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Sticky Cards for Monitoring Dispersing Balsam Woolly Adelgid (Hemiptera: Adelgidae) Crawlers in Subalpine Fir Stands

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Abstract

Balsam woolly adelgid (BWA), *Adelges piceae*, is an invasive insect colonizing true fir in North America. Following its recent range expansion into Utah, BWA has caused significant mortality of subalpine fir (*Abies lasiocarpa*). The first instar (crawler) is the only motile life stage and is responsible for dispersal among trees, usually by wind. Due to BWA's small size, detection and monitoring is challenging. In this study, monitoring for dispersing crawlers using sticky cards was compared to a more labor-intensive bark sampling method in four northern Utah stands with the goal of identifying a simplified approach for crawler detection. Sticky card orientation (horizontal or vertical) for optimal crawler capture and a mesh covering for bycatch reduction were tested. Sticky cards were effective in detecting dispersing crawlers and counts generally tracked unsettled crawler densities observed on bark samples. Horizontal card placement had higher crawler captures than vertical cards, and the addition of a mesh covering on the card reduced bycatch as compared to uncovered cards. Results provide evidence that sampling with horizontally-placed, mesh-covered sticky cards can be an effective tool for detection and monitoring of dispersing BWA crawlers, thus supporting phenology research and decision-making for optimal timing of BWA management.

Keywords: invasive insect, forest pest, true fir, integrated pest management

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Introduction

The balsam woolly adelgid (BWA), *Adelges piceae* (Ratzeburg) (Hemiptera: Adelgidae), is an invasive forest insect native to south-central Europe (Havill et al. 2020). Likely imported to North America via infested nursery stock, BWA was first reported in Maine in 1908 with detections following in southeastern Canada and the eastern United States (U.S.) (Amman 1962; Balch 1952; Havill et al. 2021; Kotinsky 1916; Speers 1958). In the western U.S., BWA was first found in California in 1928 and Oregon in 1930 (Annand 1928; Keen 1952). Balsam woolly adelgid has since expanded its range into the Intermountain West with first reports in Idaho in 1983 (Livingston and Dewey 1983) and northern Utah in 2017 (Davis et al. 2022; Rideout et al. 2023).

Balsam woolly adelgid utilizes its long stylets to feed on the parenchyma tissue of true fir species (genus: *Abies*). Host species exhibit varying degrees of susceptibility to mortality by BWA with vulnerable species including Fraser fir (*A. fraseri* (Pursh) Poir.) and balsam fir (*A. balsamea* (L.) Mill.) in eastern North America and grand fir (*A. grandis* (Douglas ex D. Don) Lindl.) and subalpine fir (*A. lasiocarpa* (Hook.) Nutt.) in western North America. BWA may attack white fir (*A. concolor* (Gord. & Glend.) Lindl. ex Hildebr.), but mortality rates are low (Ragenovich and Mitchell 2006). Feeding by BWA leads to decreased water flow, photosynthesis, and respiration. Mortality of native North American firs can occur in varying lengths of time dependent upon environmental conditions, population levels, and location of infestation on the tree (Cook et al. 2010; Davis et al. 2022; Hain 1998; Mitchell 1967; Puritch 1973)

Balsam woolly adelgid has three nymphal instars and is asexual in its introduced range in North America. Voltinism of this species varies depending on the region, though a bivoltine life cycle is expected in much of northern Utah (Rideout et al. 2023). The first instar, “the crawler”, is often the overwintering life stage and is roughly 0.4 mm in length (fig. 1A) (Balch 1952). This is the only stage capable of motility, and upon hatching, the crawler may wander up to 30 m on the bark surface, probing for two hours to three days in search of a suitable feeding site (Balch 1952). During this unsettled period, crawlers may be passively dispersed among trees and across forested landscapes primarily by wind and occasionally by animals (Atkins and Hall 1969). Upon choosing a feeding site, the crawler will insert its stylets and begin feeding on parenchyma cells. Crawlers then begin exuding wool-like strands of wax which continues throughout its nymphal development to the adult stage when wool becomes most apparent (Bryant 1974). Maturity into adulthood typically occurs by mid-June, followed by an egg-laying period lasting roughly two weeks. Development throughout the summer leads to a second generation of adult maturity and egg-laying occurring in August–September (Amman 1962; Woods and Atkins 1967). Crawlers therefore present in September and October will typically overwinter.

