BY RACHEL CARSON

UNDER THE SEA-WIND

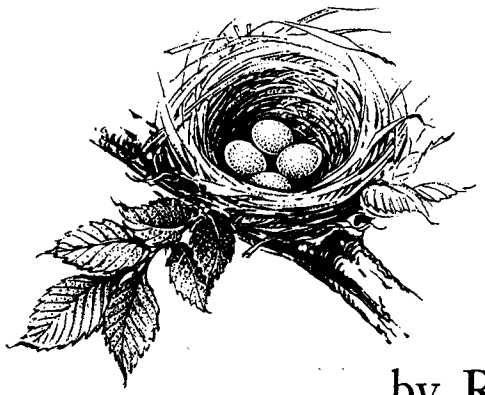
THE SEA AROUND US

THE EDGE OF THE SEA

SILENT SPRING

Silent Spring

Twenty-fifth Anniversary Edition



by Rachel Carson

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To Albert Schweitzer
who said

"Man has lost the capacity to foresee
and to forestall. He will end by
destroying the earth."

The sedge is wither'd from the lake,
And no birds sing.

KEATS

✧ ✧ ✧

I am pessimistic about the human race because it is too ingenious for its own good. Our approach to nature is to beat it into submission. We would stand a better chance of survival if we accommodated ourselves to this planet and viewed it appreciatively instead of skeptically and dictatorially.

E. B. WHITE

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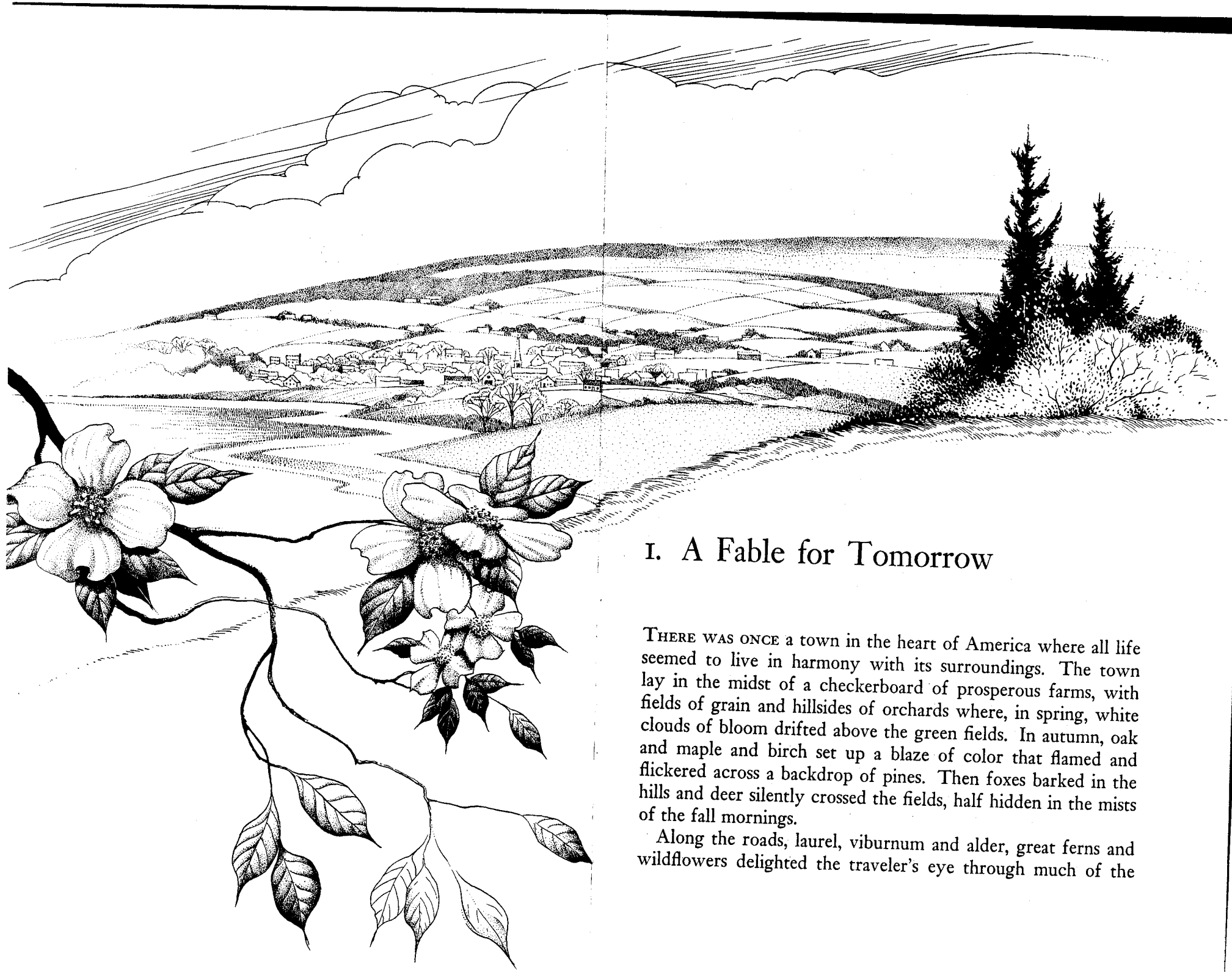


1. A Fable for Tomorrow

THERE WAS ONCE a town in the heart of America where all life seemed to live in harmony with its surroundings. The town lay in the midst of a checkerboard of prosperous farms, with fields of grain and hillsides of orchards where, in spring, white clouds of bloom drifted above the green fields. In autumn, oak and maple and birch set up a blaze of color that flamed and flickered across a backdrop of pines. Then foxes barked in the hills and deer silently crossed the fields, half hidden in the mists of the fall mornings.

