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Weather can cause problems for plants
Testing mosquitoes for eastern equine encephalitis virus
Ladybugs are killing hemlock woolly adelgids

THE CONNECTICUT AGRICULTURAL EXPERIMENT STATION, founded in 1875, is the first experiment station in America. It is chartered by the General Assembly as an independent State agency governed by a Board of Control. Station scientists make inquiries and experiments regarding plants and their pests, insects, soil and water quality, food safety, and perform analyses for State agencies. Factual information relating to the environment and agriculture is provided freely and objectively to all. The laboratories of the Station are in New Haven and Windsor; its Lockwood Farm is in Hamden. Copies of this and other publications are available upon request to Publications; Box 1106; New Haven, Connecticut 06504

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Summer drought and winter temperatures can cause problems for woody ornamentals

By Sharon M. Douglas

At least half the problems on woody plants diagnosed by the Plant Disease Information Office in recent years have been caused by the weather. This has been reflected by the stories in our local newspapers with headlines such as:

We needed it! Heavy downpour a relief

Shadow of death hangs over stressed-out trees

Warm February is a tie with record set in 1954

Some of the unusual weather extremes include drought, record breaking snowfall and cold, and a warm winter with extreme temperature fluctuations and lack of snow cover. Singly and in combination, these weather factors have caused significant stress and damage to woody ornamentals in Connecticut.

WINTER INJURY

Woody ornamentals have been injured by late spring frosts (spring 1996 and 1997), cool summers followed by warm autumns and sudden drops in temperature (winter 1996-1997), excessive temperature fluctuations (winter 1996-1997), abnormally cold winter temperatures (winter 1995-1996), and drying winds and lack of snow cover (winter 1996-1997).

Accurate diagnosis of winter injury is difficult because symptoms are not evident until weeks or months *after* the injury has occurred. For example, winter damage to the cambium of a flowering cherry may not be evident until early summer when branches suddenly collapse and die.

Symptoms of winter injury can vary. Common symptoms include tip and branch dieback, foliar browning, sunscald, and bark splitting. Excessive drying is also common on evergreens. It occurs when water evaporates from leaves or needles on windy or warm sunny days during the winter or early spring. This water is not replaced since the roots cannot take up water from cold or frozen soil. On broadleaved evergreens (e.g., rhododendron and mountain laurel), the most familiar foliar symptoms are marginal browning and longitudinal rolling along the mid-vein. Needled evergreens (e.g., hemlock, arborvitae, pine, and juniper) exhibit slightly different symptoms which appear as browning of the tips of needles, needle drop, and tip and twig dieback. Entire branches or shrubs can be affected in some cases.

On deciduous trees and shrubs, bark may be injured by cold weather. Cracks and dead areas appear and bark begins to peel from the trunk as the tree grows in spring and summer. This damage is common on trees with thin bark such as crabapples, flowering cherries and almonds, and maples. Periods of extremely cold and unusually warm winter temperatures also damage flower and leaf buds. As a result, injured deciduous trees and shrubs may not flower or leaf out properly in the spring.

Cold temperatures can also cause lethal or sub-lethal damage to cambial tissues of branches and twigs. This injury causes branches to suddenly wilt or begin to die back by early to mid-summer. In these situations, injured vascular tissues cannot keep up with the water demands associated with active growth and branches collapse.

Winter injury also predisposes plants to secondary or opportunistic pests. Among these secondary problems have been unusually high incidences of branch and twig diebacks caused by *Botryosphaeria* sp. and *Phomopsis* sp. Although these fungi are normally not considered aggressive pathogens, they have been associated with substantial damage on cherry, crabapple, willow, arborvitae, and rhododendron.

DROUGHT

The 1997 growing season was dry in most regions of Connecticut. Records at Lockwood Farm in Hamden indicated a rainfall deficit of 6.79 inches (compared with the 30-year average) at the end of July. This followed 1995, which had the worst drought in 30 years and the driest summer since 1944.

Drought or dry soil results in damage and death of the roots. The root system of a woody ornamental has four types of roots: 1) framework roots consisting of primary and secondary woody roots, 2) transport and storage roots, 3) non-woody feeder roots, and 4) root hairs. Almost 99% of this root mass is in the top three feet of the soil. The feeder roots and root hairs, which are in the top 12 inches of the soil, are responsible for uptake of water and nutrients. Unfortunately, they are the first portion of the root system to be affected by drought since they are very sensitive to drying. When feeder roots and root hairs become non-functional, a water deficit develops because these roots can no longer provide sufficient water to the top of the plant.

