of snow, below the frost-hardened soil, in crevices in the bark of trees, and in the shelter of caves, the parasites and the predators are able 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, whose life span ended with the summer that is gone. The female polistes wasp has taken shelter in a forgotten corner of some attic, carrying 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 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 creatures have long been our allies in keeping the balance of nature tilted in our favor. Yet now we have turned our artillery against our friends. The terrible danger is that we have grossly underestimated their value in holding off a dark tide of enemies, and that without their help the enemies can overrun us.

The prospect of a general and permanent lowering of environmental resistance becomes increasingly real as the number, variety, and destructiveness of insecticides grows. Each year, we may expect 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?” somebody asks. “Surely it won’t really happen—not in my lifetime, anyway?” It is happening now. By 1958, scientific journals had already recorded some fifty species involved in violent dislocations of nature’s balance, and more are being found every year. A recent review of the subject contained references to two hundred and fifteen papers reporting or discussing unfavorable upsets in the balance of insect populations because insecticides had killed off various predators and parasites. Sometimes the end result of chemical spraying has been a tremendous upsurge of the very insect that the spraying was intended to control, as when black flies in Ontario became seventeen times as abundant after spraying as they had been before, and as when, in England, an outbreak of the cabbage aphid—an outbreak that had no parallel on record—followed a broad program of spraying. At other times, spraying has been reasonably effective against the target insect but has let loose a Pandora's box of destructive pests that had never before been abundant enough to cause trouble. The spider mite, for example, has become practically a world-wide 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 Arachnida, the class that also includes spiders, scorpions, and ticks. It has a prodigious appetite for the chlorophyll that makes the world green. It inserts its stiletto-sharp mouth parts in the outer cells of leaves or evergreen needles and extracts the chlorophyll. A mild infestation gives trees or shrubbery a mottled, or salt-and-pepper, appearance. When there is a heavy one, foliage turns yellow and fans, which is what happened in some of the Western National Forests a few years ago, following a program of spraying some eighty-five thousand acres of forested lands with DDT. The spraying was done by the United States Forest Service in 1956, with the intention of controlling the spruce budworm, but the next summer it was discovered that a problem worse than budworm damage had been created. 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, and then in other areas of Montana and in Idaho, the forests began to look as though they had been scorched. It was evident that this summer of 1957 had brought the most extensive infestation of spider mites in history. Almost all the sprayed area was affected; nowhere else was any such damage evident. Why does the spider mite appear to thrive on insecticides? Obviously, it is relatively insensitive to them, but there seem to be two other reasons as well. In nature, the spider mite is kept in check by various predators, such as ladybugs, gall midges, predaceous mites, and several pirate bugs, and all of these are extremely vulnerable to insecticides. The other reason has to do with population pressure within the spider-mite colonies. Normally, a colony of mites is a densely settled community, huddled under a protective web for concealment from its enemies. When such a colony is sprayed, the mites, irritated by the chemicals, scatter in search of places where they will not be disturbed. In doing so, they find a far greater abundance of space and food. Their enemies are now dead, so there is no need for them to spend their energy in secreting a protective web. Instead, they devote it all to producing more mites; it is not uncommon for their egg production to increase threefold.

The situation brought about by insecticides abounds in ironies. In the apple orchards of Nova Scotia in the late nineteen-forties, the worst infestations of the codling moth—a cause of "wormy" apples—were in the orchards that had been regularly sprayed. In unsprayed orchards, the moths were not abundant enough to cause real trouble. Far off, in the eastern Sudan, a few years later, some sixty thousand acres of cotton were sprayed with DDT. One of the most destructive enemies of cotton is the bollworm, but the more the farmers sprayed, the more bollworms appeared. Unsprayed cotton suffered less damage to its fruits and, later, to its mature bolls than sprayed cotton, and in twice-sprayed fields the yield of seed cotton dropped significantly. Although some of the leaf-feeding insects were eliminated, any benefit that this might have brought was more than offset by bollworm damage. In America, farmers have repeatedly traded one insect enemy for a worse one as spraying has upset the population dynamics of the insect world.

