Pseudoscymnus tsugae in Connecticut Forests: The First Five Years

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Abstract

Predator sampling and trends from six representative *Pseudoscymnus tsugae* release sites in Connecticut over the last 5 years are described for *P. tsugae* establishment, recoveries, dispersal, hemlock crown health, and levels of *Adelges tsugae*. Soil types and site quality for each site were characterized. The trends observed are discussed in terms of the interaction of abiotic factors such as abnormal winter temperature fluctuations, drought, and site quality. Patterns of high winter mortality for *A. tsugae* in the release sites obscured assessments of *P. tsugae* impacts. But infested hemlocks in older sites showed remarkable levels of new shoot production after a cool and very wet spring and summer in 2000. The results also are discussed in terms of implications for forest management objectives.

Keywords:

Adelges tsugae, hemlock woolly adelgid, *Pseudoscymnus tsugae*, hemlock, forest management.

Introduction

For half a century, hemlock woolly adelgid, *Adelges tsugae* (Annand), has been attacking eastern and Carolina hemlock, *Tsuga canadensis* Carriere and *T. caroliniana* Engelmann stands in eastern North America. In contrast, the first exotic predator to be introduced into North America for biological control of *A. tsugae* has only been released in the eastern United States in the past 6 years. *Pseudoscymnus tsugae* Sasaji and McClure (Coleoptera: Coccinellidae), native to Japan, was first released in Windsor, Connecticut in May 1995 (Cheah and McClure 1996). The oldest release sites in North America are in Connecticut where more than 140,000 beetles have been released in 20 sites. The following is a preliminary discussion of currently emerging patterns in *P. tsugae* establishment and trends in hemlock health for six representative Connecticut study sites, 1996 to 2001. An attempt also is made to interpret the complex interactions at some of these sites involving environmental factors such as abnormal weather patterns and the influence of site quality on the ability of hemlocks to recover from potentially devastating adelgid infestations.

Overview of Biology and Life History of P. tsugae. At a mere 2 mm in length, *P. tsugae* is a tiny black coccinellid of the little known but prolific Tribe Scymnini, adults and larvae of which are important predators of many insect pests e.g., aphids, adelgids, mealybugs, scales (Gordon 1976). Intensive earlier research on the biology and life history of *P. tsugae*, a hitherto unknown species, focused on quantifying its potential for mass rearing and suitability for biological control of *A. tsugae* in eastern North America (Cheah and McClure 1996, 1998). Many attributes of *P. tsugae* point to its promise for biological control of *A. tsugae*. Both adult and larvae will feed on all stages of *A. tsugae* on *T. canadensis* (Cheah and McClure 1996) and the species is relatively prey-specific, avoiding scales and aphids and other insect associates on hemlock, although capable of feeding and developing to adult on other adelgid species (Cheah in preparation). Its comparable fecundity, longevity and relative development time, and excellent synchrony with its prey in the laboratory and field indicate a long season of impact on the pest population with two overlapping field generations occurring to predate on three generations of *A. tsugae* in Connecticut (Cheah and McClure 1998, 2000). Preliminary studies in 1996 and 1997 included field releases and attempts to quantify the predator's short-term impact on adelgid populations. Results from those studies showed that in 5 months, *P. tsugae* was able to significantly reduce local adelgid populations on monitored release branches, in contrast to similar control branches which excluded predators (McClure et al. 1999; McClure and Cheah 1999). However, the more important questions remained to be answered:

1. Is *P. tsugae* able to adapt and establish in a variety of natural hemlock sites after 5 years?
2. Is hemlock recovery in release sites compromised by intrinsic site quality?
3. Is *P. tsugae* having an impact on adelgid populations?

In an effort to answer some of these questions, the following is a summary and discussion of patterns of *P. tsugae* recoveries and trends in adelgid levels and hemlock health in representative release sites in Connecticut from the last 5 years.

Materials and Methods

Five Year Release Sites: Bloomfield and New Hartford. Two sites on reservoir watershed lands (Bloomfield and New Hartford) belonging to the Metropolitan District Commission, were selected for the long-term study of *P. tsugae* introductions and establishment. At both sites, hemlock is a major component of the release area. Initial releases of around 1,000 adults per site in 1996 were augmented area-wide in late May and June 1997, 1998, and 1999 to approximately 10,500 adults per site after first recording successful overwintering in mid-spring. The lower hemlock crown in the release area was sampled through the summer and fall in 1997 to 2000 using a plastic bat to dislodge predators from sampled branches onto a beating sheet (1 m^2). The areas adjacent to the immediate release areas also were sampled for dispersal. In each site, the recovery rate for *P. tsugae* stages was determined by the number of stages recovered in the total time spent sampling by one to four people.

Representative hemlocks in each release area (n = 10 trees) also were identified and tagged for crown evaluations using the standard Forest Health Monitoring criteria: live crown ratio, crown density, foliage transparency, percentage crown dieback and live branches (5% classes). In recording crown estimates of new shoot production and level of adelgid infestations, a broader range was adopted due to the challenging nature of determining trends in the upper crown of mature trees, and binoculars were used to assess upper crown conditions when possible. New shoot production and adelgid infestations were estimated in classes of 0 to 10%, 11 to 50%, 51 to 75% and > 75% (after Tigner 1997, unpublished). At the New Hartford site, an infested control area was located about one mile from the release area on the opposite side of the reservoir, and consisted of mature hemlocks lining an access road. Five trees were tagged here for crown evaluations. An assessment of hemlock mortality in a 30 by 17 m area at the two release sites was made in 2001. All live and dead hemlocks within the area were identified by tree class (suppressed, intermediate, and codominant).

Both release and control sites were moderately to heavily infested at the time of predator release. Adelgid infested hemlock tip samples from the lower crown (n = 10 to 20/site) were randomly selected in late February or March each winter beginning in winter 2000 for estimates of sistens winter mortality in each of the release sites. Counts were made under a dissecting microscope to determine the proportion of live and dead adelgids (minimum of 1,000 adelgids/site) per sample.