In addition to direct damage to the root system, drought triggers metabolic changes. Among these are changes in hormone levels and other physiological factors (e.g., factors that influence the number of leaves that will emerge the next year or that are responsible for the closing of stomates).

Symptoms of drought vary with the plant species and the severity of the water deficit. These include loss of turgor in needles and leaves, drooping, wilting, yellowing, premature leaf or needle drop, bark cracks, and twig and branch dieback. Leaves on deciduous trees often develop marginal scorch and interveinal necrosis whereas needles on evergreens turn brown. Drought-stressed trees and shrubs can also exhibit general thinning of the canopy, poor growth, and stunting. In extreme cases, drought can result in plant death.

As with winter injury, symptoms of drought are often not evident in the top of the tree or shrub until long after the event has occurred; *even as much as one to two years later!* For example, in 1996, many trees showed branch and twig dieback which had been caused by the drought of 1995.

Drought also weakens and predisposes plants to secondary invaders and opportunistic pests. For example, Verticillium wilt has been particularly severe on drought-stressed Japanese maples. Other diseases such as Rhizosphaera needlecast of spruce and Diplodia tip blight of pine have caused notably more damage to weakened when compared to vigorous plants. Drought-stressed ornamentals also show increased sensitivity to de-icing salts, air pollutants, and pesticides.

Although landscape trees and shrubs often exhibit symptoms of drought and severe water stress, plants growing naturally in wood lots or forested areas are only affected by *unusually* severe drought. Planting practices are frequently key sources of this problem since we often plant in unfavorable sites, don't prepare the rootball properly, plant too deep or too shallow, or mulch so thickly that water doesn't penetrate into the soil.

Seedlings and new transplants are particularly sensitive to drought because their roots occupy the uppermost layers of soil where the most rapid drying occurs. Recent transplants also lose many important feeder roots during the process. For example, balled and burlapped trees are estimated to contain only 5-20% of their original root mass after digging. The medium in which the transplant is growing can also be important for container-grown ornamentals. Many of the soilless mixes used in containers are highly porous and subsequently dry out very quickly and are very difficult to re-wet. Since it often takes woody transplants 2 years to become completely established in a new site, they should be given extra care and attention during periods of drought.

Established trees and shrubs are also affected by drought, especially in marginal sites such as those with pavement over roots, street trees, and those in pockets of soil on ledges or in sandy soils. When stressed by drought, trees which were improperly planted quickly decline and often die. Drought has been particularly damaging to established Japanese maples, dogwoods, elms, white pines, and hemlocks.

The unusual weather extremes that I have highlighted have certainly taken their toll on many of the woody ornamentals in our landscape. However, if you have trees, shrubs, or plants with problems and you are uncertain as to the cause, The Plant Disease Information Office of the Experiment Station can assist with diagnosis and with outlining strategies to help minimize the problem.

STRATEGIES FOR MANAGING WEATHER-RELATED STRESS

Although the weather can't be controlled and there are no "cures" once the damage is done, there are steps that can minimize the effects of winter injury and drought. These include:

- Selection of the appropriate site and following good planting practices since stress can magnify even the most subtle improper planting practices; inspection of the root system for general health and determining the location of the root collar before planting to ensure planting at the proper depth
- Maintenance of optimum growth by using proper growing practices
- Watering during periods of low soil moisture; trees and shrubs require approximately one inch of water per week; this is best applied at one time as a slow, deep soaking to a depth of approximately 12-18 inches; deep soaking just before the ground freezes in the fall; mulching to increase moisture retention during the winter
- Avoidance of late summer and early fall fertilization which stimulates and encourages growth late in the season which may not harden-off properly for the winter
- Pruning and removal of dead twigs or branches which can serve as sites for secondary invaders or opportunistic pests
- Physically protecting plants from water loss and drying winds which is especially important for new transplants or plants in exposed locations; burlap wraps and sprays of anti-transpirants can be used
- Use of native plants or plants matched to the site; for example, avoid planting broadleaved evergreens in open, windy locations where they would be subjected to drying winter winds or avoid planting drought-sensitive species such as dogwoods, some oaks, or hemlocks in sites where sandy or gravely soils present problems during drought

Experiment Station studying mosquitoes and eastern equine encephalitis

By Theodore G. Andreadis

Eastern equine encephalitis (EEE) is a very rare but serious disease. It is caused by a virus (*Alphavirus*) and is transmitted by the bite of infected mosquitoes. The virus is normally found in wild song birds that inhabit certain fresh water swamps (red maple/white cedar) where it is maintained in a natural enzootic transmission cycle involving the mosquito, *Culiseta melanura* (Fig. 2). This mosquito does not bite humans, and the virus does not usually cause disease in wild birds.