Indeed, both the fire-ant-eradication program in the South and the spraying in the Middle West against the Japanese beetle had precisely this effect; the former permitted the sugar-cane borer to gain a foothold, and the latter resulted in an enormous increase in the corn borer. A particularly ironic series of events has occurred in the citrus groves of California. In 1872, a scale insect that feeds on the sap of citrus appeared in the state, and within the next fifteen years the fruit crop in many groves was so near a complete loss that the growers gave up and pulled out their trees. In 1888, however, a parasite of the scale insect was imported from Australia—a small lady beetle called the vedalia. Within only two years, the scale insect was under such thorough control that one could search for days among the orange groves without finding a single specimen. The importation of the vedalia had cost the government a mere five thousand dollars, and its activities had saved the fruitgrowers several millions of dollars a year. This was the world's most successful and famous experiment in biological control. Then, in the nineteen-forties, the citrus growers began to use the glamorous new chemicals in an effort to get rid of other insects, and the populations of the vedalia in many sections of California were wiped out. The scale insect quickly reappeared, and the damage to the citrus trees exceeded anything that had been seen for fifty years. "This possibly marked the end of an era," Dr. Paul DeBach, of the University of California's Citrus Experiment Station in Riverside, said in 1956. Now control of the scale insect has become enormously complicated. The vedalia can be maintained only by repeated releases and by the most careful attention to spray schedules, so as to minimize the beetles' 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, growing other crops, for severe damage has been done by insecticidal drift.

If Darwin were alive today, he would be astounded and delighted by the impressive verification that his theories of the survival of the fittest are receiving from the insect world. Under the stress of intensive chemical spraying, the weaker members of the insect populations are being weeded out, and in many areas and among many species only the strong and fit remain, defying our efforts to control them. Nearly half a century ago, a professor of entomology at Washington State College, A. L. Melander, asked the now purely rhetorical question "Can insects become resistant to sprays?" If Melander thought the answer obscure, or slow in coming, that was only because he asked his question in 1914 instead of forty years later. In the pre-DDT era, when inorganic chemicals were applied in quantities that would seem extraordinarily modest today, strains of insects emerged here and there that could survive spraying or dusting. About 1908, Melander himself ran into difficulty with one of the scale insects. For some years past, the insects, which are a common pest of fruit trees, had been satisfactorily controlled by spraying with lime sulphur, but that year, in the Clarkston area of Washington, they became refractory; they were harder to kill there than elsewhere. And suddenly the scale insects in other parts of the country seemed to get the same idea—that it was not necessary for them to die under the sprayings of lime sulphur. In Illinois, Indiana, Arkansas, and other states, thousands of acres of fine orchards were destroyed by the insects. Then, in certain areas of California, the time-honored method of placing canvas tents over citrus trees and fumigating them with hydrocyanic acid began to yield disappointing results—a problem that led to research at the Citrus Experiment Station, beginning about 1915 and continuing for a quarter of a century. In the nineteen-twenties, still another insect learned the secret of resistance—the codling moth, which had docilely succumbed to lead arsenate for the previous forty years.

It was the advent of DDT and its many relatives, however, that ushered in the true Age of Resistance. It should have surprised no one with even the simplest knowledge of insects or of the dynamics of any animal population that within a matter of a very few years an ugly and dangerous problem had clearly defined itself. Yet awareness of the fact that insects possess an effective weapon for countering aggressive chemical attack seems to have dawned slowly. In fact, even now only the research workers who are concerned with insects that are vectors, or carriers of disease, appear to have become thoroughly aware of the nature of the situation; the agriculturists, for the most part, still put their faith in the development of ever more toxic chemicals. But if understanding of the phenomenon of insect resistance has developed slowly, it has been far otherwise with resistance itself. Before 1945, only about a dozen species were known to have developed resistance to any of the pre-DDT insecticides. With the new chemicals and the new methods of intensive application, resistance began a meteoric rise, which by 1960 had reached the alarming level of a hundred and thirty-seven species. And no one conversant with the situation believes that the end is in sight. More than a thousand technical papers have now been published on the subject, and the World Health Organization has enlisted the aid of some three hundred scientists in all parts of the world, declaring that "resistance is at present the most important single problem facing vector-control programmes." Dr. Elton, the distinguished British student of animal populations, has said, "We are hearing the early rumbling of what may become an avalanche in strength."

