The

Connecticut

Agricultural

Experiment

Station,

Windsor

CAES

The Connecticut Agricultural Experiment Station

Putting Science to Work for Society since 1875

Bulletin 1081

August 2021

Collaborative Biological Control in Connecticut with *Sasajiscymnus tsugae*, Introduced Predator of Hemlock Woolly Adelgid (HWA)

Carole Cheah, Ph.D.
Valley Laboratory

Collaborative Biological Control in Connecticut with *Sasajiscymnus tsugae*, Introduced Predator of Hemlock Woolly Adelgid (HWA)

Carole Cheah, Ph.D.
Valley Laboratory

ABSTRACT

Hemlock woolly adelgid, *Adelges tsugae* (HWA), is a serious exotic forest and nursery pest of native hemlocks in eastern North America. Recent severe winters from 2014-2018 with polar vortex events brought subzero arctic blasts which killed high numbers of HWA and greatly reduced adelgid populations in the Connecticut landscape, giving our hemlocks a reprieve. However, the winter of 2020 was the 6th warmest on record in Connecticut with negligible HWA winter mortality. This was followed by another mild winter in 2021 with no polar vortex event. Connecticut is suddenly experiencing a resurgence and reinvasion of HWA which is heavy in many areas. Biological control of HWA remains Connecticut's major strategy of safely managing HWA and saving the hemlock forests. Long term data from release sites indicate the efficacy of this strategy with many original hemlocks surviving for over 20 years. From 1995 - 2007, >176,000 of the tiny HWA specialist ladybeetle predator, *Sasajiscymnus* (formerly *Pseudoscymnus*) *tsugae*, native to southern Japan, were reared at the Kenneth White Insectary, Valley Laboratory, Windsor and released in Connecticut's hemlock forests at 26 statewide sites, mostly on state lands. This HWA biological control program has been recently revived and expanded to include partnerships with land trusts, town conservation commissions, water companies, and other public and private preserves to release *S. tsugae* to combat the resurgence of HWA after mild winters. Tree-Savers of Pennsylvania is the sole commercial producer of *S. tsugae* and is an example of technology transfer of predator rearing methods developed at the Valley Laboratory which has allowed the public to access and implement biological control of HWA. A valuable partnership has developed with Tree-Savers in recent years. Through purchases and generous donations of *S. tsugae* from Tree-Savers, augmentative releases of *S. tsugae* in Connecticut in 2017, 2020 and 2021 have increased to >60 hemlock sites in total. Currently, > 200,000 *S. tsugae* have been released throughout Connecticut since 1995.

Introduction

Connecticut has an estimated 1.76 million acres of forest land and is 58% forested (1). Most of Connecticut's forests are privately-owned (71%) while 28% are state and locally owned lands. According to the 2020 Connecticut Forest Plan, Connecticut's forest coverage ranges between 56-61% depending on the data type used (2). Eastern hemlock, *Tsuga canadensis*, is the sixth most common tree species in Connecticut forests in terms of live trees ≥1 inch dbh (diameter at breast height), and the most abundant conifer in terms of growing stock ≥ 5 inch dbh, overtaking eastern white pine (1). In 2019, eastern hemlock and eastern hemlock-white pine forest types are estimated at 28,100 acres in Connecticut (1) with an estimated 42 million hemlock trees (2). Hemlocks predominate in the northwestern corner of the state, based on the 1997-1998 Connecticut Forest Inventory conducted by the USDA Forest Service Forest Inventory Analysis (FIA) (Fig. 1) (3).

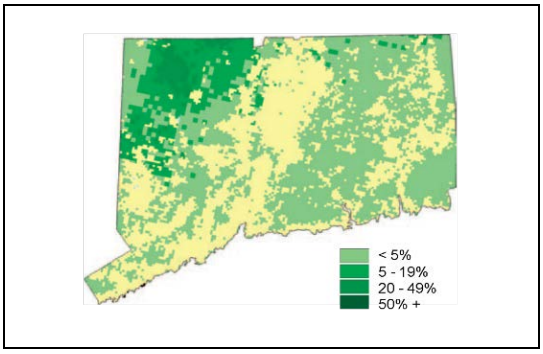


Figure 1. Estimated distribution of eastern hemlock in Connecticut in terms of hemlock basal area (3) (Wharton et al. 2004)

Hemlocks are an important component of watershed forests that capture, filter, store and protect Connecticut's drinking water reservoirs,

especially in the north (Fig. 2), and the protection of headwater streams and their hemlock buffer zones are a major priority. The upper Farmington River is our only National Wild and Scenic River and hemlocks are a major component of the upper Farmington River's watershed forests in northwest Connecticut (Fig. 2). Eastern hemlocks are long-lived, shade-tolerant and are considered a foundation species (4) as they provide critical structure, shelter, and habitat for many communities of plant and animal species. The cool shade provided by hemlocks also provide essential thermoregulation for native trout streams and rivers and are integral to many recreational areas in Connecticut state lands, land trust, bird sanctuaries and public preserves.