Although many important details of the transmission cycle are poorly understood, human and domestic animal cases seem to occur when populations of *Culiseta melanura* mosquitoes and viral infection in wild birds increase to the point where the virus is transported out of the swamp via infected mosquitoes and/or birds. Other mosquito species with broader feeding preferences (*Aedes* species and *Coquilletidia perturbans*) may then acquire EEE by feeding on these infected birds and subsequently transmit the virus to humans, horses or other hosts the next time they feed (epidemic cycle) (Fig. 2). Humans and horses may develop clinical illness but are "dead-end" hosts because they do not produce significant virus in the blood (viremia), and thus do not contribute to the transmission cycle.

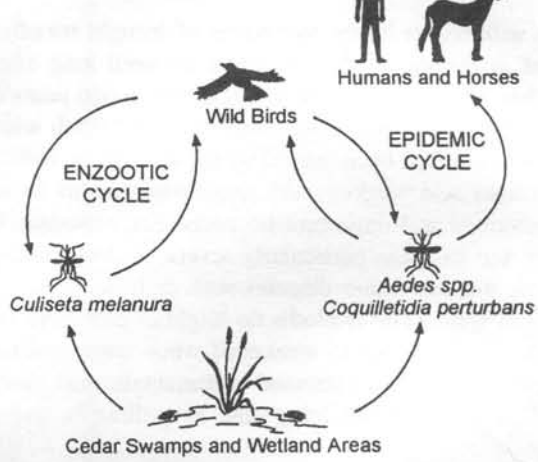

Figure 2. Natural transmission cycle of eastern equine encephalitis.

Figure 1. Theodore G. Andreadis in mosquito identification laboratory.

Human infections with EEE typically involve the central nervous system, and symptoms usually appear within 2 to 10 days after being bitten by an infected mosquito. These symptoms begin with a sudden onset of fever, general muscle pain, and a headache of increasing severity. The disease may progress to more severe symptoms including seizures and coma. Approximately half of all people with clinical symptoms will die from EEE, and, of those who recover, most will suffer permanent brain damage. Children and the elderly seem to show a higher level of susceptibility to EEE, but inapparent systemic infections may also occur. In addition to humans, EEE can produce a fatal disease in horses and many exotic birds such as pheasants, quail, ostriches, and emus. There is no treatment for the disease, but an effective vaccine is available for horses.

HISTORY OF EEE IN CONNECTICUT

Outbreaks of EEE have occurred irregularly in Connecticut since 1938. The majority of these outbreaks have been reported from the eastern portion of the state during late summer and early fall (August-October). Cases of EEE have been limited to horses and domestic pheasants, and unlike Massachusetts, New York and Rhode Island, no human cases have ever been documented in Connecticut. Most locations where EEE has occurred typically have been in close proximity to freshwater swamps or in swamp-forest border locations. There has been no discernible periodicity, but EEE activity in Connecticut historically has coincided with major outbreaks in humans and horses in southeastern Massachusetts and Rhode Island. The most recent outbreak involving animals occurred in 1990-91 and affected horses in Canterbury, Haddam, Salem, and Waterford.

