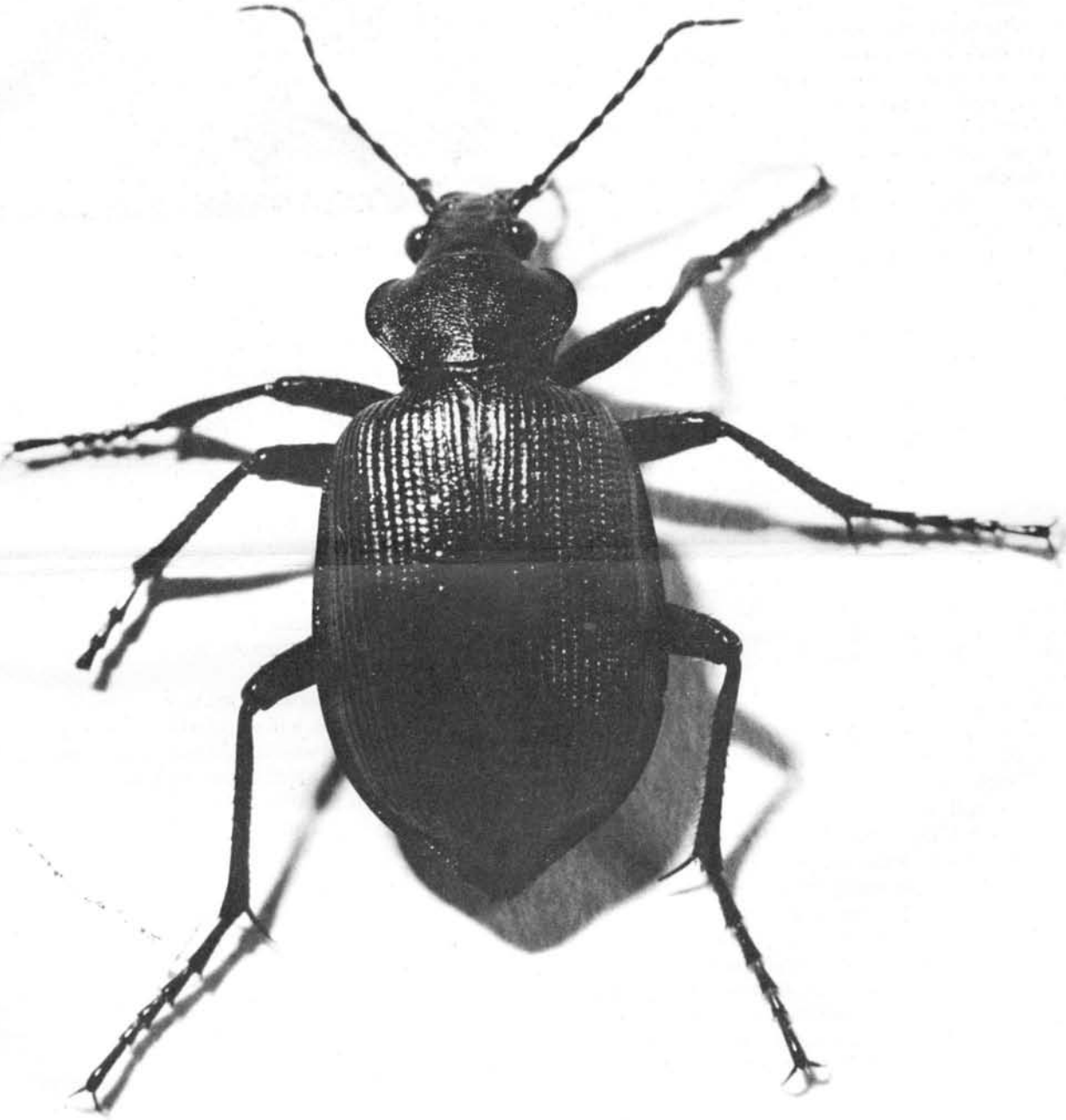
FRONTIERS
OF PLANT SCIENCE

FALL 1986



Caterpillar hunter beetle. See page 2

THE CONNECTICUT AGRICULTURAL EXPERIMENT STATION NEW HAVEN

Biological control of gypsy moths: help from a beetle

By Ronald M. Weseloh

Despite a microbial spray *(Bacillus thuringiensis*, also known as *Bt)* and chemicals, nothing yet can prevent gypsy moth populations from periodically exploding and causing severe defoliation. Because the gypsy moth was accidentally released in New England without the natural enemies which attack it in Europe, a large effort was made early in this century to import and release its natural enemies. Twelve, ranging from parasitic flies to a virus disease, have become established and attack gypsy moths in Connecticut. If they work, natural enemies are an ideal control because they are cheap and usually specific and harmless to other organisms, even if the pest becomes scarce. When natural enemies don't work, we may learn how to help them become more effective controls.