In 2001, a cooperative study to attempt detection of *P. tsugae* and adelgid spread was launched with foresters from the Forestry Division, Connecticut Department of Environmental Protection and the Metropolitan District Commission (MDC). The surrounding forests of the MDC and the Nepaug State Forest were scouted for accessible infested hemlocks for a whole tree sampling procedure. Eight trees at distances ranging from 740 to 2,600 m from the release area were marked for felling onto large plastic white sheets. Foliage and debris dislodged during the tree felling were collected from the sheets. Branch samples were clipped from the lower, middle, and upper crowns of each tree and refrigerated for examination under a dissecting microscope.

Three Year Sites: Granby and Union. In 1999, two sites were located in northern Connecticut state forests for the comparison of two patterns of *P. tsugae* releases. At both sites, a plot center was identified and four transects in the four (approximate) cardinal compass directions were set up at 100 m intervals to 200 m intervals to establish sampling points for detection of predator dispersal. The site in the Enders State Forest, Granby, is a steep, heavily wooded hemlock gorge with the 200 m points of the southwest and south transects located on the opposite side of the river. The site in Bigelow Hollow State Park, Union, is situated on the upper section of a wooded ridge and surrounded by extensive hemlock stands. Transects there radiate out down slope from the plot center at the top of the ridge.

Releases of 10,000 *P. tsugae* adults/site were made in April 1999, with a single point release on a hemlock in the plot center at Granby and multiple points of release at the plot center, and 100 m transect points (2,000 adults/point) at Union. Five hemlocks were selected and tagged at the plot center and each transect point for adelgid and crown evaluations (n = 45 trees/site). On the lower crown of each tree, four tips at the four compass directions were selected for adelgid counts on 30 cm of new and/or old shoot growth. Counts were made in the spring and fall/winter each year to estimate seasonal adelgid trends. Hemlock crown evaluations were estimated in three classes: < 10%, 10 to 50%, and > 50% for percentage tip dieback, new shoot production, and adelgid levels. The Forest Health Monitoring criteria for other crown ratings as described above were retained. The same procedure as described above was used for assessments of overwintering sistens mortality.

Other Release Sites: Washington and Barkhamsted. A site in Washington at the Steep Rock Association was established in 1998 to track dispersal of P. tsugae using a single point release of 10,000 P. tsugae on the top of a wooded hemlock ridge. Transects running north, east, and west at intervals of 50 m were laid out to 200 m, and four hemlocks were selected and tagged at each transect point for crown ratings after the method described for 1996 sites (16 trees/transect; n = 48). Predator sampling was again limited to the lower crown at each transect point.

One of the more recent release sites was selected to address the limitations of sampling only the lower crown and to determine the impacts of a larger release. The People's State Forest in Barkhamsted has a heavy hemlock component and access via a road to enable bucket truck sampling. Twenty-five hemlocks along a 0.45 mile uphill stretch of road were tagged for release of 20,000 *P. tsugae* in May 2000. A further 10 trees were marked for hemlock crown ratings and adelgid counts and overwintering assessments were carried out as before.

Results and Discussion

Bloomfield and New Hartford. Representative *P. tsugae* release sites in northern Connecticut are summarized in Table 1, describing soil types, woodland suitability groups or site qualities, and the type of *P. tsugae* releases. The Bloomfield site is the poorest, with shallow Holyoke soils (Site quality IV to V, fair to poor) (Table 1) where bedrock comprises 50% of the surface (Shearin and Hill 1962). The New Hartford site occurs on excessively drained gravelly sandy soils of the Terrace Escarpment type (Gonick et al. 1970), which are moderately favorable for hemlock growth (Woodland Suitability Group 6) (Table 1). Such site predisposition to drought stress on hemlock health cannot be ignored in evaluating any biological control attempts in hemlock stands.

The results of four years' sampling (1997 to 2000) are shown in Figure 1a (New Hartford) and Figure 1b (Bloomfield). *P. tsugae* was able to establish to overwinter successfully in 1997 with as few as 1,000 adults released in 1996. Overwintering success has been recorded in 4 out of 5 years at Bloomfield and in all 6 years in New Hartford through a succession of mild and erratic winters. In later years (2000 and 2001), *P. tsugae* was more readily recovered at the infested fringes of the release area. *P. tsugae* recovery rates in these two sites peaked in early September 1998 when many adults (60 adults at Bloomfield and 77 adults at New Hartford) and several larvae were readily recovered in the release areas at both sites, verifying independent studies that had shown the production of a second field generation by *P. tsugae* (Cheah and McClure 2000). Adults were still active and recovered during sampling into December at both sites during one of the warmest winters on record (NRCC 2000). In New Hartford, spring and summer predator recoveries have remained steady until 2001, while declining in Bloomfield, in parallel with a reduction in adelgid levels (Figure 2 and 3b), which particularly affected sampling in the lower crown. A new procedure utilizing whole tree felling for sampling in New Hartford in July 2001 detected one adult *P. tsugae* in a new area, with moderate adelgid infestations 640 m (0.4 miles) from the release area, but none in seven other hemlocks felled within 2,600 m (1.6 miles) of the release area.

