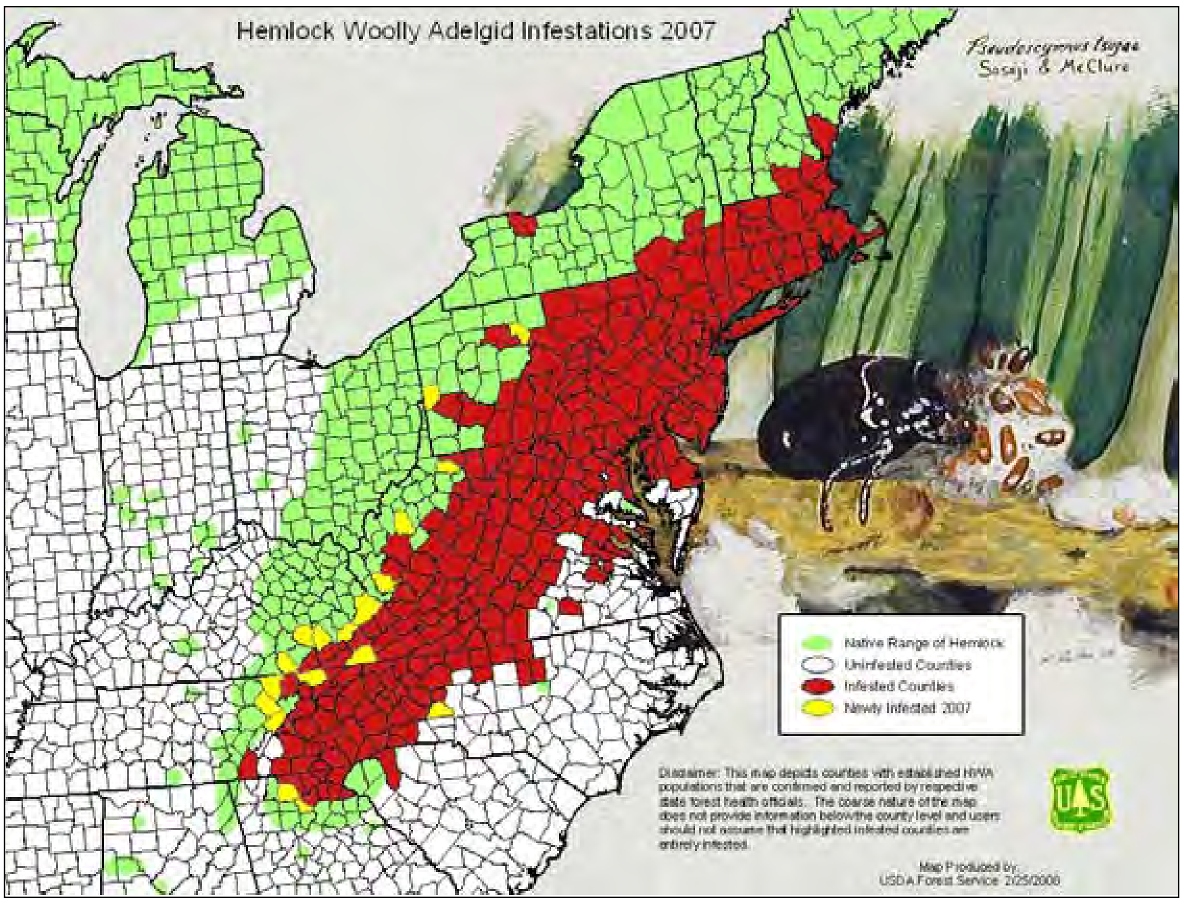
Forest Health Technology Enterprise Team

TECHNOLOGY
TRANSFER

Hemlock Woolly Adelgid

FOURTH SYMPOSIUM ON HEMLOCK WOOLLY ADELGID IN THE EASTERN UNITED STATES

HARTFORD, CONNECTICUT
FEBRUARY 12-14, 2008



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Predator Beetles at Work: Evidence-based Assessments of Private *Sasajiscymnus tsugae* Release Sites in Western North Carolina

