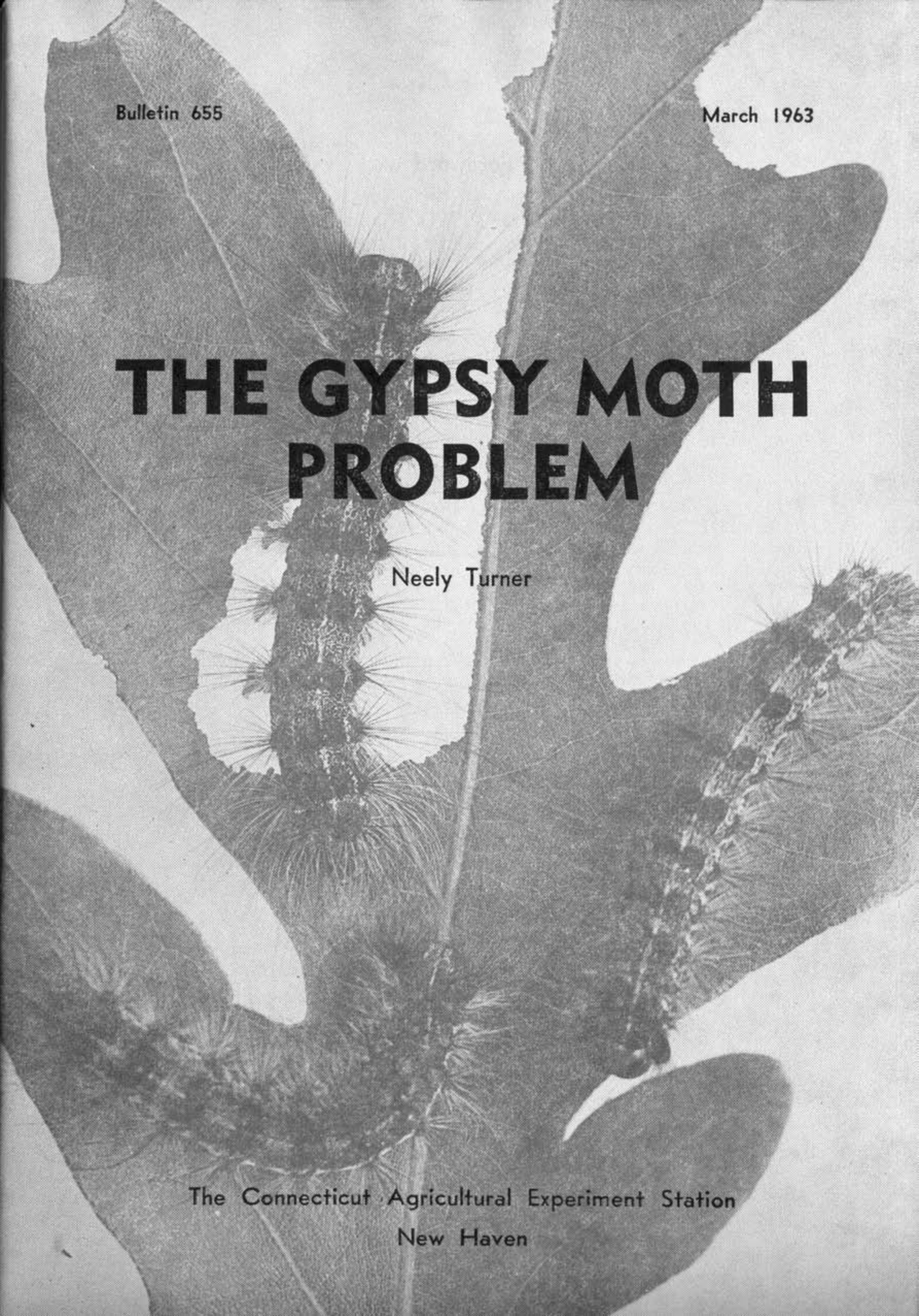

Bulletin 655

March 1963

THE GYPSY MOTH PROBLEM

Neely Turner

The Connecticut Agricultural Experiment Station

New Haven

SUPPLEMENT TO BULLETIN 655

The Gypsy Moth Problem

March, 1963

The 1963 General Assembly action in repealing section 22-92 of the General Statutes adds another step to the discussion of Public Policy on the Gypsy Moth on pages 20 and 21. The policy now returns control of the pest to individual owners of woodlands.

The statute printed on pages 20 and 21, the section headed "Procedures Now in Use," and statements on reimbursement on pages 23 and 24 are no longer valid.

Regulation of airplane spraying for control of gypsy moths was also changed, effective January 1, 1964. Responsibility for this function was assigned to the State Board of Pesticide Control, with administration under the Commissioner of Agriculture and Natural Resources.

July, 1963

THE CONNECTICUT AGRICULTURAL EXPERIMENT STATION
NEW HAVEN

Foreword

The gypsy moth has been the subject of more than a score of Station publications since 1906. In these booklets and papers, entomologists have presented information as it became known on the biology of the pest, its control, and its damage to trees. The most recent general account was a concise summary published as Circular 186 in 1954.

This Bulletin is intended to meet an increasing number of requests for more complete information, including some for documentation to support the brief statements in Circular 186.

Citations for information taken from many Station publications have been omitted in the interest of simplicity. I therefore here acknowledge extensive use of information in the publications of W. E. Britton and Roger B. Friend. I have cited the publications of Station staff members Raimon L. Beard, Stephen Collins, Charles C. Doane, Stephen W. Hitchcock, and Robert C. Wallis because the references are to research done recently or still in progress, or because the papers were published in journals not readily available to the general reader.

Figures on infestation and spraying were obtained by field scouts under the direction of Ralph Cooper, Deputy State Entomologist.

The author is responsible for the manuscript, but acknowledges the suggestions and comments of Raimon L. Beard, Stephen W. Hitchcock, and Bruce B. Miner of the Station staff, and of Lewis Gannett of Cornwall.

NEELY TURNER

Contents

The Gypsy Moth Problem

Neely Turner

THE GYPSY MOTH

Origin

The gypsy moth, *Porthetria* (*Lymantria*) *dispar* L., is an insect native to the temperate regions of Europe, Africa, and southern Asia. About 1869 it was introduced into Massachusetts and found the climate and woodlands highly favorable. It became a serious pest and a great nuisance because the caterpillars wandered over lawns, gardens, houses, and roads.

The Commonwealth of Massachusetts established a commission which studied the insect, developed effective control measures, and attempted eradication. After a few years the work was dropped because of cost and of low infestations.

The gypsy moth spread and once more increased in numbers. In 1905 an infestation was found in Mystic, Connecticut. Prompt action was taken to eradicate it, mostly by such hand methods as creosoting egg masses and trapping larvae under burlap bands. About the time this colony had been destroyed, another appeared in Wallingford. It too was eradicated. However, in 1913 so many infestations were found in the eastern part of the State that attempts at eradication failed. Efforts to stop its spread to the west were also unsuccessful, and by 1952 it was present in all sections of the State.

Life History

The gypsy moth passes the winter in the egg stage. The eggs are laid on the bark of trees, stones, buildings, fence posts, or junk (Figure 1). From 300 to 500 eggs occur in each egg mass, which is covered by hairs from the body of the female moth. The egg mass looks and feels like a firmly attached piece of chamois skin.

The caterpillars hatch from the eggs late in April or early in May, spend a few hours on the egg mass, and then move about to feed on the young leaves of host trees. Most of the feeding is done at night, and the small caterpillars are inconspicuous during the day. Wallis (1959) has confirmed that young caterpillars tend to migrate up trees for the first 3 weeks of feeding. During the second 3 weeks, he found, increasing numbers of half-grown larvae migrate down tree trunks. By the time the larvae are fully grown, migration is about equal in both directions.

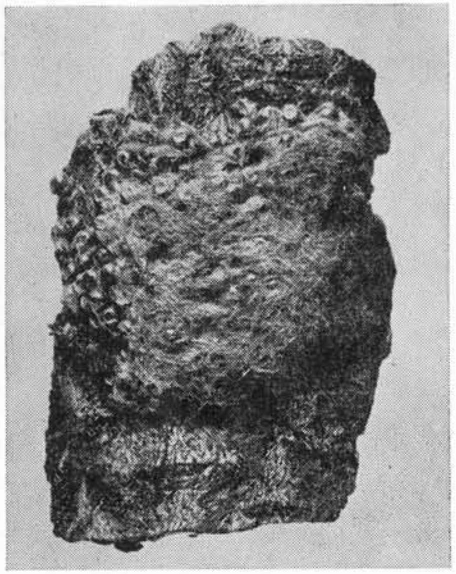

Figure 1. Egg mass of gypsy moth on bark removed from the tree on which the eggs were laid. About three times actual size.

The observations of Bess et al. (1947) indicated that migration down to litter was more common in woodlands with undergrowth and moist litter than in stands with dry, undecomposed leaves and little undergrowth.

The amount of feeding varies considerably. Wallis (1957) observed that less foliage was consumed when the relative humidity was high, apparently because the larvae could not dispose of the water. Thus the same number of gypsy moths may cause more defoliation on dry ridges than in moist valleys.

The fully grown caterpillars are almost 2 inches long with a brownish or gray background color. There are three light stripes along the back, and tufts of hairs. Each segment, except the first, has a pair of tubercles, the first five pairs (from the head) are blue, the last six brick red.

The caterpillars complete their feeding late in June and early in July, and crawl about seeking a protected place for pupation. The pupa is naked, but may have a few strands of silk spun loosely about it.