Figure 2. Hemlock-white pine watershed forests in 2020 of the Barkhamsted reservoir (top) and the upper Farmington River (bottom), a National Wild and Scenic River in Connecticut

Hemlock woolly adelgid, *Adelges tsugae* (HWA), is a serious exotic forest and nursery pest of native hemlocks in eastern North America. First reported in 1985 to the CAES in New Haven, HWA was widespread through Connecticut in the 1990s. In the late 1980s and 1990s, hemlocks in Connecticut's southern and central regions suffered heavy decline and many trees died: the outlook for eastern hemlocks was bleak. Early landscape assessments (1997-1998) in the lower Connecticut River Valley showed that all sizes and age-classes of hemlock were killed by HWA within 4-15 years of infestation and hemlocks rarely recovered (5). However, biological control of HWA has been the foremost strategy in Connecticut for managing HWA, beginning with the first release in Windsor in 1995 (Cheah 2019). From 1995-2007, >176,000 adult ladybeetles of *Sasajiscymnus tsugae* (formerly *Pseudoscymnus*) *tsugae* (Fig. 3), a major native predator of HWA from southern Japan, first discovered by Japanese and CAES scientists (6), were reared at the Valley Laboratory, Windsor, and subsequently released into Connecticut's heavily HWA–infested forests at 26 statewide sites (7). This species is the primary HWA predator released and established in Connecticut for 26 years and has helped to reduce HWA (8), protect and preserve Connecticut's hemlocks for over 2 decades. As a result, Connecticut hemlock forests have persisted in spite of >35 years of HWA attack. Long-term annual hemlock tree data from 1998-2001 biocontrol release sites have indicated the efficacy of this strategy: many of the original hemlocks which were heavily infested with HWA, have recovered and survived to this day.

Figure 3. Adult and mature larva of *Sasajiscymnus tsugae* feeding on hemlock woolly adelgid (HWA)

Battling HWA Resurgence

Recent severe winters from 2014-2018 with successive polar vortex events brought subzero arctic blasts, which killed high numbers of HWA and greatly reduced adelgid populations in the Connecticut landscape, giving our eastern hemlocks a reprieve (9). In 2017, Tree-Savers, a company from Pennsylvania, which is the sole commercial mass producer of *S. tsugae*, made a generous donation of 2,000 *S. tsugae* to Dr.

Cheah who then sought to implement small releases of 100-300 beetles at seven new sites around the state which were showing signs of minor adelgid resurgence in spring 2017. Included were three new non-state land sites in the Town of Monroe, Roxbury Land Trust and Great Mountain Forest in Norfolk and Canaan (Fig. 4). There has been minimal HWA resurgence in most of these sites since.

Webb Mountain Park, Monroe

Mine Hill, Roxbury Land Trust

Great Mountain Forest, Canaan

Figure 4. Small scale releases in 2017 in new Connecticut sites in town open space and private forests from Tree-Savers' donation of *S. tsugae*

However, the winter of 2020 was the 6th warmest on record in Connecticut with negligible HWA winter mortality. This was followed by another mild winter in 2021 with no polar vortex event to kill HWA. Extreme wind chills in January 2021 did not affect HWA winter survival (< 10% HWA mortality statewide). While HWA populations can be greatly reduced by severe winters in Connecticut and the Northeast, warm, mild winters conversely result in high survival resulting in HWA rebound from winter survivors and reinvasion from other regions. The lack of polar vortex events in Connecticut in 2020 and 2021 has led to the increasing spread of HWA in 2021. The adelgid is also spreading into our forests from surrounding regions and some trees are succumbing to native hemlock borer attacks and increases in elongate hemlock scale infestations, having been weakened by recent severe droughts in 2015-2017, and in 2020. Connecticut is currently experiencing a heavy resurgence of HWA, even in northern regions (Fig. 5) and safe environmentally sensitive mitigation strategies are urgently needed again to control adelgid outbreaks and help counter widespread HWA-induced decline in hemlocks.

Figure 5. Heavy recent resurgence of HWA in northern Connecticut in spring 2021

Connecticut's HWA biological control program with *S. tsugae* was recently revived in 2020 and expanded to include collaborative partnerships with land trusts, town conservation commissions, water companies, other public and private preserves and others to purchase and release *S. tsugae* to combat the alarming resurgence of HWA after recent mild winters. A close partnership and collaboration has developed between Tree-Savers Director, Jayme Bonewicz, and Dr. Cheah and has re-energized the HWA biological control program in Connecticut (Fig.6)

Figure 6. Dr. Cheah and Jayme Boniewicz, Director of Tree-Savers, at Plant Science Day, 2017. A donation of several thousand *S. tsugae* from Pennsylvania delivered in person by Tree-Savers staff in spring 2021

This partnership is an example of technology transfer of HWA biological control predator rearing methods initially developed at the CAES Valley Laboratory then shared with the private sector which in turn, has amplified the mass rearing procedures and distribution (Fig. 7) which has allowed the public to access and implement biological control of HWA (Fig. 8).

Figure 7. Mass rearing S. tsugae at Tree-Savers, Pennsylvania. https://www.treesaverspa.com/

Figure 8. Tree-Savers' shipments of *S. tsugae* to Connecticut

Through coordinated efforts between Dr. Cheah and Tree-Savers, purchases of *S. tsugae* by the Connecticut Department of Energy and Environmental Protection (DEEP) Forestry Division, land trusts, other non-profit organizations, towns, communities of homeowners, and individuals, have led to more augmentative small scale releases of *S. tsugae* in Connecticut in 2020 and 2021. These efforts were further amplified by generous donations of *S. tsugae* from Tree-Savers. This ladybeetle has now been released in >60 hemlock forest sites throughout Connecticut from 1995-2021, more than doubling the total number of release sites in Connecticut with the recent expansion of this program. In 2021, *S. tsugae* was released in 28 sites, 25 of which were new hemlock forest

locations. Currently, > 198,000 *S. tsugae* have been officially released throughout Connecticut since 1995 but the number is even higher as recent private homeowner and community releases are growing in popularity. Total numbers of *S. tsugae* released in Connecticut as of summer 2021, including private releases, exceed 200,000 in the 26-year program (Fig. 9) and represent one of the largest and most intensive ongoing HWA biological control efforts with *S. tsugae*. Connecticut, unlike other states, implements an intensive approach to forest biological control of HWA statewide as no chemical control methods are used, due to the sensitive riparian and wetland ecosystems where hemlocks are the predominant species.