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ABSTRACT

Private site releases of *Sasajiscymnus tsugae* predator beetles offer an important opportunity to expand our knowledge about biological control of the hemlock woolly adelgid (HWA), *Adelges tsugae*. Because of cost considerations, private site beetle releases may utilize much lower release densities (100-300 per acre) than reported for USDA releases on public lands (1,000-5,000 per acre). Evidence-based assessments can be facilitated by the accessibility of private sites. This report focuses on the development and application of measurement strategies for a two-year assessment of a set of riparian woodland sites and a one-year assessment of a set of woodland and neighborhood sites. A digital measurement strategy for quantifying changes in hemlock crown density is proposed, and observations on beetle behavior at release sites are suggested. Low-density releases proved effective in both neighborhood and woodland settings. Tests of low-density waterway releases suggest a strategy for initiating biological control coverage in riparian woodland areas. Need for evidence-based USDA policies and practices concerning biological control of HWA is noted.

RELEASES

2006

The research reported here was initiated in 2006 as an environmental intervention to save a large number of severely HWA-defoliated eastern hemlocks (*Tsuga canadensis*) on a 150-acre headwaters tract on the Blue Ridge escarpment in Western North Carolina. The waterways and hemlocks on the property were mapped by the landowner/author in 2005. In April 2006, 3,000 HWA predator beetles, *Sasajiscymnus tsugae* ("Sassie"), purchased from a local private insectary lab (Conservation Concepts) were released in hemlock areas across the property.

Cost considerations motivated the author to draw upon published results from prior field work in Connecticut (McClure 2001; McClure and Cheah 2003) to design a low-density, colony-based release design intended to establish self-sustaining predator beetle colonies in the field. This release effort included several dose-response components to assess different release densities, ranging from 30 to 100 beetles per release site and 100 to 300 beetles per multi-site colony.

The larger hemlock trees on the property were located primarily along approximately 9000' of small waterways on the property and ranged in size from 20-35" DBH and up to over 100' in height. All were heavily defoliated from an HWA infestation of unknown duration first noted in 2003. Some dead trees were present in the worst infestation area and several large hemlocks had been "topped" by wind gusts in 2003. Ten large trees around a pond had been treated in July 2004 with imidacloprid trunk injections, with no visible subsequent effects on tree health or new foliage production. Most of the larger trees on the property had produced little or no new foliage in the 2005 growth season.

Because there were no expectations for short-term results, no baseline observations of the trees were recorded prior to predator beetle releases. Careful observations of hemlock foliage changes were begun in mid-June 2005 in response to dramatic production of new foliage on large trees around the pond. By mid July, the same kinds of new crown foliage production were visible on crowns of larger trees in the vicinity of beetle release areas. After leaf-fall in mid-October, most of the larger trees along the waterways were observed to have produced visible amounts of new crown foliage. (This new-crown-growth phenomenon was not observed in comparable size trees along the waterways on other properties in the immediate area.) This production of new crown growth did not appear to be limited to the large trees in the immediate area of predator beetle releases but extending hundreds of feet—in one instance, over 1000' along a waterway onto an adjacent property.

Some release site trees produced new foliage on lower branches as well; the amount of new foliage produced appeared to be greater on trees with substantial sunlight exposure. Prior chemical treatment may have also have contributed to the quantity of growth buds and, hence, the amount of new foliage produced. However, this was confounded with the effect of sunlight: all previously treated trees were also exposed to considerable sunlight because of their location around the pond. Nonetheless, the positive association between sunlight exposure and amount of new foliage production was indisputable.

Smaller trees and the middle and lower branches of most of the larger trees (with the exception of some release area trees with full sunlight exposure) typically produced little or no new foliage in this first year, while crowns of larger trees in the same area showed substantial new growth. It was hypothesized that this new growth was made possible by reductions in adelgid density due to predation by adult beetles and larvae (McClure and Cheah 2003; Evans 2004). To test this hypothesis, sample twigs collected from these new growth areas in October/November 2006 were examined for HWA crawlers, and very low crawler densities were observed. (New growth twigs collected from adjoining areas had very high crawler densities.)