Along the roads, laurel, viburnum and alder, great ferns and wildflowers delighted the traveler's eye through much of the

year. Even in winter the roadsides were places of beauty, where countless birds came to feed on the berries and on the seed heads of the dried weeds rising above the snow. The countryside was, in fact, famous for the abundance and variety of its bird life, and when the flood of migrants was pouring through in spring and fall people traveled from great distances to observe them. Others came to fish the streams, which flowed clear and cold out of the hills and contained shady pools where trout lay. So it had been from the days many years ago when the first settlers raised their houses, sank their wells, and built their barns.

Then a strange blight crept over the area and everything began to change. Some evil spell had settled on the community: mysterious maladies swept the flocks of chickens; the cattle and sheep sickened and died. Everywhere was a shadow of death. The farmers spoke of much illness among their families. In the town the doctors had become more and more puzzled by new kinds of sickness appearing among their patients. There had been several sudden and unexplained deaths, not only among adults but even among children, who would be stricken suddenly while at play and die within a few hours.

There was a strange stillness. The birds, for example — where had they gone? Many people spoke of them, puzzled and disturbed. The feeding stations in the backyards were deserted. The few birds seen anywhere were moribund; they trembled violently and could not fly. It was a spring without voices. On the mornings that had once throbbed with the dawn chorus of robins, catbirds, doves, jays, wrens, and scores of other bird voices there was now no sound; only silence lay over the fields and woods and marsh.

On the farms the hens brooded, but no chicks hatched. The farmers complained that they were unable to raise any pigs — the litters were small and the young survived only a few days. The apple trees were coming into bloom but no bees droned

among the blossoms, so there was no pollination and there would be no fruit.

The roadsides, once so attractive, were now lined with browned and withered vegetation as though swept by fire. These, too, were silent, deserted by all living things. Even the streams were now lifeless. Anglers no longer visited them, for all the fish had died.

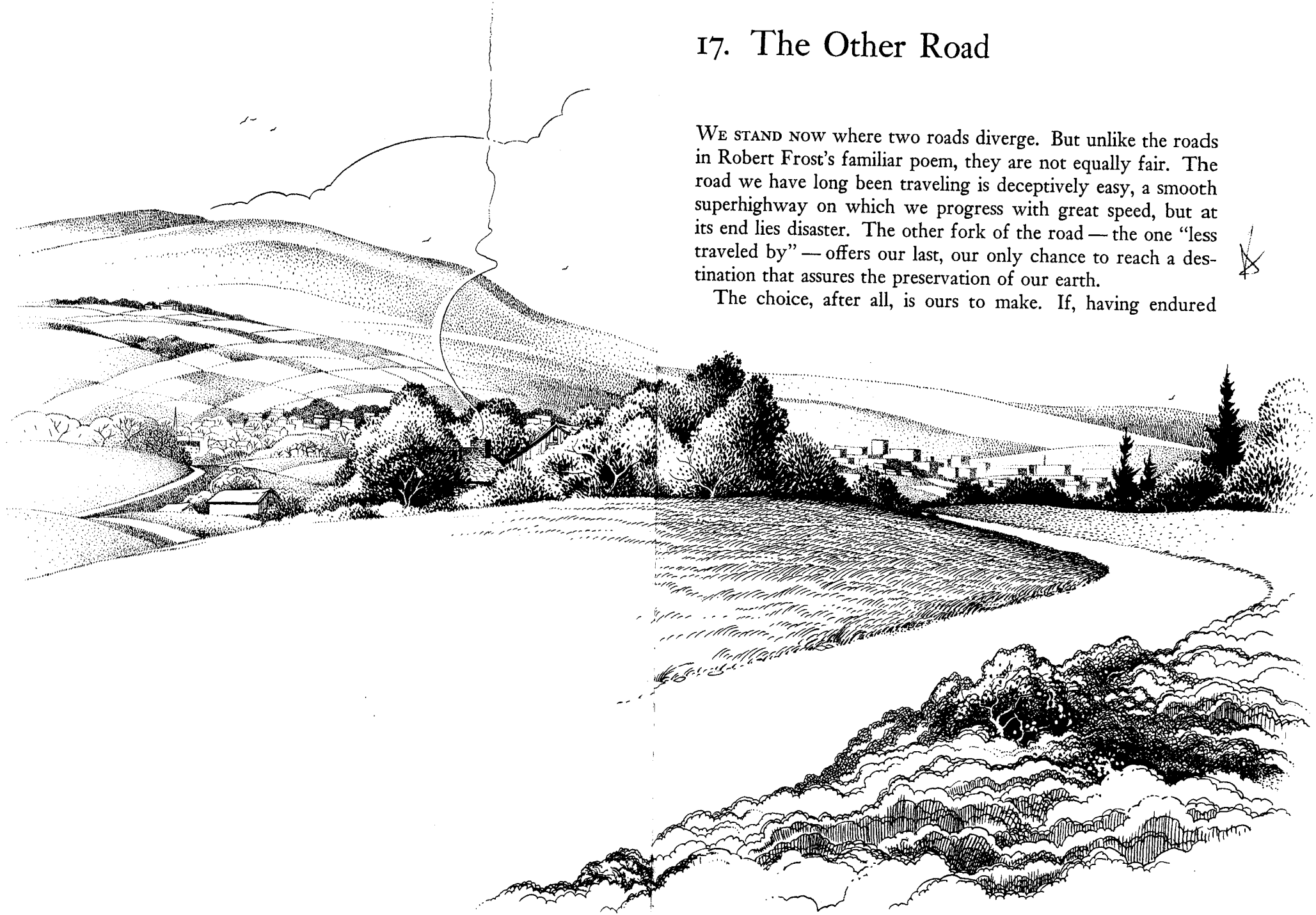
In the gutters under the eaves and between the shingles of the roofs, a white granular powder still showed a few patches; some weeks before it had fallen like snow upon the roofs and the lawns, the fields and streams.