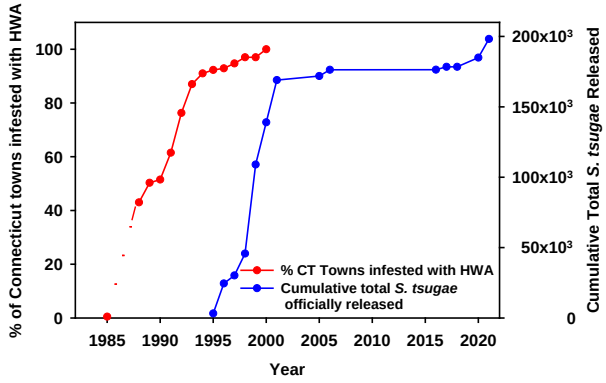


Figure 9. Graph showing the spread of HWA in Connecticut towns since 1985 and cumulative biological control releases of *S. tsugae* from 1995-2021 (Cheah 2021)

Although recent releases are small and experimental, approximating 100-1,000 per site (Fig. 10), the reproductive potential of *S. tsugae* is substantial. Every adult female is able to lay an average of 280 eggs, up to a maximum of >500 eggs over 3 months (10). Where HWA is abundant, *S. tsugae* is capable of exponential population increases in a year as studies have shown that there can be 3 overlapping generations of *S. tsugae* predating on HWA in field populations (11, 12). Connecticut's current biological control strategy is to seed small colonies of *S. tsugae* in emerging HWA populations and to expand and augment these populations in subsequent years to enhance establishment in response to resurgent HWA populations, especially following mild winters. Amplification of *S. tsugae* during laboratory mass rearing is remarkable: 40x population growth is possible with unlimited HWA in a single rearing season (data from Tree-Savers in 2021). It is this tremendous reproductive potential, together with predation of all HWA stages by all stages of *S. tsugae* for >8 months, the amenability of this species to laboratory mass rearing and the availability of this predator to the public for implementation that underpins the Connecticut approach. The past successive severe winters that greatly reduced HWA populations (13) until recently, have resulted in a more level playing field between prey and predator and current efforts will test the efficacy of implementing small scale releases of *S. tsugae* for managing HWA resurgence to support hemlock recovery.

The desire to manage HWA and protect eastern hemlocks in environmentally sensitive ways to minimize non-target impacts on the environment, non-target species and to conserve pollinators has led to the increased public interest in using biological control for HWA with *S. tsugae* in Connecticut and is being addressed by this collaboration and partnership between multiple organizations. This specialist ladybeetle HWA predator is the only one readily available to the public through commercial rearing. Many participants from diverse sources, including state lands foresters, water company foresters, land trust managers, town conservation commissions, birders, hikers, rock climbing enthusiasts, residential communities and others have partnered with Dr. Cheah to target recent HWA outbreaks in 2020 and 2021.

Figure 10. *S. tsugae* adults prepared for release in hemlock forests

Releases of *S. tsugae* in 2020

Over 6,500 *S. tsugae* were released in 2020 to target HWA resurgence on state lands, other preserves and MDC watershed forests in northern Connecticut. Efforts were not diminished by the covid pandemic and Tree-Savers donated 47% of released beetles in Connecticut in 2020. The majority (71%) were released through purchases by CT DEEP Forestry division and supplemented by Tree-Savers' donations in seven state parks and forests in Pomfret (Mashamoquet Brook State Park), Voluntown (Pachaug State Forest), East Haddam (Devil's Hopyard State Park) (Fig. 11), Union (Bigelow Hollow State Park), Eastford (Natchaug State Forest), Barkhamsted (People's State Forest) and Torrington (Burr Pond State Park) (Fig. 12).

Figure 11. CT DEEP foresters and staff releasing *S. tsugae* at the Pachaug State Forest and the Devil's Hopyard State Park in early summer 2020

Burr Pond State Park

Figure 12. Staff at Burr Pond State Park releasing *S. tsugae* in June 2020

Another 18% were released in 2020 at the Steep Rock and Hidden Valley Preserves, Steep Rock Association in Washington (Fig. 13), and at the Great Mountain Forest in Canaan through purchases and donations.

Hidden Valley Preserve, Washington

Figure 13. Releasing *S. tsugae* on understory hemlocks along Hidden Valley and Steep Rock Preserve trails, Steep Rock Association in Washington CT in May 2020

The Metropolitan District Commission also purchased *S. tsugae* for the first time in 2020 to initiate HWA biological control at the Barkhamsted and Colebrook reservoir watershed forests (Fig. 14).

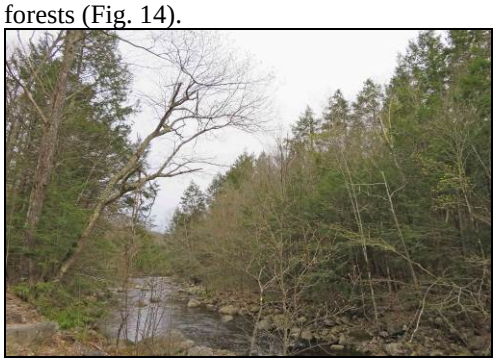


Figure 14. Foresters of the Metropolitan District Commission release *S. tsugae* along the Hubbard River hemlock watershed forests of the Barkhamsted Reservoir in spring 2020.