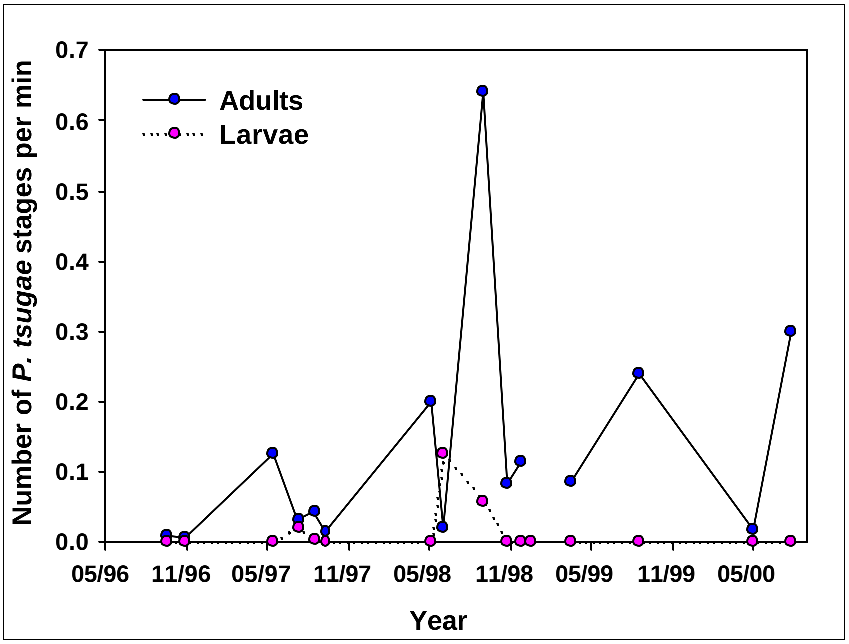
In 1998 and 1999, the northeast region suffered severe droughts while the first half of January 2000 was extraordinarily warm (60s to 70s °F), with average temperatures 8 to 10°F above normal. In mid-January, temperatures very abruptly changed overnight to below zero on more than one

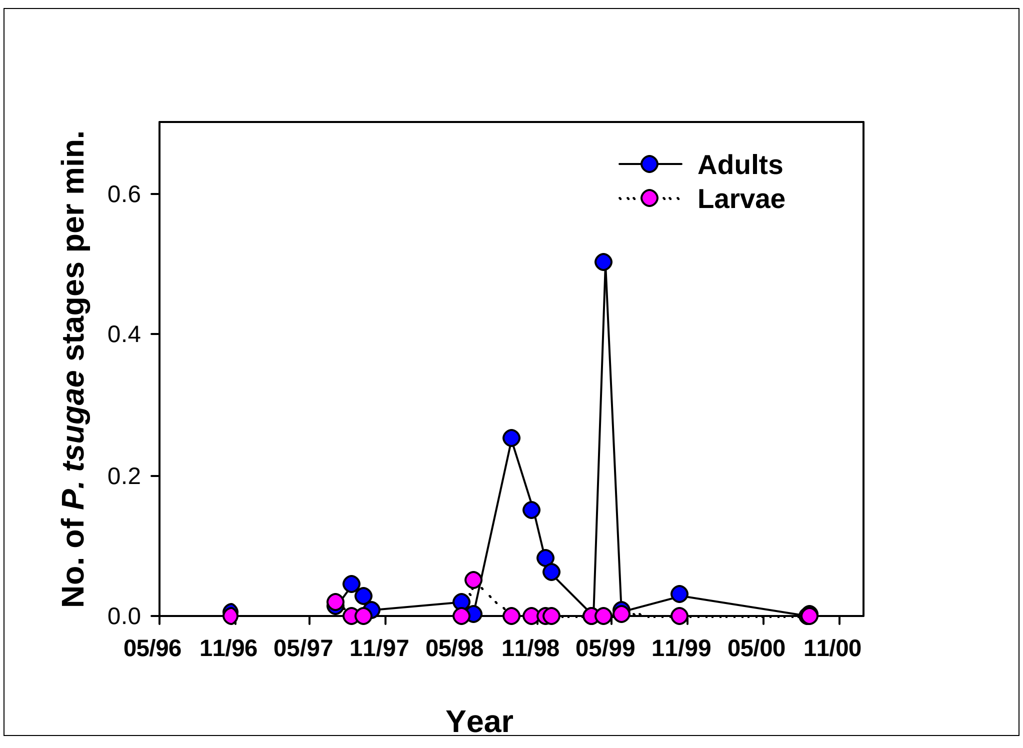
Table 1. Soil Types and Woodland Suitability/Site Quality Groups for Selected Connecticut *P. tsugae* Release Sites

Site	Town	County	Soil Type	Woodland Suitability	Release Type/ Year
MDC Reservoir	Bloomfield	Hartford	RkE (Rocky land, Holyoke) Bedrock ≥50% of surface 15-35% slope	IV-V* Fair to Poor	Augmentation to 10,000 1996 - 1999
MDC Reservoir	New Hartford	Litchfield	Tg (Terrace Escarpments) (Hinckley/Merrimac/Windsor) Gravelly sandy; >15% slope	Group 6 **	Augmentation to 10,000 1996 – 1999
Steep Rock Preserve	Washington	Litchfield	Rh (Rock land)/ HxE (Hollis extremely rocky fine sandy loam); 15-35% slope	Group 11 **	Single point; 10,000 1998
Enders State Forest	Granby	Hartford	ChD/CrD (Charlton stony fine sandy loam) 15-25% slope	III – IV* Good to Fair	Single point; 10,000 1999
Bigelow Hollow S.P.	Union	Tolland	BpD/BnD (Brimfield extremely rocky fine sandy loam) rock outcrops 5-50% of surface;15-25% slope	Group 6 **	Radial, 5 points; 10,000 1999
People's State Forest	Barkhamsted	Litchfield	CrD (Charlton stony fine sandy loam) 15-35% slope	Group 8 **	Longitudinal along road; 20,000 2000

* Estimated site quality of forest soils; Soil Survey for Hartford County, Connecticut (Shearin and Hill 1962).

** Woodland suitability groups; Soil Surveys of Litchfield and Tolland Counties, Connecticut (Gonick et al. 1970; Ilgen et al. 1966).





