

SCIENTIFIC NOTE

Influence of diameter of a sampling device on detectability of wool of the hemlock woolly adelgid (Hemiptera: Adelgidae) in the canopy of eastern hemlock (Pinaceae)

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Abstract

Ball sampling is an active technique of sampling the upper canopy of hemlock, *Tsuga* sp. (Pinaceae), to detect the nonnative hemlock woolly adelgid, *Adelges tsugae* Annand (Hemiptera: Adelgidae). We tested a 7.5-cm-diameter wooden ball fitted with Velcro® with a BigShot® slingshot that sends the ball into the upper hemlock canopy. The 7.5-cm ball detected wool with fewer sampling attempts per tree and had a higher detection rate after 10 sampling attempts than a 5-cm wooden ball using a much smaller HyperDog® slingshot did. However, sampling with the 7.5-cm ball took 20% longer per tree and fatigued shooters after only 30–40 shots due to the size and effort required to use the larger slingshot. A larger sampling device (= greater Velcro® surface area) significantly improved detection of adelgid wool and is recommended, provided a more efficient launching system is developed.

Hemlock, *Tsuga canadensis* (Linnaeus) Carrière (Pinaceae), in eastern Canada is embattled with the nonnative, invasive hemlock woolly adelgid, *Adelges tsugae* Annand (Hemiptera: Adelgidae), which was introduced from Japan to the eastern United States of America on ornamental plantings likely before 1951 (Stoetzel 2002; Havill *et al.* 2006). Since 2012 and 2017, increasing areas of the Canadian provinces of Ontario and Nova Scotia, respectively, have become infested by the adelgid as the pest continues to spread northwards into Canada (North American Plant Protection Organization 2012; Canadian Food Inspection Agency 2017). The province of New Brunswick may well be the next Canadian jurisdiction to be invaded by *A. tsugae* due to the proximity of the infestation in Nova Scotia and southeastern Hancock County, Maine, United States of America (Cornelson *et al.* 2024; Maine Department of Agriculture, Conservation and Forestry 2024). This insect can kill trees within 3–15 years after infestation (McClure 1990; Limbu *et al.* 2018; Emilson and Stastny 2019), and we have noted similar rates of decline and loss in Nova Scotia.

A key feature of adelgid management is early detection of infestations to mitigate impacts to high-value stands (Emilson and Stastny 2019; Derry *et al.* 2024; Venette *et al.* 2024). However, early detection of *A. tsugae* is difficult because the pest often establishes in the upper canopy of hemlock (Evans and Gregoire 2007). Several methods have been developed to assess the upper canopy (Fidgen *et al.* 2015, 2016; Kirtane *et al.* 2022; Sanders *et al.* 2023). Of these, ball sampling is

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the only active method for surveying the upper canopy for *A. tsugae* (Fidgen *et al.* 2016, 2019). This technique involves shooting Velcro®-fitted balls at the canopy to trap adelgid wool (Fidgen *et al.* 2016, 2019; MacQuarrie *et al.* 2021). Ball sampling is popular with community scientists (*e.g.*, Entomological Society of America 2019; Ford 2023; Prince Edward Island Invasive Species Council 2022) and is presently in use in Canada and the United States of America as a complementary approach to other methods of detecting the adelgid (MacQuarrie *et al.* 2021).

We have noticed that the slingshot used to sample hemlock with Velcro-covered balls is sometimes different than the one used in earlier research on the technique (*e.g.*, HyperDog Ball Launcher®; Hyper Pet, Wichita, Kansas, United States of America), but the ball used to sample the trees is the same. Specifically, some people use more powerful slingshots such as the Notch BigShot® (Greensboro, North Carolina, United States of America) instead of the HyperDog. These powerful slingshots are used to throw heavy beanbags into the tree canopy for the installation of climbing ropes. The slingshot's greater power provided an opportunity to develop a stronger and larger (*i.e.*, greater Velcro surface area) sampling device for this style of slingshot. Although a doubling of the surface area of Velcro on a 5.6-cm racquetball (25 cm² *versus* 48 cm²) did not improve the detection of adelgid wool (Fidgen *et al.* 2019), a much larger ball with increased mass and a much larger surface area of Velcro may improve wool detection. The main objective of this study was to see if a heavier and larger ball would improve the detectability of the hemlock woolly adelgid. We also evaluated the number of sampling attempts needed to detect wool for the first time ("first wool"), the total time needed to detect first wool, and the total time needed to take 10 samples per tree with a 7.5-cm-diameter device. This ball was compared to a 5-cm-diameter wooden ball, which is similar in size to the racquetball used in earlier research.

Work was carried out in May–July 2022, 2023, and 2024 at six sites in southwestern Nova Scotia, Canada, that have *A. tsugae* infestations (Fig. 1). Trees at these sites were selected based on their having no to moderate infestations of *A. tsugae* on asymptomatic trees, as determined by visual assessment of the foliage from the ground, pole pruning of five to ten 30-cm-long branch tips from the lower half of the crown, or both methods. We sampled 20, 18, and 10 trees in 2022, 2023, and 2024, respectively, for a total of 48 trees.