Releases of *S. tsugae* in 2021

In 2021, the number of *S. tsugae* obtained from Tree-Savers for release was doubled to >13,500. Thousands of *S. tsugae* (>6,000) were generously donated to the Connecticut biological control program by Tree-Savers and released in 13 new state lands locations (including 2 popular state campgrounds) in 11 towns with the cooperation and participation of Connecticut Department of Energy and environmental Protection (DEEP) foresters, park managers and staff (Fig. 15 and 16). The towns in which *S. tsugae* were released on state lands in 2021 are Barkhamsted (People's and American Legion State Forests), Canton (Nepaug State Forest), Colchester (Salmon River State Forest), Coventry (Nathan Hale State Forest), Eastford (Natchaug State Forest), East Haddam (Devil's Hopyard State Park), Hartland (Tunxis State Forest), Killingly (Old Furnace State Park), Plymouth (Mattatuck State Forest), Thomaston (Black Rock State Park) and Torrington (Burr Pond State Park). Releases were primarily made along popular hiking trails and recreation areas.

Figure 15. Protecting hemlocks at Old Furnace State Park, northeastern Connecticut in 2021

Beaver Brook Recreation Area, People's State Forest

Agnes Bowen Trail, People's State Forest

Salmon River State Forest

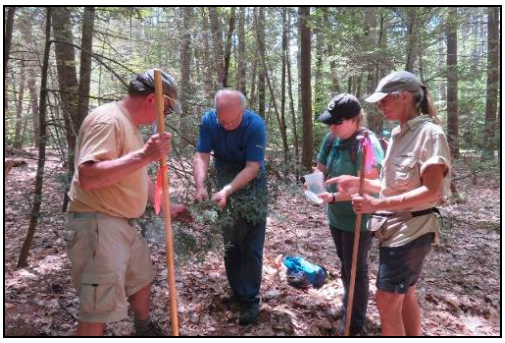
Spruce Brook Trail, Salmon River State Forest

White Cliffs Trail, Mattatuck State Forest

Falls Brook Trail, Tunxis State Forest

Figure 16. CT DEEP managers and foresters help in releasing *S. tsugae* in the People's State Forest, Salmon River State Forest, Mattatuck State Forest and Tunxis State Forest in spring 2021

Volunteer organizations such as the Friends of the American Legion and People's State Forests (FALPS), local land trusts and town conservation commissions and other volunteers provide an invaluable resource in scouting and reporting HWA outbreaks, assisting in implementing biocontrol releases and monitoring of hemlock stand conditions. A grant in June 2021 from the Farmington River Coordinating Committee (FRCC) enabled further augmentation releases of *S. tsugae* along popular hiking trails in the People's State Forest and the American Legion State Forest campground with the help of volunteers from FALPS (Fig. 17).



Austin Hawes Campground, American Legion State Forest

Robert Ross Trail, People's State Forest

American Legion State Forest

Elliot Bronson Trail, People's State Forest

Figure 17. CT DEEP staff and volunteers from FALPS assist in HWA biological control releases funded by an FRCC grant in the upper watershed forests of the Farmington River in Barkhamsted.

Purchases and donated releases of *S. tsugae* were also implemented to protect valued hemlock resources in seven other towns by town conservation commissions, land trusts and other community organizations, with training and assistance provided by Dr. Cheah.

In April 2021, releases of *S. tsugae* were made at the Pomfret Audubon's hemlock gorge through a volunteer's generous donation of *S. tsugae* and on three important hemlock areas by the Wyndham Land Trust in Pomfret and Thompson (Fig. 18).

Bafflin Sanctuary, Pomfret Audubon

Pomfret Audubon

Wyndham Land Trust

Figure 18. Volunteers and the Wyndham Land Trust (WLT) preserve manager release *S. tsugae* at the Pomfret Audubon and WLT hemlock preserves in northeastern CT in spring 2021

The Towns of Woodbury and New Hartford, through their Conservation Commission/Land Trust, purchased several hundred *S. tsugae* for release on hemlock preserves popular with the public for hiking and recreation (Fig. 19 & 20)




Nonnewaug Falls, Woodbury

Figure 19. Members of the Woodbury Conservation Commission released *S. tsugae* to protect Nonnewaug Falls in May 2021, the first purchase by a town in Connecticut

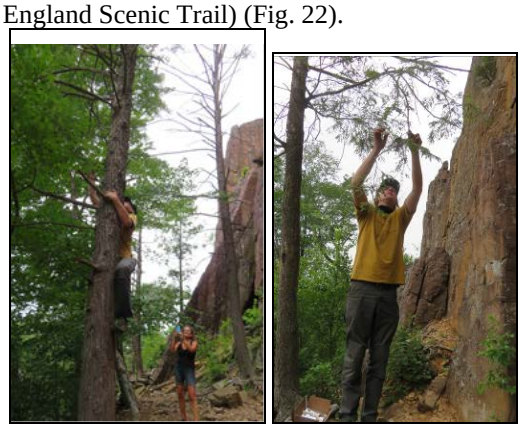
With the support of the New Hartford Land Trust, volunteers also helped in releases at Jones Mountain, Town of New Hartford, where heavy HWA infestations were detected in spring 2021 (Fig. 20):


Figure 20. Volunteers from the New Hartford Land Trust help release *S. tsugae* on Jones Mountain, Town of New Hartford, June 2021

Southbury Land Trust members also helped scout for HWA and conducted releases to protect hemlock watershed forests along the Pomperaug River at the Platt Farm Preserve (Fig. 21).