Moths emerge in 10 to 14 days. The wings of the female are dirty white with brown markings, and the abdomen is covered with buff hairs. The male is smaller and much darker in color, with a very small abdomen. It emerges a few days before the female. The female is too heavy for flight, mating and egg-laying take place near the location of the pupa. Adults live only about 2 weeks (Figure 2).

Methods of Spread

Since female moths cannot fly, natural spread can occur only in the caterpillar stage. Newly-hatched caterpillars are very light and are heavily clothed by hairs. They are easily blown about by the wind, sometimes for considerable distances.

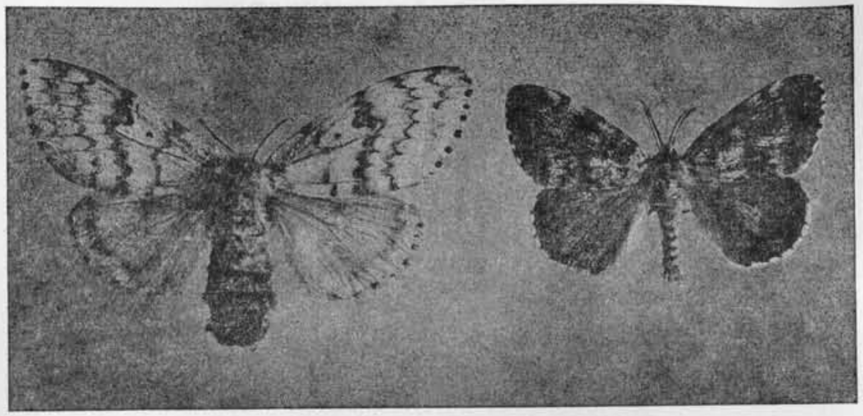

Figure 2. Adult gypsy moths: left, female; right, male. Actual size.

Transfer of stone, lumber, logs, trees, or wood on which there are egg masses also spreads infestation. This is of minor importance in most Connecticut woodlands.

There has been much speculation about the occasional spread of the gypsy moth into large areas previously uninfested. The general spread into Connecticut in 1913 was supposed to be a wind spread of small larvae. The general spread westward from New England, found about 1940, may have resulted from the blowing of eggs on bark debris during the 1938 hurricane.

Economic Importance

The gypsy moth defoliates large areas of woodland during its outbreaks. It is commonly stated that a single defoliation does not kill many hardwood trees unless there is a severe drouth at the same time. Both Baker (1941)* and House (1959)* estimated a 5 per cent net loss from a single severe defoliation. This is not much greater than the usual mortality of trees in a crowded woodland.

Tierney (1947)* and Crossman (1948)* observed considerably greater losses from multiple defoliation. In 34 locations in the Connecticut River section of Massachusetts, Tierney gave the range of mortality as 10 per cent to 80 per cent of the oaks following 3 years of heavy defoliation. Crossman concluded, "From 25 to 50 per cent of the oak is dead on a large part of the acreage mentioned above (55,000 acres in Massachusetts, Maine and New Hampshire) and in many small pockets it ranges from 75 to 100 per cent, scattered throughout the area." Both included photographs of dead trees on large areas.

White pines are more susceptible than oaks to damage by defoliation. Both Baker and House reported a total loss of about 28 per cent from a single complete defoliation. House found that only 11 per cent of the dominant and co-dominant pines died, most of them in the second year after defoliation.

* A more detailed summary of these reports is being published in Station Bulletin 658, available on request.

Hemlocks were most susceptible. House reported that 68 per cent of the dominant and co-dominant hemlocks were killed by a single complete defoliation, mostly in the year of injury.

Both Baker and House found a net loss of growth in diameter following a single heavy defoliation. Both recorded a substantial decrease in growth of undefoliated trees in the same period. House attributed this to lack of woodland management, and estimated it at three times the loss from defoliation.

Perry (1955) has published an estimate of damage in dollars from the figures of House. The study covered the period 1933-1952, when the acreage defoliated in Connecticut was low. Perry assigned market value for both trees and cordwood. The estimate of the value of trees killed by defoliation was $2.00 a defoliated acre. Loss in growth was estimated at $0.57 a defoliated acre. These areas did not contain any commercial timber. In other parts of New England, Perry estimated the loss to commercial forests at about $5.00 a defoliated acre.

In Connecticut there have been no instances of repeated defoliation of large areas by the gypsy moth at this time. The probability of death of hardwoods here has been relatively low, of pine moderate, and of hemlock relatively high. The stumpage value of the trees killed, and the loss of growth in trees that survived, has been low in dollars per acre. Probability of serious injury to the pine and hemlock understory, trees of future value, has been high, but the damage has been more to the potential value of woodlands than to present value.

Nuisance

From the first outbreak of the gypsy moth in Massachusetts in 1889 until the 1962 outbreak in Connecticut, the nuisance of the pest has been enormous. The report of Forbush and Fernald (1896) has pages of description of the havoc. The nuisance of such an infestation has not been lessened over the years. The owner of the house in Figure 3 was just as annoyed in 1960 as were the residents of Massachusetts in 1896.

The nuisance of crawling caterpillars in parks and picnic areas of forests is considerable. It is common for the use of such areas by visitors to decrease sharply during a severe infestation of gypsy moth or other defoliating caterpillar.

Defoliation in woodlands around water reservoirs creates special problems. Heavy defoliation produces hundreds of pounds of frass which soon is washed into the water by rain. The effect on the quality of the water is immediate in small reservoirs. Moreover, the nutritive elements in the frass increase the growth of algae in water, creating an additional problem of longer duration.

Food Plants

The gypsy moth larvae can feed on a wide variety of plants. Forbush and Fernald (1896) published a long list of plants damaged by the pest, as well as a few the insects would not eat. Mosher (1915) extended the study by laboratory tests, and classified food plants in four groups.

Group I was described as favored food, and included apple, aspen, beech, white, gray and red birch (Figure 4), larch, linden, the oaks, and common willows.

Figure 3. Gypsy moth larvae on a suburban home, May 27, 1960.

Group II contained species that were called favored food *after* the young larvae had fed on species in Group 1. This included hemlock, the pines, and spruces.

Group III were not favored, but a few larvae could develop on them. The trees were black and yellow birch, the cherries, elm, the hickories, Norway, red, silver and sugar maples, and pears. The trees in this group were usually not likely to be injured.

Group IV included the unfavorable food species black, red, blue and white ash, balsam, butternut, cedar, dogwood, elder, mountain laurel, locusts, mountain and striped maple, sycamore, tulip tree, and black walnut. The gypsy moth might eat a bit but could not survive on these plants.

Possible application of this information is discussed on page 16.

Variations in Abundance

Long periods of relative scarcity, rapid increases in numbers, outbreaks, and sudden declines of the population are characteristics of the gypsy moth wherever it occurs. Forbush and Fernald (1896) referred to such fluctuations in Europe and Asia. Kellus (1942), Ryvkin (1959), and Edel'man (1958) have discussed outbreaks in the different regions of the USSR. Monastero (1956) described defoliation in Italy, Szalay-Marzso (1959) in Hungary, and Kovacevic (1958) in Yugoslavia. Bess (1961) mentioned an outbreak in Japan in 1953-55.

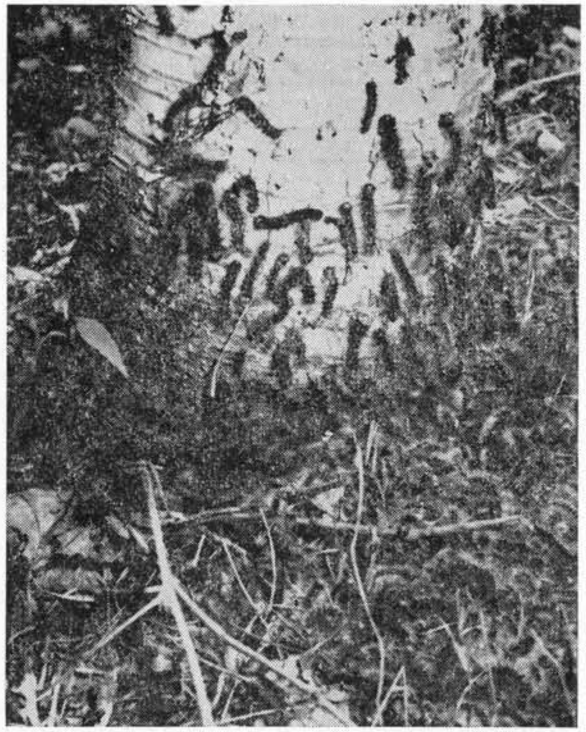

Figure 4. Migrating larvae at the base of a white birch tree, June 27, 1962.

The situation in Connecticut is reasonably well documented. Until 1938, all the relatively small infestations were sprayed, and defoliations occurred only in very small areas missed in scouting. In 1938 and 1939, the outbreak in Hartford County was too extensive to be sprayed by the methods then in use. More than 1,000 acres were defoliated each year in addition to the sprayed areas. The record since 1945 is given in Table 1.

Thus the gypsy moth in Connecticut is behaving much as it has in Europe and Asia.

A majority of the species of pest insects do not fluctuate in this manner. Most change much less violently in number, whether they be scarce or abundant on the average. The reasons for this departure from the usual have been sought by entomologists since the early part of the last century. The theories that have been proposed cannot be reconciled with the facts. It is sufficient to note that this sort of fluctuation is much more characteristic of insects in woodlands than of pests of agricultural or garden crops. The eastern tent caterpillar, cankerworm, linden looper, and orange-striped oakworm fluctuate in abundance in the same way as gypsy moth.