No witchcraft, no enemy action had silenced the rebirth of new life in this stricken world. The people had done it themselves.

This town does not actually exist, but it might easily have a thousand counterparts in America or elsewhere in the world. I know of no community that has experienced all the misfortunes I describe. Yet every one of these disasters has actually happened somewhere, and many real communities have already suffered a substantial number of them. A grim specter has crept upon us almost unnoticed, and this imagined tragedy may easily become a stark reality we all shall know.

What has already silenced the voices of spring in countless towns in America? This book is an attempt to explain.

17. The Other Road



We stand now where two roads diverge. But unlike the roads in Robert Frost's familiar poem, they are not equally fair. The road we have long been traveling is deceptively easy, a smooth superhighway on which we progress with great speed, but at its end lies disaster. The other fork of the road — the one "less traveled by" — offers our last, our only chance to reach a destination that assures the preservation of our earth.

The choice, after all, is ours to make. If, having endured

much, we have at last asserted our "right to know," and if, knowing, we have concluded that we are being asked to take senseless and frightening risks, then we should no longer accept the counsel of those who tell us that we must fill our world with poisonous chemicals; we should look about and see what other course is open to us.

A truly extraordinary variety of alternatives to the chemical control of insects is available. Some are already in use and have achieved brilliant success. Others are in the stage of laboratory testing. Still others are little more than ideas in the minds of imaginative scientists, waiting for the opportunity to put them to the test. All have this in common: they are *biological* solutions, based on understanding of the living organisms they seek to control, and of the whole fabric of life to which these organisms belong. Specialists representing various areas of the vast field of biology are contributing — entomologists, pathologists, geneticists, physiologists, biochemists, ecologists — all pouring their knowledge and their creative inspirations into the formation of a new science of biotic controls.

"Any science may be likened to a river," says a Johns Hopkins biologist, Professor Carl P. Swanson. "It has its obscure and unpretentious beginning; its quiet stretches as well as its rapids; its periods of drought as well as of fullness. It gathers momentum with the work of many investigators and as it is fed by other streams of thought; it is deepened and broadened by the concepts and generalizations that are gradually evolved."

So it is with the science of biological control in its modern sense. In America it had its obscure beginnings a century ago with the first attempts to introduce natural enemies of insects that were proving troublesome to farmers, an effort that sometimes moved slowly or not at all, but now and again gathered speed and momentum under the impetus of an outstanding success. It had its period of drought when workers in applied entomology, dazzled by the spectacular new insecticides of the

1940's, turned their backs on all biological methods and set foot on "the treadmill of chemical control." But the goal of an insect-free world continued to recede. Now at last, as it has become apparent that the heedless and unrestrained use of chemicals is a greater menace to ourselves than to the targets, the river which is the science of biotic control flows again, fed by new streams of thought.

Some of the most fascinating of the new methods are those that seek to turn the strength of a species against itself — to use the drive of an insect's life forces to destroy it. The most spectacular of these approaches is the "male sterilization" technique developed by the chief of the United States Department of Agriculture's Entomology Research Branch, Dr. Edward Knipling, and his associates.

About a quarter of a century ago Dr. Knipling startled his colleagues by proposing a unique method of insect control. If it were possible to sterilize and release large numbers of insects, he theorized, the sterilized males would, under certain conditions, compete with the normal wild males so successfully that, after repeated releases, only infertile eggs would be produced and the population would die out.

The proposal was met with bureaucratic inertia and with skepticism from scientists, but the idea persisted in Dr. Knipling's mind. One major problem remained to be solved before it could be put to the test — a practical method of insect sterilization had to be found. Academically, the fact that insects could be sterilized by exposure to X-ray had been known since 1916, when an entomologist by the name of G. A. Runner reported such sterilization of cigarette beetles. Hermann Muller's pioneering work on the production of mutations by X-ray opened up vast new areas of thought in the late 1920's, and by the middle of the century various workers had reported the sterilization by X-rays or gamma rays of at least a dozen species of insects.

But these were laboratory experiments, still a long way from practical application. About 1950, Dr. Knipling launched a serious effort to turn insect sterilization into a weapon that would wipe out a major insect enemy of livestock in the South, the screw-worm fly. The females of this species lay their eggs in any open wound of a warm-blooded animal. The hatching larvae are parasitic, feeding on the flesh of the host. A full-grown steer may succumb to a heavy infestation in 10 days, and livestock losses in the United States have been estimated at $40,000,000 a year. The toll of wildlife is harder to measure, but it must be great. Scarcity of deer in some areas of Texas is attributed to the screw-worm. This is a tropical or subtropical insect, inhabiting South and Central America and Mexico, and in the United States normally restricted to the Southwest. About 1933, however, it was accidentally introduced into Florida, where the climate allowed it to survive over winter and to establish populations. It even pushed into southern Alabama and Georgia, and soon the livestock industry of the southeastern states was faced with annual losses running to $20,000,000.