Figure 21. Releasing *S. tsugae* at the Platt Farm Preserve`along the Pomperaug River with members of the Southbury Land Trust in May 2021

Releases of *S. tsugae* were also made to protect and conserve remaining hemlocks at a popular rock climbing preserve, Ragged Mountain Foundation, in Southington, which is adjacent to the Metacomet Trail (part of the New England Scenic Trail) (Fig. 22).



Ragged Mountain Foundation, Southington

Figure 22. Rock climbers release *S. tsugae* at the Ragged Mountain Foundation, Southington, June 2021.

Homeowners are also increasingly turning to biological control with *S. tsugae* where appropriate, to protect their infested hemlock trees without chemicals. Communities in Ashford and Mansfield (Fig. 23) also purchased and released *S. tsugae* to help control HWA in residential settings where chemical control is not favored in the landscape or near waterways. Biological control to reduce HWA stresses and resultant hemlock decline may have profound impacts in sustaining trees and mitigating secondary hemlock borer outbreaks. Without any intervention, stressed hemlocks could die from adelgid, scale and secondary hemlock borer infestations and would pose hazards along hiking trails, at picnic areas and campgrounds, or near buildings. The alternatives of removal of dead or dying hemlocks would be a costly operation and popular recreation areas might need to be closed to the public.

Ashford

Mansfield

Figure 23. Biological control being implemented in residential community landscapes in Ashford and Mansfield in spring 2021

The MDC expanded releases of *S. tsugae* in 2021 to efforts to control HWA in hemlock forests along important feeder brooks for the Barkhamsted Reservoir, the primary water supply for the city of Hartford and its surrounding area (Fig. 24). Chemicals cannot be used in reservoir watershed forests to control pests and diseases and biological control is an important and safe alternative strategy to mitigate pest damage and tree mortality.

Releasing *S. tsugae* along the Hubbard River

Figure 24. An MDC forester releases *S. tsugae* on reservoir watershed hemlocks in June 2021

Training in hemlock pest identification, forest health assessments of hemlock pest threats and introducing biological control opportunities to state, municipal and private foresters, land trust and preserve managers, students (Fig. 25), hikers, nature lovers and the general public will be the focus of current and future HWA biological control outreach to diverse stakeholders in research and outreach funded by the USDA National Institute of Food and Agriculture's McIntire Stennis Cooperative Forestry program. Acting to protect and conserve hemlocks in all settings, state, private, municipal, including rare old growth hemlocks, and wilderness areas (Fig. 26), will also be an important mission of Connecticut's HWA biological control program using *S. tsugae*. Over 60 hemlock sites throughout Connecticut have been protected with *S. tsugae* since 1995 (Fig. 27) and the hope is to continue to expand biological control with *S. tsugae* in future years to towns, land trusts, municipal and private communities. Efforts in Connecticut will utilize diverse collaborative efforts to locate HWA outbreaks, and implement and establish *S. tsugae* to expand biological control of HWA to mitigate further spread and damage to our eastern hemlock stands.

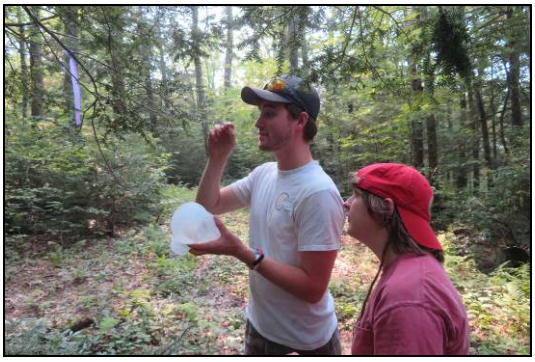


Figure 25. Forestry interns releasing *S. tsugae* in the remote hemlock wilderness of Wampee Pond, Great Mountain Forest in July 2021

Figure 26. Remote wilderness in Great Mountain Forest where old growth hemlocks still thrive, and are now threatened by the recent arrival of HWA.

Frequently Asked Questions (FAQs):

1) Are there downsides to introducing the non-native ladybeetles in the local area? Could they create a different problem?

There have been no negative impacts after introductions of Sasajiscymnus (formerly Pseudoscymnus) tsugae ladybeetles in the 26 years of its release, either in Connecticut or other states in the eastern U.S.A. In CT, >200,000 S. tsugae have been released since 1995, and there has never been a single negative report. Several million S. tsugae have been released throughout the range of HWA in many eastern states, again with no negative reports. It is highly unlikely that S. tsugae will pose any future problems nor threats to the environment because of its specificity in feeding on HWA. It can feed on other adelgids but these are also pests and S. tsugae highly prefers HWA. This species is closely associated with hemlock, does not feed on non-target species and because it tends to be solitary in habit, does not aggregate in the wild or on residential properties and therefore poses no nuisance factor as some other generalist ladybeetles do. This is the first HWA biological control agent released in the US and Connecticut was the first state to release S. tsugae in 1995.