With this in mind, the two proposed theories of most interest are (1) interaction with parasites, and (2) the result of control by insecticides.

DeBach and Smith (1941) tested the hypothesis that interaction between host and a parasite could produce fluctuations. They were able to

Table 1. Acreage of woodland in Connecticut damaged by the gypsy moth

Year	Defoliated	Sprayed	Total
1945	16	0	16
1946	496	0	496
1947	0	0	0
1948	0	0	0
1949	0	4,353	4,353
1950	475	0	475
1951	200	2,400	2,600
1952	1,500	7,000	8,500
1953	20,000	10,000	30,000
1954	14,000	133,822	147,822
1955	6,842	11,385	18,227
1956	3,458	15,963	19,421
1957	4,800	53,474	58,274
1958	117	9,000	9,117
1959	6,000	7,000	13,000
1960	20,000	19,000	39,000
1961	15,800	45,600	61,400
1962	83,300	54,530	137,830

demonstrate that this was true in laboratory tests, thus confirming the hypothesis advanced by Lotka (1925) and Volterra (1926). When hosts are scarce they are hard for parasites to find, and hosts increase more rapidly than parasites. As the hosts increase in number, parasites can find them more easily, and eventually overwhelm the hosts, usually in the course of a "major outbreak." This is a good description of events, but it sheds little light on a remedy.

Nicholson (1954) has generalized from his experiments with blowflies that use of insecticides may cause an increase in the numbers of insects. Beard (1960) has been unable to confirm the results using houseflies. Some data are available as to insecticides and gypsy moth numbers. At the time of the major outbreak in 1954, several towns decided not to spray for control of the pest, and some have continued this policy. Table 2 shows the acreage infested in three such areas, and in three towns in which infestations were sprayed. The areas infested in successive years in each set of towns were not in the same location. Nevertheless there is no evidence that spraying resulted in either more frequent or longer continuing infestation than absence of spraying.

Influence of Weather

It is obvious that the general weather conditions in Connecticut are suitable for the gypsy moth to develop major infestations. Most of the studies of effects of weather have been directed at low winter temperatures that kill eggs. Thus Friend (1945) attributed the collapse of the 1943 infestation to winter temperatures of —24° F. Such extremely low temperatures occur infrequently in this State.

Hitchcock (personal communication) collected egg masses from many sections of the State after the winter of 1961-62. Twenty egg masses from valleys in Southbury, Newtown, and New Hartford had a high winter mortality. Eighteen egg masses from Monroe, Haddam, Newtown, and Shelton hatched less than 50 per cent. Seventy-seven masses from other parts of the State hatched normally. Thus the winter temperatures were low enough to kill eggs in only a few locations.

Table 2. Acreage heavily infested in Connecticut in towns sprayed and not sprayed

Year	Towns not sprayed			Towns sprayed		
	A	B	C	D	E	F
1954	15,400	18,700	11,000	8,100	21,460	8,275
1955	10,000	3,750	3,500	0	0	1,280
1956	370	4,000	765	0	0	3,600
1957	10,634	2,200	5,500	0	0	3,700
1958	1,000	0	3,400	0	0	0
1959	0	0	115	0	0	0
1960	0	0	0	0	0	0
1961	0	225	365	1,900*	3,600*	0
1962	85	0	2,470	1,250	10,350	4,600

* Not Sprayed

Summary

When fact has been separated from fancy, the underlying causes of gypsy moth outbreaks remain obscure. This can be said: there is no good evidence of any specific act or acts of owners of woodlands which precipitates the outbreaks. Outbreaks seem just as "natural" as the woodlands are "natural." If this be true, the only "natural cure" may be a change in the nature of woodlands.

CONTROL OF THE GYPSY MOTH

When the gypsy moth became a pest in 1889, control of insects was in its infancy. Economic entomologists believed then as now that the best control was "natural control." If study did not show the way to accomplish this, they investigated manipulation. If manipulation did not work or was not used, the possibility of control by insecticides was considered.

The entomologists of the day investigated all three areas, and the magnificent report of Forbush and Fernald (1896) contains the record. Parasites were scarce or non-existent, and hand control was imperfect at best.

A few years earlier some unknown farmer in the Middle West had used Paris green to protect his potato plants. Paris green was tried on trees and found too injurious for practical use. A chemist of the Massachusetts Commission, Mr. F. C. Moulton, thought that this was because Paris green contained some soluble arsenic. He believed an insoluble compound might work, and prepared and tested arsenate of lead. Its success took care of shade trees in villages and of fruit trees in orchards. To this day the same material applied in the same way will protect the trees from many insects.

Between 1905 and 1929 parasites and predators were introduced, and research on these continues. The polyhedral virus disease is still under study (see page 14). Between 1917 and 1947, three separate studies on control by management were published (see page 16). A substantial study of the ecology of the gypsy moth was published by Bess (1961).

The only changes in practical gypsy moth control since 1896 have been the introduction of parasites, and a substantial reduction in cost of spraying infested woodlands. It may well be, as Brown (1961) has suggested, that the key to a solution to the gypsy moth problem is yet to be discovered.

Parasites and Predators

The gypsy moth became established in the United States without its natural parasites and predators. In 1905, the Commonwealth of Massachusetts and the Federal Bureau of Entomology started the introduction of parasites and predators from Europe and Asia. Importation was interrupted by two wars, but by 1929 about 575,000 individuals of 46 species had been imported and released. More than 90,000,000 had been transferred from points where colonies were established in Massachusetts to other areas infested by the gypsy moth within the United States (Burgess and Crossman, 1929).*

In Connecticut, both egg and larval parasites were transferred from east to west as the gypsy moth spread in that direction. Natural spread of the parasites proved to be sufficiently rapid to make hand transfer unnecessary.

Friend (1945) reported that the two species of egg parasites, *Anastatus disparis* R. and *Oencyrtus kuwanae* How., were well established in Connecticut. The degree of parasitism varied from a fraction of 1 per cent to 31 per cent in 1922 from both species. Bess (1961) reported that *disparis* was hardy in the colder portions of New England and *kuwanae* was better adapted to southern New England. Total parasitism by the two varied from 17 per cent to 37 per cent.

In his recent studies of *kuwanae* in Connecticut, Hitchcock (1959) determined that about one-third (occasionally as high as one-half) of the eggs were parasitized in the field. In the laboratory, the *kuwanae* adults could and did oviposit in 55 per cent of the eggs in normal egg masses, probably because of the presence of large numbers of parasites. Thus, this parasite is limited in its potentialities, because it can at best reach only slightly more than half the eggs, and seldom that many in the field.

Friend (1945) reported that larval parasites were very effective in Connecticut. The wasp *Apanteles melanoscelus* Ritg. commonly affected 20 to 30 per cent of the larvae, occasionally as many as 67 per cent. Another fly, *Sturmia scutelata* R-D., sometimes affected about half the female pupae, and in one collection was present in every gypsy moth. These figures agree with those published later by Bess (1961). Bess did conclude that on the average these larval parasites were less destructive to gypsy moths than were egg parasites.

* Neither the study of parasites abroad nor the possible importation of additional species stopped at the time of publication of this comprehensive report. Search for additional effective species has continued, but none has been found. As this is written there is an active project in southern Europe, and arrangements are going forward to attempt establishment here of some species that failed to stand the Connecticut climate earlier. This project is under the supervision of the U.S. Forest Service.

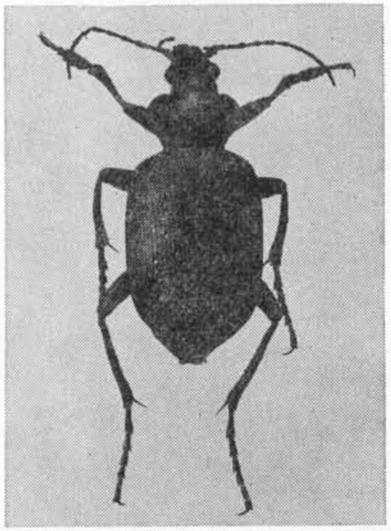

Figure 5. Calosoma beetle, about 1½ times natural size.

Friend (1945) reported two other parasites, *Hyposoter disparis* Uris and *Phorocera agilis* R-D., are present in Connecticut, and Bess (1961) mentioned the native wasp *Theronia fulvescens* Cress.

The remarkable carabid beetle *Calosoma sycophanta* L. has become established in all parts of Connecticut (Figure 5). It was released originally in Stonington in 1914. Both the larvae and adult eat gypsy moth larvae and pupae (Figure 6), and of course will feed on other insects as well. It is difficult to evaluate the effects of this predator, because of its mobility. Bess (1961) recorded that as high as 13.2 per cent of larvae and pupae not parasitized were eaten by Calosomas.

Forbush and Fernald (1896) reported in detail on bird predators of gypsy moth larvae. Relatively few species of birds would eat the large hairy gypsy moth caterpillars regularly. Birds might be effective predators when few gypsy moths were present, but could not cope with major outbreaks.

Hamilton and Cook (1940) believed that small rodents, such as mice and shrews, were far more important predators than birds.