If we presume that observed foliage changes are a result of predator beetle behavior, then we can use these foliage changes as indicators to indirectly observe and track the movement of the beetles during the first season after release. Use of this method suggests that, after release, the beetles tend to move to the tops of the largest hemlocks in the area to feed and lay eggs. Then, they move to adjacent tall trees, repeating the process over and over again, sometimes over considerable distances. Note that the new growth used as an indicator here is produced during the spring hemlock growth cycle (May/July in this area). Therefore, this indicator only represents the first approximately three months behavior of released and F_2 beetles.

It is important to remember that the larger trees in this area were severely defoliated - the process observed here might differ for healthier trees with heavier adelgid densities. The released beetles were approximately 4 weeks of age and hence reproductively active—the process might differ for younger beetles that are not yet reproductively active, but in these situations, the released beetles appeared to move considerable distances during the first several months.

Why were the beetles' early activities apparently concentrated at the crowns of the larger hemlocks? Several hypotheses have been suggested. Perhaps on heavily defoliated trees, the crown holds the largest adelgid population (food supply). Perhaps the beetles were attracted to higher locations or to the light that was present at such locations. Or perhaps those light conditions facilitated growth buds that could be released due to the beetles predation.

2007

The largely unanticipated short-term results from the 2006 releases prompted a number of new efforts for the 2007 release season. These included 1) a quest for a reliable measurement strategy for documenting changes in hemlock crown density, 2) the refinement of a low-density release strategy that would be cost-effective in private applications, 3) grass-roots efforts to involve community groups in planning and implementing beetle releases, and 4) continued (second year) observation of the 2006 release sites noted above.

1) Measuring Changes in Hemlock Crown Density

The magnitude of short-term changes observed in hemlock foliage in 2006 (changes that could not be quantified in the absence of baseline measurements) motivated a search for an objective measurement strategy for hemlock foliage change. The standard USDA crown density measurement strategy, using multiple trained raters with crown density-foliage transparency cards (Cheah et al. 2005), was not readily applicable to private sites where no professional raters were available. An alternative digital strategy involving no human judgement component seemed preferable for such private applications. The foliage changes that were so obvious to the human eye should also be detectable in photographic images. But how could information on hemlock crown density (HCD) be extracted from such images?

The quest for a digital measurement strategy built on the inputs and knowledge of several individuals with professional graphic and photographic backgrounds. Christine von Lersner (2007) first suggested ideas for using Adobe Photoshop software to extract pixel density information from photographs. Rita and Steve Buchanan (pers. comm.) followed up with suggested refinements in the procedure using the Histogram display from Photoshop Elements to quantify pixel density information.

My contribution to defining the problem was to focus on a special type of photograph: one that silhouettes the hemlock crown against an open sky. (While such trees are not representative of trees in hemlock areas; the hope was that they could be useful for comparisons over time and across different areas.) In such photographs, the hemlock trunk, branches and foliage (density) are represented by darker pixels, while the background (transparency) is represented by lighter pixels. The first operation utilizes the Histogram in Photoshop Elements to chart the percentage dark/light content of the pixels in a digital photograph from darkest to lightest. The second operation uses the histogram to calculate the cumulative density at a darkness level representing hemlock foliage. This density level can be compared with corresponding measures for other photos to measure change in one tree or to make numerical comparisons between different trees.

The photos and data below (Figure 1) illustrate the application of this measurement strategy to a 2007 *Sasjiscymnus tsugae* release site on hemlocks near the Horsepasture River in Sapphire, North Carolina. Two sets of photos were taken in mid-April and mid-July, approximately three months apart. Below are the 'before' and 'after' photos for a site containing a pair of defoliated hemlocks. At the top are the photos, cropped in order to focus the measurement procedure on the same crown areas for comparison. At the bottom are the histogram outputs for the two photos.

