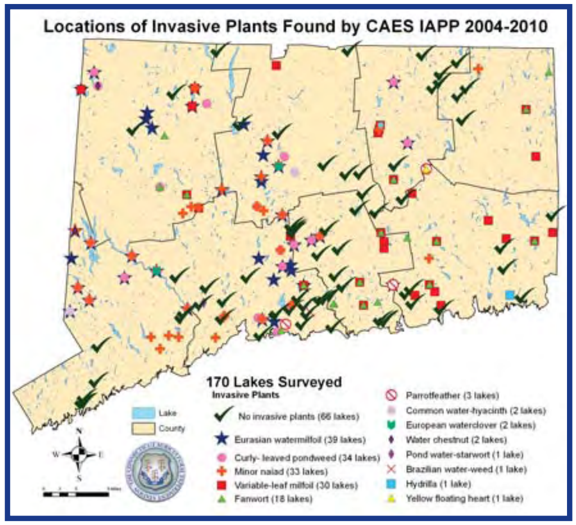
Frontiers of Plant Science

A REPORT FROM THE CONNECTICUT AGRICULTURAL EXPERIMENT STATION

IN THIS ISSUE



Locations of invasive aquatic plant species as found by CAES IAPP surveys

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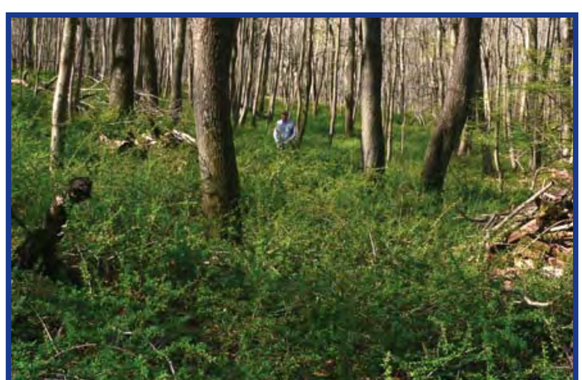

Dense stand of Japanese barberry

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Connecticut's Invasive Aquatic Plant Problem – Searching for Solutions

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Connecticut is home to more than 3,000 lakes and ponds that provide drinking water, wildlife habitat, recreational opportunities, increased real estate values and "green" energy in the form of hydroelectricity. These bodies of fresh water are among the State's most valuable natural resources. One of the greatest threats to our lakes and ponds is the invasion of non-native aquatic plants. With few natural enemies, these plants can spread rapidly and destroy native ecosystems. The Connecticut Agricultural Experiment Station Invasive Aquatic Plant Program (CAES IAPP) began surveying lakes and ponds in 2004 to determine the extent of the invasive aquatic plant problem. To date, nearly 200 surveys have been completed comprising 170 individual water bodies and many lakes that have been surveyed multiple times (Figure 1). Over 100 species of plants have been documented with 13 being classified as invasive. Approximately two-thirds of the water bodies contained one or more non-native species with some lakes and ponds containing four invasive species. Connecticut may act as the gateway for invasive aquatic species into New England because most of the species are native to warmer climates and will likely appear here before moving north in a global warming scenario. We discovered pioneer invasions of yellow floating heart (*Nymphoides peltata*) in Lebanon, Brazilian waterweed (*Egeria densa*) in Guilford, hydrilla (*Hydrilla verticillata*) in Mystic and parrot feather (*Myriophyllum aquaticum*) in Guilford, Branford and Weston. In most cases control efforts are underway. Invasive species have disrupted native ecosystems and become a severe nuisance in many water bodies. For instance, the plant population in Candlewood Lake, our largest lake, is dominated by a single invasive species called Eurasian watermilfoil (*Myriophyllum spicatum*). Our annual surveys find between 200 and 500 acres of the weed depending on the effectiveness of the previous winters water level drawdown. The milfoil grows nearly 10 feet tall, limits boating, is a hazard to swimmers and poses a threat to the downstream Rocky River hydrogenerating facility. In two other of the State's largest lakes, Lillinonah and Zoar, our surveys find nearly three quarters of the plant population consists of three invasive species; Eurasian water milfoil, minor naiad (*Najas minor*) and curly leaf pondweed (*Potamogeton crispus*). These lakes also have hydrogenerating facilities that are at risk. CAES IAPP is comparing the water chemistry where invasive species occur and these data suggest the plants have distinct preferences that can help predict which water bodies are most susceptible. For instance, Eurasian watermilfoil, minor naiad and curly leaf pondweed often occur together in water with high conductivity and alkalinity. The two other most common invasives; Cabomba (*Cabomba caroliniana*) and variable milfoil (*Myriophyllum heterophyllum*) prefer lower conductivity and alkalinity. Lake managers and government officials can improve early detection and rapid response efforts by using our water chemistry correlations to prioritize which lakes have the greatest chance of getting certain invasive species. Controlling invasive plants in aquatic ecosystems is particularly challenging because care must be taken to protect native plants and water quality must be insured. In addition, most aquatic plant control measures are very costly. CAES IAPP has ongoing experiments using mechanical, biological and chemical controls. In Lake Quonnipaug, Guilford, we have conducted yearly removal of Eurasian milfoil in the town beach area using an electric cutter (Figure 2). By timing the cutting to occur just before the beach opens people utilize the infested area and the abrasive nature of their activities prevents regrowth for the remainder of the season. In Candlewood Lake, we have introduced milfoil weevils (Figure 3) as a biological control agent for milfoil and are studying ways to improve the current system of yearly alternate shallow and deep winter drawdowns. In Grannis Lake, East Haven, we introduced grass carp in 2007 (Figure 4). These fish are known to eat aquatic vegetation but further information is needed on their effects on non-target plants. We have successfully suppressed milfoil in Bashan Lake, East Haddam and Crystal Lake in Middletown with environmentally sensitive herbicides. Although these management strategies hold promise, highly effective long-term solutions to invasive aquatic plant problems will likely require a combination of prevention and improved management options based on continued research. For more information on the CAES IAPP program visit our webpage at www.ct.gov/caes/iapp.

Figure 1 . Locations of invasive aquatic plant species as found by CAES IAPP surveys.

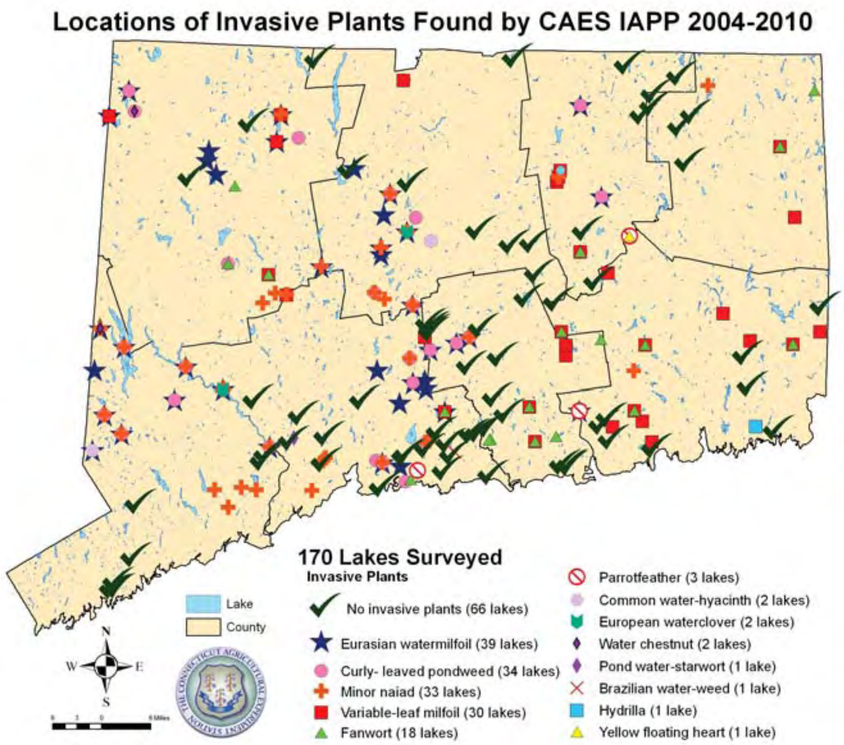

Figure 2. CAES IAPP principal investigator Greg Bugbee testing electric underwater weed cutter.

Figure 3. Dr. Michelle Marko (kneeling, right) leads the introduction of 16,000 milfoil weevils into Candlewood Lake.