Bess, Spurr, and Littlefield (1947) attempted to determine the reasons for differences in infestation in different parts of New England. They found that conditions which encouraged larvae to migrate to litter led to smaller survival. In the course of their studies, deer mice were found eating large numbers of large larvae and pupae in some locations. When large larvae were released in an area in which all mammals had been trapped and new invasions prevented by fences, survival of gypsy moths was high. This led them to suggest that the continued low infestation of the gypsy moth in Eastford, Connecticut, might be the result of predation by mammals.

In the final report of his studies, Bess (1961) emphasized the effectiveness of mammals in what he calls "the more mesophytic woodlands with considerable litter." This would indicate that predation by mammals could not be depended upon for gypsy moth control in many areas where outbreaks occur most frequently, because these are dry woodlands with small amounts of litter.

Figure 6. Larva of a Calosoma beetle feeding on a gypsy moth larva.

There is one other bit of evidence worth consideration. In 1958, a massive outbreak of the orange-striped oakworm occurred in woodlands in the eastern part of the State. Like the gypsy moth, large oakworms migrate freely. Moreover, the oakwarms pupate in the litter and soil, in a place most accessible to predation by mice and shrews. The defoliation of about 37,000 acres by oakworms would indicate that rodents are not necessarily dependable predators.

Diseases

The wilt disease of gypsy moth was noticed first in Massachusetts between 1900 and 1910. Glaser and Chapman (1913) proved that the disease was caused by a virus which formed polyhedral bodies. They fed the virus to "healthy" gypsy moth larvae and produced the disease. Its origin is unknown, but similar diseases occur in many parts of the world. Glaser and Chapman made the very significant observation that the virus appeared most commonly when the infestation was high, and seldom attacked individual larvae feeding alone.

Steinhaus (1946) records natural epidemics of wilt disease in several species of caterpillars attacking forest trees, in armyworms, and in larvae of the alfalfa butterfly.

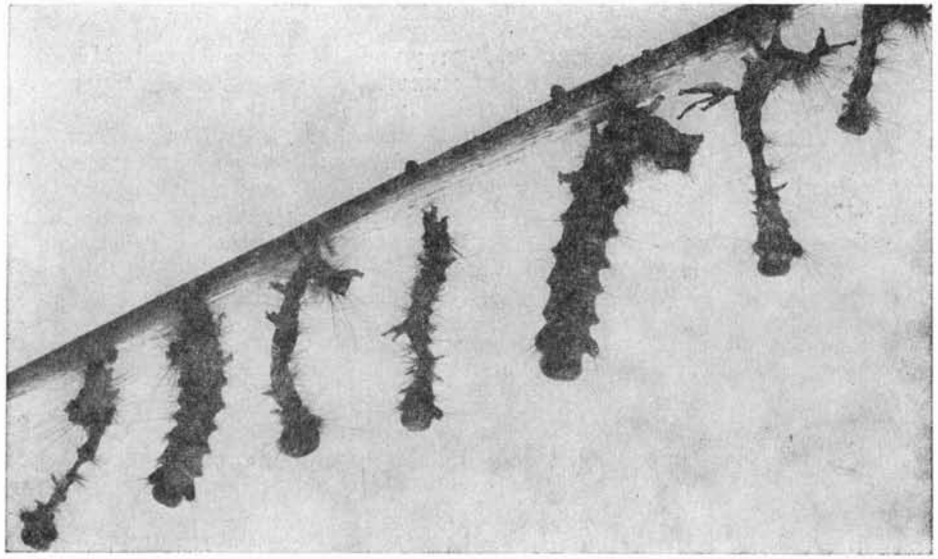

Figure 7. Gypsy moth larvae killed by polyhedrosis.

It is this wilt disease that kills many of the larvae of the gypsy moth in the course of a major outbreak. The larvae become sluggish and die in a few hours, frequently hanging by a leg (Figure 7).

Efforts to increase the effectiveness of the virus by spraying it on foliage have been made from time to time, most recently by Dowden (personal communication). The percentage of infection was not changed by this spraying when the larvae were equally abundant in unsprayed areas. Wallis (1957) has proved that the virus is present in the eggs, and suggests that it becomes active when the larvae are crowded, when good food is exhausted, or when the humidity is high for long periods of time. Wallis tried "chemical stressors" that had increased evidence of a virus of silkworms in experiments of Yamafugi and Yoshihara (1951). These were without effect in the case of the gypsy moth.

Friend (1945) concluded that these natural enemies were as well established as the gypsy moth and were affecting the abundance of the pest, The studies of Bess (1961) confirm this, and give results of careful counts demonstrating the proportion of the gypsy moths so removed. They obviously do not prevent outbreaks of gypsy moths in large areas in this country, or even in the areas of Europe and Asia where the gypsy moth is a native pest.

In the absence of conclusive data on the subject, it is assumed that gypsy moth parasites and predators are responsible for the low level of the pest between outbreaks. They may also be responsible for increasing the interval between outbreaks. What happens to the parasites or to the gypsy moths that results in an outbreak is still unknown.

Management

Control by management was proposed by Clement and Munro (1917). They advocated removal of susceptible trees, especially those of low commercial value, and encouragement of conifers. Nineteen years later, Behre, Cline, and Baker (1936) renamed this silvicultural control. They presented data showing a strong correlation between percentage of favored host trees and amount of defoliation. Bess, Spurr, and Littlefield (1947) made another approach by emphasizing that site conditions as well as percentage of favored hosts governed the amount of infestation.

Each of these groups went into considerable detail with suggestions for application of their principles. Each emphasized that the changes proposed were in the direction of improvement whether or not gypsy moth was a problem.

There seems little doubt that the principles advocated in these studies will reduce the hazard of serious damage by the gypsy moth. A few commercial forests have been so treated over the past 20 or 30 years. Many state forests are now undergoing this type of improvement. However, if this method is to solve the problem, application will have to proceed at a far greater rate than in the past.

In its application, some spraying may be required to protect pines and hemlocks from defoliation until the composition of the forest reaches a resistant stage.

The basic principle is management to reduce the proportion of oaks, gray birch, and aspen on dry sites and encouraging replacement by hemlock, white pine, and shrubs. On more moist sites, the percentage of favored hosts can be considerably higher without risking heavy infestation. Here, too, diverse undergrowth would be helpful.

The Service Foresters of the State Park and Forest Commission and the Extension Forester of the University of Connecticut are available for consultation as to specific problems. Commercial management of woodlands is also available.

Hand Methods

Control by what may be called hand methods was in use before sprays were developed.

Creosote oil colored with lampblack to distinguish treated areas was painted on egg masses to kill eggs. This method was limited in effectiveness by inability to find all the egg masses. It was used in the effort to eradicate the gypsy moth from Connecticut through the days of the Civilian Conservation Corps (about 1940). This method was not sufficiently effective to prevent defoliation except on limited areas.

Caterpillars can be trapped under burlap bands wrapped around tree trunks, and destroyed. Pupae may be hand-picked from under such bands.

These hand methods are practically applicable only to shade trees or to very small areas of woodland. They require relatively large amounts of labor.

Spraying

Spraying of heavily-infested trees remains the one sure way known to avoid defoliation by gypsy moth caterpillars. Forbush and Fernald (1896) thought this method was particularly useful on shade trees and

in orchards. Shortly after their report, arsenate of lead was applied in woodlands as part of an effort to prevent spread of the pest or even to exterminate it. Friend and Turner (1930) calculated the cost of spraying woodlands in Connecticut at between $11.51 and $21.31 an acre using arsenate of lead and ground sprayers.

Houser (1922) first used aircraft to apply insecticides in 1921, and suggested that the method was suitable and economical. The proposal received little attention because as Graham (1929) said, "$5.00 an acre is expensive for woodlands." When DDT was developed, interest increased because of the reduction in cost.

In 1945, Friend conducted extensive experiments in cooperation with the U.S. Coast Guard and the Federal Bureau of Entomology. The effectiveness of the sprays was remarkable. Friend (1946) said: "A dose of one pound of DDT an acre will practically eliminate the gypsy moth from an area, and one-half pound per acre will give excellent control." Numerous tests by other agencies, including the U.S.D.A., duplicated and confirmed these results.

The effects of these sprays on animals other than gypsy moth were studied at length. Brues (1947) found that the insect fauna of sprayed woodlands was actually more representative than in similar unsprayed areas. Numerous tests (summarized by Hoffman and Linduska (1949) and others) showed no measurable effects on birds and mammals. Evidence on aquatic animals was conflicting, and Hoffman and Linduska (1949) concluded that the 1 pound to the acre rate was near the maximum amount safe to aquatic life.

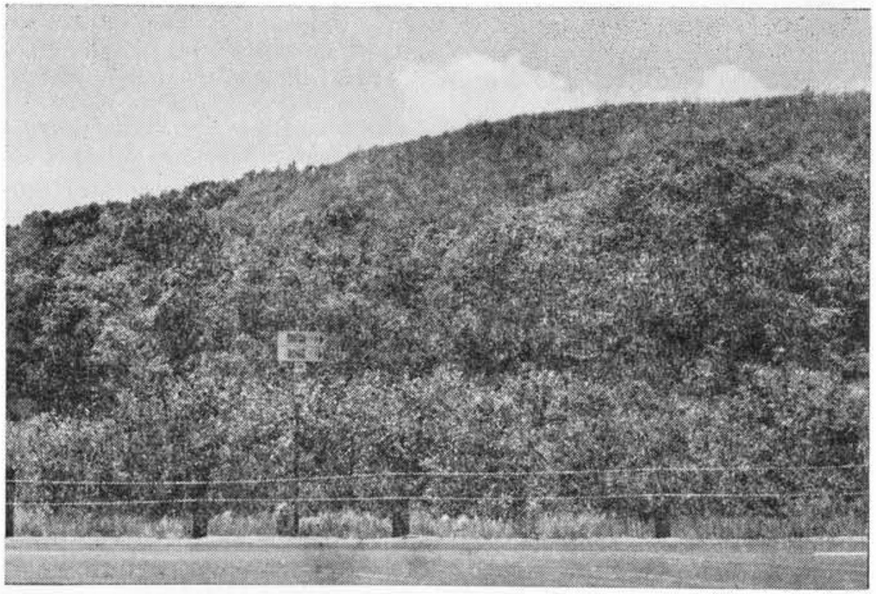

Figure 8. Although not readily apparent in this monochrome, the trees in the foreground were sprayed, those on the hillside were not and have been heavily defoliated. 1962.