EMERGENCY SURVEILLANCE IN 1996

In late August and early September, 1996, Rhode Island officials reported the finding of an unusually large number of EEE-infected mosquitoes in several areas in the town of Westerly. In response to this finding, The Experiment Station initiated an emergency mosquito trapping and EEE virus testing program in adjacent areas of southeastern Connecticut. Our objectives were to: (1) determine if there were EEE-infected mosquitoes in Connecticut and if there were, (2) how widespread and abundant they were, and most importantly, (3) did they represent a threat to humans and horses in the area. Dr. John Anderson coordinated the trapping effort in the field, I identified the mosquitoes in the laboratory, and the virus testing was done at the Yale Arbovirus Research Laboratory by Shirley Tirrell-Peck. Mosquito trapping began on September 5 and was continued through October 18. Mosquitoes were collected with CO_2-baited CDC light traps from 80 different locations in 20 towns. These included mixed hardwood swamps, isolated wood lots in residential areas, and coastal salt marshes in: Chester, Clinton, East Lyme, Groton, Guilford, Ledyard, Lyme, Madison, Montville, New London, North Stonington, Norwich, Old Lyme, Old Saybrook, Preston, Stratford, Stonington, Voluntown, Waterford, and Westbrook. Over the course of 6 weeks we trapped, identified and tested 6,440 mosquitoes. We collected 16 species of mosquitoes, and eight of these were found to be infected with EEE (Table 1). These included two human-biting saltmarsh mosquitoes (*Aedes cantator* and *Aedes sollicitans)* and four human-biting fresh water mosquitoes (*Aedes trivittatus, Aedes vexans, Coquillettidia perturbans* and *Culex pipiens)*. EEE was found in six different locations in Stonington (including Barn Island, the Pawcatuck region, and behind the Vine Street and Stonington High Schools); three locations in North Stonington; and on Great Island in Old Lyme. The first EEE isolation was made on September 8 and the last on September 28. These findings were unprecedented and represented the largest number of EEE isolations ever recovered from field-collected mosquitoes in Connecticut. Furthermore, this was the first finding of EEE in salt marsh mosquitoes in the state.

These events were followed closely by the public and the media. As a result of our findings, school schedules were altered (start 1 hour late, no recess or after school activities), an extensive horse vaccination program was initiated, Barn Island was closed to the public, and both ground and aerial spraying was ordered by Governor John Rowland. The operation was coordinated by the Department of Environmental Protection. About 15,000 acres were sprayed aerially in Stonington, North Stonington and Old Lyme, and over 500 miles were treated with truck mounted sprayers. As a result of these efforts and those of the Department of Public Health, the risk to the public was reduced, and fortunately, no human or horse cases were reported. Two emu deaths were reported from a farm less than 2 miles from a collection site in North Stonington where we recovered EEE from three different species of mosquitoes.

THE 1997 EEE TESTING PROGRAM

The events of 1996 prompted Connecticut to develop and implement its first comprehensive mosquito management and EEE testing program. The program involves The Connecticut Agricultural Experiment Station, the Department of Environmental Protection and the Department of Public Health. It is a health-based program that focuses on preventive efforts and mosquito monitoring for early detection of EEE. The program is funded through 1998.

The Experiment Station plays a major role in this program and is responsible for trapping and identifying mosquitoes and testing them for EEE. During April and May we surveyed the state and selected 37 permanent locations to trap mosquitoes (Fig. 3). These included: (1) locations where EEE-infected mosquitoes were found in 1996, (2) locations where recent EEE-related horse deaths have occurred and, (3) red maple/white cedar swamps that support vector mosquito populations.

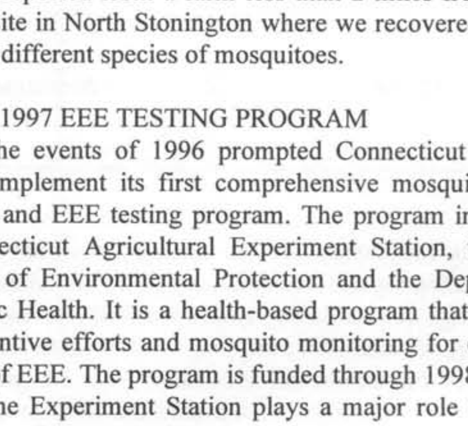

Figure 3. Locations of the 1997 mosquito trapping sites.

Trapping was conducted from June 9 through October 16, and traps were set once every 10 days at each location. John Shepard assisted in the coordination of the mosquito trapping in the field and the identification of mosquitoes in the laboratory. The virus testing was done at the Yale Arbovirus Research Laboratory. A total of 44,556 mosquitoes (25 species) were collected, identified and tested for EEE (Table 1). Unlike 1996, very little EEE activity was

Table 1. EEE isolations from mosquitoes in Connecticut 1996-1997.