Figure 4. Introducing grass carp into Grannis Lake, East Haven

Gregory J. Bugbee assistant scientist in the Department of Environmental Sciences. He is the principal investigator in the Invasive Aquatic Plant Program. He has lead aquatic plant surveys of nearly 200 Connecticut lakes and ponds and directed research projects on invasive aquatic plant control statewide. In addition to his work on nuisance aquatic plants, he oversees the Station's Soil testing laboratory.

Connecticut's Threatened Landscape: Natural Enemies for Biological Control of Invasive Species

Dr. Carole A. Cheah
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While many non-native plant, insect or diseases have been reported in our state, few have established and spread to the extent that native species are now nearly extinct as a result of these unwelcome introductions. In the absence of effective predators, parasites or disease to hold populations in check in the region of introduction, these invading species often overwhelm their hosts or other associated species and can cause widespread and serious decline and even death of their hosts, eg. chestnut blight, Dutch elm disease and gypsy moth. The use of natural enemies from the alien pest's native homeland to try to control populations of invasive non-native species is an ancient technique. Examples of biological control date back to 200 A.D. when ants were used in China to control citrus pests, while this approach became increasingly popular in the early to late 19th century in western Europe. The desired biological control agent should exhibit very narrow feeding habits that target the pest in question (host specificity) in order to avoid damaging non-target effects on other native species. However, most cases of biological control are efforts of trial and error as there are no guarantees that an introduced agent will adapt, disperse and impact its targeted host or prey species in the timeframe necessary or expected, to reduce pest populations to non-damaging levels to save native species. In some cases, the length of time that elapses before an introduced natural enemy is sufficiently adapted and subsequently effective in depressing target populations may be many years during which common opinion is that the introduction has failed. Introductions of both *Entomophaga maimaiga*, a fungus which kills the gypsy moth and *Harmonia axyridis* Pallas, the Halloween ladybeetle, a predator of aphids in orchards, were both deemed failures of biological control, initially. A tiny ladybeetle from Japan whose life cycle is closely synchronized with its target prey, an alien insect tree pest, and a prolific but specific, plant-feeding beetle from China are two examples of imported natural enemies introduced into our Connecticut landscape in the last 15 years in an effort to mitigate resulting damaging effects on our native vegetation and ecosystems. These two examples of biological control target two very different landscapes in both infestation history and habitat structure. We explore the history and current status of their introductions in this discussion.

Hemlock woolly adelgid

Our native eastern hemlock, *Tsuga canadensis* Carriere, comprises about 8% of species, and 9% of area in Connecticut forests and is a critically important ecological component of many plant and animal, terrestrial and aquatic communities. Representative of mature successional forests, hemlocks are long lived for several hundred years and invaluable for providing deep shade and thermoregulation of streams for native brook trout and rare salamanders, while providing unique habitats for many species of birds such as the Blackburnian warbler, and winter cover for other animals. It is a graceful, aesthetic and common component of our many state parks, forests, wildlife preserves and reservoir watersheds where riparian hemlock serves to maintain stream water quality and hold nitrogen and carbon reserves. In 1985, an exotic insect, the hemlock woolly adegid, *Adelges tsugae* Annand, or HWA, was discovered in Connecticut (Fig. 1). Originating from southern Japan, this insect is the starting point for this treatise of recent biological control efforts by The Connecticut Agricultural Experiment Station. Hemlock woolly adelgid was originally identified and described on the west coast by Annand in 1928 but is believed to have been accidentally introduced on the east coast in Richmond, Virginia around 1952. Recent genetic studies at Yale University have shown that the populations affecting eastern hemlock forests are identical to that from southern Honshu, Japan, confirming the first early studies on the life cycle, impact and biology of HWA at the Experiment Station. In 60 years, HWA has spread northwards into southern Maine and Vermont, expanded its range to cause widespread decline and hemlock mortality in the southern Appalachians and is now moving into western Pennsylvania. Hemlock woolly adelgid is an unusual, largely sessile insect, exhibiting a unique generation that is adapted to feeding during cool winter temperatures. Individuals are parthenogenetic (all females) in the US and, therefore, are capable of egg-laying without mating. There are two generations a year (fall-winter-spring and spring-early summer), which are typically developing and feeding on stems of branch tips from October to July in Connecticut. At high densities, adelgid feeding, particularly on new shoots, causes rapid depletion of tree reserves, suppression of new shoot production and eventual branch tip dieback (Fig. 2). The adelgid, which also feeds on another southern native species, the Carolina hemlock, quickly established and expanded its range in our state until it was present and thriving in all 169 Connecticut towns by 2000. In those 15 years, Connecticut's moisture-sensitive, shallow-rooted hemlocks, particularly in the coastal region, had already been stressed in the interim by severe droughts in 1985, 1995 and 1999, outbreaks of native pests such as the hemlock looper and hemlock borer, and further attacks by another exotic pest, the elongate hemlock scale. However, it was primarily the adelgid's prolific reproductive capacity to rapidly overwhelm compromised hemlocks, which resulted in widespread mortality of once majestic groves of hemlocks, particularly in the coastal regions, and later along the Connecticut River Valley. Warming climate patterns, particularly milder winters in the past twenty-five years have also allowed the adelgid to greatly expand its range northwards into New England as the insect, which is active in fall and winter, survived in greater numbers. The outlook was bleak for eastern hemlock and prompted the search for natural enemies from the native homeland of the adelgid, southern Japan, initiated in 1992 by the Experiment Station. A series of imported collections of natural enemies from infested Japanese hemlock in Osaka, Japan in the early 1990s to the Station resulted in the identification of a potentially important new predator of the adelgid, a hitherto unknown tiny ladybeetle, now known as *Sasajiscymnus* (formerly *Pseudoscymnus*) *tsugae* Sasaji and McClure (Fig. 3a & b).

When the first federally-approved release of the beetle was made in Connecticut in 1995 (the first in the USA), the adelgid had already had a 10-year head start advancing unchecked through Connecticut's landscape. Populations of the adelgid were at their zenith in the mid-late1990s in Connecticut, which coincided with the peak of *S. tsugae* rearing and releases by the Station in every county (Fig. 4). This mass rearing and research into the beetle's attributes occurred at the Station's Valley Laboratory in Windsor for experimental releases of > 176,000 mated, reproductive adults at optimal times into 26 state forests, parks and other threatened hemlock stands in Connecticut (Table 1). New adults are reproductive within a month of emergence and overwintered adults can live > 1 year. All stages of the ladybeetle will feed on all stages of the adelgid. It is the only introduced HWA predator capable of two field generations a year, mirroring that of its prey. *S. tsugae* does not diapause, i.e. enter into an obligate period of suspension of development and reproduction, and multiple generations can be reared relatively easily on healthy collections of HWA in the laboratory. The availability of HWA is the major limiting factor for its mass rearing. *S. tsugae* rapidly dispersed, adapted to the Connecticut climate and survived hot summers and varying winter extremes in the first 10 years of its release. The mass rearing and release methodology developed at the Station was expanded to New Jersey's beneficial insect laboratory in 1997 and thence, to other states, for a federally funded national biological control program for HWA.

While all stages from larvae, pupae to adults of *S. tsugae* could be found through intensive forest ground sampling after the year of release in 65% of Connecticut release sites from 1996-2001, highly infested and damaged sites in some marginal habitats showed initial decline and some subsequent mortality caused by secondary pests against a backdrop of severe droughts and mild winters. Bucket tree sampling of mature hemlocks in Connecticut and New Jersey has shown that the beetle is highly mobile and dispersed to upper canopies where adults and larvae have been retrieved at 5-20m. However, this method of sampling is limited, expensive and not suitable for many release sites. Although previous intensive sampling showed that the beetle had adapted to survive varying winters in the past, *S. tsugae* recovery continues to be an unfunded challenge in the complex, vertical and expansive forest landscape. But, an encouraging trend became evident recently, which signifies hope for Connecticut's hemlocks. Adelgid-damaged hemlock stands in Connecticut began to show widespread recovery in 2005, to a greater degree in stands where *S. tsugae* had been released, and after a succession of severe winter extremes in 2003 and 2004, and a brief but lethal cold spell in 2009, all of which killed a high percentage (>90%) of adelgids. More importantly, this pattern of recovery occurred even in the milder, southern coastal climatic division. Lack of severe drought events 2002-2010 (Fig. 5) and above normal precipitation and cool temperatures during the growing season have contributed greatly to hemlock growth and recovery.