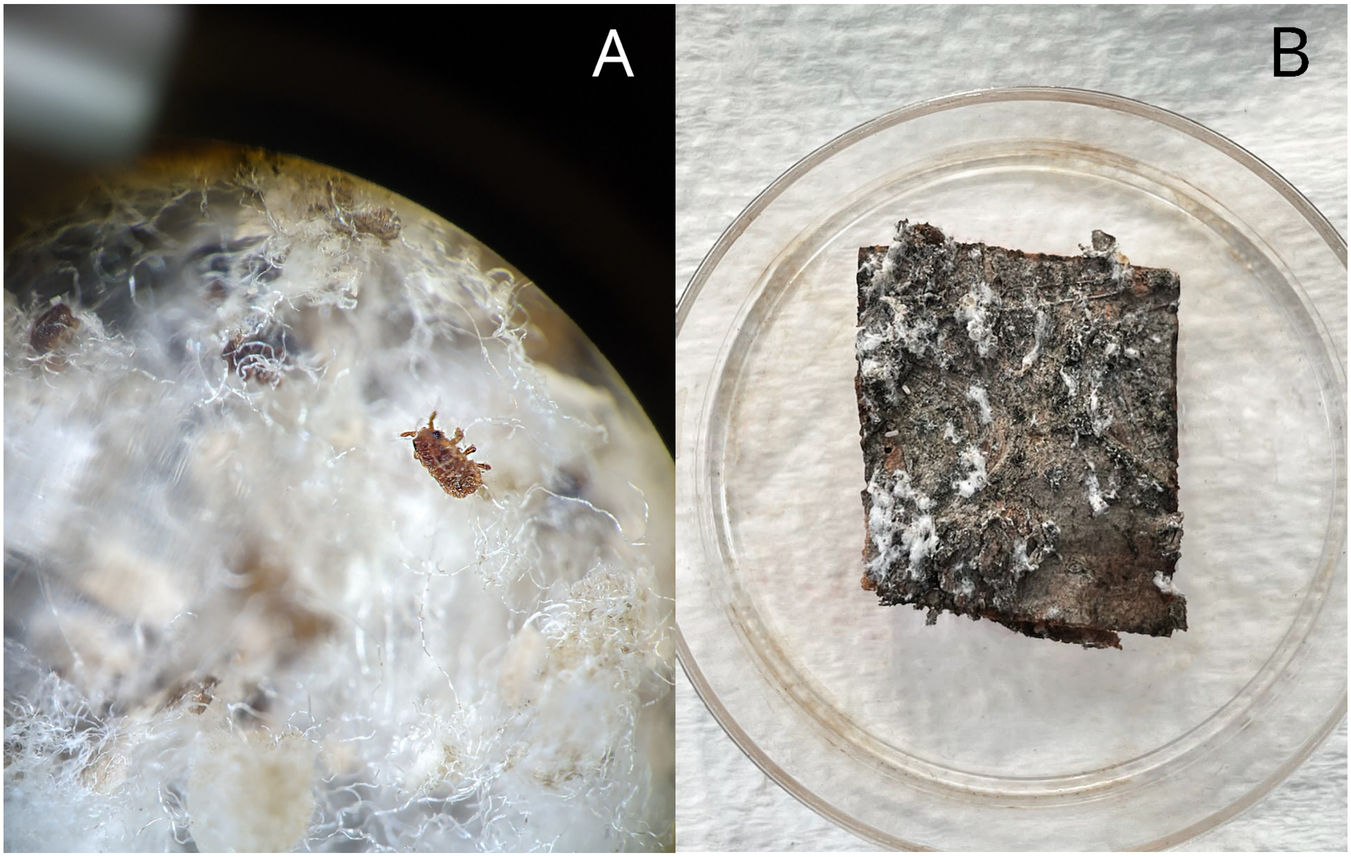

Figure 1—(A) Unsettled balsam woolly adelgid crawler (approx. 0.4 mm in length) on bark sample. (B) Balsam woolly adelgid-infested subalpine fir bark sample (6.45 cm^2) with visible adelgid-produced white, woolly masses. Courtesy photos by E. Rideout, Utah State University.

Current Approaches to Monitoring

Rapid and reliable detection of BWA has proved challenging due to the insect's small body size and cryptic nature. Detection on a tree typically occurs after the population has grown dense enough to form visible masses of wool (fig. 1B) (white, waxy strands) on the tree bole or when injury symptoms such as branch gouting appear (Arthur and Hain 1984; Bryant 1974; Hrinkevich et al. 2016; Mitchell and Buffam 2001; Overhulser et al. 2004). To support early detection and potential for intervention before severe injury and spread occurs, development of a monitoring method for dispersing crawlers is critical to implementation of an integrated pest management (IPM) approach (Rideout et al. 2023).