One natural enemy of the gypsy moth is a ¾ to 1 inch long, irridescent beetle known as *Calosoma sycophanta*, or more commonly, the caterpillar hunter beetle (cover). It was originally introduced from Europe to Massachusetts in 1905-1910, and from Massachusetts to Connecticut in 1914, nine years after the gypsy moth reached our state. Where gypsy moths are abundant in June, the beetles run over the ground and up trees or fly from tree to tree in search of caterpillars, which they eagerly devour. When food is unlimited the abdomens of females swell, and in late June they begin to lay oval, white eggs about ⅛ inch long in the soil. Egg-laying females are ravenous predators — each one consuming over 15 caterpillars per day for the 2-3 weeks while they lay about 100 eggs. After egg laying is complete, adult beetles burrow into the soil to pass the winter.

During late June and early July the eggs hatch in 3-4 days, producing grub-like larvae (Fig. 1), which are about ¼ inch long and black. The larvae burrow through the soil and climb tree trunks, looking for gypsy moths, which at this time are in the pupal stage. Using their sharp, sickle-shaped jaws, beetle larvae attack and eat pupae many times larger than themselves. By eating almost constantly, the larvae grow to a length of 1½ inches in just a few weeks. They then burrow into the soil where they construct an oval chamber about 1 inch in diameter and complete their development. In about a week they change into pupae, and about 2 weeks later, into adults, which stay in their chambers until the next June when the cycle starts again.

Many scientists have been impressed by the activities of *Calosoma* during gypsy moth outbreaks. Although several have suggested the beetle may be important in causing gypsy moth populations to decline, the beetle is seldom evident during the first year of an outbreak. It usually becomes conspicuous only in the second or third year. No one knows why this happens. Some have suggested that the adult beetle stays in hibernation in years when gypsy moths are not abundant, only coming out when its favorite prey is plentiful. If this is true, each adult would have to live considerably longer than the 3-4 years they are known to live because outbreaks typically occur less frequently than that. After such a long rest, surviving females might need a year of feeding before they can reproduce. Or perhaps only a few beetles survive and must increase in numbers during the first outbreak year to become abundant enough to be noticed in following years. It's also possible that adults fly from one outbreak to another, in which case outbreaks near old outbreaks would have the greatest chances of being found.

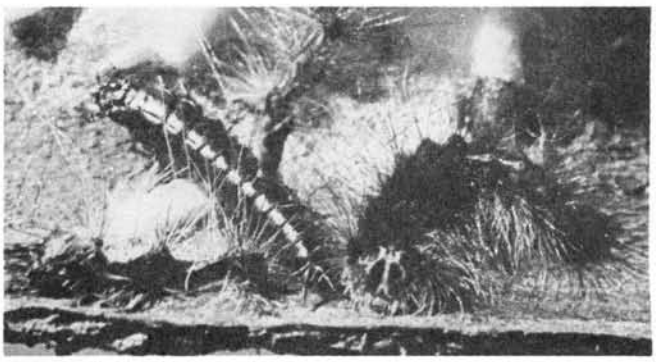


Fig. 1. Larva of *Calosoma sycophanta*.

Improving *Calosoma's* impact on the gypsy moth during an outbreak will depend on learning how adult beetles behave between outbreaks. For instance, if beetles are already present, it may be possible to stimulate them to become active before they ordinarily would be. Or if beetles fly into an area, it might be possible to attract them artificially. The needed information can be found by learning about the population sizes, survival rates, and rates of emigration of beetles before and during gypsy moth outbreaks.

I began by sampling two forested sites: one near Stafford Springs and one in Chester. At both sites I started when gypsy moth populations were high and *Calosoma* was abundant. I sampled adult beetles using traps, which consisted of a 2-inch band of clear plastic sheet placed around a tree trunk and a waxed paper cup directly beneath a hole in the plastic big enough for beetles to pass through. Beetles climbing trees in search of caterpillars encounter the band, which they cannot cross because the plastic is too slippery, are guided through the hole, and fall into the cup. Beetles can neither climb nor fly out because they can't take off vertically. I put 100 traps on 100 trees, each about 60

feet apart in a 10 by 10 grid over 10 acres at each site. Two or three times a week during June, trapped beetles were marked by punching small holes through their wing covers (Fig. 2) before releasing them. By varying the number and location of holes, over 15,000 beetles can be marked differently. The pattern of recapture reveals how abundant the beetles are, how well they survive, and how fast they move in and out of the plots in response to changes in gypsy moth numbers.