Figures 1a and 1b. Lower crown recovery of *P. tsugae* in New Hartford (a) and Bloomfield (b).

occasion (NRCC 2000), resulting in heavy mortality of adelgids in northern Connecticut (Table 2). Winter mortality of *A. tsugae* was 83% in Bloomfield and 76% in New Hartford, in stark contrast to only 10% in 1999. Adelgid levels in all three sites (including the control site) have been declining over the past five years (Figures 2 and 3b). However, *P. tsugae* was readily recovered from both sites in the spring or summer of 2000 and also in five other northern Connecticut release sites. The wild winter temperature fluctuations were followed by an abnormally cool spring and summer with above normal precipitation in 2000 (NRCC 2000), conditions much favored for hemlock growth

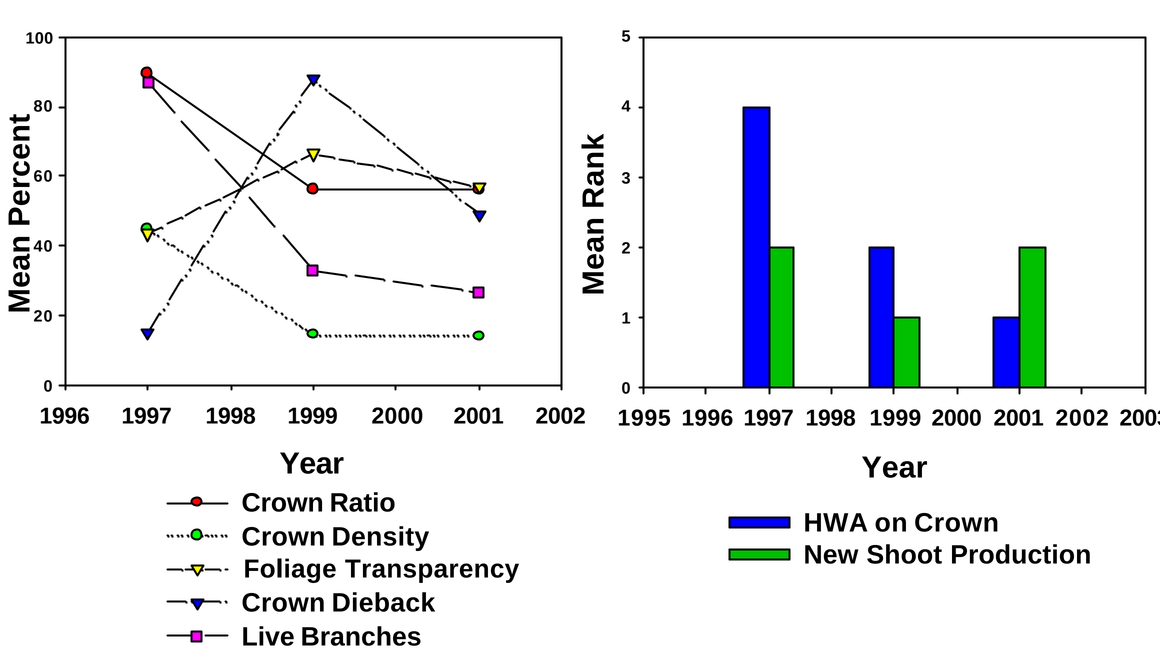


Figure 2. Five-year trends in hemlock health at the Bloomfield release site.

% Overwintering Mortality of HWA

Site	2000	n	2001	n
Bloomfield	83.3 ± 28.0	1139	46.5 ± 18.3	1196
New Hartford	75.9 ± 15.0	1041	40.0 ± 9.7	1001
Granby	92.9 ± 8.0	1144	60.6 ± 6.7	1086
Union	94.6 ± 4.5	1073	61.8 ± 15.2	1018

Table 2. 2000 and 2001 Overwintering HWA Sistens Mortality at four Northern *P. tsugae* Release Sites in Connecticut

and recovery. In the New Hartford site, there had been considerable hemlock decline in 1999 with very heavy crown dieback and increasing foliage transparency in 1999 (Figure 3a), but this was followed by some remarkable recovery in 2001, with 50 to 75% of surviving crowns producing new shoots (Figure 3b). In the corresponding control site, trends in declining hemlock health were similar and there was also measurable refoliation, but to a lesser degree (< 50% of crowns) than in the *P. tsugae* release site (Figure 3b). New shoot production was particularly evident in the uppermost live crowns of codominant hemlocks in the release areas. Previously declining hemlocks at the Bloomfield site showed a similar pattern of new shoot production (Figure 2), although tree mortality was four times that of New Hartford (Table 3) and hemlock borer activity was recorded in several trees. Suppressed and intermediate hemlocks on the rocky thin soils in Bloomfield suffered much higher mortality, and in New Hartford, the foliage of understory suppressed hemlocks appeared to be relatively free of adelgid. A further factor complicating hemlock health trends is the presence of elongate hemlock scale, *Fiorinia externa* Ferris, in the Bloomfield and New Hartford release sites (McClure et al. 1999) while the control site has negligible infestations.