Sometimes resistance develops so rapidly that the ink is scarcely dry on a report hailing successful control of species by means of some specific chemical before an amended report has to be issued. In South Africa, for example, cattlemen had long been plagued by the blue tick, from which, on one ranch alone, six hundred head of cattle had died in a single year. The tick had for some years been resistant to arsenical dips. Then, about 1947, the chlorinated hydrocarbon called BHC was tried, and for a very short time all seemed to be well. Reports issued early in the year 1949 declared that the arsenic-resistant ticks could be controlled readily with the new chemical; later that year, a bleak notice of developing resistance had to be published. The situation prompted a writer in the *Leather Trades Review*, a weekly published in London, to comment, in 1950, "News such as this quietly trickling through scientific circles and appearing in small sections of the overseas press is enough to make headlines as big as those concerning the new atomic bomb if only the significance of the matter were properly understood."

To that list of about a dozen agricultural insects that showed resistance to the inorganic chemicals of an earlier era there have been added a host that are resistant to such chlorinated hydrocarbons as DDT, BHC, lindane, toxaphene, dieldrin, and aldrin, and even to the organic phosphates, from which so much was hoped. In 1960, the total number of resistant insects of importance in agriculture had reached sixty-five. Perhaps the most troublesome case of resistance in this area is that of the codling moth, which is now resistant to DDT in practically all of the world's apple-growing regions. Resistance in cabbage insects is creating another serious problem. Potato insects are escaping chemical control in many sections of the United States. Six species of cotton insects, along with an assortment of thrips, fruit moths, leafhoppers, caterpillars, mites, aphids, wireworms, and others, are now able to ignore the farmer's assault with chemical sprays.

Although insect resistance is a matter of concern in agriculture and forestry, it is in the field of public health that it has awakened the most serious apprehensions. The relation between insects and many diseases of man is an ancient one. Mosquitoes of the genus Anopheles may inject into the human blood stream the single-celled organism of malaria. Other mosquitoes transmit yellow fever. Still others carry encephalitis. The housefly, which does not bite, may nevertheless, by contact, contaminate human food with the bacilli of some types of dysentery, and in many parts of the world it also plays an important part in the transmission of eye diseases. The list of diseases and their insect vectors also includes typhus and body lice, plague and rat fleas, African sleeping sickness and tsetse flies, and various fevers and ticks, among innumerable others. These pose an important problem, which must be solved. No responsible person contends that insect-borne disease should be ignored. The question that has now urgently presented itself is how responsible it is to attack the problem by methods that are rapidly making it worse The world has heard much of the triumphant war against disease through the control of insect vectors, but it has heard little of the other side of the story —the defeats and also the shortlived triumphs that now strongly support the view that the insect enemy has actually been made stronger by our efforts. What is even more alarming, we may have destroyed our very means of fighting it. A distinguished Canadian entomologist, Dr. A. W. A. Brown, was engaged by the World Health Organization to make a comprehensive survey of the resistance problem. In the resulting monograph, published in 1958, Dr. Brown has this to say: "Barely a decade after the introduction of the potent synthetic insecticides in public-health programmes, the main technical problem is the development of resistance to them by the insects they formerly controlled." In publishing his monograph, the World Health Organization said, "The vigorous offensive now being pursued against arthropod-borne diseases such as malaria, typhus fever, and plague risks a serious setback unless this new problem can be rapidly mastered." What is the measure of this "setback"? The list of resistant species now includes practically all the insect groups of medical importance. Apparently the black flies, the sand flies, and the tsetse flies have not yet become resistant to chemicals. On the other hand, resistance among houseflies and body lice has now developed on a global scale; malaria programs are threatened by resistance among mosquitoes; and the Oriental rat flea, the principal vector of plague, has recently demonstrated resistance to DDT—a most serious development. Countries reporting resistance among a large number of species represent every continent and most of the island groups.