Year	No. Tested	EEE isolations	Location	Mosquito
1996	6,440	36	Stonington (28)	*Culiseta melanura* (19)
			North Stonington (7)	*Culex pipiens* (8)
			Old Lyme	*Culiseta morsitans* (3)
				Aedes sollicitans (2)
				Aedes cantator
				Aedes trivittatus
				Aedes vexans
				Coquillettidia perturbans
1997	44,556	2	Stonington	*Culiseta melanura*
				Culiseta morsitans

detected. Only two isolations were obtained, but both came from bird-feeding mosquitoes that were collected behind the Stonington High School on September 9 and 29. In response to this finding, we intensified trapping in this region and the Department of Environmental Protection issued a precautionary warning for people in the affected area to avoid mosquito bites with personal protective measures. No further EEE isolations were made from either bird or human-biting mosquitoes that were collected in our additional traps, and pesticide spraying was not needed.

In late October, we were notified of the death of three emu due to EEE. These highly susceptible birds were penned at the Waterford Country School in Quaker Hill and were afflicted from September 27 to October 1. This location was approximately 6.3 miles north of our trap site in Great Neck. We found a large swamp adjacent to the school where we intend to trap mosquitoes during 1998. We also visited Deep Hollow Emu Farm in Oakdale, which was only 3 miles from the school. We were informed by William Utz that none of his birds had shown any symptoms of EEE. These observations reinforce the highly focal nature of EEE, which can be limited to mosquitoes and birds in a single swamp, and demonstrate our need for continued trapping and testing of mosquitoes in high risk areas.

Released Japanese ladybugs are multiplying and killing hemlock woolly adelgids

by Mark S. McClure and Carole A. S-J. Cheah

A tiny ladybird beetle, also known as a ladybug, has been imported from Japan by Station scientists to help control the deadly hemlock woolly adelgid, *Adelges tsugae.* The adelgid, which is also native to Japan, is an aphid-like pest of eastern hemlock (*Tsuga canadensis*) and Carolina hemlock (*T. caroliniana*) in the eastern United States. In Connecticut it was first observed in Middlebury and New Haven in 1985; it now occurs in all towns except Canaan, Colebrook, Goshen, Norfolk, North Canaan, Stafford, Torrington, Willington, and Winchester. Fortunately, hemlocks in nurseries and in most ornamental landscapes can be protected from the adelgid by using various cultural and chemical control practices (to learn how, write for a free copy of Station Bulletin 925 to: Publications, Box 1106, New Haven, CT 06504). Unfortunately the adelgid has been uncontrolled in forests and in heavily wooded ornamental landscapes because native predators are ineffective and trees cannot be treated thoroughly with chemical pesticides. The ladybug, however, discovered in 1992 in Japan by Dr. McClure and subsequently named *Pseudoscymnus tsugae,* has shown great potential for biological control, a process whereby natural enemies control pest numbers.

The importation of any living organism into the United States must be approved by the USDA, Animal and Plant Health Inspection Service (APHIS). Approval requires submission of a report which details all known information on the organism, its potential impact on the environment, and the risks and benefits of its release. Ladybugs are predators

Figure 1. Mark McClure, left, and Carole Cheah, right, in the Experiment Station's beetle-rearing facility.

of numerous insect pests including scales and aphids; few ladybugs are harmful. Furthermore, our studies with *P. tsugae* determined that this ladybug is highly specific to adelgids, all of which are considered pests, and that releasing the beetle would have no adverse impact on the environment. On the basis of our research and reports to APHIS, we received permission to receive shipments of *P. tsugae* from Japan and to release it in Connecticut.

Since 1994 we have been rearing *P. tsugae* at our Windsor laboratory. From a starting population of less than 50 adult beetles, we now have reared more than 55,000 adult ladybugs for studies on its biology and for field experiments.

We have released nearly 50,000 adult ladybugs in hemlock forests in Bloomfield, Cheshire, Hamden, New Fairfield, New Hartford, Pomfret, Washington, and Windsor, CT and in Charlottesville and Montebello, VA. Our studies are evaluating the potential of the ladybug to become established and to control hemlock woolly adelgid in the northern and southern ends of the infestation. This past spring we also provided the New Jersey Department of Agriculture with a back-up colony of *P. tsugae*.