Federal environmental assessments (EAs) were prepared for Sasajiscymnus tsugae (then known as Pseudoscymnus tsugae) for (1) field release in Connecticut in 1995, and (2) for field releases in multiple eastern states in 1999, to control infestations of HWA within the continental United States. These EAs are consistent with USDA, APHIS' National Environmental Policy Act (NEPA) implementing procedures (Title 7 of the Code of Federal Regulations (CFR), part 372). An EA examines the potential effects on the quality of the human environment that may be associated with the release of a non-native species and considers the potential effects of the proposed action and its alternatives, including no action. There were Findings of No Significant Impact (FONSI) granting approval for the field releases of S. tsugae in the US.

2) Are there measurable results?

For large areas, it is not likely to see hemlock recovery as a measurable result from widespread heavy HWA attack in the timespan of a single year. However, multiple year tree data from many older S. tsugae release sites in Connecticut do show little tree mortality and sustained hemlock recovery from heavy HWA infestations after several years, under the right environmental conditions, and without prolonged drought stress (12,14). Biological control is a long term management tool and hemlock recovery is a complex multi-factor process (7). It will take several years for S. tsugae to establish and impact the HWA infestations to the extent that the afflicted hemlocks start to show recovery.

But in spite of the many other stressors on our hemlocks (severe drought, elongate hemlock scale, hemlock borer, poor growing sites to mention a few, many of the original trees are still alive in 20-23-year old S. tsugae release sites in Connecticut, some even thriving, in spite of periodic HWA resurgence. The lack of widespread hemlock mortality in CT after the first biocontrol releases from 1995-2001 is evidence that introductions of S. tsugae have played a role in conserving Connecticut hemlocks for over two decades.

3) When is the best time to deploy the beetles?

Years of Connecticut research showed that an April-May release when average daily temperatures are 55-60 °F (13-16 °C), weather permitting, is optimal so that the beetles have a chance to reproduce and increase their numbers before the next winter. But releases have been implemented in late June into July although the beetles will not reproduce in the summer. However, they are well-adapted to hot, humid, rainy summers, actively feeding on the dormant first instars of the next HWA generation. The laboratory-reared beetles have better survival and reproduction in warmer spring temperatures but in time will become adapted to field conditions. They should not be released before sudden cold spells or turbulent weather to maximize survival.

4) How far do the ladybeetles range?

Sasajiscymnus tsugae ladybeetles are very tiny and cryptic, being entirely black and only about 2 mm in length. They fly readily and have been documented by bucket-truck sampling, to disperse upwards after release into the upper crowns of hemlock trees at heights of 50-65 ft (15- 20 m) (14). They are extremely difficult to track after release in expansive forests, partly due to the lack of suitable methods of sampling.

Current tree lower limb beat sampling is most inadequate as this technique only checks for beetles from ground level to about 7ft (2m) so most of the hemlock crown is not sampled. But there has been some incidental data showing

they can disperse many miles to non-release stands but this remains an area under-researched. In one year, dispersal of 0.5miles was observed at a Connecticut release site.

5) Do they need contiguous stands of HWA-infested hemlock?

They fly readily as adults so anecdotally, are capable of local and widespread dispersal in search of HWA. They are also long lived (1 yr + in caged field conditions).

6) Do they have predators?

Yes. Under laboratory and field conditions, S. tsugae adults and larvae have been observed to be killed and fed on by lacewing larvae, larger ladybeetle larvae, predatory fly larvae, predatory bugs and spiders.

7) Will there be some equilibrium reached where HWA will always exist and just be held in check by the ladybeetles?

It is the goal of biological control that an equilibrium between predator and prey is reached so that even if the pest persists, it is at low enough levels that are not damaging to the host tree or plant. Rarely are pests eradicated by biological control. Reality is quite different in the field: abiotic environmental factors such as severe winters can suddenly decimate HWA levels in this case, and the lack of adelgid prey would also affect survival of the predator, S. tsugae. These extreme unpredictable winter conditions could affect the persistence of this specialized predator which primarily feeds and reproduces on HWA. Hence, the objectives of the current program ae to augment in older release sites and introduce and establish S. tsugae in new sites where there is recent HWA resurgence.

8) Can the ladybeetles overwinter in New England?

Yes, our data showed that S. tsugae was readily recovered after severe Connecticut winters (12). They have also been recovered in Maine, Pennsylvania, New Jersey and in the southern Appalachians and are considered to be established. Most recently, a 2020-2021 cage study in New Hartford, Connecticut, showed that S. tsugae not only survived heavy snow, extreme wind chills on a hemlock branch in January 2021, but survived to reproduce and multiply during the hot and very rainy, humid summer of 2021.

References:

(1) USDA Forest Service. 2020. Forests of Connecticut, 2019. Resource Update FS-240. Madison, WI: U.S. Department of Agriculture, Forest Service. 2p. https://doi.org/10.2737/FS-RU-240.