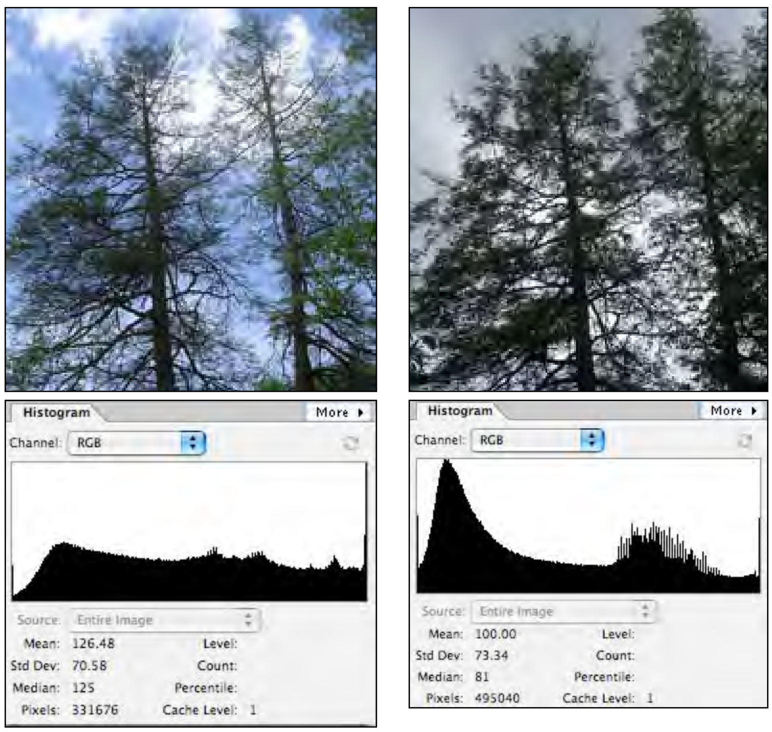

Figure 1. Digital measurement strategy for hemlock crown density: mid-April (left) photograph and histogram and mid-July (right) photograph and histogram.

These photographs indicate that there appears to be more foliage on the trees in mid-July than mid-April. The histogram allows us to quantify these density differences in terms of the percentage of pixels in the darker color range. The histogram is a plot representing the distribution of pixel values across the spectrum on the horizontal axis and pixel frequency on the vertical axis. It also provides cumulative percentile information—from dark to light—at any specified level that can be used to obtain quantitative measures of pixels representing hemlock crown density.

The corresponding histograms for these two photos illustrate even more clearly the extent of foliage growth on the hemlocks in the two pictures. The histogram for the April photo shows a relatively uniform pixel value distribution moving horizontally from dark (left) to light (right), with a spike at the far right for the white clouds. The histogram for the July photo shows a definite peak for darker pixels in the lower part of the distribution, attributable to new foliage.

We can use these histograms to measure hemlock crown densities by calculating the percentile of darker pixels in a photograph. The proposal here is to use cumulative percentile numbers derived from a photograph's histogram to represent the crown density in the pictured tree(s) as well as to measure changes in that density over time. However, this will require selecting a darkness-level benchmark to capture hemlock foliage growth.

Table 1. Comparisons of hemlock crown density measurement benchmarks.

	Darkest 1/2	Darkest 1/3	Darkest 1/4
mid-April	51.12%	34.75%	25.35%
mid-July	61.99%	51.30%	44.39%
3-month change	10.87%	16.55%	19.04%

The histograms illustrate that changes due to new foliage growth appear well down into the darker end of the spectrum. This will help us to identify the "best" point in the spectrum for measuring these foliage changes. The table above contains readings for three different darkness levels: darkest half, darkest third, and darkest fourth. A review of histograms for these and other photographs suggests that differences due to foliage changes are concentrated in the darkest 20% of the spectrum. The results in the table indicate that either the 25% or 33% benchmarks would have considerable sensitivity to the three-month foliage changes represented here. Specifically, the 25% benchmark, representing the darkest 25% of the pixel color spectrum, indicates a 19.04% increase (due to new foliage growth), while the 33% benchmark, representing the darkest 33% of the pixel color levels, indicates a 16.55% increase (due to new foliage growth).