P. tsugae is not the same ladybug that appears in large numbers on the sides of light colored houses in the fall. The ladybug with the annoying aggregating behavior is another Asian species, *Harmonia axyridis,* which is a much larger beetle, about the size of a small pea, and mainly orange in color with black spots. *P. tsugae* is only about the size of a poppy seed and is jet black (Fig. 2); fortunately it does not display the annoying aggregating behavior of *H. axyridis*. Despite its being somewhat of a nuisance at times, *H. axyridis* is undoubtedly eating huge numbers of aphids and, therefore, is a great benefit to farmers and gardeners. In fact, *H. axyridis* even attacks hemlock woolly adelgid during the spring, although the adelgid is not a preferred prey.

Any natural enemy needs to possess a number of important attributes if biological control is to be successful.

- Its life cycle must be compatible with that of the host
- It must be able to disperse in the forest
- It must be able to overwinter and survive weather conditions throughout the year and become established
- It must find mates and reproduce
- It must reduce numbers of the pest

Our studies thus far have revealed that the Japanese ladybug, *P. tsugae,* possesses many of the important qualities of a successful biological control agent.

Indeed, we have found that *P. tsugae* feeds on all life stages of its prey and that its life cycle is well synchronized with that of the adelgid. For example, both insects have two generations each year in the field. Spring egg laying by ladybugs normally coincides with peak egg laying and hatching of adelgids; furthermore a second generation of ladybugs occurs in June around the time that the second generation of adelgids does. Also, when adelgids are inactive for about 14 weeks during the summer, adult ladybugs are able to survive by feeding on dormant young adelgids. Three or more generations of *P. tsugae* can be reared each year in the laboratory under controlled temperature conditions.

To determine the dispersal ability of *P. tsugae* we hung yellow sticky traps that are attractive to both male and female adult ladybugs in a hemlock forest at various distances from our release trees. In addition we sampled hemlock branches for beetles by inspecting them or by tapping them with a stick while holding a white sheet beneath to catch the falling ladybugs. We found that adult ladybugs actively explore branches for adelgids and move off release trees to nearby ones if need be. We have been able to find some on

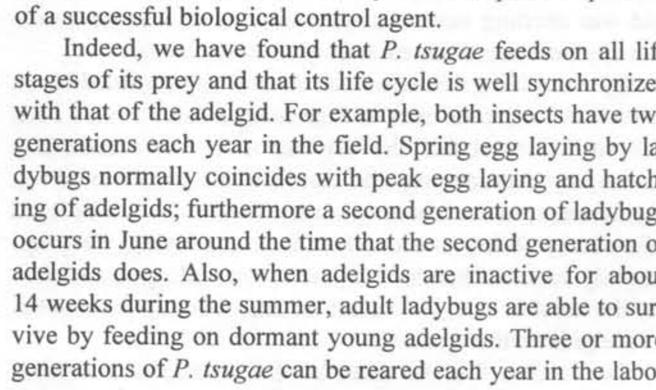

Figure 2. Adult of the Japanese ladybug, *Pseudoscymnus tsugae*, feeding on eggs of hemlock woolly adelgid.

hemlocks more than 100 meters away from release trees during the same season as release, which is no easy task considering that these ladybugs are tiny.

To investigate the cold hardiness of *P. tsugae* in Connecticut and in Virginia, we returned to release sites in April and May in hopes of finding live ladybugs. We were delighted when yellow sticky trap catches and sampling of hemlock branches in spring revealed that adult ladybugs survived the winter in 1995-1996 (an extremely cold, snowy winter) and 1996-1997 and 1997-1998 (both were mild, relatively snowless winters). Several adult ladybugs that had wintered over were observed on infested branches that had been broken by snow and had fallen from trees which suggests that ladybugs probably spend the winter in the litter on the forest floor. The ability of *P. tsugae* to survive a variety of winter conditions in both states confirmed establishment and was exciting news because doing so is a major hurdle that any introduced natural enemy must overcome.

By examining branches for several hours monthly on release and adjacent trees at each release site we have been able to document that the ladybug is in fact successfully developing, reproducing, and sustaining its population level. Furthermore, in the laboratory, adult females have displayed an uncanny ability to economize their egg laying. They apparently seek out hemlock branches with adelgids and then lay the number of eggs that can be supported by the number of adelgids on that branch.