Trees that had been heavily declining with loss of needles have shown an amazing resilience and ability to sprout new foliage from dormant buds under optimal environmental conditions. While the tiny ladybeetle has been challenging to recover with inadequate and simplistic beat sampling methods, which only target the accessible lower canopy, concurrent annual hemlock health assessments from 2005-2010 at release and non-release sites in Connecticut showed that eastern hemlocks perpetuated and even recovered with abundant new shoot production at the majority of release sites in comparison with non-release sites. This more optimistic scenario has largely continued to the present. The fullness of previously damaged hemlock crowns with luxuriant new growth at 75% of *S. tsugae* release sites compared to that in healthy, uninfested stands and damaged non-release stands depicts this remarkable recovery (Fig. 6).

Connecticut winters, during the tenure of HWA, have alternated between mild and unpredictably cold cycles, and have been responsible for dramatic depressions of adelgid populations in the past. The history of winters in Connecticut from 1989-2009 is shown in Fig. 7. In the first phase of the adelgid invasion, HWA levels had always rebounded after severe winters in the past, such as in 1994, 1996, and 2001, and caused subsequent hemlock decline and dieback. However, HWA populations in Connecticut's forests have not recovered to statewide damaging levels in the last 5 years, perhaps due to the resulting balance of adelgid and its natural enemy complex, including *S. tsugae*, combined with less favorable and unpredictable climatic conditions. Today, hemlock woolly adelgid is less of a major threat to our eastern hemlocks, while another exotic pest, the elongate hemlock scale, *Fiorinia externa* Ferris, stands poised, to further weaken and stress hemlocks without intervention.

Mile-a-Minute Weed

Invasive species include insects, microbes, fungi and plants. Our second example is an annual herbaceous vining weed from Asia capable of prolific seed production and rampant growth in hot sunny conditions. *Persicaria perfoliata* (L.) H. Gross (formerly *Polygonum perfoliatum* L.), more commonly known as the mile-a-minute weed (MAM), is believed to have entered Connecticut just prior to 2000 in Greenwich. In the interim, it has spread to 19 towns, primarily in the southern and western sections of the state. Its accidental introduction in contaminated nursery stock in Pennsylvania was thought to have occurred in the 1930s, and it is now firmly established as a serious and problematic weed threatening native vegetation diversity and forest regeneration in the mid-Atlantic states. The characteristic triangulate pale green leaves and stems, encircled in sheaths called ocrea, bear sharp, recurving barbs and fruit that are borne in bright iridescent blue clusters when ripe (Fig. 8a & b). This plant prefers sunny disturbed, riparian and cleared areas for germination and colonization and can rapidly grow to crowd and overwhelm surrounding vegetation from undergrowth to small trees within a single growing season (Fig. 9), incurring repeated efforts and costs in eradication and control. Fruit are dispersed along waterways, by birds, animals and accidental transportation in contaminated soil, and can remain viable in the soil for up to six years. Populations of MAM have also recently expanded into neighboring states, and this has fuelled the urgency of mechanical, chemical and biological control efforts to curtail its spread in southern New England. In Connecticut, the densest MAM populations occur in lower Fairfield and Litchfield Counties although recent populations also have been discovered as far east as Sprague in New London County. The MAM biological control program in Connecticut is very recent, in comparison with the HWA program.

The tiny plant-feeding weevil of greatest potential for controlling MAM, *Rhinoncomimus latipes* Korotyaev, was first introduced into Connecticut in 2009. This beetle was originally collected from MAM plants in Henan province and studied in central China, then in quarantine facilities in Delaware for its host-specific feeding habits and ability to impact MAM in a program coordinated and funded by the USDA Forest Service. A mass rearing program at the New Jersey Phillip Alampi Beneficial Laboratory produces weevils for the biological control release program. Its federal permit for first release in the USA was granted in 2004 after an extensive environmental assessment. In cooperation with the University of Delaware, supported by funding from the USDA Forest Service and USDA APHIS PPQ, researchers from the Experiment Station and the University of Connecticut have collaborated to implement and monitor releases of *R. latipes* and assess its impact on MAM in Connecticut. Many town officials and volunteers have assisted in the releases. In July 2009, 7,000 weevils were released at five towns in New Haven, Fairfield and Litchfield Counties, and an additional 6,000 weevils were released in three other towns in Fairfield County in 2010 (Fig. 10). Adults emerge from overwintering sites in early to mid spring and are thought to have great impact on young MAM seedlings. The beetle is effective as both adult and larvae: adults preferentially feed at the growing tips on young leaves and emerging fruit (Fig.11a), thus reducing seed production and growth, and lay eggs (Fig. 11b) on leaves, ocrea and growing tips. When larvae hatch, they bite into and enter the stems to feed and cause collapse of the plant through their tunneling habit (Fig. 11c). This weevil is capable of several generations in the spring and summer and at least two generations have been observed in Connecticut. In late spring 2010, weevils were recovered at all 2009 sites, even in riparian sites that had been severely flooded, surviving their first Connecticut winter and inflicting substantial feeding damage to MAM plants in selected sites (Fig. 12). Weevils are active in feeding and reproduction throughout the growing season until the first frost, which kills the MAM vine. Adults are thought to overwinter in leaf litter. Dispersal of adults was also observed at about 0.5 miles from several release points. Indications are that the weevil is adapting to the Connecticut climate, although it is still very early in the program to determine if this agent will be successful and capable of reducing MAM populations and spread in Connecticut.

Fig. 1. Hemlock woolly adelgid infesting eastern hemlock

Fig. 2. Hemlock decline from HWA attack

Fig. 3. *Sasajiscymnus tsugae*, introduced predator, feeding on eggs of hemlock woolly adelgid: (a) adult (b) larva

a)

b)

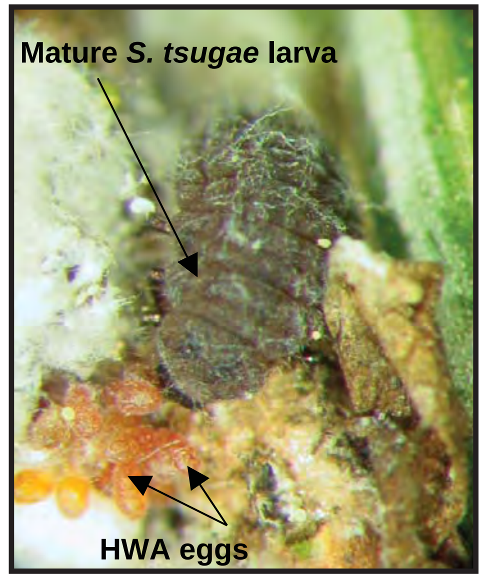


Fig. 4. Release sites of *S. tsugae* (>176,000) in Connecticut 1995-2007 in relation to eastern hemlock distribution