Monitoring BWA phenology has been achieved by tracking adelgid life stages on the tree bole using a field microscope, though this method is laborious and infeasible for most pest managers (McMullen and Skovsgaard 1972; Tunnock 1959). While still labor-intensive, a proven approach to monitoring BWA phenology involves collection of infested bark samples (fig. 1B) followed by identification of BWA life stages in the laboratory (Mitchell et al. 1961). Targeted monitoring of dispersing BWA crawlers in the southern Appalachian region using Tanglefoot®-coated traps showed that crawlers could be detected (Lambert and Franklin, 1967). Similarly, Fidgen et al. (2020) monitored the hemlock woolly adelgid (HWA) (*Adelges tsugae* Annand) by placing sticky card traps beneath infested branches of host trees Eastern hemlock (*Tsuga canadensis* (L.) Carrière) and Carolina hemlock (*T. caroliniana* Engelm.). A similar monitoring approach has not been attempted with BWA in subalpine fir forests.

The objective of this study was to compare the efficacy of sticky cards with bark samples to assess detection of dispersing BWA crawlers from late June to early November when BWA is active in subalpine fir forests of the Intermountain West. If successful, a sticky card protocol could be more convenient, cost-effective, and likely to be adopted by forest managers and researchers to support detection, monitoring, and treatment decision-making.

Methods

Study Sites

This study was conducted from 16 June to 03 November 2022 in four mixed-conifer stands composed primarily of subalpine fir and secondarily of Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), white fir, and quaking aspen (*Populus tremuloides* Michx.). Study sites ranged in elevation from 2,039 to 2,456 m and were located within the Uinta-Wasatch-Cache National Forest in northern Utah (table 1).

Table 1—Study site descriptions for balsam woolly adelgid crawler monitoring in the Uinta-Wasatch-Cache National Forest, northern Utah, 2022 (ordered from lowest to highest elevation).

Site	Elevation (m)	County	Latitude	Longitude
Green Canyon	2,039	Cache	41.80404	-111.70213
Big Mountain Pass	2,274	Salt Lake	40.82903	-111.65133
Laketown	2,326	Rich	41.72479	-111.37652
Rock Canyon	2,456	Cache	41.67355	-111.41008

Bark Samples

From 21 June to 03 November 2022, 6.45 cm^2 (1 in^2) pieces of bark were removed weekly from four BWA-infested subalpine fir trees at each of the four sites totaling 16 trees using a 2.54 cm (1 in) width wood chisel.[1] Bark samples were collected from the north and south aspects of each tree at both the base and 1 m height above the base. Samples were placed in individual 50 mL centrifuge vials[2] for transport to the U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station in Logan, Utah.

In the laboratory, each bark sample was placed in a 35 mm glass petri dish[3], and BWA life stages (egg, 1st–3rd instars, adult) were enumerated based on morphology described by Balch (1952) with the aid of a stereomicroscope (25× magnification) (fig. 1B). To remove adelgids that adhered to the sides of the centrifuge tube, the tube was rinsed with distilled water and poured into a 35 mm glass petri dish. Adelgids in the rinse water were counted and included in sample count totals. Samples were processed

[1] DeWalt Industrial Tool Company, Towson, MD, USA

[2] VWR International, Radnor, PA, USA

[3] Thermo Fisher Scientific, Waltham, MA, USA

within two hours of collection or stored in the refrigerator at 5 °C and processed within three days. If the latter occurred, the sample was allowed time to warm to room temperature before processing. Counts of first instar crawlers found on bark samples were log-transformed and the mean and standard deviation across sites were calculated by sample week.

Sticky Card Samples

One-sided yellow sticky cards[4] (23 x 14 cm) with grid squares the same size as bark samples (6.45 cm^2; 35 squares per card) were deployed on wooden stakes (2 cm width by 1 m height). At each site, wooden stakes were driven 10 cm deep on the north side of each of the four study trees at a distance of 60 cm from the tree bole. Cards were deployed and replaced weekly; first at the Big Mountain Pass site on 16 June and at other sites on 8 July. The final card sample was retrieved on 03 November.

Two card orientations were tested from 16 to 28 June: (1) horizontal with the card attached by a tack on top of the stake (92 cm above the ground) with the sticky side up; and (2) vertical with the card placed 6 cm below the horizontal card on the side of the stake facing the study tree (fig. 2A). Based on preliminary results showing a substantial reduction in crawler capture on the vertically oriented cards, all cards were deployed in the horizontal orientation only, beginning in July. Upon retrieval of the cards, plastic cling wrap was stretched across the tacky side of each card to protect the sample during transportation.