Table 3. 2001 Hemlock Mortality at 5-year Release Sites in Connecticut

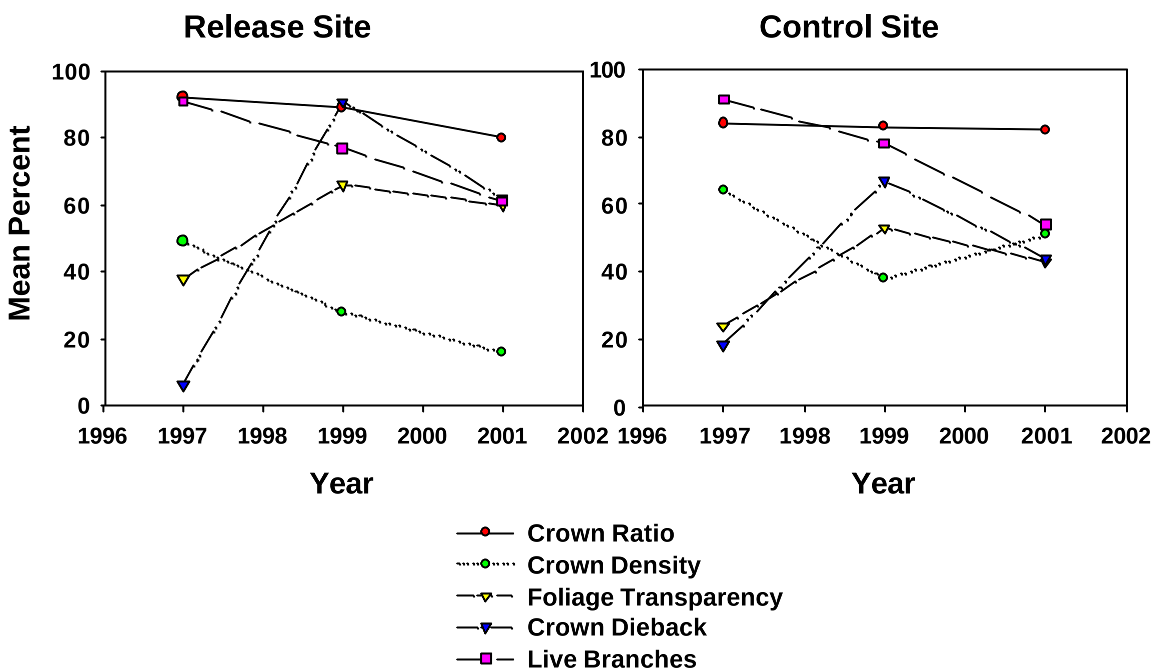


Figure 3a. Five-year trends in hemlock health at the New Hartford release and control sites.

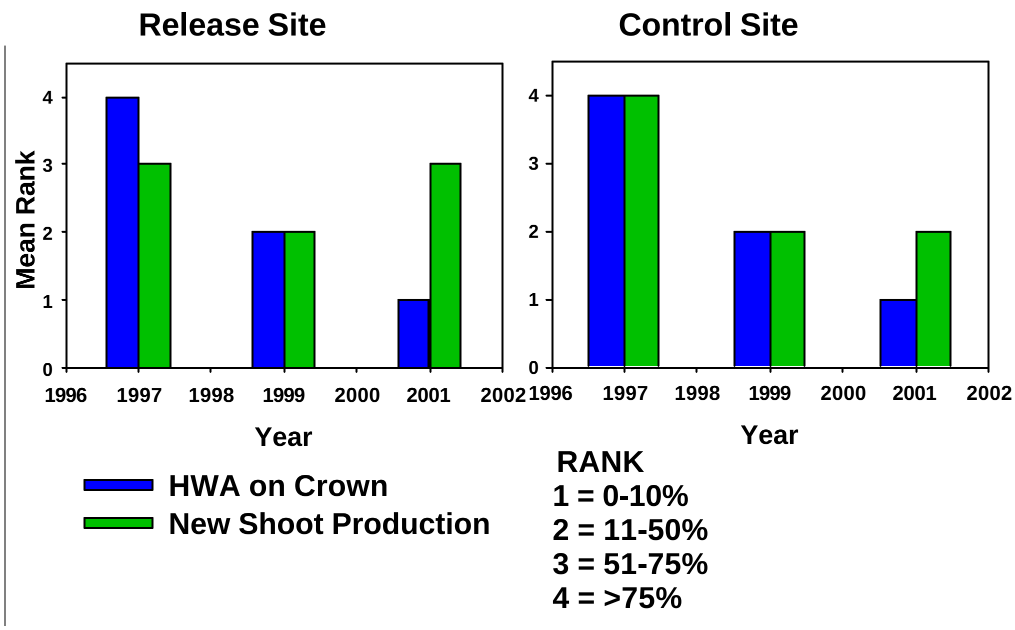


Figure 3b. Five-year trends in HWA levels and new shoot production at the New Hartford release and control sites.

Tree Class	Bloomfield % Tree Mortality	n	New Hartford % Tree Mortality	n
Suppressed	55.0	28	0	22
Intermediate	100.0	7	22.2	9
Co-Dominant	40.0	5	42.8	7
All Classes	52.5	40	13.1	38

Three-Year Sites: Granby and Union. Both the Granby and Union sites exhibited very patchy, variable distributions of adelgid on the lower crowns along the transects. The Granby site consists of well-drained Charlton stony, fine sandy loam soilswhich are rated as good to fair sites for hemlock (Site quality III to IV) (Table 1) (Shearin and Hill 1962). Starting in the spring of 1999, adelgid densities up to 100 m (n = 100 tip samples) at the Union site (0.34 ± 0.69 adelgid/cm) were, however, twice that of the Granby site (0.18 ± 0.47 adelgid/cm). A significant reduction in adelgid levels at a release site as compared to a comparable control site would indicate a measure of *P. tsugae* impact. As a single point introduction of *P. tsugae* was made at the Granby site, transect points at 200 m from the release center were analyzed as "controls" for comparisons in the early stages of the study. However, as with previous sites, the sudden drop in temperatures in January 2000 also brought about heavy adelgid mortality at the center and all transect points (Figure 4), masking any predator impact. The following year, in spring 2001, individual tip estimates of adelgid densities at the release center were compared with densities at the 200 m transect points and found not to be significantly different for the center, N 200 m, SE 200 m and SW 200 m (Wilcoxon Signed Rank Test for non-normal distributions; $p > 0.05$). There were no live adelgids at the E 200 m point in spring 2001. Adelgid densities in these sites are very variable and patchy by nature and contribute to the limitations of this density sampling method. Crown evaluations at the Granby release center revealed a moderate resurgence of adelgid levels in 2000 at the release center but a decline again in 2001(Figure 5a). New shoot production trends revealed an even more important pattern occurring in the central release area. This important indicator of hemlock health remained at > 50% for all three years, while there were marked decreases at the 200 m points (Figure 5b). At the 100m points, adelgid levels remained at < 10%, with the exception of the east transect. The impact of *P. tsugae* at 100 m remains uncertain at this time while moderate winter