It must be stated emphatically that the purpose of these sprays was to prevent damage to woodlands heavily infested by the gypsy moth (Figure 8). In this respect this control of gypsy moth is analogous to treatment of human infections with antibiotics. The treatment relieves the emergency but does not confer immunity to future attacks.

EXPERIMENTAL METHODS PROPOSED FOR CONTROL

Sterilization

The success of Knipling and his co-workers in eradicating the screw-worm from Curacao and from the southeastern United States has aroused interest in this method for control of the gypsy moth. Knipling (1959) has outlined the requirements for successful use of this technique as: (1) susceptibility to sterilization without interfering with flight and mating, (2) possibility of rearing, treating, and releasing sterile males at a time when the population of pest insects is at a minimum, and (3) preferably a single mating of each female. With the gypsy moth, the difference between the amount of irradiation necessary to sterilize and the dosage injuring moths is very narrow. There is also no way to rear large numbers of gypsy moths except on fresh leaves of trees.

The method offers little promise for use during an outbreak. It might be successful in preventing development of an outbreak if the technical difficulties could be solved.

The use of chemical sterilants has been reviewed by Borkovec (1962). Several types of compounds that produce sterility in insects have been discovered. The idea is intriguing, but the problems of practical use are enormous. Because of the mode of action, such compounds may be more dangerous to wildlife than insecticides. At best they offer limited practical use.

Genetic Sterility

Goldschmit (1934) found races of the gypsy moth separated geographically and sufficiently different genetically that crosses between them were sterile. Downes (1959) has suggested release of males of the "strong" race from eastern Asia and central Japan, which should produce sterile females when mated with the "weak" race in the United States. The one experimental trial of the U.S. Forest Service was unsuccessful because of different times of emergence of the imported moths.

This method would also require methods of rearing gypsy moths in large numbers.

Lures

It has been known for years that the flightless female moths attracted males by a chemical lure. Living females, and "tips" cut from their abdomens, were used to determine the presence of male moths in woodlands. Later, extracts were prepared and used. Studies on the chemistry of the attractant were made by Haller and his associates (1944).

Recently Jacobson, Beroza, and Jones (1961) have identified one of the two male attractants as (+)-10-acetoxy-1-hydroxy-*cis*-7-hexadecene. They were able to synthesize this compound in small quantities. Synthesis of related compounds produced one which can be made in quantity. Billings (1962) designated it as gyplure, *cis*-9-octadecen-1,12-diol-12-acetate.

The earliest tests of use of natural lure for control of the gypsy moth were reported by Forbush and Fernald (1896). They were unable to trap enough male moths to reduce the number of fertile eggs laid by the females.

Tests made by Doane (1961) demonstrated that the gyplure available at that time could not compete in attractiveness with living female moths. Investigation is continuing, but it is obvious that the use of the material is still far from practical.

Bacillus thuringiensis

Bacillus thuringiensis was discovered in Germany in 1911 and used in Yugoslavia and Hungary for control of the European corn borer before 1929, according to Franz (1961). Steinhaus (1951) first used it in this country to control alfalfa caterpillar.

The bacillus is cultured and prepared for use in the spore stage. The spores are accompanied by a crystalline material highly toxic to some insects and by toxins. It is usually applied to foliage and acts only after swallowed by the insects. It is definitely pathogenic to a few insects, and produces an epidemic among them. On other species, including gypsy moth, the action is more like that of an insecticide than a disease.

Like many other materials of biological origin, preparations of *B. thuringiensis* spores vary greatly in amount of crystalline material and number and viability of spores. There is the added problem of formulating living spores for proper distribution. Brown (1961) reports that results on gypsy moth have not been encouraging.

Tests made in Connecticut by the Plant Pest Control Division, U.S.D.A., in 1958 demonstrated only that the preparations available could not be applied by aircraft. More recent tests have been more promising. Those of Lewis (1962) of the U.S. Forest Service, New Haven, were effective enough to justify further efforts to improve formulations.

It should be understood that general use of this material as a "natural insecticide" raises problems similar to those encountered with synthetic insecticides. Its effects on insects other than defoliators have not been determined, and knowledge of its effects on both terrestrial and aquatic wildlife is incomplete.

PUBLIC POLICY ON THE GYPSY MOTH*

In 1907, two years after appearance of the gypsy moth in this State, the Connecticut General Assembly declared the insect to be a public nuisance and authorized the state entomologist "to suppress and exterminate" the gypsy moth, and appropriated funds for the purpose. For a decade the effort seemed to be succeeding, but then, as it seems to do about once in 20 years, the gypsy moth moved in numbers. Even so, the effort to suppress and exterminate remained the law and the policy until World War II.

Dr. Roger B. Friend, then state entomologist, completed a study of the pest and an appraisal of the work, and published his classic report in 1945. (This report has been reprinted and is available from this Station on request.) He concluded that the gypsy moth had become widely distributed and thoroughly established in Connecticut, and that natural factors of control were operating. He proposed that the idea of eradication be dropped, and that suppression be confined to areas in danger of serious defoliation.

This policy was followed for several years. However, it was very difficult to "guess" the acreage that might be affected 2 years in advance for preparation of a budget. For whatever reason, the appropriations for this spraying dwindled, and by 1952 the heavily infested area was so large that spraying was discontinued by permission of the Station Board of Control. With the approval of the Board, owners of woodlands in which the infestation was severe were notified of the situation. The 1953 infestation and the prospects of an even more extensive outbreak in 1954 prompted representatives of the infested towns to press for action. The Governor met with town officials and representatives to the General Assembly and asked for recommendations. An emergency plan was proposed on the basis (1) that it was impractical and uneconomical for individuals to deal with this problem, (2) that both the potential damage and nuisance warranted the expenditures and (3) that the state government had part of the obligation to keep Connecticut green. This plan provided for the state entomologist to furnish maps of the infested area, and to assist towns which elected to spray. It also provided for reimbursement for part of the cost of spraying from special funds. This plan was adopted by proclamation of the Governor.

The 1955 General Assembly considered several proposals in regard to gypsy moth spraying, and passed the following statute. The Assembly also appropriated funds for spraying in the spring of 1955.

The Gypsy Moth Statute

Sec. 22-92 Gypsy Moth Control

Whenever the existence of gypsy moths reaches or threatens to reach epidemic proportions in this state, the state entomologist may declare that an emergency exists and so certify to the finance advisory committee, which committee may add from the resources of the general fund to the appropriation of the experiment station sufficient funds, not exceeding forty thousand dollars for the biennium, to meet the emergency. Said state entomologist shall, in cooperation with the state park and forest commission, spray state park and forest lands infested with gypsy moths, and may pay the expense thereof from such funds. Said state entomologist, in agreement with the legislative body of any town, city or borough in which an emergency exists, shall designate the areas in such town, city or borough requiring emergency spraying and assist officials and representatives in coordinating spraying activities, and said entomologist may reimburse such towns from the above funds to the extent of one-half the cost of spraying such areas, or a prorated amount from the sums available, but not more than sixty cents per acre.

It is obvious that this statute deals only with spraying heavily infested woodlands. The purpose is to prevent serious defoliation and nuisance. The word "emergency" is evidence of the intent of the statute.

Procedures Now in Use

The statute does not define "epidemic proportions." The criteria now in use are (1) that a block contain sufficient favored hosts to feed enough caterpillars to defoliate trees, (2) that the infestation in a substantial portion of a block is enough to produce more than 50 per cent defoliation, and (3) that the population of gypsy moths in the block is increasing. A block is an area of woodland clearly marked by such visible boundaries as roads, open land, rivers, lakes, etc.

The criterion for defoliation is a series of counts of egg masses clearly visible in a specified area. A series of such counts in areas chosen at random provides an average number of egg masses per acre. Experiments in the past demonstrated that woodlands were defoliated more than 50 per cent when there was an average of 500 egg masses per acre *by this system.*

The forecast of "epidemics" by this system has been more than 95 per cent accurate in nine seasons. That is, more than 95 per cent of the unsprayed blocks have had either substantial visible defoliation, or an increase in infestation sufficient to cause defoliation the following season. Occasionally a small area with an infestation below the average has some visible defoliation. The extent of these "misses" has never exceeded 2 per cent of the infested acreage.

The results of scouting and spraying under provisions of the statute are reported annually, and published in the Connecticut Digest of Administrative Reports. A summary is given in Table 3.

Regulation of Airplane Spraying

Airplane spraying has been regulated by state statute since 1947. The original statute required the Director of The Connecticut Agricultural Experiment Station to determine the materials that could be used; the Director of the State Board of Fisheries and Game, the areas that could be treated; and the Director of Aeronautics, the flight rules. Changes in the statute have been made from time to time. The Director of the State Department of Health has been given the responsibility for human health aspects.