Cards were stored in the refrigerator at 5 °C for up to two weeks until BWA life stages were counted under a stereomicroscope (25× magnification). For cards with estimates of more than 500 crawlers, seven squares (6.45 cm^2) were randomly selected for counting and counts increased by five times to reflect an estimate of the entire card surface.

Mean counts of BWA per card square (per 6.45 cm^2) were calculated by dividing the full card count by 35 squares to be directly comparable to bark sample mean counts (6.45 cm^2). These values were then log-transformed, and the mean and standard deviation were calculated across sites per sample week.

Invertebrate (insect and arachnid) and vertebrate (bird and bat) bycatch led to losses of card samples and variable weekly sample sizes across the sites and methods. To reduce bycatch, a fine polyethylene mesh screen (1 mm opening) was cut to the same size as the sticky card and stapled on the tacky side of each card (fig. 2B). Resulting observations showed that the mesh-covered cards captured less bycatch and provided greater ease of card handling during placement and retrieval. All cards were deployed with mesh covers beginning the week of 05 September through termination of sampling on 03 November.

[4] Alpha Scents Inc., Canby, OR, USA

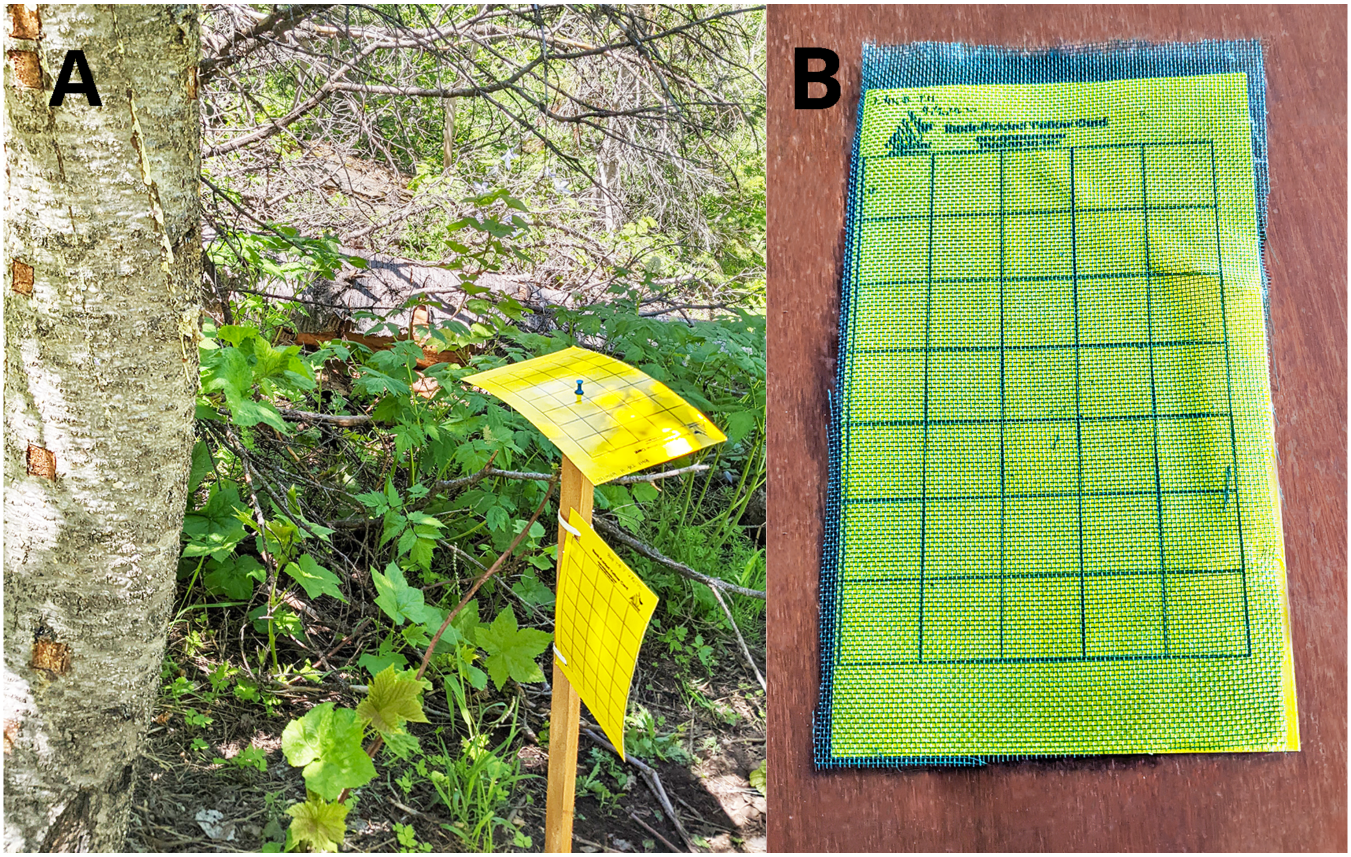

Figure 2—(A) Horizontal and vertical orientation of sticky cards tested for efficacy of capturing dispersing balsam woolly adelgid crawlers. More crawlers were detected on cards in the horizontal orientation. (B) Polyethylene mesh (1 mm opening) was added to the sticky cards to reduce bycatch while monitoring for balsam woolly adelgid crawlers. Mesh-covered cards resulted in reduced bycatch, sustained crawler captures, and enhanced handling ease when compared to cards without mesh. Courtesy photos by E. Rideout, Utah State University.