(2) Peracchio, D. 2020. Connecticut's 2020 Forest Action Plan. 249 pp. https://portal.ct.gov/-/media/DEEP/forestry/2020-Approved-CT-Forest-Action-Plan.pdf

(3) Wharton, Eric H.; Widmann, Richard H.; Alerich, Carol L.; Barnett, Charles H.; Lister, Andrew J.; Lister, Tonya W.; Smith, Don; Borman, Fred. 2004. The Forests of Connecticut. Department of Agriculture Forest Service. Northeastern Research Station. Resource Bulletin NE-160. https://www.fs.fed.us/ne/newtown_square/publications/resource_bulletins/pdfs/2004/ne_rb160.pdf

(4) Ellison, A. M., Bank, M. S., Clnton, B. D., Colburn, E. A., Elliot, K., Ford, C. R., Foster, D. R., Klieppel, B. D., Knoeep, J. D., Lovett, G. M., Mohan, J., Orwig, D. A., Rodehouse, N. L., Sobczak, W. V., Stinson, K. A., Stone, J. K., Swan, C. M., Thompson, J., Von Holle, B. and Webster, J. R. 2005. Loss of foundation species: consequences for the structure and dynamics of forested ecosystems Front Ecol Environ 3:479-486

(5) Orwig, D. A., Foster, D. R. and Mausel, D. L. 2002. Landscape patterns of hemlock decline in New England due to the introduced hemlock woolly adelgid. J. of Biogeography 29:1475-1487

(6) Sasaji, H. and McClure M. S. 1997. Description and distribution of *Pseudoscymnus tsugae* sp. nov. (Coleopetera: Coccinellidae), an important predator of hemlock woolly adelgid in Japan. Annals of the Entomological Society of America 90:563-568

(7) Cheah, C. 2019. Hemlock woolly adelgid (HWA) and other factors impacting eastern hemlock. Connecticut Agricultural Experiment Station Factsheet January 2019. Available online: https://portal.ct.gov/media/CAES/DOCUMENTS/Publications/Fact_Sheets/Valley_Laboratory/Hemlock-Woolly-Adelgid-Factsheet-Dec-2018-Cheah-Final.pdf?la=en

(8) McClure, M. S., Cheah, C. A. S-J. and Tigner, T. 2000. Is *Pseudoscymnus tsugae* the

solution to the hemlock woolly adelgid problem?: An early perspective. Proceedings of a Symposium on Sustainable Management of Hemlock Ecosystems in Eastern North America 1999. (eds. K. McManus, K. Shields and D. Souto) p. 89-95. USDA Forest Service General Technical Report NE-267

(9) Cheah, C. A. S.-J. 2017. Predicting winter mortality of hemlock woolly adelgid in Connecticut by climatic divisions. Northeastern Naturalist Volume 24, Special Issue 7, 2017 B90-118 DOI: 10.1656/045.024.s713
Available as pdf at: https://portal.ct.gov/CAES/Publications/Publications/Hemlock-Woolly-Adelgid

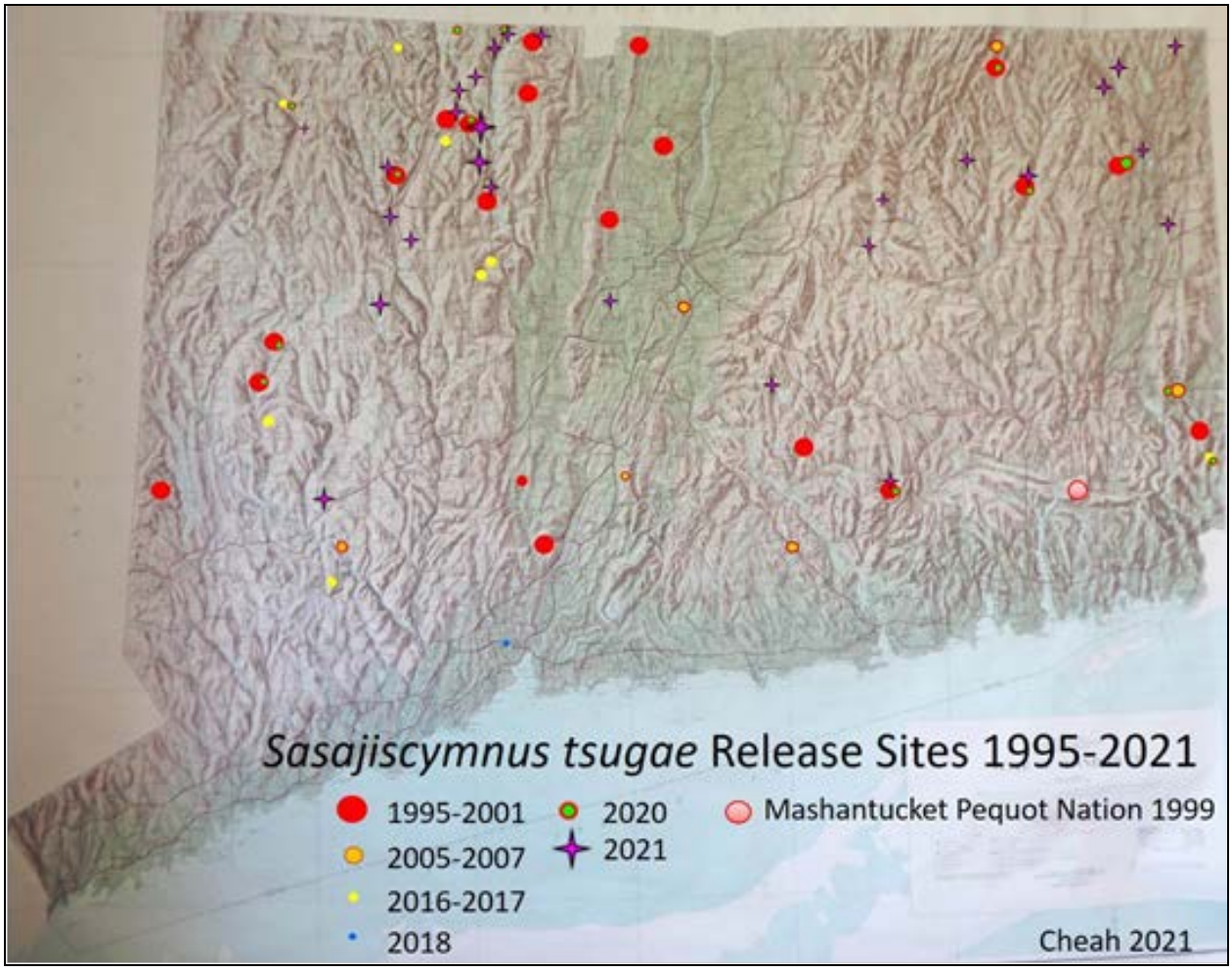
(10) Cheah, C. A. S-J. & McClure, M. S. 1998. Life history and development of *Pseudoscymnus tsugae* (Coleoptera: Coccinellidae), a new predator of the hemlock woolly adelgid (Homoptera: Adelgidae). Environmental Entomology, 27, 1531-1536.
https://doi.org/10.1093/ee/27.6.1531