In the first year there were about 100 adult beetles and at least 100,000 caterpillars per acre at both sites. In Stafford, female beetles were about as abundant as males, but were only about half as likely as males to move away from the plot. In Chester, males were about three times as abundant as females, but males and females were equally likely to move away. Many beetle larvae were produced at both sites.

I could measure the impact of larvae because they feed mainly on gypsy moth pupae and leave characteristic marks, in the form of large, ragged holes, in the pupal skins. These marks are distinct from those left by other natural enemies. The impact of *Calosoma* larvae varied, depending on where the pupae were. On the trunks of trees within about 6 feet of the ground, where gypsy moth pupae are numerous, about 70% were killed by immature beetles. At 40 feet the number of pupae killed diminished to 35%. On small twigs and leaves only about 30% were killed. I estimated that 40% of all pupae were destroyed by beetle larvae, and that each female produced about 30 offspring. Thus, although gypsy moths were 1000 times as abundant as adult beetles, enough larvae were produced to destroy many of the pests.

The activities of *Calosoma* larvae helped cause declines of gypsy moth populations in both Stafford and Chester, but they were not totally responsible for these declines. Other gypsy moth natural enemies were also involved. At Stafford, parasitic flies destroyed about 40% of gypsy moth pupae on small twigs and leaves, locations where *Calosoma* larvae are not abundant. In Chester, even though beetle larvae were as important as at Stafford, parasitic flies killed less than 2% of pupae on twigs and leaves. The differences in the activities of these other natural enemies were probably responsible for the much lower gypsy moth populations which occurred later at Stafford as compared to Chester. However, without the very large contribution by *Calosoma*, it is unlikely that decreases would have occurred at either site. The impact of other natural enemies was not large enough without the beetle.

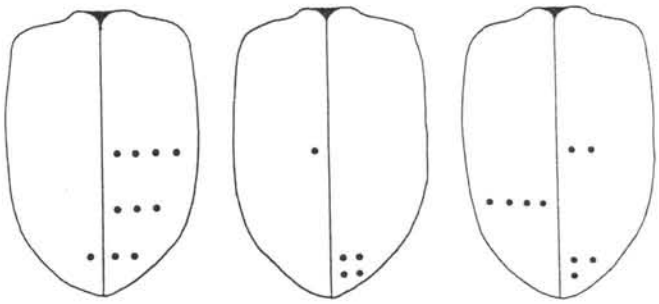


Fig. 2. Example of hole patterns in wing covers used to mark beetles. The markings at the left are 100432, in the center are 001004, and at the right 040203. Each beetle is numbered according to the number of holes in each of six areas, starting clockwise at the bottom left.

The next year, differences in gypsy moth populations at the two sites apparently had large effects on the beetle. In Stafford, where gypsy moths were scarce, adult beetles were abundant but inactive, and almost no larvae were produced. Thus, beetles apparently remain in an area after an outbreak rather than fly away. In Chester, where gypsy moths were moderately abundant, beetle adults were numerous and active at first. Then, throughout most of June, I captured few adults, perhaps because of cool, wet weather or more likely because the beetles hibernated because prey were lacking.

Beetles are not common at either site now. I am continuing to monitor both areas to see how *Calosoma* responds when outbreaks occur again. By following the populations as they declined, I have learned that a few adult beetles can produce enough larvae to have a large impact on gypsy moths; and adult beetles seem to stay in an area when gypsy moths decrease in abundance. Thus, if relatively few beetles were released as a biological control agent, they would probably remain in the same area, and, if gypsy moths were numerous, destroy many pests.

Why does a volatile pesticide, like EDB, persist in soils for years?

By Brij L. Sawhney

Ethylene dibromide (EDB) has been used as a soil fumigant since 1948. Its use was banned in 1983 because it was found to be a potential carcinogen. Recently, EDB has been found in domestic wells in Connecticut many years after it was used in nearby fields to control soil pests. Because EDB is both volatile (that is, it evaporates readily) and biodegradable, it should dissipate or degrade long before it reaches ground water. Its pres-

ence in ground water wells as long as 20 years after it was used, thus, presents a paradox.