Variability in light conditions is always a concern in photographic comparisons, and field comparisons will often exhibit such variability. However, it appears that the proposed use of the histogram adequately separates the variability in backlight levels from that of hemlock foliage. Background light is represented on the right side of the distribution—note the spike for white clouds for the April photograph. But the hemlock crown density is derived from the darkest portion of the histogram spectrum and does not appear to be unduly influenced by the relative lightness or darkness of the background. A more serious concern may be the exposure of subject trees to illumination from the front, biasing the foliage measurement. This issue warrants further investigation, but overcast, dusk, and dawn appear to offer the best conditions for photos to be used in this measurement technique.

2) Low-Density Beetle Release Strategies

My 2006 releases utilized much lower beetle release densities than typically noted in the literature. While this was primarily driven by cost considerations, a careful effort was made to include a dose-response component in the release design, utilizing systematic variations in the number of beetles released at different sites as well as the number of beetles per hemlock acre. Asaro et al. (2005) previously reported that per tree releases of 300 beetles were as effective in reducing adelgid densities as releases of 3,000, but lower release densities were apparently not considered and per acre densities were not reported. The per-tree densities implemented here ranged from 30 to 100 per site, and the per-acre (of hemlocks) release densities ranged from 100 to 300 per acre. (It should also be noted that all the trees in these release areas were well above the 50% defoliation level that is often cited as the upper limit for effective biological or chemical treatment.)

One bit of good news from these trials was that even small releases of 50 beetles per tree and 100 per hemlock acre appeared to be effective at initiating the biological control process over a substantial area. While some positive correlation was noted between release density and quantity of new foliage production, the relationship was not strong. Other situational issues such as tree health, sunlight, and stage of infestation appear to be more important determinants of quantity of foliage production after beetle release. This should not be too surprising, as the first several months of beetle activities could not affect the production of hemlock growth buds. It could only "release" the buds that had already been produced but were being suppressed by the ongoing adelgid infestation (Evans 2004).

The colony-based aspect of the release design utilized multiple sites within 100' of one another, with 30-50 beetles per site (depending on tree size) to define a self-sufficient colony. Such colonies could then be spaced as local conditions and resources dictate. Extension of these low-density release procedures to a wider range of private release sites in 2007 allows further assessment of a variety of issues and procedures.

3) Expanding Private Beetle Release Efforts

News about the surprising results of the 2006 releases was circulated through local media in Brevard and Cashiers and through presentations to local property owner and other public interest groups. This led to a grass-roots movement in the Brevard area involving public officials, private landowners, and residential developers that led to the 2007 release of about 25,000 "Sassie" beetles purchased from Conservation Concepts and EcoScientific Solutions. Efforts in the Sapphire/Cashiers area were a bit more limited, resulting in the release of about 12,000 purchased beetles.

While these release efforts were limited by the supply of beetles available, several obstacles to the involvement of private individuals in biological control of HWA were noted. Foremost among these were active USDA Forest Service media efforts (by personnel in Asheville, Pisgah National Forest and Nantahala National Forest) to discourage landowner involvement, both for larger woodland tracks and for neighborhood-level applications. This was reinforced by numerous statements by local Forest Service and other USDA officials stating that there was "no information" about the effectiveness of HWA predator beetles and by an active media campaign by chemical interests (led by a private arborist) (Slade 2007; Preston 2007) dismissing the effectiveness of HWA biological control efforts. While the latter efforts are understandable in light of economic incentives, the former suggest the need for more careful attention to evidence-based HWA policies on the part of USDA/Forest Service policy-makers.

Not all the private releases noted above were known to the author, and not all of those known have yet been carefully assessed. The discussion here will employ a case-study format to present some sites where assessment efforts have been completed and where ample evidence on first-year results is available.

Most hemlocks in the Brevard area appeared to be in an earlier stage of HWA infestation than trees at the 2006 sites and were in a less-defoliated condition. In contrast, many hemlocks in the Cashiers and Sapphire area were just as or possibly even more defoliated than 2006 sites ,with a significant number of dead trees present in some locations.

Generally speaking, the results at these 2007 private release sites paralleled those observed in 2006 and reported above. The dramatic renewals of new top growth in defoliated larger trees were apparent here as well, but the large hemlock tree-hedges (15-30' in height) that were common in Brevard neighborhoods also proved to be very responsive to beetle-induced re-foliation. Several wild 2007 "test releases," designed to obtain more accurate distance measures for predator beetle releases on waterways, will also be reported.