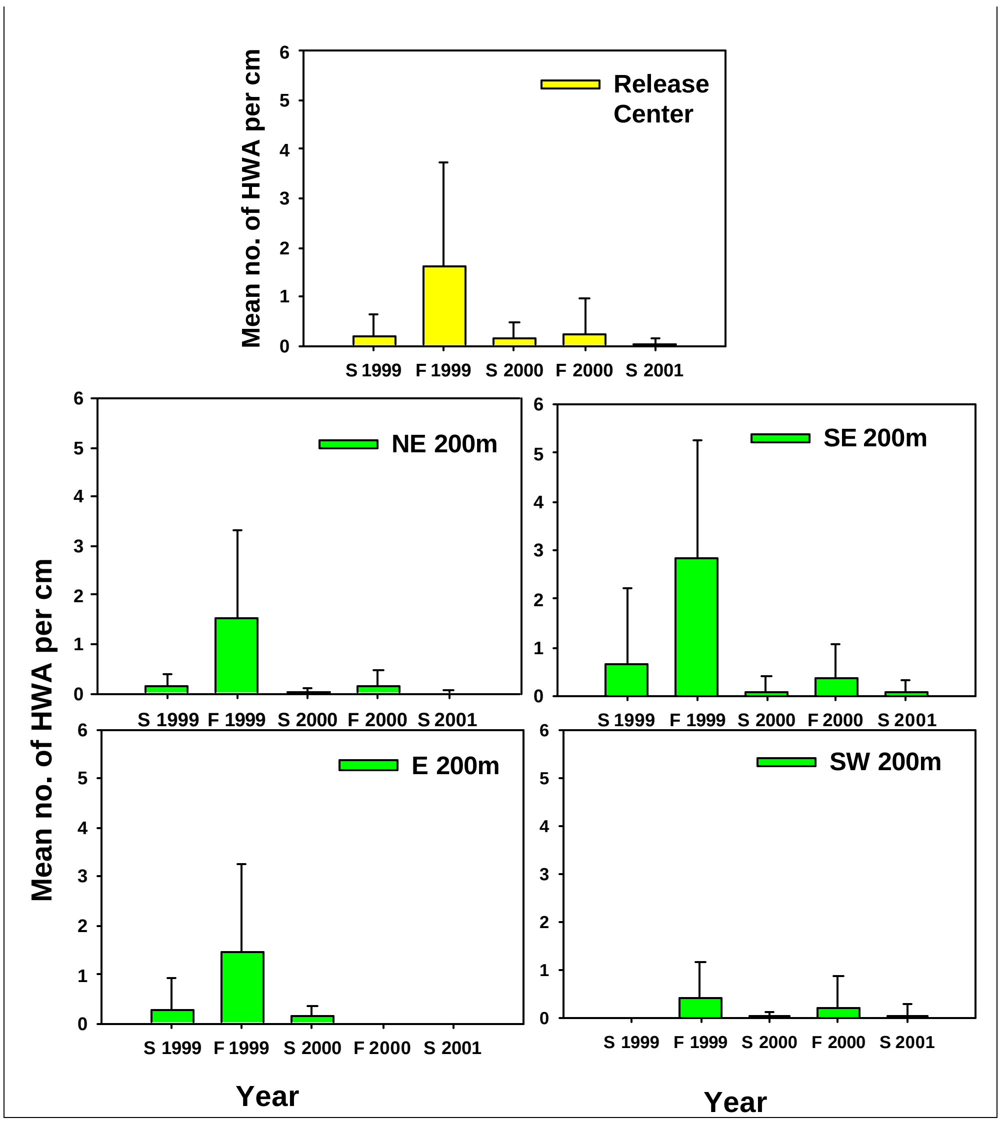


Figure 4. Lower crown HWA densities at the Granby release and 200 m transect points (1999 to 2001).

mortality continues to depress adelgid populations.

The Union site is composed of shallow, somewhat excessively drained soils of the Brimfield series, which are extremely rocky, fine sandy loam. This site is rated as Woodland Suitability Group 6 with restricted moisture capacity due to exposed bedrock which occupies 5 to 50% of the surface (Ilgen et al. 1966). At the Union site, crown patterns of adelgid infestation and new shoot production also

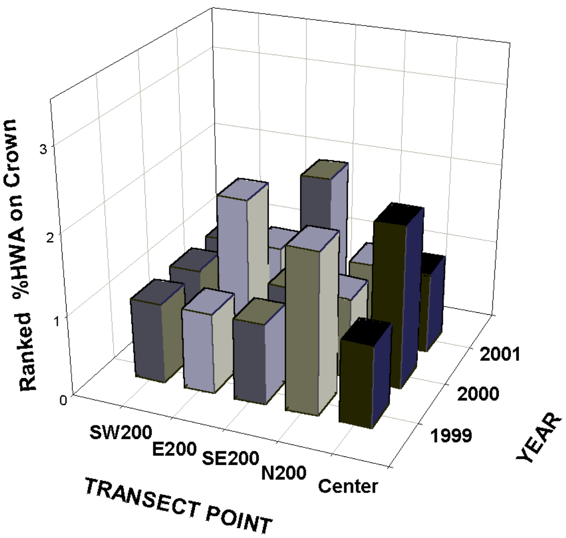


Figure 5a. Trends in HWA levels at the Granby release and 200 m transect points (1999 to 2001).

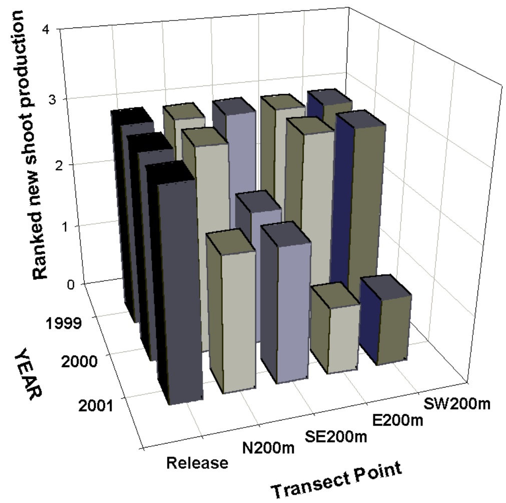


Figure 5b. Trends in new shoot production at the Granby release and 200 m transect points (1999 to 2001).

were variable where smaller numbers of *P. tsugae* were released in a radial pattern at the center and 100 m transect points. At this site, the 200 m transect points were not valid for use as controls as *P. tsugae* has been recorded as dispersing to 100 m or more in a single season. Analysis here concentrated instead on 3 year patterns at the entire release area to 100 m from the plot center. General adelgid densities on the lower crown indicated a decline (Figure 6a) but crown assessments indicated resurgence of adelgids in 2000 with much variability in new shoot production (Figures 6b and 6c). This may explain the difficulty in recovering *P. tsugae* in 2000 at both sites with the limitations of sampling only the lower crown. Patterns of *P. tsugae* recovery rates were compared between the two sites (Figure 7). Although *P. tsugae* appeared to be more readily recovered in the same year of release at the Granby site, there were no significant differences in the rates of recoveries at Granby compared to that at the release center and three of the 100 m release points in Union ($p > 0.05$).