Complications with protocol implementation resulted in missing data for 3 weeks in July and reduced card sample sizes for some dates in September to early November (table 2). The total sampling time period for the horizontal card and bark samples was 20 weeks from 21 June to 03 November (excluding 06 to 20 July) with varying weekly sample sizes for bark and cards. Sample weeks with lower card numbers likely have reduced rigor of results compared to other weeks during the study; therefore, data presented in the table and graphs represent sites for which both card and bark samples were available for each weekly sampling period.

Table 2—Weekly sample sizes of the assessed monitoring methods for dispersing balsam woolly adelgid crawlers across the sampling comparison period, 22 Jun to 03 Nov 2022. Date column indicates mid-week dates for bark collection and sticky card removal.

Sample Week	Bark	Card	Study Sites
22-Jun	12	5	1
29-Jun	12	4	1
06-Jul	0	0	0
13-Jul	0	0	0
20-Jul	0	0	0
27-Jul	24	7	2
03-Aug	36	12	3
10-Aug	40	12	3
17-Aug	44	12	3
24-Aug	63	15	4
31-Aug	64	12	4
07-Sep	48	6	3
14-Sep	32	6	2
21-Sep	32	8	2
28-Sep	48	12	3
05-Oct	24	8	2
12-Oct	64	16	4
19-Oct	47	16	4
26-Oct	32	7	2
03-Nov	32	8	2

Results and Discussion

General alignment of crawler population peaks and troughs in weekly samples for both methods indicate that sticky cards were effective in monitoring crawler activity (fig. 3). Across all study sites, the average bark square (6.45 cm^2) detected 3.2 times the number of crawlers found on card sample squares (6.45 cm^2). During the study, BWA crawlers were detected on bark samples during all weeks of the study period and on sticky cards in all weeks except for those with missing data in July. Sticky cards captured three non-crawler life stages on 46 cards representing all sites (241 eggs, 1 second instar, 2 adults) during the sampling period. A notable difference between the two sampling methods is that bark samples reflect point-in-time crawler counts as compared to card samples, which reflect total crawlers detected over the previous week. These results demonstrate that sticky cards are useful for detecting crawler presence and timing and could be used in conjunction with bark sampling to enhance studies of BWA phenology.