S. tsugae release sites in relation to hemlock distribution 1995-2007

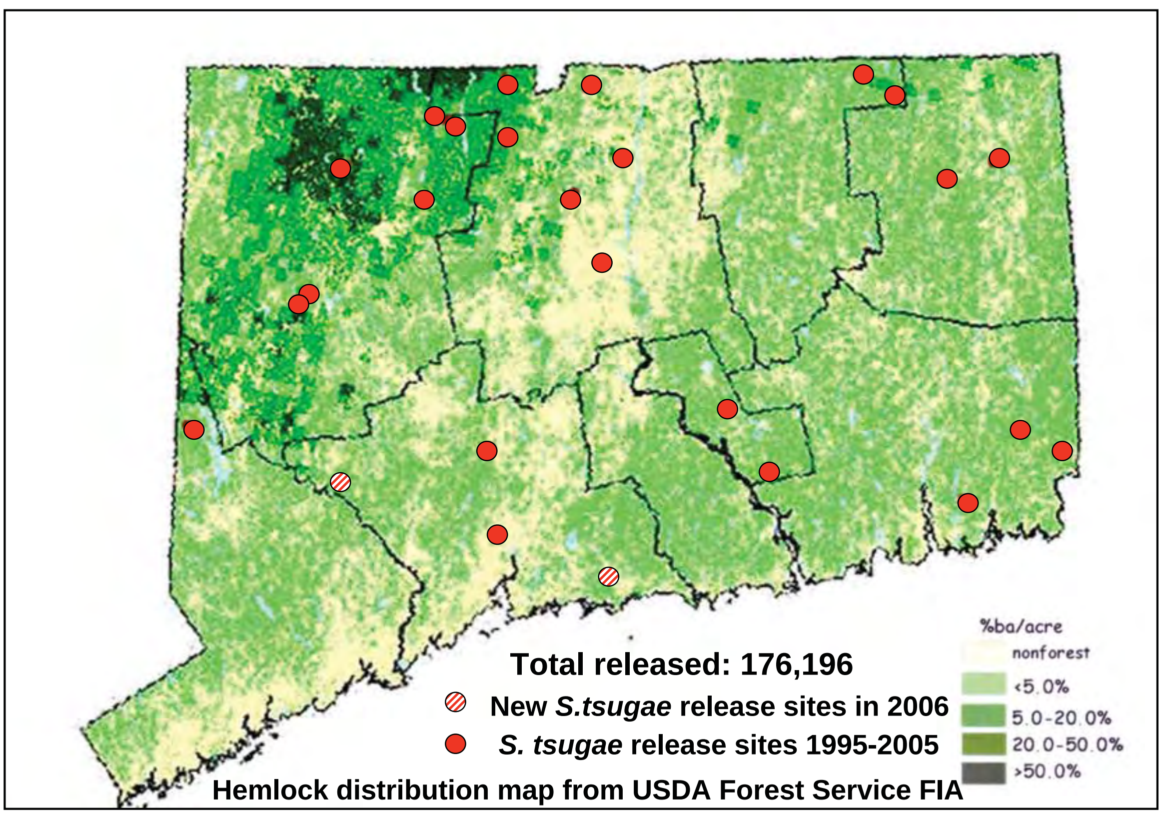


Fig. 5. Patterns of severe or extreme drought in Connecticut 1980 – 2010. Data are derived from the Northeast Regional Climate Center.

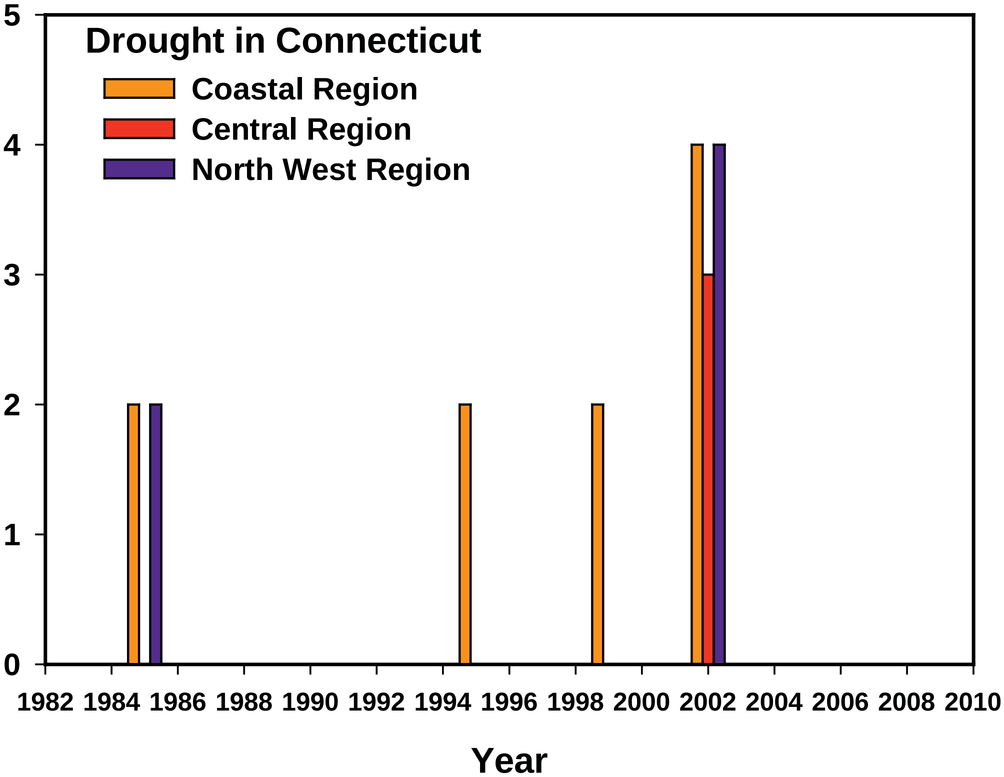


Fig. 6. Comparison of foliage transparency, a measure of hemlock crown health and fullness, in Connecticut *S. tsugae* release, non-release and baseline (uninfested) sites

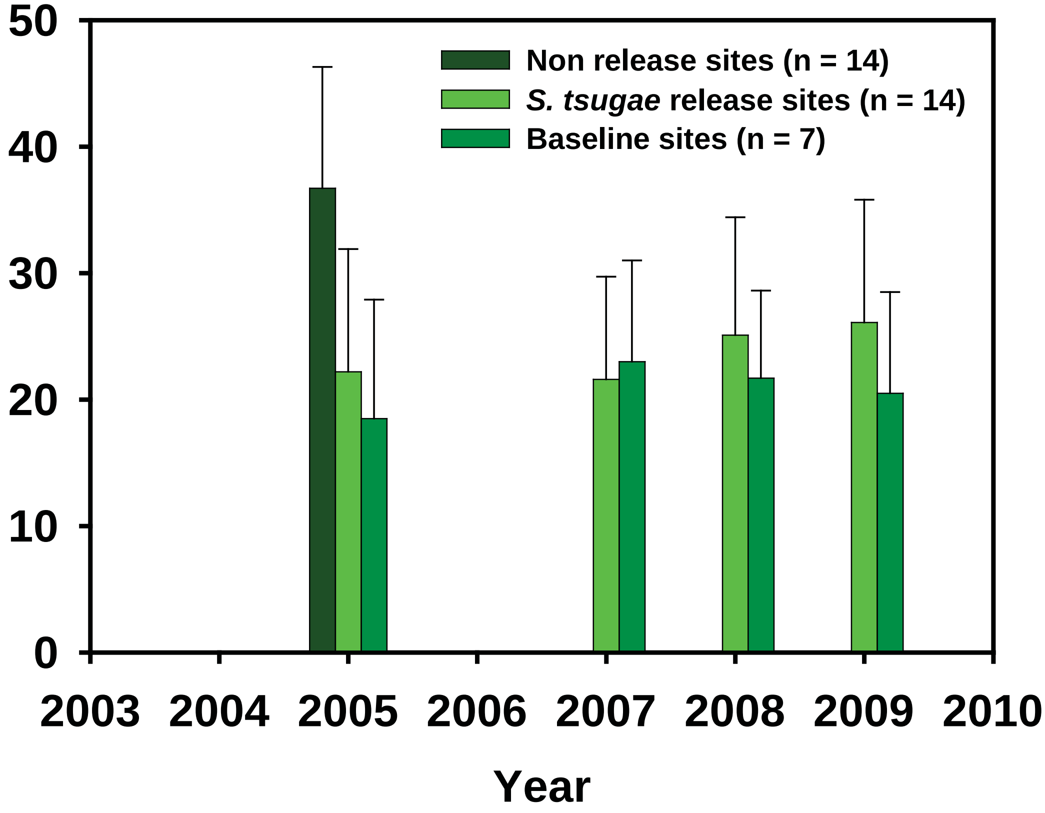
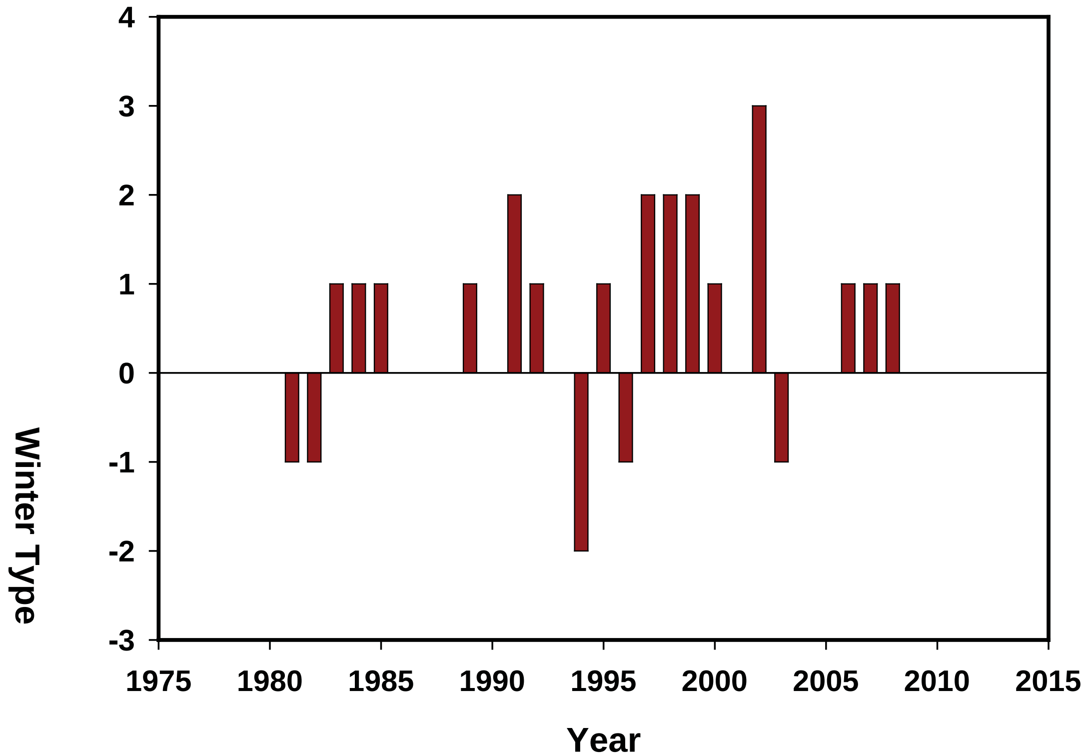