The present statute (Sec. 15-99) authorizes legal representatives of

* A comprehensive account of policy in other states and of the Federal Government has been published in American Forests for July 1960 under the title *Pests, Pesticides and People.* The study was sponsored by the Conservation Foundation, 30 East 40th St., New York 16, and was also issued as a reprint (41 pp.).

Table 3. Gypsy moth spraying under the gypsy moth statute*

Year	Towns infested No.	Towns infested Acreage	Towns sprayed No.	Towns sprayed Acreage	Towns NOT sprayed No.	Towns NOT sprayed Acreage
1954	36	200,000	22	133,822	14	66,178
1955	11	38,381	4	11,385	7	26,996
1956	10	17,143	8	15,963	2	1,180
1957	19	60,000	15	53,474	4	9,526
1958	5	12,000	3	9,000	2	3,000
1959	10	9,500	8	7,000	2	2,500
1960	29	42,000	13	19,000	16	23,000
1961	39	58,000	25	45,500	14	12,500
1962	60	136,000	20	54,530	40	81,470

* Total acreage in this table was determined by blocks. Defoliation in Table 1 was an estimate of the area actually defoliated and not of the blocks in which it occurred.

these four state agencies to regulate application of chemicals by aircraft through rules and regulations. These rules must be filed with the Secretary of State, and authority for them approved by the Attorney General. They are then published in the Connecticut Law Journal, and in due course are approved for enforcement. The present rules were adopted by a favorable vote of each representative of each agency on April 2, 1958, were published in the Connecticut Law Journal June 3, 1958, and have been reviewed by an appropriate committee of each regular session of the General Assembly since that time.

The rules provide for preparation of a Manual of Policies and Procedures which is adopted each season, or as changes are necessary, by affirmative vote of each legal representative of the four agencies. The rules permit application of a maximum of ½ pound of DDT per acre to control gypsy moth larvae before May 25 each season.

Representatives of The Connecticut Agricultural Experiment Station and of the State Department of Fisheries and Game have been given responsibility for inspection of areas for which applications for gypsy moth spraying are received.

The U.S.D.A. Plant Quarantine Division regulations require nurseries to be sprayed with 2 pounds of DDT per acre before certification for shipment of nursery plants (which might carry gypsy moth egg masses) into uninfested states. This higher dosage may be approved for nurseries only.

All permits for application of DDT by aircraft for any purpose prohibit spraying of pastures or forage used for dairy cattle, open waters, or fruit and vegetable crops not included in the application.

The vast majority of applications for airplane spraying for gypsy moth control have come from town governments under the provisions of Sec. 22-92 of the Statutes.

The rules state that an application must be signed by the owner of the property or crop to be treated, or by a duly constituted legal representative. When a town government acts legally to spray for the gypsy moth, the signature of a town official meets the requirements. It has been ruled that legislative bodies of towns, boroughs, and cities have such legal authority.

To Spray or Not to Spray

The present gypsy moth statute offers owners of woodlands two options: (1) they may act as individuals, each making his own decision and paying his own bill, or (2) they may act as groups inside governmental units, in which case part of the cost of spraying comes from State funds. The compilation in Table 3 shows that in about one-half of the infestations and two-thirds of the acreage the individuals in towns have decided on group action.

There has been a great deal of discussion about decisions on spraying to prevent defoliation by the gypsy moth. It seems helpful to consider the basis of the decisions to spray for control of other insect pests.

When insect control is involved, the decision to spray or not to spray is almost always made by the individual having the problem. Economists may say that the decisions are usually made on the basis of costs and benefits. In commercial agriculture and horticulture, this is a realistic criterion. Thus, the fruit grower sprays his apples, the florist his flowers, and the nurseryman his shrubs because people won't buy such products infested or damaged by insects. The potato grower sprays because he can double the yield per acre when he controls insects and disease.

The cost and benefit comparison gets a little fuzzy when it comes to lawns, flower gardens, ornamental shrubbery, shade trees, and the suburban forest of Connecticut. The suburbanite may treat his lawn to control Japanese beetle grubs or chinch bugs because he puts a greater value on the *appearance* of his lawn than on the cost of treatment. Similarly people may spray shade trees to control cankerworms because the *removal of annoyance* of dangling caterpillars is worth the cost.

The Conservation Foundation commissioned Worrell (1960), forest economist of Yale University, to consider gypsy moth spraying as a competent and unbiased observer. He compiled all of the facts available and viewed them from all angles. He did propose (Worrell, 1960) a set of criteria which started with the statement that "the total benefits of the program should exceed its total costs." He set up steps to take in determining costs and benefits, but made no attempt whatever to estimate these for gypsy moth spraying. He implied that unless costs and benefits could be determined there was serious doubt that spraying would comply with the "cost-benefit criterion of the public interest."

The problem is not the lack of information on costs and benefits (although there are serious gaps in knowledge of both), but rather the wide differences of opinion as to the values or weights of both costs and benefits. As a matter of fact, the immediate general benefits are the intangible value of green trees in June and July, and the equally intangible freedom from nuisance. These benefits are measurable only by comparison. Dollar values can be used only in isolated instances. Thus the owner of summer cottages can measure the rate of vacancies while the properties are also occupied by gypsy moths. The immediate major cost is the expense of spraying, but there is a possibility of change in fauna differing from the change when no spraying is done. This must be weighed against the possibility of a change in flora when no spraying is done.

The different values people placed on benefits and costs of gypsy moth spraying were discussed extensively at hearings of the General Assembly in 1955. Having heard these, the Assembly decided to provide: (1) a means of learning in advance of serious outbreaks, and (2) assistance for those people who wanted to act as groups rather than as individuals.

The gypsy moth is indifferent to man-made laws. As these laws and procedures have so far been executed, it is clear that sprayed areas have not become devoid of wildlife, nor have unsprayed areas become treeless wasteland. The gypsy moth is a nuisance: how serious a nuisance is for citizens to decide.

APPENDIX

There have been many requests for more complete documentation of (1) the effects of spraying on animals other than the gypsy moth, and (2) the probable effects both of spraying and of allowing infestations to go their way on the trees in woodlands. There is a very large amount of scientific literature on the first point and relatively little on the second.

Spraying and Other Insects

The effects of DDT spraying on the insect fauna of a woodland were studied by Brues (1947). He collected insects from a woodland sprayed June 2, 1945, with DDT at the rate of 1.46 pounds per acre, and two comparable unsprayed woodlands about 5 miles from the sprayed area. Collections were started at the time of spraying and continued until September 19.

It is difficult to summarize the results of this study in a few words. Brues remarked on the unexpected abundance and variety of insects in the sprayed plots. Aside from reductions in numbers of some beetles, there were more insects in the sprayed areas. Furthermore, the *proportion* of parasites and predators was at least as high in sprayed as in unsprayed woodlands.

Brues' (1947) summary bears quoting:

> Many other comparisons of a minor nature might be drawn, but the data presented show quite clearly that the single spraying of the woodland at Athol caused little really significant change in the composition of the insect fauna.
>
> Greater abundance of insects in general in the sprayed plot is, however, very obvious and deserves a careful inquiry as to the factors involved. At the time the spraying was done, on June 2, the trees and other vegetation were in excellent condition. Although very numerous, the small gypsy moth caterpillars had as yet caused an entirely negligible amount of damage, and the woodland was in the normally healthy state that prevailed in years gone by, before the gypsy moth invasion.
>
> With the practically complete destruction of these caterpillars, the main damage to foliage during the remainder of the summer was averted and the plot remained in a normally healthy condition. Thus, there was an abundance of vegetation with normal shade and moisture in contrast to the consequent parched conditions which prevail in a woodland suffering a heavy infestation of gypsy moth. Herein appears to lie the explanation of the greater abundance of the native insect fauna which requires food, shelter and moisture to maintain itself at the normal level. In other words, with the gypsy moth population removed, the native fauna was able to return to at least an approximation of its original complexion. There can be no doubt that the application of DDT caused considerable damage to other insects present in the treated plot. This was evident by the numerous specimens which succumbed immediately and fell into the trays that had been set out just before spraying. Nevertheless it is evident that this mortality was far less in the aggregate than that produced by the conditions resulting from a heavy infestation of gypsy moth like that which prevailed in surrounding territory.
>
> It would appear, therefore, that a single spraying of DDT of the strength used in the Athol woodland, applied at this time when the

larvae are still at an early stage of their growth is sufficient to eradicate them almost completely without causing any significant change in the general insect fauna. This was certainly true throughout the course of the summer, and no further consequences could be expected to develop at a later date.

Dowden (1961) has studied the abundance of gypsy moth parasites on Cape Cod. A very large spraying operation was done there in 1949, and additional sprays applied in areas where gypsy moth persisted in 1950, 1951, 1955, and 1956. In spite of all this spraying, most of the parasites introduced earlier were recovered in 1960. The remarkable fact was that the parasites were able to find sufficient host insects to persist under these conditions.

The biology of the parasites in relation to the time of spraying suggests an answer. The egg parasites are inside gypsy moth eggs, and do not emerge for about a month after the time of spraying. The larval parasites are still hibernating, either in the bodies of last year's host or in the ground.

DDT is very toxic to honey bees. In the field it is much less hazardous than arsenate of lead. The few losses that have occurred were the result of dusting such honey plants as alfalfa in full bloom, according to Brown (1951). Sprays are much less hazardous, and spraying of woodlands with DDT up to 5 pounds per acre has caused no mortality of bees in the neighborhood.