Case 1: In-town neighborhood area. A condominium 4-plex in downtown Brevard had a 15' hemlock hedge along the front and one side, totaling about 400'. Trees were in mid-level infestation, with adelgids present at all levels, foliage "graying," and bare tips present on many branches. A release was made of 200 beetles at 25 beetles per site, distributed at equal intervals along the hedge. By mid-July, all areas of the hedge were covered with extensive new growth. Adjoining properties benefited as well. Two larger (30') and more severely defoliated tree hedges—one 150' in length, running parallel to the complex across a two-lane highway, and the other perpendicular to this and running 300' feet away from the property—were also covered with new foliage.

Case 2: Residential development area. Sherwood Forest, a large environmentally-oriented development (1,000 acres) in the Brevard area, initiated biological control efforts to replace chemical control efforts. About 6,000 beetles were released on "green" and trail areas as well as on privately-owned tracts of residents and of adjoining property owners. Assessments after leaf-fall indicated substantial re-foliation of larger hemlocks in release areas and along waterways. Plans are in place to extend biological control coverage to additional acreage.

Case 3: Municipal efforts for biological control of HWA. Proposals were made in fall 2007 to both the City of Brevard and Transylvania County for purchase of predator beetles for release at municipal sites in the Brevard area (see Acknowledgements). City officials readily agreed to a 1,000 beetle purchase for release in several small parks and a 400-acre watershed area adjacent to the city. County deliberations included USDA extension officials (see Acknowledgements) in a series of meetings that lead to a positive vote by County Commissioners for a similar purchase. The County release was directed to an 8-acre mansion property (Silvermont) in downtown Brevard. This property contained approximately 300 medium-size to large hemlocks and was surrounded on all sides by private properties containing large hemlocks.

Brevard City park and watershed releases involved younger trees in relatively early infestation areas, where hemlock health was not yet significantly impaired and defoliation was at an early stage. Spot checks at these release sites indicate reductions in adelgid densities and continued production of new growth but none of the dramatic foliage changes observed on more severely defoliated trees.

The County release was done by ecology students at Brevard College. These trees were larger and more heavily infested than those in the city. Heavy HWA infestations had moved from the ground level to higher-level branches, and some "graying" of the hemlock foliage was apparent. While a formal assessment will be conducted by the release group, significant new growth is apparent on the crowns of many hemlocks in the release area.

Case 4: Wild waterway test areas. Observations from 2006 releases along waterways suggested an unexpectedly long range of influence by newly released "Sassie" predator beetles. Several tests were conducted to further examine this issue. The first was a relatively isolated waterway (Democrat Creek) in a new Nature Conservancy tract: Silver Run Preserve in the Nantahala National Forest.

This site was located in the vicinity of the 2006 release area, and the medium to large trees along the waterways were severely defoliated with little new foliage being produced. In March 2007, two sets of 50 *Sasajiscymnus tsugae* beetles were released at locations near the confluence where two tributaries come together to form the creek, which then runs several miles south before emptying into the Whitewater River. (The Whitewater River is benefiting from numerous USDA-sponsored beetle releases by the Clemson insectary beginning in 2005, creating large areas of re-foliating hemlocks along this waterway.)

Dramatic new crown growth was observed at these two release sites by mid-July, but a more careful assessment was delayed until after the fall of deciduous leaves in mid-November. Because of the defoliated state of hemlocks in this area, new crown growth offered a clear indicator of developments. New growth was observed at least 1,500 feet down the creek to the south, about 800 feet east up one tributary, and 600 feet to the north up the other tributary.

At a second waterway release site utilizing 100 beetles, new crown growth was observed for an area extending over 2,000 feet downstream and about 500 feet upstream. This suggests that a series of low-density waterway releases might be an effective strategy for extending biological control into riparian areas.