Fig. 7. Connecticut winters 1980 – 2009, based on mean winter temperatures



0 = Near normal; 1 = Above Normal, 2 = Much Above Normal, 3 = Record Warmest,
-1 = Below Normal, -2 = Much Below Normal;
Data from the National Oceanic and Atmospheric Association,
National Climate Data Center, *Climate at a Glance*

Fig. 8. Identifying characters for Mile-a-minute weed: (a) triangulate leaves, stems with barbs (b) ripening fruit and ocrea

a)

b)

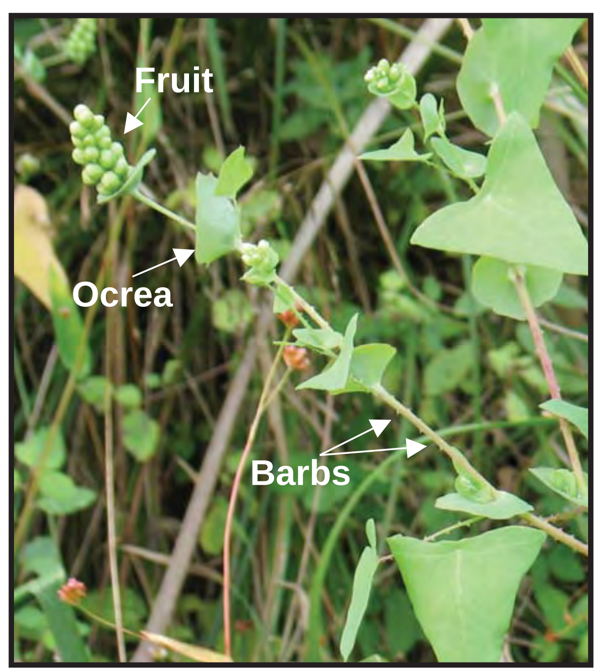


Fig. 9. Rampant growth of mile-a-minute weed in Greenwich

Fig. 10. Map showing the 2010 distribution of Mile-a-Minute Weed in Connecticut and location of 2009 & 2010 releases sites for *Rhinoncominus latipes.* Data on confirmed reports of MAM were derived from http://www.hort.uconn.edu/mam/distribution.html.

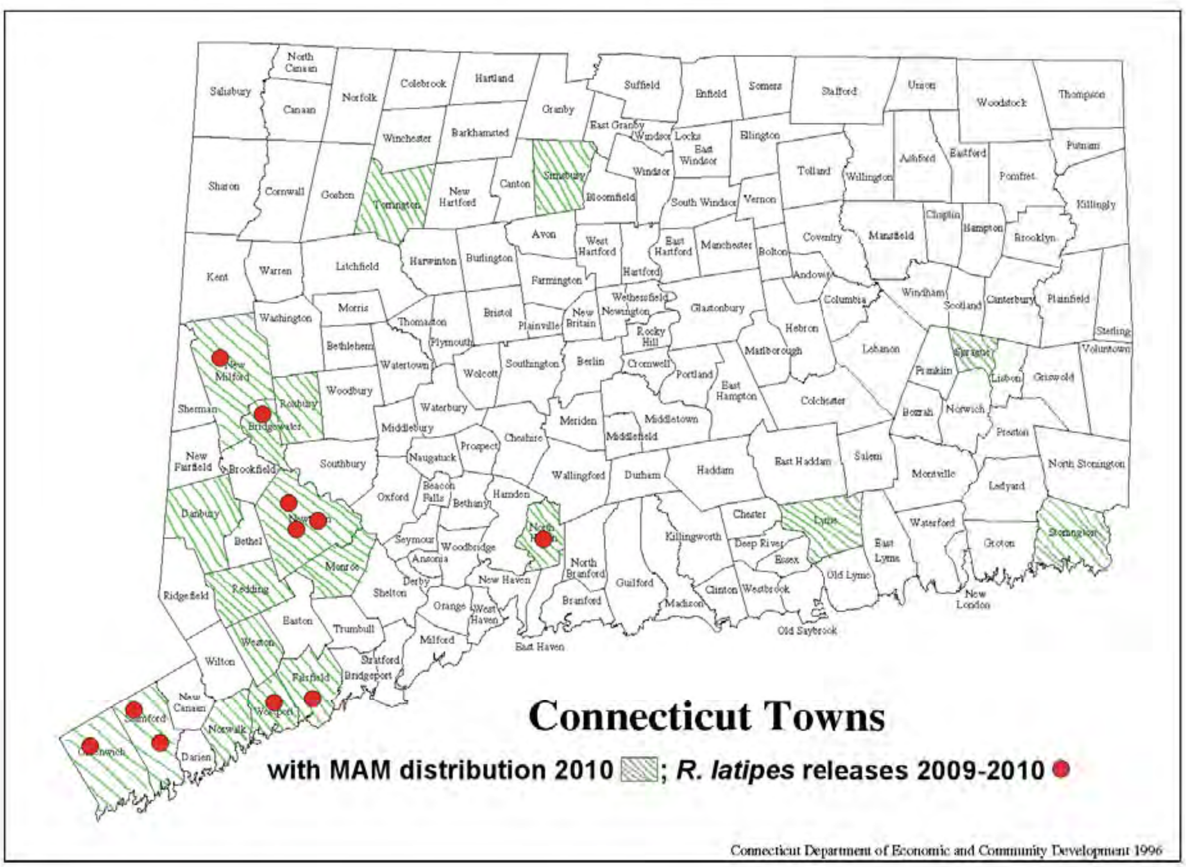
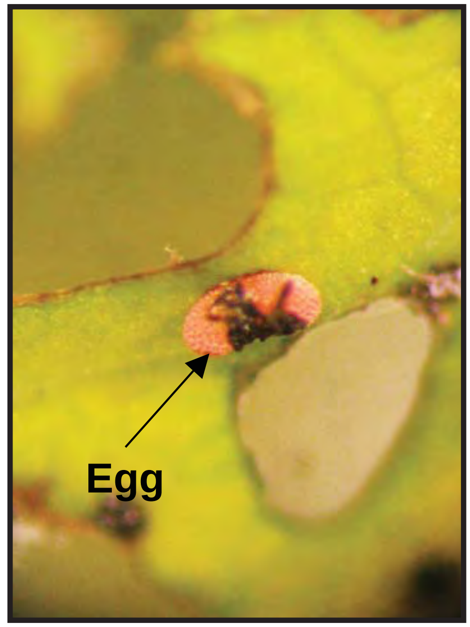
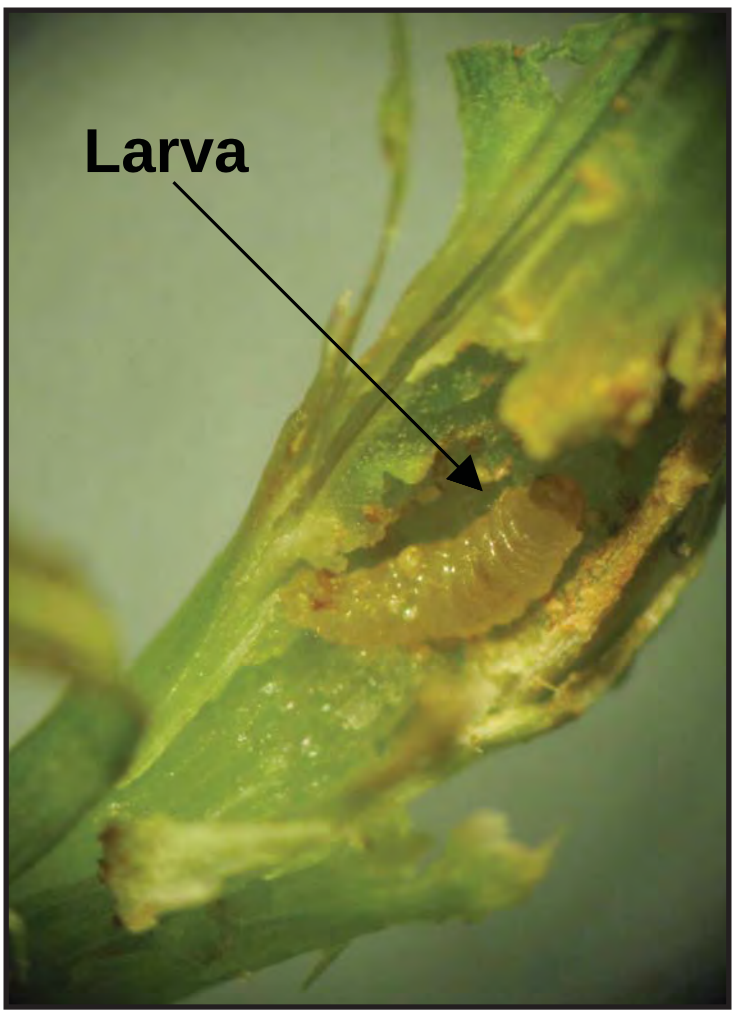