Probably the first medical use of modern insecticides occurred in Italy in 1943, when the Allied Military Government launched a successful attack on typhus by dusting enormous numbers of people with DDT, to control body lice. This program led to one of the earliest and most widely publicized achievements of DDT. Then, in the winter of 1945-46, DDT controlled lice that had afflicted some two million people in Japan and Korea. Some premonition of trouble might have been gained by the failure of DDT to control a typhus epidemic in Spain in 1948, but even after that encouraging laboratory experiments led entomologists to believe that lice were unlikely to develop resistance. Events in Korea in the winter of 1950-51 were therefore startling. When DDT powder was applied to a large group of Korean soldiers, the extraordinary result was an increase in the infestation of lice. Some of these lice were collected and tested, and it was found that five-percent DDT powder caused no increase in their natural mortality rate. Similar results among lice collected from vagrants in Tokyo, from an asylum in Itabashi, and from refugee camps in Syria, Jordan, and eastern Egypt confirmed the ineffectiveness of DDT for the control of lice, and thus of typhus. By 1957, when the list of countries in which lice had become resistant to DDT was extended to include Iran, Turkey, Ethiopia, West Africa, South Africa, Peru, Chile, France, Yugoslavia, Afghanistan, Uganda, Mexico, and Tanganyika, DDT's initial triumph in Italy seemed dim indeed. In 1946, again in Italy, extensive applications of residual sprays for the control of malaria mosquitoes were begun. The first signs of trouble appeared only a year later. Houseflies and also mosquitoes of the species *Culex pipiens*—the common house mosquito—began to show resistance to the sprays. In 1948, a new chemical, chlordane, was tried as a supplement to DDT. This time, good control was obtained for two years, but by August of 1950 chlordane-resistant flies had appeared, and by the end of that year all the houseflies, and the *Culex pipiens* as well, seemed to be resistant to chlordane. As rapidly as new chemicals were brought into use, resistance developed. By the end of 1951, methoxychlor, dieldrin, and BHC had joined the list of chemicals that were no longer effective. The flies, meanwhile, had become enormously abundant. The same cycle of events took place elsewhere. What happened in one Egyptian village epitomizes the problem. Insecticides gave good control of flies in 1950, and during the same year the infant-mortality rate was reduced by nearly fifty per cent. The next year, flies were resistant to DDT and chlordane. The fly population returned to its former level; so did infant mortality. In the United States, resistance to DDT among flies had become widespread in the Tennessee Valley by 1948. Resistance in other areas followed. Attempts to restore control with dieldrin met with little success; indeed, in some places the flies developed strong resistance to this chemical within two months. After running through all the available chlorinated hydrocarbons, control agencies turned to the organic phosphates, but the story of resistance was simply repeated. The present conclusion of experts is that "housefly control has escaped insecticidal techniques and once more must be based on general sanitation."

The first malaria mosquito to develop resistance to DDT was *Anopheles saccharovi*, in Greece. Extensive indoor spraying was begun in 1946, with the usual early success; by 1949, however, observers noticed that adult mosquitoes were resting in large numbers under road bridges, though they were absent from houses and stables that had been treated. Soon this habit of outside resting was extended to caves, outbuildings, and culverts, and to the foliage and trunks of orange trees. Apparently, the adult mosquitoes had become sufficiently tolerant of DDT to escape from sprayed buildings and rest and recover in the open. A few months later, they were able to remain in houses, and were found resting even on treated walls. This was a portent of the extremely serious situation that has now developed. Resistance to insecticides by mosquitoes of the anophelene group has surged upward at an astounding rate, being created by the very thoroughness of the house-spraying programs designed to eliminate malaria. In 1956, only five species of these mosquitoes displayed resistance; by early 1960 the number had risen to twenty-eight. In West Africa, the Middle East, Central America, Indonesia, and Eastern Europe, the resistant mosquitoes include some very dangerous malaria vectors. Among other mosquitoes, the pattern is being repeated. A tropical mosquito that carries parasites responsible for such diseases as elephantiasis has become strongly resistant in many parts of the world. In Some areas of the United States, the mosquito vector of western equine encephalitis, which can be transmitted to man, has developed resistance. An even more serious problem concerns the vector of yellow fever, which for centuries was one of the great plagues of the world.