A vast amount of information on the biology of the screw-worm had been accumulated over the years by Agriculture Department scientists in Texas. By 1954, after some preliminary field trials on Florida islands, Dr. Knipling was ready for a full-scale test of his theory. For this, by arrangement with the Dutch Government, he went to the island of Curaçao in the Caribbean, cut off from the mainland by at least 50 miles of sea.

Beginning in August 1954, screw-worms reared and sterilized in an Agriculture Department laboratory in Florida were flown to Curaçao and released from airplanes at the rate of about 400 per square mile per week. Almost at once the number of egg masses deposited on experimental goats began to decrease, as did their fertility. Only seven weeks after the releases were started, all eggs were infertile. Soon it was impossible to find

a single egg mass, sterile or otherwise. The screw-worm had indeed been eradicated on Curaçao.

The resounding success of the Curaçao experiment whetted the appetites of Florida livestock raisers for a similar feat that would relieve them of the scourge of screw-worms. Although the difficulties here were relatively enormous — an area 300 times as large as the small Caribbean island — in 1957 the United States Department of Agriculture and the State of Florida joined in providing funds for an eradication effort. The project involved the weekly production of about 50 million screw-worms at a specially constructed "fly factory," the use of 20 light airplanes to fly pre-arranged flight patterns, five to six hours daily, each plane carrying a thousand paper cartons, each carton containing 200 to 400 irradiated flies.

The cold winter of 1957–58, when freezing temperatures gripped northern Florida, gave an unexpected opportunity to start the program while the screw-worm populations were reduced and confined to a small area. By the time the program was considered complete at the end of 17 months, 3½ billion artificially reared, sterilized flies had been released over Florida and sections of Georgia and Alabama. The last-known animal wound infestation that could be attributed to screw-worms occurred in February 1959. In the next few weeks several adults were taken in traps. Thereafter no trace of the screw-worm could be discovered. Its extinction in the Southeast had been accomplished — a triumphant demonstration of the worth of scientific creativity, aided by thorough basic research, persistence, and determination.

Now a quarantine barrier in Mississippi seeks to prevent the re-entrance of the screw-worm from the Southwest, where it is firmly entrenched. Eradication there would be a formidable undertaking, considering the vast areas involved and the probability of re-invasion from Mexico. Nevertheless, the stakes are high and the thinking in the Department seems to be that some

sort of program, designed at least to hold the screw-worm populations at very low levels, may soon be attempted in Texas and other infested areas of the Southwest.

The brilliant success of the screw-worm campaign has stimulated tremendous interest in applying the same methods to other insects. Not all, of course, are suitable subjects for this technique, much depending on details of the life history, population density, and reactions to radiation.

Experiments have been undertaken by the British in the hope that the method could be used against the tsetse fly in Rhodesia. This insect infests about a third of Africa, posing a menace to human health and preventing the keeping of livestock in an area of some 4½ million square miles of wooded grasslands. The habits of the tsetse differ considerably from those of the screw-worm fly, and although it can be sterilized by radiation some technical difficulties remain to be worked out before the method can be applied.

The British have already tested a large number of other species for susceptibility to radiation. United States scientists have had some encouraging early results with the melon fly and the oriental and Mediterranean fruit flies in laboratory tests in Hawaii and field tests on the remote island of Rota. The corn borer and the sugarcane borer are also being tested. There are possibilities, too, that insects of medical importance might be controlled by sterilization. A Chilean scientist has pointed out that malaria-carrying mosquitoes persist in his country in spite of insecticide treatment; the release of sterile males might then provide the final blow needed to eliminate this population.

The obvious difficulties of sterilizing by radiation have led to search for an easier method of accomplishing similar results, and there is now a strongly running tide of interest in chemical sterilants.

Scientists at the Department of Agriculture laboratory in Orlando, Florida, are now sterilizing the housefly in laboratory

experiments and even in some field trials, using chemicals incorporated in suitable foods. In a test on an island in the Florida Keys in 1961, a population of flies was nearly wiped out within a period of only five weeks. Repopulation of course followed from nearby islands, but as a pilot project the test was successful. The Department's excitement about the promise of this method is easily understood. In the first place, as we have seen, the housefly has now become virtually uncontrollable by insecticides. A completely new method of control is undoubtedly needed. One of the problems of sterilization by radiation is that this requires not only artificial rearing but the release of sterile males in larger number than are present in the wild population. This could be done with the screw-worm, which is actually not an abundant insect. With the housefly, however, more than doubling the population through releases could be highly objectionable, even though the increase would be only temporary. A chemical sterilant, on the other hand, could be combined with a bait substance and introduced into the natural environment of the fly; insects feeding on it would become sterile and in the course of time the sterile flies would predominate and the insects would breed themselves out of existence.

The testing of chemicals for a sterilizing effect is much more difficult than the testing of chemical poisons. It takes 30 days to evaluate one chemical — although, of course, a number of tests can be run concurrently. Yet between April 1958 and December 1961 several hundred chemicals were screened at the Orlando laboratory for a possible sterilizing effect. The Department of Agriculture seems happy to have found among these even a handful of chemicals that show promise.