Dispersal and Distribution in the Canopy. The sharp fluctuations in temperature in January 2000 inflicted 100% adelgid mortality at the Washington site, where 10,000 *P. tsugae* were released in 1998. This site is the poorest rated for tree growth (Woodland Group 11) (Table 1), with thin soils and over-exposed bedrock which composes more than 50% of the surface (Gonick

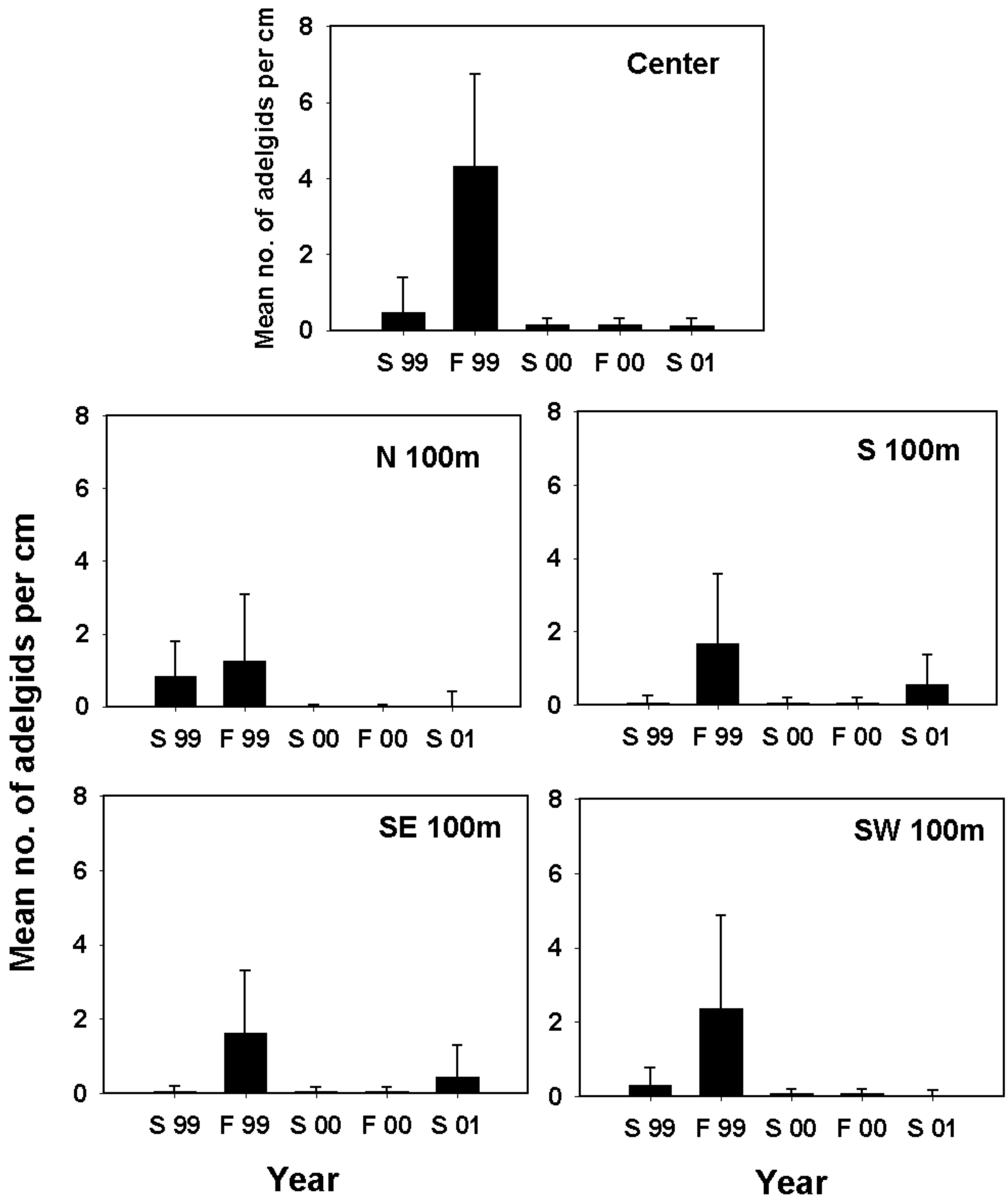


Figure 6a. Lower crown HWA densities at multiple release points at the Union site (1999 – 2001).

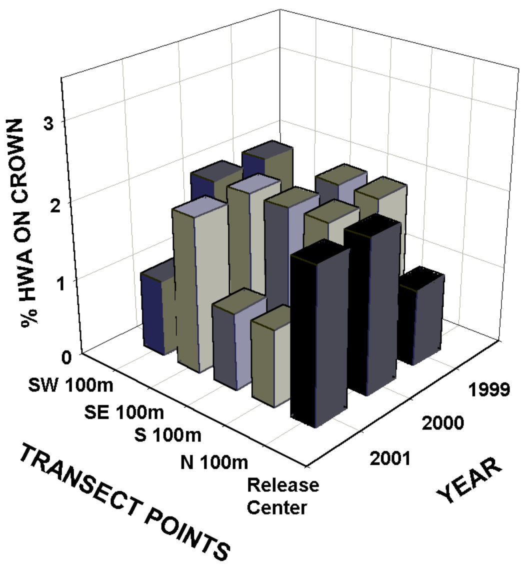


Figure 6b. Trends in HWA levels at multiple Union release points (1999 – 2001).