Resistant strains of this mosquito have occurred in Southeast Asia and are now common in the Caribbean region. The consequences of resistance in terms of malaria and other diseases are indicated by reports from many countries. An outbreak of yellow fever in Trinidad in 1954 followed failure to control the vector mosquito because of its resistance. There has been a flareup of malaria in Indonesia and Iran. In Greece, Nigeria, and Liberia, the mosquitoes continue to harbor and transmit the malaria parasite. In Western sections of the United States, loss of control over the mosquito vector of encephalitis poses a problem. A reduction of diarrheal disease that had been achieved in Georgia in the early nineteen-fifties through fly control was wiped out within about a year. A decline in acute conjunctivitis in Egypt in the late nineteen-forties, also achieved through fly control, did not last beyond 1950.

Less serious in terms of human health, but vexatious as man measures economic values, is the fact that salt-marsh mosquitoes in Florida are also showing resistance. These are not carriers of disease, but their presence in bloodthirsty swarms had rendered large areas of coastal Florida uninhabitable until control—of an uneasy and temporary nature—was established. But by the late nineteen-forties control had been lost. The fact that the ordinary house mosquito is developing resistance should give pause to many communities that now regularly arrange for wholesale spraying. This species is resistant to DDT and several other insecticides, in Italy, Israel, Japan, France, and parts of the United States, including California, Ohio, New Jersey, and Massachusetts.

The wood tick, vector of spotted fever, has recently developed resistance, imitating the brown dog tick, whose ability to escape a chemical death has been widely and thoroughly established for some time. This ability poses problems for human beings as well as for dogs. The brown dog tick is a semitropical species, and when it occurs in the north it must live through the winter in heated buildings, rather than out-of-doors. John C. Pallister, of the American Museum of Natural History, reported in the summer of 1959 that his department had been getting a number of calls from neighboring apartments on Central Park West. "Every now and then, a whole apartment house gets infested with young ticks, and they're hard to get rid of," Mr. Pallister said, "A dog will pick up ticks in Central Park, and then the ticks lay eggs and they hatch in the apartment. They seem immune to DDT or chlordane or most of our modern sprays. It used to be very unusual to have ticks in New York City, but now they're all over here and on Long Island, in Westchester, and on up into Connecticut. We've noticed this particularly in the past five or six years." Throughout much of North America, the German cockroach has become resistant to chlordane, once the favorite weapon of exterminators, who have now turned to organic phosphates, like malathion. However, laboratory findings on resistance to this group of insecticides in 1960 confront the exterminators with the problem of where to go next.

Agencies concerned with vector-borne disease are at present coping with their problems by switching from one insecticide to another as resistance develops. But this cannot go on indefinitely, despite the ingenuity of the chemists in supplying new materials. Dr. Brown has pointed out that we are travelling a one-way street. No one knows how long the street is. If the end is reached before control of disease-carrying insects is achieved, our situation will indeed be critical.

The chemical industry is perhaps understandably loath to face up to the unpleasant fact of resistance. Even in 1959, when more than a hundred major insect species were showing definite resistance to chemicals, one of the leading journals in the field of agricultural chemistry spoke of "real or imagined" insect resistance. Yet, however hopefully the industry may turn its face the other way, the problem simply does not vanish. The cost of insect control by means of chemicals is increasing steadily. For one thing, it is no longer possible to stockpile materials well in advance; the most promising of insecticidal chemicals today may be a dismal failure tomorrow, and the very substantial financial investment entailed in backing and launching an insecticide may be swept away. Rapidly as technology may invent new uses for insecticides and new ways of applying them, it is likely to find the insects keeping a lap ahead.