To understand this paradox, Drs. Joseph J. Pignatello, Spencer M. Steinberg and I analyzed soils that had been previously fumigated to learn if EDB is still present in these soils, and if so, could it continue to leach to ground water? These investigations have implications not only for soil-applied pesticides, but also for other chemicals such as solvents from spills and dump sites, inadvertently introduced into soil.

We collected surface soil samples from a field in the Warehouse Point section of East Windsor where tobacco had been grown for a number of years and was last fumigated in 1983; a field in the Broad Brook section of East Windsor where tobacco was grown until 1973 when it was last fumigated; and an experimental plot at the Lockwood Farm of The Connecticut Agricultural Experiment Station in Hamden, which was fumigated only once in 1985 for another experiment. The soils were air-dried and passed through a 2 mm sieve.

Table 1 shows the residual EDB in the surface 8 inches of these soils.

Table 1. Concentrations of EDB in the fumigated soils.

Soil	Date last fumigated	EDB concentration (parts per billion)
Broad Brook	1973	20-42
Lockwood Farm	1985	130
Warehouse Point	1983	125

Concentrations of EDB in the Broad Brook soil were determined in five separate samples from the same field while those in the Lockwood Farm and Warehouse Point soils were determined in composite samples. The concentrations in the Broad Brook soil varied more than two-fold. Although the Broad Brook and the Warehouse Point soils were probably fumigated many times, the amounts and frequency of EDB applied are not known. The data in Table 1 show no apparent relationship between the time of last fumigation and the amounts of residual EDB retained by the soils. Preliminary results in another study show that EDB is still present in a former tobacco farm soil in Simsbury that was last fumigated in 1967. A number of domestic wells in this area have been found contaminated with EDB.

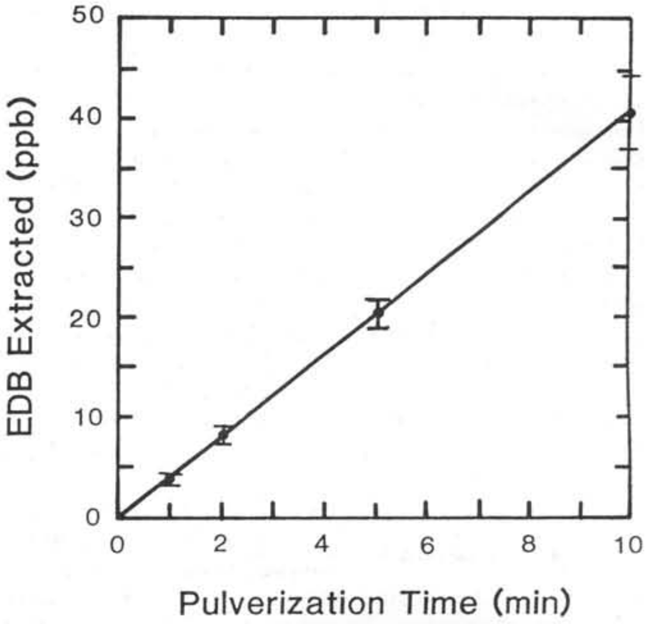
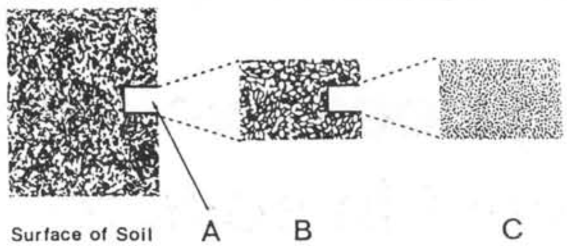


Fig. 1. Release of EDB as affected by pulverization that breaks up soil aggregates and facilitates removal of EDB from micropore surfaces.

To learn how EDB is retained in the fumigated soils, we tried to remove EDB from the fumigated soils using both physical methods and biological degradation. The physical treatments used were: washing it from soil with five consecutive washings with water, suspending the soil in water for up to 10 days, and purging it from dry soil with a stream of air. These laboratory treat-

How is EDB retained by soils?