Now other laboratories of the Department are taking up the problem, testing chemicals against stable flies, mosquitoes, boll weevils, and an assortment of fruit flies. All this is presently experimental but in the few years since work began on chemosterilants the project has grown enormously. In theory it has

many attractive features. Dr. Knipling has pointed out that effective chemical insect sterilization "might easily outdo some of the best of known insecticides." Take an imaginary situation in which a population of a million insects is multiplying five times in each generation. An insecticide might kill 90 per cent of each generation, leaving 125,000 insects alive after the third generation. In contrast, a chemical that would produce 90 per cent sterility would leave only 125 insects alive.

On the other side of the coin is the fact that some extremely potent chemicals are involved. It is fortunate that at least during these early stages most of the men working with chemosterilants seem mindful of the need to find safe chemicals and safe methods of application. Nonetheless, suggestions are heard here and there that these sterilizing chemicals might be applied as aerial sprays — for example, to coat the foliage chewed by gypsy moth larvae. To attempt any such procedure without thorough advance research on the hazards involved would be the height of irresponsibility. If the potential hazards of the chemosterilants are not constantly borne in mind we could easily find ourselves in even worse trouble than that now created by the insecticides.

The sterilants currently being tested fall generally into two groups, both of which are extremely interesting in their mode of action. The first are intimately related to the life processes, or metabolism, of the cell; i.e., they so closely resemble a substance the cell or tissue needs that the organism "mistakes" them for the true metabolite and tries to incorporate them in its normal building processes. But the fit is wrong in some detail and the process comes to a halt. Such chemicals are called antimetabolites.

The second group consists of chemicals that act on the chromosomes, probably affecting the gene chemicals and causing the chromosomes to break up. The chemosterilants of this group are alkylating agents, which are extremely reactive chemicals, capable of intense cell destruction, damage to chromosomes, and production of mutations. It is the view of Dr. Peter Alexander of the Chester Beatty Research Institute in London that "any alkylating agent which is effective in sterilizing insects would also be a powerful mutagen and carcinogen." Dr. Alexander feels that any conceivable use of such chemicals in insect control would be "open to the most severe objections." It is to be hoped, therefore, that the present experiments will lead not to actual use of these particular chemicals but to the discovery of others that will be safe and also highly specific in their action on the target insect.

Some of the most interesting of the recent work is concerned with still other ways of forging weapons from the insect's own life processes. Insects produce a variety of venoms, attractants, repellants. What is the chemical nature of these secretions? Could we make use of them as, perhaps, very selective insecticides? Scientists at Cornell University and elsewhere are trying to find answers to some of these questions, studying the defense mechanisms by which many insects protect themselves from attack by predators, working out the chemical structure of insect secretions. Other scientists are working on the so-called "juvenile hormone," a powerful substance which prevents metamorphosis of the larval insect until the proper stage of growth has been reached.

Perhaps the most immediately useful result of this exploration of insect secretion is the development of lures, or attractants. Here again, nature has pointed the way. The gypsy moth is an especially intriguing example. The female moth is too heavy-bodied to fly. She lives on or near the ground, fluttering about among low vegetation or creeping up tree trunks. The male, on the contrary, is a strong flier and is attracted even from considerable distances by a scent released by the female from special glands. Entomologists have taken advantage of this fact for a good many years, laboriously preparing this sex attractant from

the bodies of the female moths. It was then used in traps set for the males in census operations along the fringe of the insect's range. But this was an extremely expensive procedure. Despite the much publicized infestations in the northeastern states, there were not enough gypsy moths to provide the material, and hand-collected female pupae had to be imported from Europe, sometimes at a cost of half a dollar per tip. It was a tremendous breakthrough, therefore, when, after years of effort, chemists of the Agriculture Department recently succeeded in isolating the attractant. Following upon this discovery was the successful preparation of a closely related synthetic material from a constituent of castor oil; this not only deceives the male moths but is apparently fully as attractive as the natural substance. As little as one microgram (1/1,000,000 gram) in a trap is an effective lure.

All this is of much more than academic interest, for the new and economical "gyplure" might be used not merely in census operations but in control work. Several of the more attractive possibilities are now being tested. In what might be termed an experiment in psychological warfare, the attractant is combined with a granular material and distributed by planes. The aim is to confuse the male moth and alter the normal behavior so that, in the welter of attractive scents, he cannot find the true scent trail leading to the female. This line of attack is being carried even further in experiments aimed at deceiving the male into attempting to mate with a spurious female. In the laboratory, male gypsy moths have attempted copulation with chips of wood, vermiculite, and other small, inanimate objects, so long as they were suitably impregnated with gyplure. Whether such diversion of the mating instinct into nonproductive channels would actually serve to reduce the population remains to be tested, but it is an interesting possibility.

The gypsy moth lure was the first insect sex attractant to be synthesized, but probably there will soon be others. A number

of agricultural insects are being studied for possible attractants that man could imitate. Encouraging results have been obtained with the Hessian fly and the tobacco hornworm.