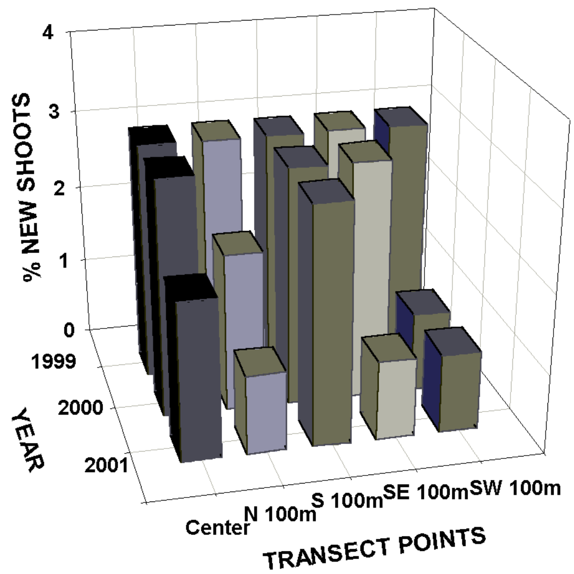


Figure 6c. Trends in new shoot production at multiple Union release points (1999 – 2001).

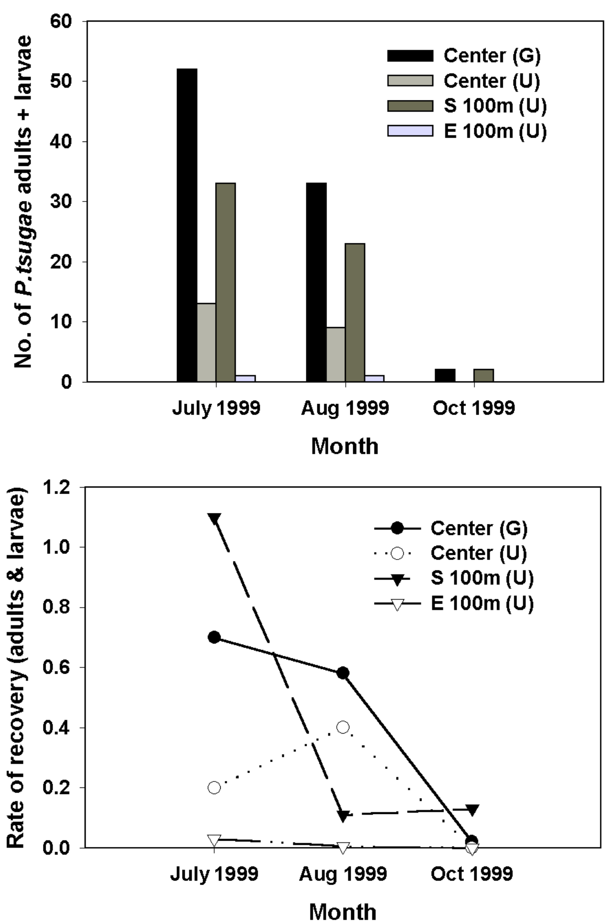


Figure 7. Comparison of P. tsugae recoveries at Granby (G) and Union (U).

et al. 1970). It is extremely prone to drought stress. As such there has been moderate tree mortality, with many codominants succumbing at the site to secondary hemlock borer attack. Concurrently, although *P. tsugae* was still recovered in the release area in 2000, a significant dispersal occurred from the ridgetop to hemlocks by the river, a distance of 0.58 mile, in 2 years. Table 4 shows the observed dispersal of *P. tsugae* in the lower crown at selected sites. Current methods of lower crown sampling are inadequate and improved sampling technology is required.

In response to the difficulties in monitoring for *P. tsugae* in older forested release sites with the limitations of the current sampling method, a cooperative effort was launched in 2001 with private arborist companies, in particular, Asplundh Tree Experts. The provision of a bucket truck for sampling along the road at the 2000 release site in Barkhamsted in 2001 yielded the recovery of one adult and eight larvae on several trees at 12 to 20 m up in the canopy. This confirms the upward spread of *P. tsugae* into the canopy after only one year and is further evidence of its adaptability to its new environm

Summary and Implications for Forest Management

It can be seen from continuously monitoring the oldest release sites in Connecticut that *P. tsugae* is indeed established at several sites and has proved its adaptability to climatic variations since 1996. Hemlock health and the extent of hemlock recovery in 3 to 5 year release sites has been influenced profoundly by site qualities. Of the six sites discussed, two are on the most unsuitable sites for tree growth (Washington and Bloomfield), and only one is located on a fair to good site (Granby). The rest of the sites are on moderately suitable sites which are well to excessively drained and thus very prone to sustained periods of drought. Low to moderate hemlock mortality was recorded in marginal sites with poor soils and little available moisture after severe droughts in 1998 and 1999, although the effects may have been somewhat tempered by the cool, rainy spring and summer of 2000. Annual trends of adelgid levels were further complicated by the intervention of extreme winter temperature fluctuations, obscuring any conclusions at this time on predation impacts. However, as a component of a co-adapted, specialized predator-prey system, populations of *P. tsugae* are intrinsically dependent on the populations of its preferred prey, *A. tsugae*. Density-independent effects of extreme temperature fluctuations on the survival of developing sistens populations over the course of a winter can dramatically depress adelgid populations to a level in the spring where *P. tsugae* may gain a numerical advantage in prey population regulation, but on a timescale yet known.

In view of the abiotic and biotic pressures on hemlocks, traditional forest management objectives may require a second look. If healthy hemlocks continue to be removed from more favorable sites to promote other species, this may eventually result in the relegation of the species to poor quality, marginal, and drought-stressed sites, where it is doubtful if the introduction of *P. tsugae* or any other potential biological control agents can have sufficient impact on adelgid infestations to save the hemlocks. Conserving more favorable woodland sites for preserving high-quality seed sources for regeneration may be a more viable option with the combined help of introduced predators like *P. tsugae* and unpredictable weather events.

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