Fig. 11. *Rhinoncomimes latipes*, a weevil introduced for biological control of mile-a-minute weed in Connecticut: (a) adult and feeding damage (b) egg on leaf (c) larva tunneling in stem

(a)



(b)



(c)

Fig. 12. Feeding damage by *R. latipes* at a second year Newtown site

All photos by Carole Cheah

Table 1: *Sasajiscymnus (=Pseudoscymnus) tsugae* release sites in Connecticut 1995-2007

	TOWN	COUNTY	SITE	YEAR OF FIRST RELEASE	TOTAL RELEASED TO DATE/SITE
1	Windsor	Hartford	North West Park	1995	3,125
2	Cheshire	New Haven	Roaring Brook Park	1995	100
3	New Hartford	Litchfield	Nepaug MDC	1996	10,760
4	Bloomfield	Hartford	Reservoir #6 MDC	1996	10,505
5	Hamden	New Haven	Sleeping Giant S.P.	1997	3,600
6	New Fairfield	Fairfield	Pootatuck S.F.	1997	2,100
7	Washington	Litchfield	Steep Rock Association (SRA)	1998	10,500
8	Pomfret	Windham	Mashamoquet S.P.	1998	5,084
9	Union	Tolland	Bigelow Hollow S.P.	1999	10,000
10	Suffield	Hartford	Metacomet Trail	1999	10,000
11	Granby	Hartford	Enders S.F.	1999	10,000
12	East Haddam	Middlesex	Devil's Hopyard S.P.	1999	10,086
13	Barkhamsted	Hartford	People's S.F. (I)	1999	5,000
14	Washington	Litchfield	Hidden Valley Preserve (SRA)	1999	5,000
15	Torrington	Litchfield	Burr Pond S.P	1999	10,160
16	Voluntown	New London	Pachaug S.F. (I)	1999	3,000
17	Barkhamsted	Hartford	People's S.F. (II)	2000	20,000
18	Hartland	Hartford	Tunxis State Forest	2001	10,000
19	East Hampton	Middlesex	Salmon River S. F.	2001	10,000
20	Eastford	Windham	Natchaug S.F.	2001	10,000
21	Wethersfield	Hartford	Standish Park	2005	250
22	Voluntown	New London	Pachaug S.F. (II)	2005	2,600
23	Haddam	Middlesex	Cockaponsett S.F.	2006	1,198
24	Southbury	New Haven	Kettletown State Park	2006	1,203
25	Union	Tolland	Bigelow S.P. Mashapaug Pond	2006	2,021
				SUBTOTAL	**166,196**
26			Mashantucket Pequot Reservation *	2000	10,000

TOTAL RELEASED TO DATE IN CONNECTICUT: 176,196*

S.P. = State Park; S.F. = State Forest ; MDC = Metropolitan District Council watershed lands

Carole A. Cheah, Ph.D. was educated in England with a Bachelor's in Zoology from the University of Oxford, a Masters in Applied Entomology and a Ph.D. in biological control from the University of Cambridge. She is currently employed as a durational research entomologist at the Connecticut Agricultural Experiment Station, supported by primary funding from the USDA Forest Service. She continues to conduct research in biological control of hemlock woolly adelgid (since 1994) at the Valley Laboratory in Windsor, and more recently, biological control of mile-a-minute vine.

Japanese Barberry: When Good Plants Become a Problem

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Japanese barberry (*Berberis thunbergii*), a thorny shrub native to Japan, was introduced to the United States in the late 1800's as a replacement for European barberry (*Berberis vulgaris*), which is the alternate host of wheat rust. Unfortunately, Japanese barberry has escaped from manicured landscapes, spread, and become naturalized in at least thirty-one states, including Connecticut, and five Canadian provinces. The following pages will first give a brief description of the threat of Japanese barberry to forest health, water quality, and increased risk of exposure to Lyme disease before concluding with practical methods of controlling Japanese barberry in our parks and forests.

Native Plants and Animals

Japanese barberry can become the dominant understory shrub in Connecticut and form dense, nearly impenetrable thickets, especially in forests that have an overabundance of white-tailed deer (Figure 1). Dense thickets of Japanese barberry and other invasive shrubs inhibit native herbaceous plant populations, such as spring wildflowers, and growth of tree seedlings. This reduction in the diversity and health of native species has several negative consequences.

First, reducing native species diversity lessens the resiliency of our forests to climate change. Each native species is adapted to a range of temperatures and moisture levels. Maintaining and increasing the diversity of native species on a site will ensure that some species adapted to whatever climatic changes occur over the next several decades will remain on the site. This principle holds for all layers of a forested plant community: trees, shrubs, herbs, vines, mosses, and lichens. Ensuring the presence of diverse native plant species in forest ecosystems is critical to the future of bird, insect and other animal populations.

Where Japanese barberry has become established and excluded other species, the only foraging opportunities available for wildlife in some forests are Japanese barberry fruit that ripen in October. Alternatively, a more diverse community of native plants provides a variety of foods including soft mast, seeds, and insects whose availability better coincides with migration and nesting seasons of migratory and resident birds. Because Japanese barberry has few insect pests, it provides less feeding opportunities for insectivorous birds including, eastern wood pewee, great crested flycatcher, and various warblers and thrushes.

In addition, each wildlife species has unique nesting and cover requirements. Monotypic Japanese barberry stands provide nesting habitat for few native birds, and is especially deleterious for ground-nesting species, such as ovenbirds and ruffed grouse. The decreased litter layer and dominance of large exotic earthworms associated with barberry stands is also detrimental for woodland salamanders.

Lastly, a Japanese barberry monoculture has a short 2-3 week-long period of flowering during early spring. This sharply limits the effective foraging period for native pollinators. Maintaining and increasing native plant species diversity increases the effective foraging period for pollinators and provides a nectar source between early spring wildflowers and those flowering during mid-and late summer flowering.

Soil and Water

Japanese barberry impacts nutrient cycling systems by altering soil biota and nitrogen cycling, as well as soil structure and function. Increased nitrification in soils has been attributed to Japanese barberry. We found that earthworm biomass is much higher in Japanese barberry infestations than in adjacent forests with native vegetation. Increased activity of some earthworm species has been linked to increased phosphorus leaching. Thus, Japanese barberry infestations may be non-point sources of nitrogen and phosphorus pollution of our streams and lakes. Therefore, control and removal of Japanese barberry can have a positive impact on water quality.