Two cases reported as DDT poisoning of bees in Connecticut have been investigated. In both the bees contained relatively large amounts of arsenic and no DDT.

Spraying and Wildlife

The general subject of pesticides and wildlife has been discussed by Rudd and Gennelly (1956). Much of the information in their summary has no bearing whatever on gypsy moth control, because the materials have not been used or even proposed for gypsy moth control. A great deal of the information on DDT is also not applicable, because it was carried out with amounts far in excess of the 1 pound to the acre dosage used for gypsy moth. As a matter of fact, many of the experiments used with these larger amounts of DDT were the result of a deliberate attempt to determine the toxic level, because no measurable effects occurred at the 1-pound dosage.

Mammals. Mackie (1949) applied DDT directly to mice, bats, chipmunks, beavers, shrews, and squirrels. It took high concentrations to kill these animals. DDT taken internally with both vegetable and animal matter did not affect the mammals. A field test at 6 pounds per acre killed no mammals.

Cottam and Higgins (1946) sprayed 117 acres in the Patuxent Research Refuge with 2 pounds of DDT per acre to determine the effect on mammals. In an unsprayed area, deer mice totalled 27 at the time of spraying and 17 after the time of spraying. In the sprayed area mice decreased from 40 to 30. In the unsprayed area shrews decreased from 14 to 8, in the sprayed area from 23 to 6. They concluded that differences in the mouse populations were not significant, and in shrews of doubtful significance.

Hoffman and Linduska (1949) reported that the critical dosage for many mammals is near the 5 pound per acre level. They also reported that racoons migrated from areas in which crayfish were killed, after eating the dead crayfish, without being affected.

Birds. Mitchell (1946) sprayed 34 nests of 11 species containing eggs, and 38 nests of 12 species containing young with DDT at the rate of 5 pounds per acre. There was no detrimental effect on hatching or survival of nestlings. Hoffman and Linduska (1949) tried similar types of tests with similar results. They concluded that birds must consume the DDT for it to harm them.

Spiers (1949) quoted Kindleigh as finding that 1 pound of DDT sprayed on forest has a negligible effect on birds. Spiers tested 3 and 4 pounds per acre on plots in Canada, and 2 pounds per acre per application for a total of 10 pounds in 19 days. Unsprayed plots had 78 territories (restricted areas taken over by nesting birds) before the time of spraying, and 77 afterwards. On the 3-pound plots comparable censuses were 75 and 67, and on the 4-pound area 88 and 90. They concluded that these sprays had no measurable effect. The repeated sprayings with the total of 10 pounds of DDT per acre reduced the bird population drastically.

Hotchkiss and Pough (1946) studied the effects on 1 pound of DDT applied June 9th for control of gypsy moth in Pennsylvania. They reported that three pairs of red-eyed vireos and "three or four pairs" of warblers "disappeared" from the sprayed area, and "one or two pairs" of song sparrows came in after spraying. The unsprayed area had 2.7 and 2.4 pairs per acre at the same time, but the decrease was not attributed to spraying.

Stewart and others (1946) used 2 pounds of DDT per acre in tests on the Patuxent Research Refuge on June 5, 1945. Censuses were started in May and continued to determine the fate of the nestlings. Results were as follows:

Treatment	*Number of birds* Before	After	*Per cent fledged*
Sprayed	117	156	52
Sprayed	150	142	52
Unsprayed	93	84	61.5

In following individual species, the redstart was the only one affected by this spray. Stewart's Tables 2 and 3 (in Stewart, 1946) do not agree, but since the conclusions were obviously based on Table 3, it is accepted as correct. They drew the conclusion that the 2-pound rate "had little or no effect on the bird population with the possible exception of the redstart."

Mitchell and others (1953) studied the effects of 3 pounds per acre in June on wrens. This heavy dose reduced the number of adults by an average of 10 per cent, and the percentage of first brood fledged in 1949 (but not in 1950). Tests in 1949 were made on June 14 and in 1950 on June 6. On the basis of this study, they suggested spraying before the second week in May in Maryland forests.

(This is the source of the requirement of the State Department of Fisheries and Game that gypsy moth spraying in Connecticut be completed by May 25 (the equivalent date as far as wren nesting is concerned)).

George and Mitchell (1947) fed larvae of the spruce budworm sprayed with DDT at 1 pound per acre to nestlings. There was no evidence of poisoning when less than half the diet was composed of treated larvae. One-fifth of the nestlings died when the entire diet was treated larvae.

Hope (1949) was able to kill birds only by repeated feeding with insects treated with unspecified amounts of DDT.

Rudd and Gennelly (1956) stated that insectivorous birds "regularly leave an area" treated with 1 pound of DDT per acre. Hayden (1959) recorded in his study in Connecticut that some species seem to migrate to the edges of plots after spraying.

The effects of occasional spraying of woodland at the rate of 1 pound per acre of DDT must not be confused with the hazard of more frequent spraying at much higher dosages. In control of elm bark beetles which transmit Dutch elm disease, the annual treatments deposit several times as much DDT per acre as gypsy moth woodland sprays. Dutch elm disease sprays are usually repeated annually, and after a few years any earthworms under the elms may be contaminated with DDT. These present a hazard to birds.

Amphibia and Reptiles. Logier (1949) killed 25 per cent of the test frogs, and 45 per cent of the toads, by feeding them insects contaminated by crawling on 10 per cent DDT spray. A snake was killed by feeding it the poisoned frogs. Langford (1949) reported that unspecified amounts of DDT were poisonous to six species of frogs and two species of snakes. The animals were killed both by direct application and by eating poisonous food.

Data on forest spraying are not very extensive. Logier (1949) reports 66 per cent mortality of frogs from direct spraying of a creek with an unspecified dosage. Both Logier (1949) and Langford (1949) predicted a 50 per cent kill of amphibia and reptiles from spraying forests.

On the other hand, Hoffman and Linduska (1949) reported small numbers of water snakes, frogs, and salamanders after spraying 52,000 acres of woodlands with DDT at 1 pound per acre. Dosages of 2 and 3 pounds of DDT per acre did kill both amphibia and reptiles. In a test in Maryland, frogs and toads placed in open-topped cages were not harmed by 2 pounds per acre.

Fish. DDT is highly toxic to fish. The literature contains numerous references to extensive death of fish from direct spraying of ponds and streams with dosages from 0.2 to 2 or 3 pounds per acre. There are also numerous instances of spraying woodlands with 1 pound of DDT per acre without mortality to fish. For instance, Surber (1946) found that fish were killed in some streams but not in others.

The work of Hoffman and Linduska (1949) showed that young fish were more susceptible than older ones, and warm-water fish killed more easily than game fish. When they fed fish with insects sprayed at the rate of 1 pound of DDT per acre, results were erratic. "Some were killed after devouring relatively few sprayed insects, others gorged themselves without adverse effect; a few exhibited DDT tremors but recovered later . . . well-fed fish survived in large numbers although they were fasted after a three-day feeding on DDT sprayed insects."

In woodland spraying, the closeness of the canopy, and the size and volume of the stream affected the results.

Hoffman and Linduska (1949) and many others have discussed the effects of death of aquatic insects on the survival of fish. In Connecticut, Hitchcock (1960) reported on the reduction of fish-food organisms. In the type of spraying which he studied, he concluded that the loss was not sufficient to cause serious concern.

Rudd and Gennelly (1956) have described the death of trout when a 100-mile segment of the Yellowstone River was sprayed in one season. In Canada spraying one-third of the Miramichi River watershed caused similar mortality of salmon. The cause has been given as an unusually complete kill of fish-food organisms. It seems probable that this type of problem is associated with spraying of large areas.

Wright (1960) has studied the effects of four successive years of spraying spruce budworm in New Brunswick on reproduction of woodcocks. Reproduction was reduced drastically in the sprayed areas. The birds contained heptachlor, which had not been used in Canadian woodlands.

Rudd and Gennelly devote some sixteen pages and four tables to effects of DDT on wildlife. They summarize the extensive literature and make some judgments about hazards. Their summaries dealing with spraying forests are as follows:

"In general, it would seem that 0.1 pound per acre as used in mosquito control and 1.0 pound per acre as used in forest insect control (see preceding category) are relatively safe levels from the standpoint of fish" (p. 73). (The word relatively is obviously operative, because their examples include some "incidents" of far greater impact than anything that has occurred in Connecticut.)

"At customary rates of application, DDT does not seem to be too harmful to amphibians and reptiles. They are usually not seriously affected by a dosage rate of 1 pound or less per acre. An oil solvent seems more toxic than DDT" (p. 76).

"Mammals are not directly endangered by DDT at normal rates of application. Under perhaps 4 pounds per acre no mortality should occur" (p. 78).

"At 1 pound per acre, direct effects on birds, either young or adults, are negligible, but indirect effects due to reduction of insect population will occur" (p. 83).

Gypsy moth spraying in Connecticut has now been done on more than 450,000 acres of woodland, most of it after 1953. The results as far as hazards to wildlife are concerned have confirmed fully the judgment of Hoffman and Linduska (1949) that the 1-pound rate is not unduly hazardous to birds and mammals, but is near the limit of safety for aquatic animals. Direct spraying of a small pond in 1954 killed pumpkinseed perch. Fish or fish and amphibians have been killed by direct spraying of ponds or parts of larger bodies of water in three separate places in 1962. Trout and frogs were killed in one stream in 1961 and another in 1962. There were reports of dead birds in the 1961 area. In 1962, the evidence indicated that the cause of the death of frogs and a trout was excessive application.