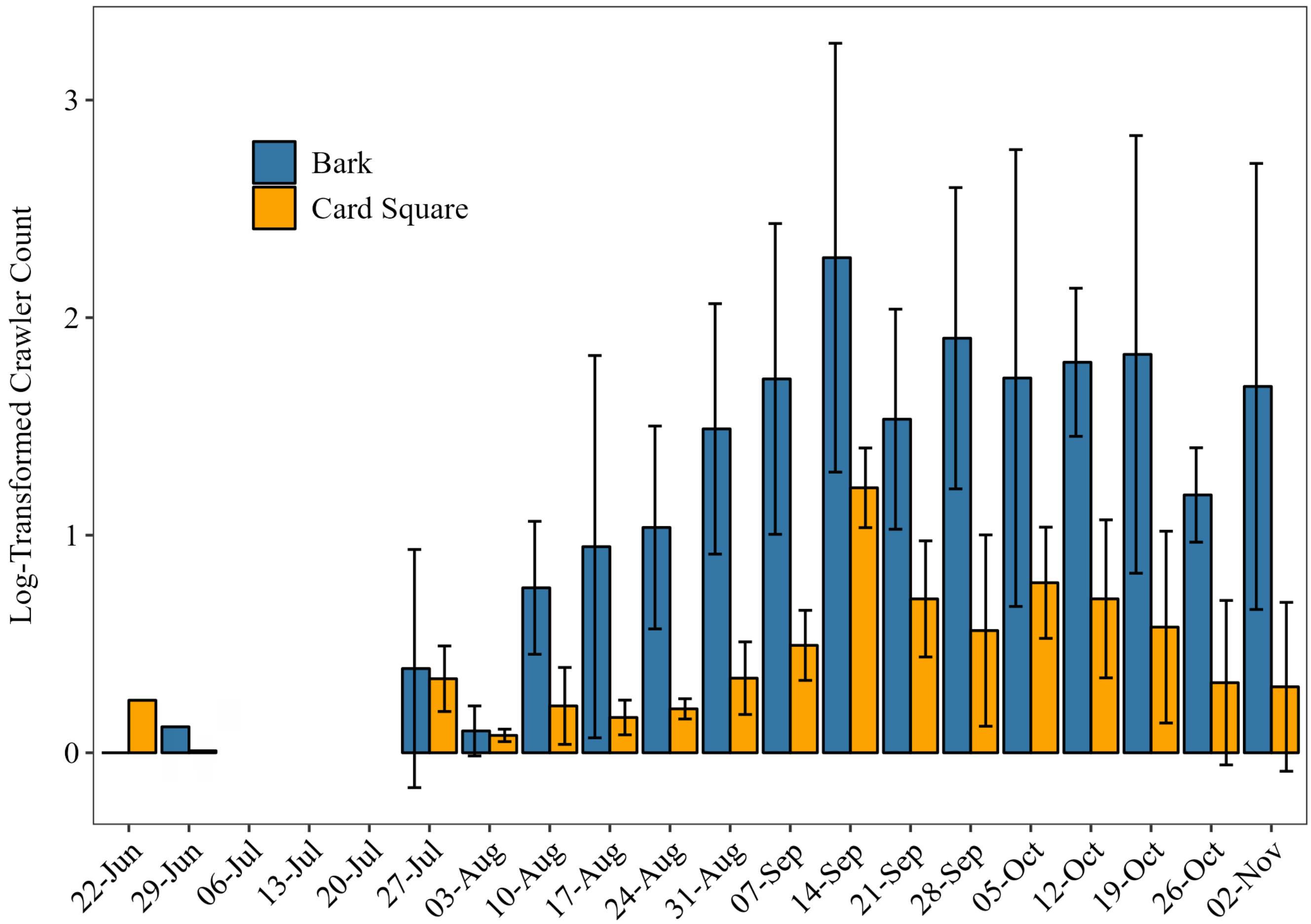

Figure 3—Weekly log-transformed means (± SD) of balsam woolly adelgid crawler counts for bark square (6.45 cm^2) and sticky card (one square; 6.45 cm^2) sampling methods at four forest sites in the Uinta-Wasatch-Cache National Forest in northern Utah, June 16 to November 3, 2022. Weekly sample sizes for each method are described in table 2. Counts were log(x+1)-transformed, summed across trees and sites per week, then averaged across sites per week. Data are plotted on mid-week dates for bark collection and sticky card removal. Error bars represent variation in means across sites each week. A mesh screen was attached to all cards beginning September 5 to reduce bycatch.

Orientation of card placement for increased crawler detection and the addition of mesh screens for bycatch reduction were tested. Across the card orientation comparison period, horizontally-positioned cards had higher mean crawler captures (17.9 ± 9.4, n = 9) than those with vertical orientation (1.2 ± 1.2, n = 6), similar to the results of Lambert and Franklin (1967). This difference may be due to the brief nature of wind gusts that may lift the crawler off the tree surface before sudden dropping, leading to higher captures on the horizontal surface versus the vertical. Results are therefore presented only for horizontal cards. Mesh screens added to the card surfaces resulted in both reduced bycatch and sample processing time, where the average time to count crawlers on sticky cards without mesh was 25 minutes compared to 15 minutes for cards with mesh. Additionally, the reduction in bycatch and debris provided by the mesh covering may allow for increased ease of handling in the field and laboratory.

Microscope magnification of 25× was required for bark sample processing due to the small surface area of the bark as well as the presence of debris and adelgid wool. In contrast, a hand lens (commonly between 10× and 25× magnification) may be suitable for processing mesh-covered cards given the bigger surface area of the sample and lack of debris. Not only does this suggest that the use of sticky cards can provide greater accessibility to pest managers in crawler detection, but the larger surface area of the cards may also be useful in early detection of dispersing crawlers.

Additionally, the card adhesive allowed for longer-term cold storage post-sampling than bark samples, which when stored for more than several days, introduced the risk of mold growth and specimen damage. Card damage or loss due to precipitation and wind did occur in this study, and wildlife and human activity may impact use of sticky cards. These concerns may be mitigated by greater frequency in card retrieval and selection of monitoring sites with lower likelihood of disturbance.