(11) Cheah, C. A. S-J. & McClure, M. S. 2000. Seasonal synchrony between the exotic predator, *Pseudoscymnus tsugae* (Coleoptera: Coccinellidae) and its prey, the hemlock woolly adelgid, *Adelges tsugae*. Agriculture and Forest Entomology 2, 241-251
https://doi.org/10.1046/j.1461-9563.2000.00073.x

(12) Cheah, C. 2011. Chapter 4. *Sasajiscymnus* (=*Pseudoscymnus*) *tsugae*, a ladybeetle from Japan. In: Implementation and Status of Biological Control of Hemlock Woolly Adelgid. Tech.Coor. Onken, B. and Reardon, R. USDA Forest Service FHTET Publication FHTET-2011-04 pp. 43-52.
Available as pdf at: https://portal.ct.gov/CAES/Publications/Publications/Hemlock-Woolly-Adelgid

(13) Cheah, C. 2016. HWA winter mortality in Connecticut: implications for management and control. Connecticut Agricultural Experiment Station Factsheet July 2016. Available online at:
http://www.ct.gov/caes/lib/caes/documents/publications/fact_sheets/plant_pathology and_ecology/hemlock_woolly_adelgid_winter_mortality__7.12.16.pdf

(14) Cheah, C. 2008. The case for *Sasajiscymnus tsugae*: Biological control has helped save Connecticut's hemlocks. Abstract for a poster in Proceedings of the Fourth Symposium on Hemlock Woolly Adelgid in the Eastern United States. Hartford, CT. Feb. 12-14, 2008. B. O. Onken and R. Reardon (Compilers) FHTET 2008-01. pp. 279-280
Available as pdf at: https://portal.ct.gov/CAES/Publications/Publications/Hemlock-Woolly-Adelgid



Connecticut *Sasajiscymnus tsugae* release sites 1995-2021 by land ownership type

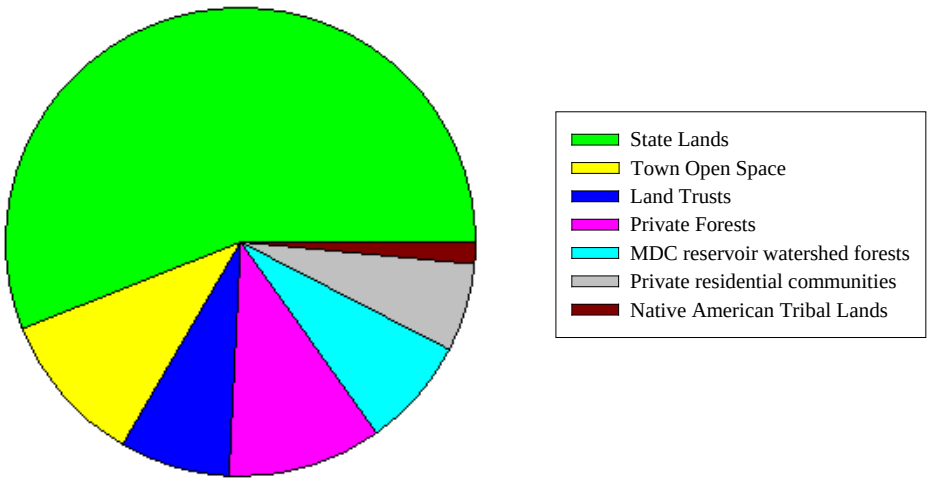


Figure 27. Cumulative 1995-2021 releases of *S. tsugae* (>200,000) in Connecticut and breakdown of releases by land type

ACKNOWLEDGMENTS: Funding from USDA National Institute of Food and Agriculture (NIFA) McIntire Stennis Cooperative Forestry Research Program 2015-2020; 2020–2024; Farmington River Coordinating Committee 2021, USDA Forest Service State and Private Forestry 1994-2009. Many Thanks to CT Department of Energy and Environmental Protection (DEEP) Forestry Division, CT DEEP State Parks; Steep Rock Association, Metropolitan District Commission (Natural Resources), Great Mountain Forest, Mt. Riga, Inc, Roxbury Land Trust, Wyndham Land Trust, Southbury Land Trust, New Hartford Land Trust; Towns of Monroe, Woodbury, New Hartford, New Haven, Woodbury Conservation Commission, Ragged Mountain Foundation, Pomfret Audubon, Friends of the American Legion and People's State Forests (FALPS), Dr. Allen Cohen; North Carolina State University, for CC predator diet, Jayme Boniewicz and team, Tree-Savers, PA, and many dedicated and enthusiastic volunteers from CT and NY. All photos by Carole Cheah.