Our studies thus far indicate that *P. tsugae* is significantly reducing adelgid numbers, not only on release trees, but also on adjacent trees. In the first experiment (Fig. 3A) we released adult ladybugs in June 1995 onto five infested hemlocks in a Windsor forest. At that time we placed some infested branches inside nylon sleeve cages to protect adelgids from the ladybugs. We left other infested branches without cages and, therefore, exposed to ladybugs. In May 1996 we compared the number of adelgids, alive and dead, on branches that were caged and not caged. Much to our delight, we found that adelgids were 88% less numerous on branches that had been exposed to ladybugs (Fig. 3A, crosshatched bar) than on caged branches (Fig. 3A, black bar), which suggests that *P. tsugae* had significantly reduced adelgid numbers. Unfortunately, the experiment could not rule out the possibility that the cages themselves, had somehow enhanced adelgid survival, for example by excluding incidental native predators or by moderating the microclimate of the branch. Therefore, we conducted a second experiment (Fig. 3B) at the Windsor site in 1996 and 1997 to determine the impact of ladybugs on adelgids without the use of exclusion cages. A new group of infested trees was selected in a different section of the hemlock forest. Adelgid egg masses present on branches prior to the release of 1,100 adult ladybugs in 1996 (Fig. 3B; black bars) and a year later in 1997 (crosshatched bars) were counted and compared. This was done for branches on which ladybugs were actually released (+) and on nearby branches without ladybugs (-). We found that 11 months after releasing ladybugs, adelgid numbers had been reduced by 87% on release branches and by 27% on nearby branches on which ladybugs had not been released. The slightly reduced numbers of adelgids from 1996 to 1997 on this latter group of branches suggests that some ladybugs may have dispersed from release branches onto these nearby ones during the course of the experiment, or that native predators may have been present on these branches.

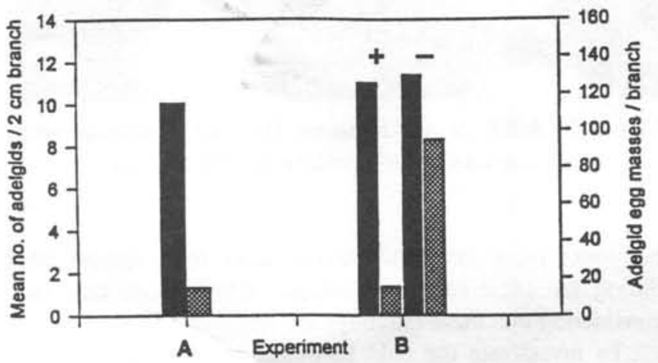

Figure 3. Ability of *P. tsugae* to reduce numbers of hemlock woolly adelgid in a Windsor forest.

Our studies during 1997 in Bloomfield, Hamden, and New Hartford, CT and in Montebello, VA were equally exciting. Comparison between areas in these hemlock forests where *P. tsugae* was released and control areas at least 500m away, revealed that adelgid densities had been reduced 47-88% in only 5 months by a starting population of only 2,400 to 3,600 adult ladybugs. These same levels of adelgid reduction were observed when branches on which ladybugs were released were compared with branches enclosed in cages to protect adelgids from ladybugs. These data confirmed the effectiveness of *P. tsugae* as a predator of hemlock woolly adelgid and dispelled previous concerns that cages themselves affect adelgid survival.

Successfully establishing *P. tsugae* in our forests may also have the added benefit of controlling other adelgids. Our preliminary studies have revealed that this ladybug also attacks and develops from egg to adult on other adelgid pests including balsam woolly adelgid, Cooley spruce gall adelgid, and pine bark adelgid. These and other alternate adelgid hosts help enhance the establishment and survival of *P. tsugae* in the conifer forests of eastern North America.

Clearly, *P. tsugae* possesses many important qualities of a successful biological control agent for hemlock woolly adelgid. However, we emphasize that additional studies are needed to substantiate that *P. tsugae is* an effective control and to justify the intensive effort that will be needed to rear enough ladybugs for release throughout the adelgid-infested area. Because the rearing of *P. tsugae* is labor intensive, it is unlikely it could be mass-reared commercially and made readily available to the public. If *P. tsugae* proves to be a successful biological control agent for hemlock woolly adelgid, we hope to release enough ladybugs to reproduce and spread from relatively few release sites throughout the entire adelgid-infested area on their own.