Applications in IPM Programs

Current management practices for BWA include thinning treatments during periods of crawler inactivity and planting of non-host species. While sticky cards deployed from late June to early November detected crawlers, counts were especially high between September and October. This finding aligns with the expected fall peak in crawler activity found in other studies (Arthur and Hain 1984; Mitchell et al. 1961). Because crawlers are also active in early summer, management activities such as tree removal and thinning should be conducted before early June and after November. Conversely, an insecticide can be useful for isolated, high-value trees (Johnson et al. 2005; Rideout et al. 2023), where the application targets the tree crown during high crawler activity in early summer and between September and October. Additionally, placement of sticky cards in the spring and fall near infested target trees could provide further insight into crawler presence and insecticide application timing.

For forest managers and researchers, sticky card traps are lower in time- and labor-intensity, while higher in accessibility and affordability as compared to bark samples. Our study results support that sticky cards used in the spring and fall and checked weekly can be a valuable tool to inform timing of BWA management practices, including thinning and application of insecticide sprays. Alongside a phenology tool such as a degree day model, this strategy may help to reduce the negative impacts caused by BWA on true fir forest stands.

References

Amman, G.D. 1962. Seasonal biology of the balsam woolly aphid on Mt. Mitchell, North Carolina. Journal of Economic Entomology. 55(1): 96–98.

Annand, P.N. 1928. A contribution toward a monograph of the Adelginae (Phylloxeridae) of North America. Stanford University Press. 152 p.

Arthur, F.; Hain, F. 1984. Seasonal history of the balsam woolly adelgid (Homoptera: Adelgidae) in natural stands and plantations of Fraser fir. Journal of Economic Entomology. 77: 1154–1158.

Atkins, M.D.; Hall, A.A. 1969. Effect of light and temperature on the activity of balsam woolly aphid crawlers. The Canadian Entomologist. 101(5): 481–488.

Balch, R.E. 1952. Studies on the balsam woolly aphid (*Adelges piceae* Ratz.) and its effects on balsam fir, *Abies balsamea* (L.). Publication 867. Mill. Ottowa, Canada: Canada Department of Agriculture. 76 p.

Bryant, D.G. 1974. A review of the taxonomy, biology and importance of the balsam woolly aphid, *Adelges piceae* (Homoptera: Phylloxeridae) on branches of balsam fir, *Abies balsamea*. Canadian Entomologist. 108: 1097–1111. https://doi.org/10.4039/Ent1081097-10

Cook, S.P.; Humes, K.S.; Hruska, R.; [et al.]. 2010. Identifying subalpine fir (*Abies lasiocarpa*) attacked by the balsam woolly adelgid (*Adelges piceae*) using spectral measurements of the foliage. International Journal of Forestry Research. 2010: 1–8. https://doi.org/10.1155/2010/498189

Davis, G.A.; Lowrey, L.; Eckberg, T.; Hicke, J.A.; Smirnova, E. 2022.Charaterizing balsam woolly adelgid infestations and associated tree mortality in Idaho. Journal of Forestry 120: 361-378. https://doi.org/10.1093/jofore/fvac007

Fidgen, J.G.; Whitmore, M.C.; Studens, K.D.; [et al.]. 2020. Sticky traps as an early detection tool for crawlers of *Adelges tsugae* (Hemiptera: Adelgidae). Journal of Economic Entomology. 113(1): 496–503. https://doi.org/10.1093/jee/toz257

Havill, N.; Griffin, B.; Andersen, J.; [et al.]. 2020. Species delimitation and invasion history of the balsam woolly adelgid, *Adelges* (*Dreyfusia*) *piceae* (Hemiptera: Aphidoidea: Adelgidae), species complex. Systematic Entomology. 46: 186–204. https://doi.org/10.1111/syen.12456

Hrinkevich, K.H.; Progar, R.A.; Shaw, D.C. 2016. A severity rating system for evaluating stand-level balsam woolly adelgid (Hemiptera: Adelgidae) damage in two *Abies* species in western North America. Forest Science. 62(2): 181–189. https://doi.org/10.5849/forsci.15-025

Johnson, K.; Taylor, G.; Remaley, T. 2005. Managing hemlock woolly adelgid and balsam woolly adelgid at Great Smoky Mountains National Park. FHTET-2005-01. In: Onken, B. Reardon, R., comps. Third symposium on hemlock woolly adelgid in the Eastern United States; 2005, Feb. 1-3; Asheville, NC. Morgantown, WV: Forest Health Technology Enterprise Team. U.S. Department of Agriculture, Forest Service, Forest Health Technology Enterprise Team: 232-233. https://www.fs.usda.gov/foresthealth/technology/pdfs/3rdSymposiumHWA05_01.pdf [Accessed 3 September 2024]