4) Second Year Observations at Beetle Release Sites

In 2007, continued observations of the 2006 beetle release sites described above have suggested further inferences concerning the behavior of beetles, hemlocks, and adelgids during the process of establishing biological control. During the winter of 2006, observations of wind-break hemlock twigs distributed across forest floors indicated that a majority of the upper-level new growth showed no adelgid re-infestation (from HWA crawlers emerging in fall 2006). Twigs with HWA present showed a range of infestation densities from light (less than 5 per twig) to heavy (most new needles affected). The adelgids were not gone, but neither were they overwhelming the recently-produced new hemlock growth.

Over the course of the 2007 growing season, the emergence of new growth continued in the 2006 new growth areas (mostly in the crown). However, in this new second-season growth also extended to grey and defoliated branches on middle to lower sections of the larger trees, as well as to smaller trees in the area. This "trickle-down" effect continued the re-foliation of the largest trees and initiated this process on middle to smaller trees in the release areas.

By fall 2007, the density of HWA crawlers on lower branches of both larger and smaller hemlocks in release areas was lower than noted in the previous year. In addition, individual beetles were regularly found on small trees in the area, although never in large quantities. During winter 2007, hemlock twigs and branches that had been cleaned of emergent crawlers were commonly found on trees of all sizes.

These observations suggest several interesting hypotheses for further investigation at these sites and others. First, it suggests that the extensive movement and egg-laying of newly released, reproductive-age beetles beyond immediate release areas (as noted in the first season) did not hinder the growth of beetle populations in the release areas to biologically effective levels. Second, it suggests that the low-density release strategies utilized (and discussed above) were effective in initiating biological control of HWA. Third, it suggests that it would be better to think of biological control of HWA as a process than as an event. Because of the extended hemlock growth cycle, the extension of biological control benefits to recovery of normal foliage on all trees in an area will be a multi-year process. However, two years into the process, trees that show foliage recovery have shown no indication of adelgid population resurgences or of damage to recovering new foliage areas.

DISCUSSION

Forest Managers

Evidence from the use of low-density releases of *Sasajiscymnus tsugae* predator beetles offers new options for extending biological control of HWA across a broader range of woodland areas. Unlike conventional, high-density beetle releases that require relatively healthy trees with heavy adelgid infestations, low-density releases can be utilized in hemlock areas with trees experiencing substantial defoliation and relatively low adelgid densities. While not all trees may be saved in such areas, a release of 100 beetles in a severely defoliated hemlock cove or waterway area can establish a self-sustaining beetle colony that will cover a substantial area and provide support for recovery of surviving hemlocks in the area, resulting in long-run protection to these ecologically critical zones. Waterway releases (e.g., at roadway crossings of creeks or rivers) offer an effective way of dispersing beetles into riparian woodlands to protect important hemlock habitats.

USFS

Evidence from low-density *Sasajiscymnus tsugae* releases in both private woodlands and neighborhood areas suggests the need for a more careful evaluation of USFS policy statements in light of evidence-based criteria. Several public statements made by USFS representatives in western North Carolina—that predator beetles cannot help trees that are more than 50% defoliated (Slade 2007) and that predator beetles are not effective for use in neighborhoods (Ellison 2007)—appear to be contrary to the evidence presented above.

More generally, the negative orientation of local USFS statements about predator beetle effectiveness seems to be based more on "opinion" than evidence, and efforts to discourage private landowners from utilizing biological control strategies appear to be misguided, at the very least. Our native hemlock habitats exist on both private and public lands. And just as predator beetle releases in state and national forest areas can benefit hemlocks on adjoining private properties (Connor 2006), private releases can benefit adjoining public lands.

So long as increasing beetle supplies to private landowners does not reduce supplies to public lands, maximizing private as well as public releases of HWA predator beetles should be encouraged. The USFS could even attempt to guide, rather than discourage, private participation in biological control of HWA. For example, there are many nature-oriented groups in our communities (e.g., hikers, anglers, and birders) that would be capable of purchasing beetles in 1000-unit lots and conducting low-density releases in environmentally sensitive public areas —areas that are not being addressed by current public release efforts.

It has taken four decades to recognize the HWA problem and another decade to find a solution. There should no delay in getting this solution deployed as widely as possible on both private and public lands. There is still time to save many of our native eastern and Carolina hemlock trees and habitat areas.

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