Leaf litter provides a natural protective barrier to reduce soil erosion. The amount of leaf litter is inversely related to earthworm biomass, i.e., more earthworms - less leaf litter. One consequence of leaf litter loss is the risk of sheet erosion and gully formation. Eroded soil materials can be transported to and deposited as sediment in adjacent streams. Higher earthworm biomass under Japanese barberry infestations corresponds with much lower leaf litter. Japanese barberry control thus can help stabilize soils in our forests and thereby reduce sedimentation into streams that drain into ponds, lakes, reservoirs and Long Island Sound.

Barberry and Lyme disease risk

Japanese barberry is associated with greatly enhanced levels of blacklegged ticks (*Ixodes scapularis*, commonly referred to as "deer ticks") that transmit the causal agents of Lyme disease, human granulocytic anaplasmosis, and human babesiosis. Originally, we speculated that Japanese barberry provides a habitat that is favorable to white-footed mouse (*Peromyscus leucopus*) survival. This rodent is a reservoir for *Borrelia burgdorferi*, the causal agent of Lyme disease in humans and pets. To determine mouse and larval tick abundances at five replicate sites in the towns of North Branford (two sites), Redding (two sites), and Mansfield, we trapped mice since 2007 in unmanipulated dense barberry infestations, areas where barberry was controlled, and areas where barberry was minimal or absent. The number of feeding larval ticks per mouse was recorded. Too few nymphal ticks were collected on mice for statistical analysis. Adult and nymphal ticks were sampled along permanent transects by dragging a 1x1 meter cloth through the forest floor and over associated vegetation in each treatment. The ticks were retained and tested for the presence of *Borrelia burgdorferi* using indirect fluorescent antibody staining methods.

Surprisingly, mouse populations did not differ between treatments. However, many more larval ticks were found feeding on mice captured in dense barberry infestations than in other treatments. There were many more adult blacklegged ticks in Japanese barberry than in areas where barberry was minimal or absent. Control of Japanese barberry decreased the abundance of adult blacklegged ticks, and more importantly, reduced by nearly 60% the number of infected adult ticks capable of transferring *Borrelia burgdorferi* to humans (Figure 2).

Control of Japanese barberry makes environmental conditions more hostile for blacklegged tick survival by severely reducing humidity levels that the ticks depend on. It is evident that this exotic invasive plant is allowing a native ectoparasite to proliferate to the detriment of human health.

Controlling Invasives

The good news is that Japanese barberry can be controlled. We have developed, tested, and refined both reduced chemical and non-chemical methods to control Japanese barberry. Since 2006, a total of fifty-one treatment combinations have been examined in collaboration with CT-Department of Environmental Protection, the University of Connecticut, water companies, private industry, towns, and landowners. Our research has shown that effective control of Japanese barberry can be achieved with a two-step technique that integrates an initial treatment (prescribed fire or mechanical cutting) with a follow-up treatment such as directed heating with a propane torch or foliar spray herbicide application. This research both evaluated the effectiveness and relative costs among treatment combinations to control Japanese barberry, and by monitoring individual clumps across a range of size classes, assessed whether treatment prescriptions are dependent on clump size.

The initial treatment in the two-step technique kills the aboveground stems by cutting with a brush saw or mower, by crushing with a bulldozer, or by lethal heating with either a propane torch or a prescribed fire. The initial treatment can be completed at any time during the year. When the aboveground portion of a barberry plant is removed or killed, new stems then develop from the surviving root systems. Because these new stems are about half the size of the original stems, less effort and material are needed to apply follow-up treatments. Using an initial treatment to reduce the size of barberry stems has the additional benefit of minimizing the potential negative impact to native vegetation by heating or herbicide application during the follow-up treatment. The initial treatment also weakens the root systems of surviving Japanese barberries by lowering starch reserves that are expended to grow new stems.

It is important to determine the scale (acres) and average height of a Japanese barberry infestation prior to controlling this invasive species. Japanese barberry quickly recovers from removal of aboveground stems without a follow-up treatment. Therefore, the scope of effective control is limited to the scale of the follow-up treatment that can be implemented within a year of initial control. As will be explained below, the initial height will help guide the choice of both initial and follow-up treatments.

The prescription for which combination of initial and follow-up treatment to use will vary with the size of barberry clumps, local fire and wetland regulations, the amount of area to be treated, site and personnel factors. For example, herbicides cannot be used in some natural areas because of deed restrictions or legally used on elementary school properties because of state law. The choice of the initial treatment to reduce clump size by killing aboveground stems will depend on such factors as the size and extent of the treatment area, the relative height and density of the infestation, and availability of local resources (e.g., personnel qualified for prescribed burning). Where feasible, prescribed burning can quickly treat large areas as the required personnel and equipment resources differ little between burns of 1 and 20 acres. For most land owners, however, mechanical control (cutting or crushing) will be used for initial treatments.

We found that cutting with either a brush saw or a rotary wood shredder mounted to a compact track loader (Figure 3) provided excellent initial control. Using a rotary shredder required nearly as much time as a brush saw because of the need to return with a brush saw to cut clumps adjacent to trees, stone walls, or large rocks that were missed by the shredder. The cost of renting a rotary shredder can greatly increase the treatment cost. However, using a brush saw as the initial treatment in barberry infestations taller than waist high quickly becomes discouraging because of multiple face and neck scratches. We suggest using mechanized equipment to flatten or cut working corridors in taller infestations to at least provide access corridors.

The estimated time for initial treatment using a brush saw was 1.4 hours/acre/10% cover ($HAC_{10\%}$) compared with 6.1 $HAC_{10\%}$ using propane torches (Figure 4). For example, if the invasive shrub cover was 50%, then the treatment time would be 1.4*(50/10) = 6.5 hours/acre using brush saws and 31.5 hours/acre using propane torches. Please note that these estimates do not include time required for travel, refueling, breaks, and maintenance. Cost estimates for prescribed burning are unknown.

A pretreatment survey of Japanese barberry height will allow a land owner to determine whether or not a follow-up treatment of directed heating with propane torches will be effective. An infestation less than 4-feet tall can be effectively treated with a propane torch with the knowledge that some of the larger clumps will survive and require further treatment (Figure 5). However, effective control of larger Japanese barberry will require several years using propane torches or a single application of herbicide.

Quality control is essential when using a propane torch. Top killing live stems without simultaneously killing latent basal buds is inefficient and could result in poor control. It is important to heat all stems in a clump until they begin to glow and char (Figure 6). Flame treatments must be conducted when the leaf litter is damp to eliminate the risk of an uncontrolled wildfire. With the above restrictions in mind, directed heating with propane torches is an effective follow-up treatment in parks, nature preserves, and forests where herbicide use is restricted.

Follow-up treatments using both glyphosate and triclopyr as foliar herbicide sprays provided excellent control for all height classes of Japanese barberry from late April through the end of September. These treatments killed over 90% of Japanese barberry clumps. We found that the use of a marker dye in herbicide mixture allowed missed clumps to be easily identified, reduced the number of clumps sprayed more than once, and minimized application to non-target, native plants.

The estimated time for follow-up treatment using a foliar herbicide spray was 0.9 $HAC_{10\%}$ compared with 3.5 $HAC_{10\%}$ using propane torches (Figure 4). For example, if the initial Japanese barberry cover was 50%, then the treatment time would be 0.9*(50/10) = 4.5 hours/acre using foliar herbicide spray and 15.5 hours/acre using propane torches.

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Further Reading

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Figure 1. Dense stand of Japanese barberry.

Figure 2. The number of blacklegged ticks infected with *Borrelia burgdorferi* is much higher in forested areas with Japanese barberry.