Combinations of attractants and poisons are being tried against several insect species. Government scientists have developed an attractant called methyl-eugenol, which males of the oriental fruit fly and the melon fly find irresistible. This has been combined with a poison in tests in the Bonin Islands 450 miles south of Japan. Small pieces of fiberboard were impregnated with the two chemicals and were distributed by air over the entire island chain to attract and kill the male flies. This program of "male annihilation" was begun in 1960: a year later the Agriculture Department estimated that more than 99 per cent of the population had been eliminated. The method as here applied seems to have marked advantages over the conventional broadcasting of insecticides. The poison, an organic phosphorus chemical, is confined to squares of fiberboard which are unlikely to be eaten by wildlife; its residues, moreover, are quickly dissipated and so are not potential contaminants of soil or water.

But not all communication in the insect world is by scents that lure or repel. Sound also may be a warning or an attraction. The constant stream of ultrasonic sound that issues from a bat in flight (serving as a radar system to guide it through darkness) is heard by certain moths, enabling them to avoid capture. The wing sounds of approaching parasitic flies warn the larvae of some sawflies to herd together for protection. On the other hand, the sounds made by certain wood-boring insects enable their parasites to find them, and to the male mosquito the wing-beat of the female is a siren song.

What use, if any, can be made of this ability of the insect to detect and react to sound? As yet in the experimental stage, but nonetheless interesting, is the initial success in attracting male mosquitoes to playback recordings of the flight sound of the female. The males were lured to a charged grid and so killed.

The repellant effect of bursts of ultrasonic sound is being tested in Canada against corn borer and cutworm moths. Two authorities on animal sound, Professors Hubert and Mable Frings of the University of Hawaii, believe that a field method of influencing the behavior of insects with sound only awaits discovery of the proper key to unlock and apply the vast existing knowledge of insect sound production and reception. Repellant sounds may offer greater possibilities than attractants. The Fringses are known for their discovery that starlings scatter in alarm before a recording of the distress cry of one of their fellows; perhaps somewhere in this fact is a central truth that may be applied to insects. To practical men of industry the possibilities seem real enough so that at least one major electronic corporation is preparing to set up a laboratory to test them.

Sound is also being tested as an agent of direct destruction. Ultrasonic sound will kill all mosquito larvae in a laboratory tank; however, it kills other aquatic organisms as well. In other experiments, blowflies, mealworms, and yellow fever mosquitoes have been killed by airborne ultrasonic sound in a matter of seconds. All such experiments are first steps toward wholly new concepts of insect control which the miracles of electronics may some day make a reality.

The new biotic control of insects is not wholly a matter of electronics and gamma radiation and other products of man's inventive mind. Some of its methods have ancient roots, based on the knowledge that, like ourselves, insects are subject to disease. Bacterial infections sweep through their populations like the plagues of old; under the onset of a virus their hordes sicken and die. The occurrence of disease in insects was known before the time of Aristotle; the maladies of the silkworm were celebrated in medieval poetry; and through study of the diseases of this same insect the first understanding of the principles of infectious disease came to Pasteur.

Insects are beset not only by viruses and bacteria but also by fungi, protozoa, microscopic worms, and other beings from all that unseen world of minute life that, by and large, befriends mankind. For the microbes include not only disease organisms but those that destroy waste matter, make soils fertile, and enter into countless biological processes like fermentation and nitrification. Why should they not also aid us in the control of insects?

One of the first to envision such use of microorganisms was the 19th-century zoologist Elie Metchnikoff. During the concluding decades of the 19th and the first half of the 20th centuries the idea of microbial control was slowly taking form. The first conclusive proof that an insect could be brought under control by introducing a disease into its environment came in the late 1930's with the discovery and use of milky disease for the Japanese beetle, which is caused by the spores of a bacterium belonging to the genus *Bacillus*. This classic example of bacterial control has a long history of use in the eastern part of the United States, as I have pointed out in Chapter 7.

High hopes now attend tests of another bacterium of this genus — *Bacillus thuringiensis* — originally discovered in Germany in 1911 in the province of Thuringia, where it was found to cause a fatal septicemia in the larvae of the flour moth. This bacterium actually kills by poisoning rather than by disease. Within its vegetative rods there are formed, along with spores, peculiar crystals composed of a protein substance highly toxic to certain insects, especially to the larvae of the mothlike lepidopteras. Shortly after eating foliage coated with this toxin the larva suffers paralysis, stops feeding, and soon dies. For practical purposes, the fact that feeding is interrupted promptly is of course an enormous advantage, for crop damage stops almost as soon as the pathogen is applied. Compounds containing spores of *Bacillus thuringiensis* are now being manufactured by several firms in the United States under various trade names.

Field tests are being made in several countries: in France and Germany against larvae of the cabbage butterfly, in Yugoslavia against the fall webworm, in the Soviet Union against a tent caterpillar. In Panama, where tests were begun in 1961, this bacterial insecticide may be the answer to one or more of the serious problems confronting banana growers. There the root borer is a serious pest of the banana, so weakening its roots that the trees are easily toppled by wind. Dieldrin has been the only chemical effective against the borer, but it has now set in motion a chain of disaster. The borers are becoming resistant. The chemical has also destroyed some important insect predators and so has caused an increase in the tortricids — small, stout-bodied moths whose larvae scar the surface of the bananas. There is reason to hope the new microbial insecticide will eliminate both the tortricids and the borers and that it will do so without upsetting natural controls.