There seems to be no agreement on the gravity of these losses. As

Rudd and Gennelly (1956) have said, "It is one thing to estimate the amount of wildlife lost from toxic chemicals and quite another to evaluate the importance of this loss. The importance placed on wildlife varies with the interests, experience and sensitiveness of individual people. If there is any common denominator, it is emotion. Irrespective of difference in individual attitudes, one may be sure that an emotional element is present. We recognize this and, accordingly, do not speak for anyone but ourselves" (p. 37).

Many naturalists have spoken for themselves and interpret the losses in Connecticut as evidence of the beginnings of a disaster. Many citizens professing equally deep interest in nature have said that this is a small price to pay to remove the threat of complete defoliation of trees.

The person who recognizes the common denominator of emotion, but still must decide whether or not to spray, faces an uncomfortable decision. Perhaps the only comfort in the situation is the certainty that Connecticut will not become a barren waste with no trees if spraying is not done, or devoid of wildlife if the spraying is done.

One man had to weigh the evidence and arrive at a legal decision. Judge D. J. Bruchhausen of the U.S. District Court heard the case seeking an injunction against gypsy moth spraying on Long Island in 1958. He ruled, "The plaintiffs have not sustained their claims that spraying causes any considerable loss of birds, fish, bees and insects. Only a few fish and birds were killed in the subject area. Furthermore, evidence of spraying programs throughout the country demonstrates that the fish, bird and bee loss has been inconsequential."

Residues in Woodlands

Friend and Cooke of this Station determined the amount of DDT reaching the ground from aircraft spraying in 1951. The tests were conducted in cooperation with the U.S.D.A. gypsy moth control unit, which furnished a biplane and pilot. Mr. R. D. Chisholm, Chemist of the Bureau of Entomology and Plant Quarantine, U.S.D.A., analyzed the residues.

Glass plates were placed on the ground at intervals of 50 feet on diagonals across 1000-acre areas. One was sprayed with a biplane, the other with a helicopter, both using ½ pound of DDT per acre. Results of the analyses are given in Table 3. The average deposit from the fixed-wing biplane was .11 pound per acre, with a range of .01 to .24 pound under trees, and .06 to .21 pound per acre in the open. Deposit from the helicopter averaged .32 pound per acre, with a range of .04 to .41 pound under trees, and .28 and 2.8 pounds per acre in the open.

Deposit exceeded the half pound per acre at one point in 25 under the airplane, and at two points under the helicopter. The three points were in the open. Two of the three showed deposits such as would be expected from overlapping of swaths. The small size of the deposit at 18 of the 25 stations under the airplane (.1 pound or less per acre) was one reason for suggesting a dosage of 1 pound per acre for practical control.

These data agree with the estimates of other workers. Cottam and Higgins (1946) estimated that DDT reached streams in woodlands at about one-fourth the rate of application. Hoffman and Linduska (1949) thought that the maximum amount was one-third. Woodwell (1961) estimated that one-fourth of the amount applied reached the litter on the forest floor.

Table 4. DDT deposits, 1951 spray area

Distance from wood edge	East side Airplane spray		West side Helicopter spray	
	Location	DDT Lbs./Acre	Location	DDT Lbs./Acre
150 feet	Open	0.71	Open	0.44
200 feet	Under oak	0.14	Under juniper	0.23
250 feet	Open	0.21	Under cedar	0.41
300 feet	Under cedar	0.06	Under apple	0.19
350 feet	Under hemlock	0.06	Under ash	0.23
400 feet	Under oak	0.07	Under maple	0.12
450 feet	Open	0.14	Under hickory	0.10
500 feet	Under hemlock	0.05	Under maple	0.13
550 feet	Open	0.07	Open	0.28
600 feet	Under maple	0.09	Under maple	0.07
650 feet	Under cedar	0.04	Under hickory	0.13
700 feet	Under oak	0.04	Open	2.80
750 feet	Under oak	0.08	Under hemlock	0.06
800 feet	Open	0.07	Under chestnut oak	0.26
850 feet	Open	0.07	Open	0.70
900 feet	Under oak	0.05	Under B. Birch	0.10
950 feet	Open	0.17	Under G. Birch	0.36
1000 feet	Under oak	0.24	Under hickory	0.36
1050 feet	Under oak	0.06	Under ash	0.04
1100 feet	Open	0.06	Under ash	0.04
1150 feet	Under oak	0.01	Under elm	0.11
1200 feet	Under oak	0.03	Under R. Oak	0.29
1250 feet	Open	0.17	Under R. Oak	0.15
1300 feet	Under oak	0.10	Under W. Oak	0.14
1350 feet	Under hemlock	0.04	Under cedar	0.21
	Av.	0.11	Av.	0.32

The "disappearance" of DDT begins as soon as the spray is deposited. Kirk (1952) has studied in detail the "loss" of DDT from potato foliage:

Conditions	*Per cent loss in 72 hours*
Exposed to sun and wind	91.5
Exposed to sun	85.5
In shade and wind	70.0
In shade, no wind	63.4

The loss was largely independent of wind. Only about 6 per cent of the deposit could have been "blown" from the leaves. Kirk attributed the loss to decomposition in light and a small amount of evaporation.

DDT is not soluble in water, but rain does wash it from foliage. Irrigation 1 to 3 days after spraying removed an average of 38.6 per cent of the deposit. This usually stays in the litter.

Kirk (1952) also studied the fate of residues in different layers of the soil. There was almost no movement down as a result of weathering. Moreover, 31 per cent of the DDT mixed in the upper inch of soil "disappeared."

Woodwell (1961) studied the persistence of DDT in litter and soil of spruce forests. These had received a 1-pound spray in 1952, and ½ pound a year annually from 1953 to 1958 inclusive (a total of 4 pounds per acre). Deposit in both litter and soil was only .46 lb. per acre, or 11 per cent of the amount applied. Woodwell also determined the amount of pp' DDT, which is the isomer toxic to insects and other animals (Brown, 1951). There was only .16 pound per acre, mostly in the litter, or 3 per cent of the total pp' DDT applied.

These experiments indicate that residues from occasional spraying for controlling gypsy moth are very far from permanent. There seems to be no information whatever on the effects of residues of this small size on animal occupants of litter or soil.

DDT is insoluble in water. In gypsy moth spraying, it is dissolved in oil which also does not mix with water. Any of the spray which reaches streams either by direct spraying or being "washed" from foliage by rain first floats on the surface. In turbulent water, there is some mechanical mixing. In either case, the oil and DDT are usually deposited on organic matter and plants on the margins, and on the mud on the bottom.

The amount of DDT in water is usually very small. Even when the amount was sufficient to kill fish, chemists seldom can find more than a trace of DDT. A sample from an "oil slick" at the edge of a pool in 1962 had 1.4 part per million of DDT.

The small amount of DDT residues reaching ponds and streams persists much longer than residues on foliage and in litter. The submerged residue is not decomposed by light, and evaporation occurs only in the air.

The studies of Hitchcock (1960) indicated that whatever residue remains from normal applications has very little effect on aquatic insects, as evidenced by the repopulation of susceptible species in the years following spraying.

Investigations of the U.S. Public Health Service reported by Nicholson (1961) at the Miami E.S.A. meeting indicated that no DDT occurred in the *water* of rivers running through farms treated heavily with DDT to control cotton insects. Other studies have found DDT in the soil eroded from farms using DDT.

Effects of Spraying

There is no question that spraying with DDT has prevented defoliation by gypsy moth in heavily-infested woodlands. There is also no question that spraying has been so effective that it is not required again for some years, although it can never achieve total eradication.

On the basis of the number of flights made, and the known mortality of wildlife, the probability of death of birds is not greater than one in 3,333. The probability of death of aquatic animals (such as fish, frogs, and reptiles) is about one in 555.

Effects of Not Spraying

There is a segment of opinion that the gypsy moth problem can be "solved" by not spraying. The argument goes that the pest will gradually eliminate the susceptible plants, leaving a resistant woodland. Ovington (See Waggoner and Ovington, 1962) has expressed the view that the use of natural outbreaks to reduce the percentage of susceptible trees is of doubtful practical value. Bess (1961) has reported that infestations on Cape Cod continued for several decades.

On the other hand, Baker (1941) reported the "loss" of large numbers of plots because of death of gray birch and aspen, caused in part by defoliation. Bess, Spurr, and Littlefield (1947) state that although "moderately heavy infestations may create more resistant forest types by reducing the favored food in the stand, frequent severe defoliation will generally create conditions highly favorable to future epidemics. The stand will be opened up, the litter will dry out and forest succession will be set back. This is particularly true in regions where the forest cover consists predominantly of favored food plants growing on poor soils. For instance, frequent heavy defoliation has undoubtedly been a factor, along with fire and over-cutting, in the continuance of the epidemic status of the gypsy moth in southeastern Massachusetts."

Collins (1961) has found that gypsy moth defoliation in Connecticut in 1957 resulted in increased growth by suppressed red maple.

The heavily-infested oak woodlands in Connecticut represent a climax type of forest. The percentage of oaks is more likely to remain high or increase than to decrease. Station study plots started in Middlesex County 35 years ago have shown a steady increase in percentage of oaks. This area has not been "disturbed" in these 35 years, but its susceptibility to insect infestation continues to increase.

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