There are good reasons for this. Out of an original population whose members vary greatly in structure, physiology, and behavior, only the "tough" insects survive chemical attack. Spraying kills off the weaklings. The survivors—the insects endowed with some inherent quality that enables them to escape harm—are the parents of the next generation, which, by simple inheritance, possesses all the "toughness" of their forebears. Inevitably, it follows that intensive spraying with powerful chemicals only aggravates the condition that it is designed to correct. After a few generations, there is no longer a mixed population of strong and weak insects but, instead, a population consisting entirely of tough, resistant strains. Dr. Briejèr reports watching flies at the Pest Control Institute in Springforbi, Denmark, "disporting themselves in DDT as much at home as primitive sorcerers cavorting over red-hot coals." Similar reports have been received from other parts of the world. In an Army camp In southern Taiwan, for example, bedbugs were found actually carrying deposits of DDT powder on their bodies. When these bedbugs were experimentally placed in cloth impregnated with DDT, they lived for as long as a month, and laid their eggs there; the resulting young grew and thrived. The means by which insects resist chemicals are not yet thoroughly understood, but it is thought that they probably vary. Some of the insects that defy chemical control are believed to be aided by some sort of anatomical advantage, but there is little accurate information on this point. The quality of resistance does not necessarily depend on physical structure, however. DDT-resistant flies possess an enzyme that allows them to detoxicate the insecticide to the non-toxic chemical DDE. The enzyme occurs only in flies that possess a hereditary factor for DDT resistance. Flies and other insects are believed to detoxicate the organic-phosphate chemicals by means of other enzymes. Some behavior pattern may also place the insect out of reach of chemicals. Many fieldworkers in spraying campaigns have noticed the tendency of resistant flies to rest on horizontal surfaces, which are seldom treated, rather than on walls, which habitually are. Resistant houseflies may share the stable fly's tendency to sit still in one place, which greatly reduces the frequency of a fly's contact with residues of poison. Some malaria mosquitoes that have been sprayed in huts have a habit that reduces their exposure to DDT so drastically as to make them virtually immune. Irritated by the spray, they leave the huts, and outside they survive.

Usually, resistance takes two or three years to develop. Occasionally, however, it will do so in only one season, or even less; at the other extreme, it may take as long as six years. The number of generations produced by an insect population in a year naturally accounts for a good part of the difference, and this varies with species and climate. Flies in Canada, for example, have been slower to develop resistance than flies in our Southern states, where long, hot summers favor a rapid rate of reproduction.

People sometimes ask hopefully, “If insects can become resistant to chemicals, can’t human beings do the same thing?” Theoretically, they can, but since this would take hundreds, or even thousand, of years, the prospect affords slight comfort to all of us living now. Resistance is not something that develops in an individual. If an individual possesses at birth some quality that makes him less susceptible than others to a certain poison, he is more likely to survive and to produce children. Resistance develops in a population only after a lapse of time measured in several or many generations. Human populations reproduce at the rate of roughly three generations per century, but new insect generations arise in a matter of days or weeks.

“It is more sensible in some cases to take a small amount of damage in preference to having none for a tune but paying for it in the long run by losing the very means of fighting.” This is the advice given by Dr. Briejèr, who is director of the Plant Protection Service of Holland. “Practical advice should be ‘Spray as little as you can,’ rather than ‘Spray to the limit of your capacity.’ Pressure on the pest population should always be as slight as possible.” Unfortunately, such an attitude has not prevailed in the corresponding agricultural services of the United States. The Department of Agriculture’s Yearbook for 1952, which is its only yearbook devoted entirely to insects, recognizes the fact that insects become resistant but says, “More applications or greater quantities of the insecticides are needed then for adequate control.” The department does not say what will happen when the only chemicals left untried are those that will render the earth not merely insectless but lifeless, yet in 1959 a Connecticut entomologist was quoted in the *Journal of Agricultural & Food Chemistry* to the effect that on at least one insect pest the last available new material was then being used. “It is more than clear that we are travelling a dangerous road,” Dr. Briejèr says. “We are going to have to do some very energetic research on other control measures, measures that will have to be biological, not chemical. Our aim should be to guide natural processes as cautiously as possible in the desired direction rather than to use brute force. We need a more high-minded orientation and a deeper insight, which I miss in many researchers. Life is a miracle beyond our comprehension, and we should reverence it even where we have to struggle against it. The resort to weapons such as insecticides to control it is a proof of insufficient knowledge and of an incapacity so to guide the processes of nature that brute force becomes unnecessary. Humbleness is in order; there is no excuse for scientific conceit here.”