In eastern forests of Canada and the United States bacterial insecticides may be one important answer to the problems of such forest insects as the budworms and the gypsy moth. In 1960 both countries began field tests with a commercial preparation of *Bacillus thuringiensis*. Some of the early results have been encouraging. In Vermont, for example, the end results of bacterial control were as good as those obtained with DDT. The main technical problem now is to find a carrying solution that will stick the bacterial spores to the needles of the evergreens. On crops this is not a problem — even a dust can be used. Bacterial insecticides have already been tried on a wide variety of vegetables, especially in California.

Meanwhile, other perhaps less spectacular work is concerned with viruses. Here and there in California fields of young alfalfa are being sprayed with a substance as deadly as any insecticide for the destructive alfalfa caterpillar — a solution containing a virus obtained from the bodies of caterpillars that have died because of infection with this exceedingly virulent disease.

The bodies of only five diseased caterpillars provide enough virus to treat an acre of alfalfa. In some Canadian forests a virus that affects pine sawflies has proved so effective in control that it has replaced insecticides.

Scientists in Czechoslovakia are experimenting with protozoa against webworms and other insect pests, and in the United States a protozoan parasite has been found to reduce the egg-laying potential of the corn borer.

To some the term microbial insecticide may conjure up pictures of bacterial warfare that would endanger other forms of life. This is not true. In contrast to chemicals, insect pathogens are harmless to all but their intended targets. Dr. Edward Steinhaus, an outstanding authority on insect pathology, has stated emphatically that there is "no authenticated recorded instance of a true insect pathogen having caused an infectious disease in a vertebrate animal either experimentally or in nature." The insect pathogens are so specific that they infect only a small group of insects — sometimes a single species. Biologically they do not belong to the type of organisms that cause disease in higher animals or in plants. Also, as Dr. Steinhaus points out, outbreaks of insect disease in nature always remain confined to insects, affecting neither the host plants nor animals feeding on them.

Insects have many natural enemies — not only microbes of many kinds but other insects. The first suggestion that an insect might be controlled by encouraging its enemies is generally credited to Erasmus Darwin about 1800. Probably because it was the first generally practiced method of biological control, this setting of one insect against another is widely but erroneously thought to be the only alternative to chemicals.

In the United States the true beginnings of conventional biological control date from 1888 when Albert Koebele, the first of a growing army of entomologist explorers, went to Australia to search for natural enemies of the cottony cushion scale that

threatened the California citrus industry with destruction. As we have seen in Chapter 15, the mission was crowned with spectacular success, and in the century that followed the world has been combed for natural enemies to control the insects that have come uninvited to our shores. In all, about 100 species of imported predators and parasites have become established. Besides the vedalia beetles brought in by Koebele, other importations have been highly successful. A wasp imported from Japan established complete control of an insect attacking eastern apple orchards. Several natural enemies of the spotted alfalfa aphid, an accidental import from the Middle East, are credited with saving the California alfalfa industry. Parasites and predators of the gypsy moth achieved good control, as did the *Tiphia* wasp against the Japanese beetle. Biological control of scales and mealy bugs is estimated to save California several millions of dollars a year — indeed, one of the leading entomologists of that state, Dr. Paul DeBach, has estimated that for an investment of $4,000,000 in biological control work California has received a return of $100,000,000.

Examples of successful biological control of serious pests by importing their natural enemies are to be found in some 40 countries distributed over much of the world. The advantages of such control over chemicals are obvious: it is relatively inexpensive, it is permanent, it leaves no poisonous residues. Yet biological control has suffered from lack of support. California is virtually alone among the states in having a formal program in biological control, and many states have not even one entomologist who devotes full time to it. Perhaps for want of support biological control through insect enemies has not always been carried out with the scientific thoroughness it requires — exacting studies of its impact on the populations of insect prey have seldom been made, and releases have not always been made with the precision that might spell the difference between success and failure.

The predator and the preyed upon exist not alone, but as part of a vast web of life, all of which needs to be taken into account. Perhaps the opportunities for the more conventional types of biological control are greatest in the forests. The farmlands of modern agriculture are highly artificial, unlike anything nature ever conceived. But the forests are a different world, much closer to natural environments. Here, with a minimum of help and a maximum of noninterference from man, Nature can have her way, setting up all that wonderful and intricate system of checks and balances that protects the forest from undue damage by insects.

In the United States our foresters seem to have thought of biological control chiefly in terms of introducing insect parasites and predators. The Canadians take a broader view, and some of the Europeans have gone farthest of all to develop the science of "forest hygiene" to an amazing extent. Birds, ants, forest spiders, and soil bacteria are as much a part of a forest as the trees, in the view of European foresters, who take care to inoculate a new forest with these protective factors. The encouragement of birds is one of the first steps. In the modern era of intensive forestry the old hollow trees are gone and with them homes for woodpeckers and other tree-nesting birds. This lack is met by nesting boxes, which draw the birds back into the forest. Other boxes are specially designed for owls and for bats, so that these creatures may take over in the dark hours the work of insect hunting performed in daylight by the small birds.

But this is only the beginning. Some of the most fascinating control work in European forests employs the forest red ant as an aggressive insect predator — a species which, unfortunately, does not occur in North America. About 25 years ago Professor Karl Gösswald of the University of Würzburg developed a method of cultivating this ant and establishing colonies. Under his direction more than 10,000 colonies of the red ant have been established in about 90 test areas in the German Fed-

eral Republic. Dr. Gösswald's method has been adopted in Italy and other countries, where ant farms have been established to supply colonies for distribution in the forests. In the Apennines, for example, several hundred nests have been set out to protect reforested areas.