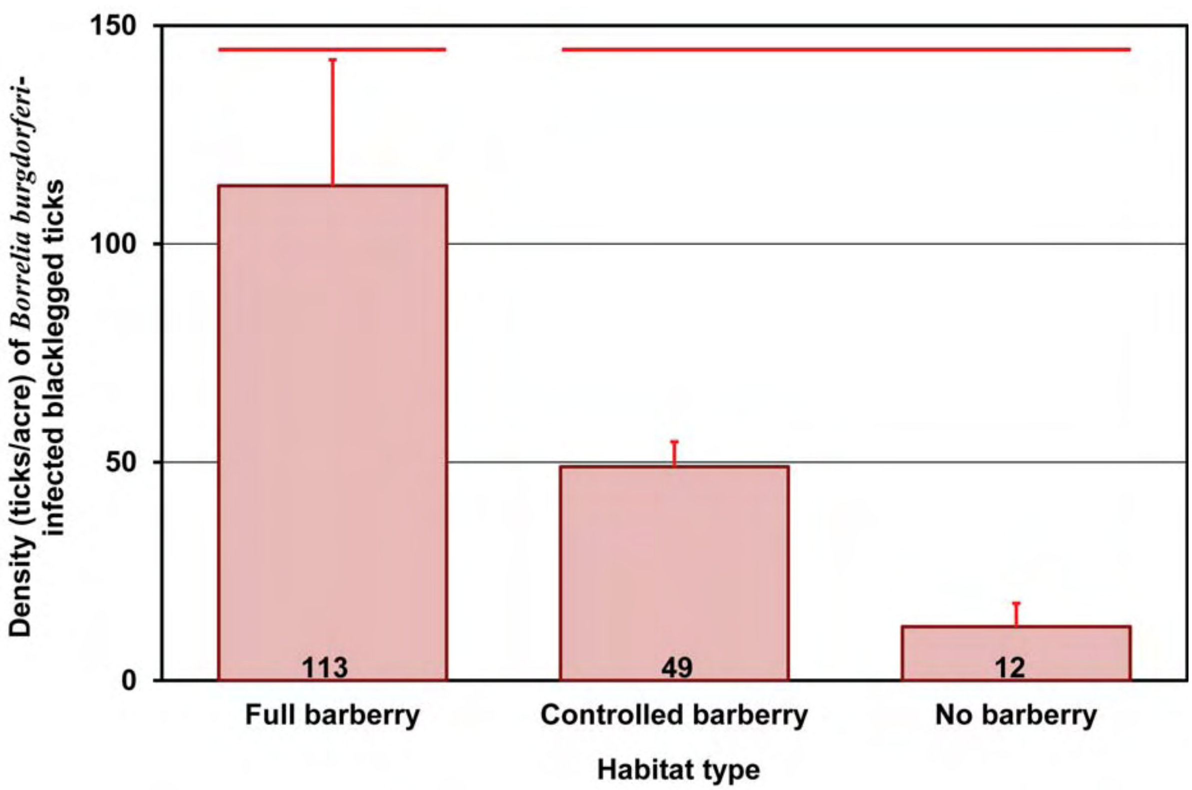

Figure 3. Initial treatment of Japanese barberry infestations can be accomplished throughout the year with (a) propane torches when vegetation and leaves are moist or wet, (b) rotary wood shredder, and (c) brush saw.

Figure 4. Treatment time (hours/acre) for a Japanese barberry infestation that covers fifty percent of a forest.

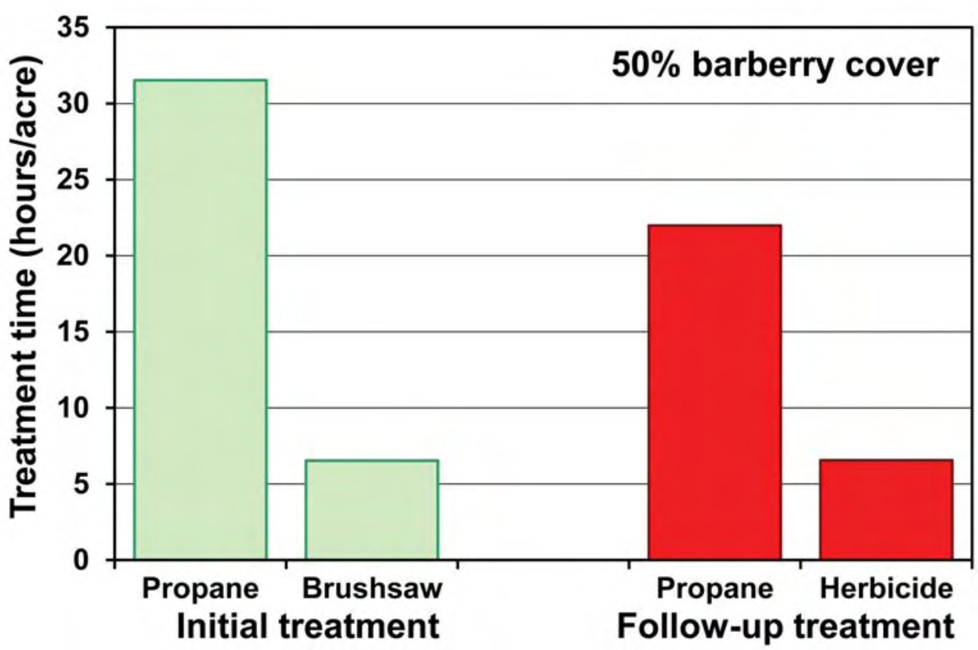

Figure 5. Mortality of Japanese barberry by size before treatment and follow-up treatment method.

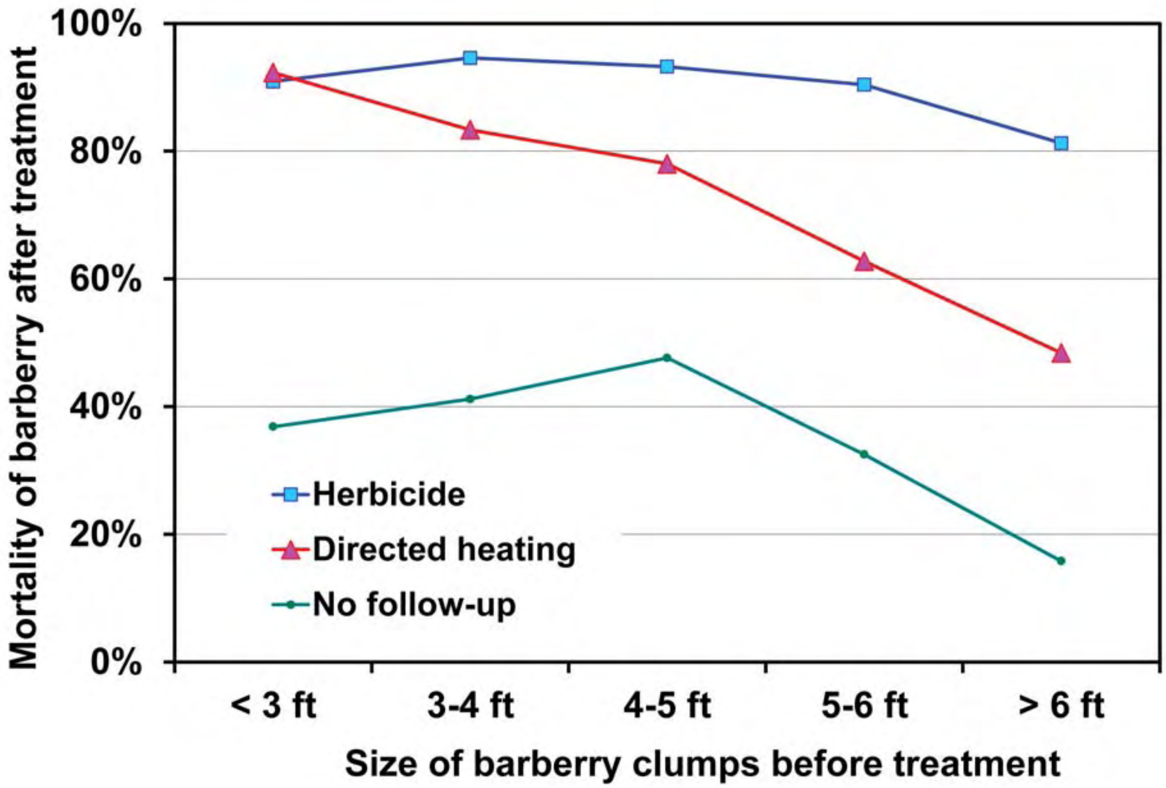

Figure 6. Barberry stems are killed by heating them until they become charred and begin to glow. Treatment should be done when leaf litter is moist or wet.

NOTES

The mission of The Connecticut Agricultural Experiment Station is to develop, advance, and disseminate scientific knowledge, improve agricultural productivity and environmental quality, protect plants, and enhance human health and well-being through research for the benefit of Connecticut residents and the nation. Seeking solutions across a variety of disciplines for the benefit of urban, suburban, and rural communities, Station scientists remain committed to “Putting Science to Work for Society”, a motto as relevant today as it was at our founding in 1875.

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