When a soil is fumigated with a pesticide, such as EDB, the pesticide spreads through the surface soil, killing the pests and dissipating into the atmosphere. A small portion of the pesticide is, however, retained by the soil. As it diffuses through the soil, a fraction is adsorbed on the surfaces of large aggregates (A) in the soil column, another fraction is adsorbed on the surfaces of particles in (B) within the aggregates (A) and some on yet smaller particles (C) which make up an individual particle in (B). Because the pores surrounding these particles are extremely small, the adsorbed EDB does not readily diffuse into the soil water to be leached by rainfall nor can the soil microbes readily enter these sites to degrade the EDB.



ments should be more effective in removing EDB than either leaching by rainfall or evaporation from the compacted soil in the field because the laboratory treatments were performed under conditions designed to increase its removal. Biological degradation involved incubating the soil for up to 38 days to facilitate microbial decompositon. We found that only a small fraction of the residual EDB was removed by any of these treatments. For example, in the Lockwood soil, less than 2% of the EDB was removed by five washings, only 5% was released into the soil suspension in 10 days, and about 8% was removed after purging the soil for 3.5 days. Similarly, very little EDB was degraded by soil microbes in 38 days. In contrast, EDB freshly added to soil suspensions in the laboratory was quickly removed by the physical methods and was degraded by soil microbes in about 10 days.

These observations led us to hypothesize that the residual EDB in the fumigated soils is adsorbed on surfaces of extremely small particles within the soil aggregates. These aggregates can vary from several millimeters to many centimeters in diameter and include hundreds of small particles (see box), creating extremely small pores. The release of EDB from these surfaces and its subsequent leaching by the percolating water are extremely slow because EDB must diffuse through the long and tortuous paths among the micropores surrounding the small particles before reaching the water surrounding the aggregates.

To test this hypothesis, we pulverized air-dried samples from the fumigated soils in a ball mill and extracted the EDB with water. Such a treatment should break up the soil aggregates into small particles and expose the surfaces facing the micropores.

The results in Fig. 1 show that as the pulverization time increased, the amount of EDB extracted also increased. For example, pulverization for 1 minute released less than 3%, while pulverization for 10 minutes released over 30% of the residual EDB in the Warehouse Point soil. Apparently, the tightly held EDB in the soil surrounding the micropores is the explanation for the paradox that EDB, despite its volatility and biodegradability, is detected in ground water long after its application to the soil. Because EDB on these soil particles is neither leached by rainfall nor readily degraded by soil microbes it can persist in the soil for a long period and its slow release provides a source of continued ground water contamination.

Importing ladybird beetles to control red pine scale

By Mark S. McClure

The red pine scale, *Matsucoccus resinosae* Bean and Godwin, is a destructive introduced pest of red pine, *Pinus resinosa* Aiton. My studies have shown that this scale insect, which is probably native to Japan, injures and kills red pines within 2 to 10 years, that no red pines are resistant, and that no predators that inhabit pine forests in Connecticut can control the scale. In Japan, however, the scale seldom becomes abundant enough to injure native pines. Therefore, I went to Japan from April through September 1984 to learn why red pine scale behaves differently in the two countries. I studied its natural history and sought predators that could be imported into Connecticut for natural control.

I found predators on scale-infested pines at 30 locations on the islands of Honshu and Kyushu. A minute pirate bug, a gall midge, and two lacewings occurred in every infested stand, but these killed less than 10% of the scales. The most abundant and important predator I found was the colorful ladybird beetle, *Harmonia axyridis* Pallas. The adult beetles, which have a variety of color patterns (Fig. 1), disperse readily among crops and forests in pursuit of aphids and scales. I observed adult beetles invading a stand of Chinese pine that was heavily infested with the scale and killing over 97% of the scales in less than 4 weeks.

In another heavily infested stand of Chinese pine in Kamigamo Forest of Kyoto University I appraised the ability of *H. axyridis* to control various stages of the scale. I caged either 0, 10 or 20 beetle larvae for 3 weeks during the spring when most scales were cysts, adults

Table 1. Percent mortality of *M. resinosae* and *H. axyridis* in cages containing different numbers of beetles when scales were either exposed or concealed on pine branches.

Stages of the scale	Number of beetles per cage	Japan		United States	
		% predation of scales	% cannibalism of beetles	% predation of scales	% cannibalism of beetles
Conspicuous (eggs, cysts, adults)	10	89	64	81	68
	20	94	85	91	82
Inconspicuous (first instar nymphs)	10	73	84	18	74
	20	81	92	29	92

and eggs (developmental stages that are visible on pine branches) and for 3 weeks during early summer when scales were first instar nymphs (a stage that hides under the bark). These densities of beetles are typical. After each 3-week experiment I removed the cages and counted how many scales and beetles survived.