Jožica, G.; Krže, L.; Čufar, K. 2009. Number of cells in xylem, phloem and dormant cambium in silver fir (*Abies alba*), in trees of different vitality. IAWA Journal. 30(2): 121–133. https://doi.org/10.1163/22941932-90000208

Keen, F.P. 1952. Insect enemies of western forests. Miscellaneous Publication No. 273. Washington, DC: U.S. Department of Agriculture. 280 p. https://www.biodiversitylibrary.org/item/132338#page/3/mode/1up [Accessed 3 September 2024]

Kotinsky, J. 1916. The European fir trunk louse, *Chermes* (*Dreyfusia*) *piceae* (Ratz.). Proceedings of the Entomological Society of Washington. 18: 14–16.

Lambert, H.L.; Franklin, R.T. 1967. Tanglefoot traps for detection of the balsam woolly aphid. Journal of Economic Entomology. 60(6): 1525–1529. https://doi.org/10.1093/jee/60.6.1525

Livingston, R.L.; Dewey, J.E. 1983. Balsam woolly aphid: Report of an Idaho infestation. IDL Rep. No. 83-7. Coeur d' Alene, ID: Department of Lands. 10 p.

McMullen, L.H.; Skovsgaard J.P. 1972. Seasonal history of the balsam woolly aphid in coastal British Columbia. Journal of the Entomological Society of British Columbia. 69: 33–40. https://journal.entsocbc.ca/index.php/journal/article/view/1787 [Accessed 3 September 2024]

Mech, A.M.; Tobin, P.C.; Teskey, R.O.; [et al.]. 2018. Increases in summer temperatures decrease the survival of an invasive forest insect. Biological Invasions. 20: 365-374. https://doi.org/10.1007/s10530-017-1537-7

Mitchell, R.G. 1967. Abnormal ray tissue in three true firs infested by balsam woolly aphid. Forest Science. 13(3):327–332. https://doi.org/10.1093/forestscience/13.3.327

Mitchell, R.G.; Buffam, P.E. 2001. Patterns of long-term balsam woolly adelgid infestations and effects in Oregon and Washington. Western Journal of Applied Forestry. 16(3): 121–126. https://doi.org/10.1093/wjaf/16.3.121

Mitchell, R.G.; Johnson, N.E.; Rudinsky, J.A. 1961. Seasonal history of the balsam woolly aphid in the Pacific Northwest. The Canadian Entomologist. 93(9): 794–798. https://doi.org/10.4039/Ent93794-9

Overhulser, D.L.; Ragenovich, I.R.; McWilliams, M.; [et al.]. 2004. Balsam woolly adelgid occurrence on true fir in Oregon. Oregon Department of Forestry Pest Management Report Salem, OR: Oregon Department of Forestry. 6 p.

Puritch, G.S. 1973. Effect of water stress on photosynthesis, respiration, and transpiration of four *Abies* species. Canadian Journal Forest Research. 3(2): 293–298. https://doi.org/10.1139/x73-040

Ragenovich, I.R.; Mitchell, R.G. 2006. Balsam woolly adelgid. Forest Insect & Disease Leaflet 118. U.S. Department of Agriculture, Forest Service. 7 p. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fsbdev2_043667.pdf [Accessed 3 September 2024]

Rideout, L.; Richardson, K.; Alston, D.; [et al.]. 2023. Balsam woolly adelgid. Utah State University Extension Fact Sheet ENT-191-18. Logan, UT: Utah State University Extension 7 p. https://extension.usu.edu/planthealth/research/balsam-woolly-adelgid-advanced [Accessed 3 September 2024]

Speers, C.F. 1958. The balsam woolly aphid in the southeast. Journal of Forestry. 56: 515–516. https://doi.org/10.1093/jof/56.7.512

Tunnock, A. 1959. Observations on the life-cycle of the balsam woolly aphid, Adelges piceae (Ratz.), in the Willamette Valley of Oregon. The Canadian Entomologist. 91(4): 208–212. https://doi.org/10.4039/ent91208-4

Woods, T.A.D.; Atkins, M.D. 1967. A study of the dispersal of balsam woolly aphid crawlers by small animals. Canadian Forest Service, Pacific Forestry Centre, Bi-monthly Research Notes. 23(6): 44. https://ostrnrcan-dostrncan.canada.ca/handle/1845/220842 [Accessed 3 September 2024]

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