Over the past decade, most of those people who are best fitted to develop natural controls have been laboring in the more exciting vineyards of chemical control. It was reported in 1960 that only two per cent of this country’s economic entomologists—that is, entomologists who are engaged in the control of insects—were working in the field of biological controls, the remaining ninety-eight per cent being engaged in research on chemical insecticides. Why does this situation exist? One important reason is that major chemical companies are pouring money into the universities to support research on insecticides. Biological-control studies are never so well endowed, for the simple reason that they do not promise anyone the sort of fortune that is to be made in the chemical industry. Such studies are left to state and federal agencies, where the salaries paid are far lower. Another reason is that many entomologists have lost sight of the fact that they are neither chemists nor engineers but biologists. F. H. Jacob, a British plant pathologist, has declared, "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." And A. D. Pickett, an entomologist in Nova Scotia, has written, "Economic entomologists must realize 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 devising methods of insect control that take full advantage of the predatory and parasitic species. Years ago, after working in the apple orchards of Nova Scotia's Annapolis Valley, which was then one of the most concentrated fruitgrowing areas in Canada, and using insecticides to destroy the codling moth, only to see it give way to the mite, Dr. Pickett concluded, "We move from crisis to crisis, merely trading one problem for another." And he and his associates thereupon struck out on a new road, instead of going along with those 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 developed a program that would make maximum use of natural controls and minimum use of insecticides, and this is now followed by about ninety per cent of the Nova Scotian fruitgrowers. Whenever insecticides are applied, only the lowest effective dosages are used—barely enough to control the pest with a minimum of harm to beneficial species. Proper timing is also an important consideration; for example, nicotine sulphate applied before the apple blossoms turn pink spares one of the important codling-moth predators, probably because it is still in the egg stage. Moreover, 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," says Dr. Pickett. Instead of these highly toxic, broad-spectrum insecticides, he places his chief reliance on ryania (derived from the stems of a tropical plant), nicotine sulphate, and lead arsenate. In certain situations, very weak concentrations of DDT or malathion are used (one or two ounces per hundred gallons, in contrast to the usual one or two pounds per hundred gallons). Although these are the least toxic of the modern insecticides, Dr. Pickett hopes by further research to find more selective substitutes for both, and for the lead arsenate as well How has this program worked? N ova Scotia orchardists who are following Dr. Pickett's modified spray program are producing as high a proportion of first-grade fruit as those who are using intensive chemical applications. They are also getting as good production. They are getting these results, furthermore, at a substantially lower cost. The outlay for insecticides used in Nova Scotia apple orchards is a mere ten to twenty per cent of what is spent for the same purpose in most other apple-growing areas. And even more important than these excellent results is the fact that the modified program worked out by the Nova Scotian entomologists is not doing violence to nature's balance.

There are other ways of attaining reasonable control of insects without contaminating the world and endangering its life. Indeed, a truly extraordinary variety of alternatives to chemical control is available. Some are already in use and have achieved brilliant successes. Others are in the stage of laboratory or field testing. Still others are little more than ideas in the minds of imaginative scientists, who are waiting for an opportunity to put them to the test. All have this in common: they are biological solutions, based on an understanding of the living organisms that they seek to control, and of the whole fabric of life to which these organisms belong. They recognize that we are dealing with having populations, with all their pressures and counterpressures. Specialists representing various areas in the vast field of biology—entomologists, pathologists, geneticists, physiologists, biochemists, ecologists—are contributing, pouring their knowledge and their creative inspiration into the formation of a new science of biotic controls. As yet, few people are aware of these developments, and the public still tends to accept the chemical pollution of the environment as inevitable. We must encourage and support both government and private research in these new fields. Our best hope of escaping from the present situation lies in these imaginative, creative approaches to the problem of sharing our earth with other creatures. ♦

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