Beetles killed the most scales (94%) when there were 20 beetles per cage and when the scale was visible (Table 1). The beetle was least effective (killing 73% of the scales) when there were 10 larvae per cage and when the scales were hidden (Table 1). In cages that contained no beetles the scale thrived.

Unfortunately beetle larvae were almost as likely to eat beetles (64% cannibalism) as scales both in the uncaged natural population at Kamigamo and in the cages (Table 1). Cannibalism was heaviest in cages containing 20 beetles and when scales were hidden (Table 1). A common obstacle in biological control is finding an alternate host for the predator when the primary host is scarce. In this case, the cannibalistic nature of the beetle ensures the survival of at least some beetles when the scale is scarce or inaccessible.

Despite its cannibalistic nature and its ineffectiveness against hidden scales, the success of the beetle as a predator of the scale in Japan indicated a potential for control of red pine scale in Connecticut. To obtain enough beetles for introduction into Connecticut, I collected hundreds of adults. These were shipped to the USDA Beneficial Insect Research Laboratory, a quarantine facility in Newark, DE, where they were tested to ensure they presented no hazard to humans, beneficial insects or plants. Because the beetle feeds only on aphids, scales and other pest insects, I can experiment with them in Connecticut.

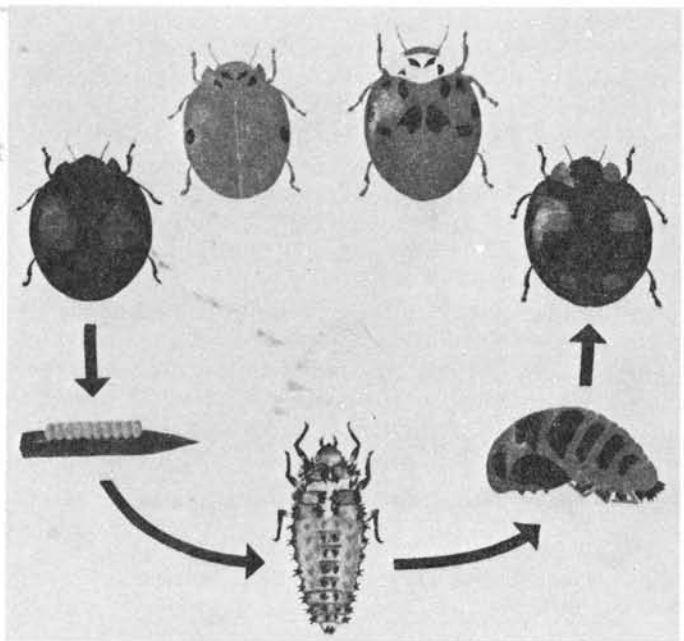


Fig. 1. Life cycle of the Asian ladybird beetle, *Harmonia axyridis*. Counterclockwise from lower left are: eggs, larva, pupa, and adults of four different color patterns (illustration by P.M. Trzcinski).

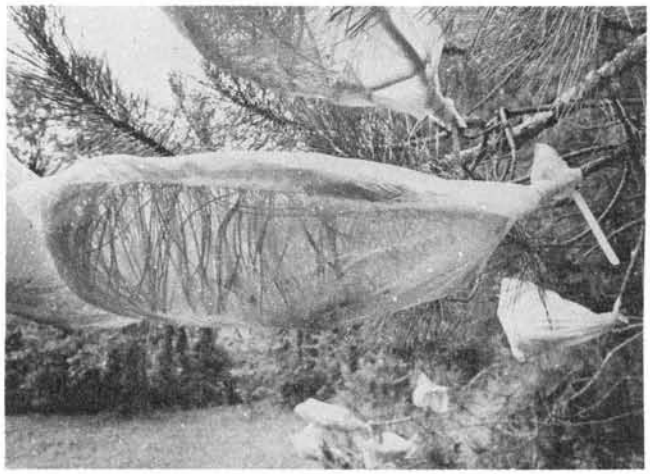


Fig. 2. Scale infested pines with cages containing different numbers of predatory beetles used in control experiments.

To grow larvae and adults of the beetle in the laboratory, they are reared at 27° C (80° F) with 16 hours of light on pea aphids, *Acrythosiphon pisum* (Harris), living on fava beans. These summer-like conditions cause the beetles to develop from egg to adult (Fig. 1) in only 3 weeks. During the fourth week females begin laying 16 eggs per day for about 7 weeks. With several generations each year, and with each adult usually producing more than 700 offspring, the beetle population can multiply rapidly.