"Where you can obtain in your forest a combination of birds' and ants' protection together with some bats and owls, the biological equilibrium has already been essentially improved," says Dr. Heinz Ruppertshofen, a forestry officer in Mölln, Germany, who believes that a single introduced predator or parasite is less effective than an array of the "natural companions" of the trees.

New ant colonies in the forests at Mölln are protected from woodpeckers by wire netting to reduce the toll. In this way the woodpeckers, which have increased by 400 per cent in 10 years in some of the test areas, do not seriously reduce the ant colonies, and pay handsomely for what they take by picking harmful caterpillars off the trees. Much of the work of caring for the ant colonies (and the birds' nesting boxes as well) is assumed by a youth corps from the local school, children 10 to 14 years old. The costs are exceedingly low; the benefits amount to permanent protection of the forests.

Another extremely interesting feature of Dr. Ruppertshofen's work is his use of spiders, in which he appears to be a pioneer. Although there is a large literature on the classification and natural history of spiders, it is scattered and fragmentary and deals not at all with their value as an agent of biological control. Of the 22,000 known kinds of spiders, 760 are native to Germany (and about 2000 to the United States). Twenty-nine families of spiders inhabit German forests.

To a forester the most important fact about a spider is the kind of net it builds. The wheel-net spiders are most important, for the webs of some of them are so narrow-meshed that they can catch all flying insects. A large web (up to 16 inches in diameter) of the cross spider bears some 120,000 adhesive nodules

on its strands. A single spider may destroy in her life of 18 months an average of 2000 insects. A biologically sound forest has 50 to 150 spiders to the square meter (a little more than a square yard). Where there are fewer, the deficiency may be remedied by collecting and distributing the baglike cocoons containing the eggs. "Three cocoons of the wasp spider [which occurs also in America] yield a thousand spiders, which can catch 200,000 flying insects," says Dr. Ruppertshofen. The tiny and delicate young of the wheel-net spiders that emerge in the spring are especially important, he says, "as they spin in a teamwork a net umbrella above the top shoots of the trees and thus protect the young shoots against the flying insects." As the spiders molt and grow, the net is enlarged.

Canadian biologists have pursued rather similar lines of investigation, although with differences dictated by the fact that North American forests are largely natural rather than planted, and that the species available as aids in maintaining a healthy forest are somewhat different. The emphasis in Canada is on small mammals, which are amazingly effective in the control of certain insects, especially those that live within the spongy soil of the forest floor. Among such insects are the sawflies, so-called because the female has a saw-shaped ovipositor with which she slits open the needles of evergreen trees in order to deposit her eggs. The larvae eventually drop to the ground and form cocoons in the peat of tamarack bogs or the duff under spruce or pines. But beneath the forest floor is a world honeycombed with the tunnels and runways of small mammals — whitefooted mice, voles, and shrews of various species. Of all these small burrowers, the voracious shrews find and consume the largest number of sawfly cocoons. They feed by placing a forefoot on the cocoon and biting off the end, showing an extraordinary ability to discriminate between sound and empty cocoons. And for their insatiable appetite the shrews have no rivals. Whereas a vole can consume about 200 cocoons a day, a shrew, depend-

ing on the species, may devour up to 800! This may result, according to laboratory tests, in destruction of 75 to 98 per cent of the cocoons present.

It is not surprising that the island of Newfoundland, which has no native shrews but is beset with sawflies, so eagerly desired some of these small, efficient mammals that in 1958 the introduction of the masked shrew — the most efficient sawfly predator — was attempted. Canadian officials report in 1962 that the attempt has been successful. The shrews are multiplying and are spreading out over the island, some marked individuals having been recovered as much as ten miles from the point of release.

There is, then, a whole battery of armaments available to the forester who is willing to look for permanent solutions that preserve and strengthen the natural relations in the forest. Chemical pest control in the forest is at best a stopgap measure bringing no real solution, at worst killing the fishes in the forest streams, bringing on plagues of insects, and destroying the natural controls and those we may be trying to introduce. By such violent measures, says Dr. Ruppertshofen, "the partnership for life of the forest is entirely being unbalanced, and the catastrophes caused by parasites repeat in shorter and shorter periods . . . We, therefore, have to put an end to these unnatural manipulations brought into the most important and almost last natural living space which has been left for us."

Through all these new, imaginative, and creative approaches to the problem of sharing our earth with other creatures there runs a constant theme, the awareness that we are dealing with life — with living populations and all their pressures and counterpressures, their surges and recessions. Only by taking account of such life forces and by cautiously seeking to guide them into channels favorable to ourselves can we hope to achieve a reasonable accommodation between the insect hordes and ourselves.

The current vogue for poisons has failed utterly to take into account these most fundamental considerations. As crude a weapon as the cave man's club, the chemical barrage has been hurled against the fabric of life — a fabric on the one hand delicate and destructible, on the other miraculously tough and resilient, and capable of striking back in unexpected ways. These extraordinary capacities of life have been ignored by the practitioners of chemical control who have brought to their task no "high-minded orientation," no humility before the vast forces with which they tamper.

The "control of nature" is a phrase conceived in arrogance, born of the Neanderthal age of biology and philosophy, when it was supposed that nature exists for the convenience of man. The concepts and practices of applied entomology for the most part date from that Stone Age of science. It is our alarming misfortune that so primitive a science has armed itself with the most modern and terrible weapons, and that in turning them against the insects it has also turned them against the earth.

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