Using beetles reared in this manner, I conducted a study similar to the one in Japan in a plantation of red pine at the Experiment Station's Lockwood Farm in Hamden. I caged infested branches (Fig. 2) with 0, 10 or 20 beetle larvae for 3 weeks when the scales were visible and for 3 weeks when they were hidden. The beetles killed up to 92% of the visible stages of the scale but less than 30% of the hidden ones (Table 1). One reason the beetles are less effective in Connecticut than in Japan is that the textured bark of red pine provides better hiding places for scale nymphs than the smooth bark of Asian pines. As in Japan, at least two out of every three beetles were cannibalized (Table 1).

During the spring and summer, I released thousands of beetles, including hundreds of adults marked with a drop of blue or yellow paint on the right forewing. I examined the pines for released beetles and their offspring for several weeks after each release. All of the adult beetles had left the plantation 2 weeks after release. Several adults laid eggs prior to their departure, and their offspring fed upon the scale in the plantation and matured within a month.

To learn if the beetle could survive winters in Connecticut, I placed adults in screen cages in the pine plantation and in an adjacent hardwood forest in October. The cages contained a stack of cored bricks (with holes) and leaf and needle litter to simulate natural overwintering sites. At least 20% of the beetles survived temperatures below -18° C (0° F) on several days. This is encouraging because beetles in the cages were less

protected from weather than they would be in natural overwintering sites.

Producing the hundreds of beetles needed for these studies was a formidable challenge. Because each beetle eats thousands of aphids before completing its development and reproducing, maintaining a balance between numbers of fava bean plants, pea aphids, and beetles is crucial. To minimize cannibalism, beetles must also be reared in small groups comprised of individuals of about the same size. The aphids must also be protected from ants, flies and wasps that can quickly decimate an aphid population in culture.

Despite the obstacles, my studies are encouraging. The ladybird beetle *Harmonia axyridis* attacks the scale and survives winter in Connecticut. Its success as a biological control depends, however, upon its ability to find and exploit alternate prey, such as aphids, to sustain it when red pine scale is inaccessible or unavailable. I will continue to search for these beetles from Japan to learn if my releases have established them here.

Gypsy moth outbreaks in Connecticut in the 1980's

By John F. Anderson

Experiment Station personnel record the location and intensity of defoliation in all 169 towns in the state each year after gypsy moth caterpillars stop feeding in late June. Accompanying a pilot in a plane flying at an altitude of about 1500 feet, two people observe and record defoliation on topographic survey maps with a scale of 1:24,000. Acreages of defoliation are calculated from the topographic maps. These data document duration of outbreaks, provide information on patterns of dispersal of caterpillars, enable Station scientists to relate outbreaks to tree mortality, and serve as a partial guide in forecasting outbreaks.

Numbers of gypsy moths in this decade reached their zenith in 1981. They declined rapidly to their low in 1984, but are again resurging (Table 1). Caterpillars from outbreaks in southeastern New York State drifted into Connecticut in the late 1970's and supplemented existing populations here. In 1980, defoliation totalled 381,868 acres in 131 towns. Although occurring in all eight counties, defoliation was most extensive in our four western counties. The following year, 1981, the outbreak had extended into all but three towns, with caterpillars consuming leaves on 1,482,216 acres of woodland. Populations began declining in 1982, particularly in western Connecticut.

In 1982 a total of 803,802 acres was infested in 97 towns. Outbreaks were primarily in the counties of Windham, Tolland and New London in 1983 when 369,267 acres were affected. In 1984, fifteen towns were infested slightly: defoliation was recorded on 7,782 acres, and none was severe. In 1985 and 1986, gypsy moths resurged in eastern Connecticut on 153,621 and 268,242 acres, respectively.

This year's infestation, 1986, was mainly in New London, Windham and Tolland counties where 94% of the defoliation occurred (Table 2, Fig. 1). Caterpillars were extremely dense in many areas and caused severe defoliation (<75%) on 71% of the infested woodlands. Eleven towns had more than half their total acreage affected. Sterling and Voluntown each had more than 90% of their area noticeably defoliated.

The number of consecutive years of defoliation recorded in a given town is usually three or less, although outbreaks in southeastern Connecticut have lasted longer. For example, in the 1960's and 1970's, Ledyard, North Stonington, and Preston experienced six or more consecutive years of defoliation. Similarly, in the 1980's, these three towns had one or more areas with noticeable defoliation each year since 1981. The

Table 1. Acreage noticeably defoliated by the gypsy moth in Connecticut, 1935-1986.

Year	Acres	Year	Acres
1935	67	1961	15,800
1936	0	1962	83,300
1937	0	1963	40,140
1938	1,131	1964*	93,552
1939	1,759	1965*	86,009
1940	0	1966*	15,895
1941	0	1967	2,731
1942	0	1968	16,416
1943	0	1969*	52,635
1944	14	1970*	425,039
1945	16	1971*	654,102
1946	496	1972	508,460
1947	0	1973	333,215
1948	0	1974	120,980
1949*	0	1975	63,411
1950	475	1976	9,809
1951*	200	1977	0
1952*	1,500	1978	3,835
1953*	20,000	1979	8,619
1954*	14,000	1980	381,868
1955*	6,842	1981	1,482,216
1956*	3,458	1982*	803,802
1957*	4,800	1983	369,267
1958	117	1984	7,782
1959	6,000	1985*	153,621
1960	20,000	1986*	268,242

*An additional 1000 or more acres of forested land were treated with insecticide.

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reasons for lingering gypsy moth populations in southeastern Connecticut are unknown.

Bacillus thuringiensis (Bt), which has been shown by Station scientists to be effective against gypsy moth infestations, is the only insecticide that may be applied to woodlands by plane or helicopter. In 1982, 1984, and 1986, Station personnel provided technical assistance in Ledyard when more than 1000 acres were treated. In all three years, suburban woodlands were sprayed twice within a 3-week period beginning about mid-May. Since *Bt* is effective against small caterpillars only, it usually must be applied before the first week of June when many caterpillars are in their fourth stage of growth. The treatments in Ledyard protected the foliage and reduced the nuisance of the caterpillars.

In 1987, we expect gypsy moths to reach outbreak levels again in eastern Connecticut. Female moths have deposited eggs in many communities east of the Connecticut River. Next spring, sufficient caterpillars to cause noticeable defoliation in some areas will likely hatch from these eggs. Specific forecasts for individual towns can be made, however, only after fall or winter surveys for gypsy moth eggs are completed. We do not anticipate outbreaks in western or most central portions of the state because dense populations of gypsy moth are absent there and in nearby sections of New York State. Since outbreaks have tended to follow a northeasterly path, the direction of prevailing winds, it is unlikely the infestation in eastern Connecticut will significantly influence densities of caterpillars in western Connecticut, although it may affect the adjacent areas of Rhode Island.

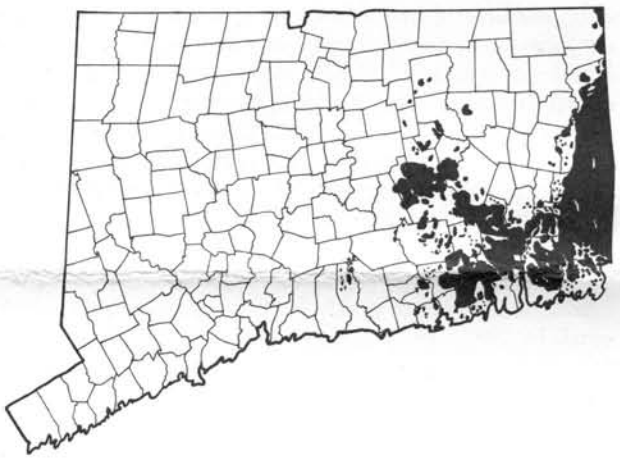

Fig. 1. The areas of Connecticut that were defoliated ten percent or more during 1986.

Table 2. Intensity of defoliation in Connecticut counties, 1986.

County	Acres/Percent Defoliation 10-25	26-50	51-75	76-100	Total defoliation	County acreage	Percent of county acreage defoliated
Fairfield	0	0	0	0	0	422,031	0
New Haven	156	351	117	78	702	399,016	<1
Middlesex	4524	1326	1209	1560	8619	248,028	3
New London	16614	14313	14274	139,191	184,392	448,576	41
Litchfield	0	0	0	0	0	607,168	0
Hartford	1677	1326	975	3822	7800	480,128	2
Tolland	3861	3783	1716	6201	15,561	268,848	6
Windham	4173	4875	2886	39,234	51,168	332,740	15
Total	31005	25974	21177	190,086	268,242	3,206,535	

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