The 7.5-cm-diameter wooden balls that were tested are made of maple (*Acer* sp.) (Sapindaceae) (Bear Woods Supply Company Inc., Vancouver, British Columbia, Canada). Each ball was painted with fluorescent-yellow paint (sun yellow, Rust-Oleum; Consumer Brands Canada, Concord, Ontario, Canada) to aid recovery when used and then fitted with 1-cm-wide strips of self-adhesive Velcro (hook side; black general purpose; Velcro USA, Manchester, New Hampshire, United States of America). The total surface area of this ball is 176.7 cm², of which 122.9 ± 0.3 cm² (~70%) was covered by Velcro. Once fabricated, these balls weighed 161.0 ± 1.8 g ($n = 12$). The 5.0-cm-diameter maple balls had a surface area of 78.5 cm², and 49.3 ± 0.3 cm² of Velcro was fitted to each (covering ~63% of the ball's surface area). Once fabricated, the 5.0-cm balls weighed 46.5 ± 1.1 g ($n = 12$). The ends of each Velcro strip glued to the balls were reinforced by a drop of super glue (LePage Ultra Gel Control Super Glue; Henkel Canada Corp., Mississauga, Ontario, Canada) to improve durability. Overall, the 7.5-cm ball was three times heavier than the 5.0-cm ball and had 2.5 times more Velcro surface than the smaller ball did.

The HyperDog slingshot was used exclusively with the 5.0-cm-diameter ball, whereas the BigShot was used exclusively with the 7.5-cm ball. Each tree was sampled by targeting the crown from all sides and heights with the balls, beginning at a random location around the periphery of the crown. Each tree was sampled using two surveyors, who began on opposite sides of the tree using each ball size. Ten samples were taken per tree with each ball. A suitable sample was one where the ball contacted three or more distal hemlock branch tips as the ball ascended the crown; otherwise, the sample was repeated. Between samples, the ball was examined for adelgid wool and cleaned with a medium-bristle toothbrush to remove debris from the Velcro (Fig. 2).

After each sample, we recorded a "1" if the Velcro on a ball had adelgid wool on it; otherwise, we recorded a "0". From this data, we determined the attempt that resulted in the first wool, the

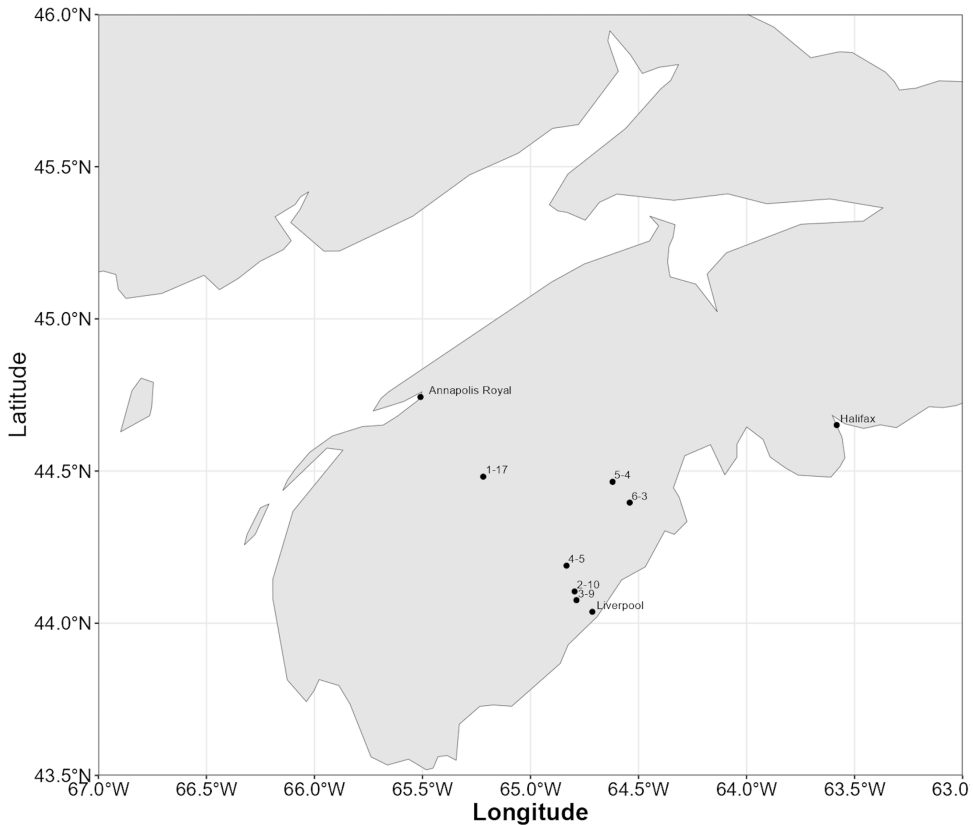


Figure 1. Location of the six sites and number of trees sampled per site (e.g., 1–17) in southwestern Nova Scotia, Canada, where *Tsuga canadensis* was sampled for wool of *Adelges tsugae* using 5.0- and 7.5-cm-diameter wooden balls fitted with Velcro as sampling devices.



Figure 2. **A**, Devices (5.0- and 7.5-cm-diameter balls) used to trap wool of *Adelges tsugae* during *Tsuga canadensis* canopy sampling; **B**, 7.5-cm-diameter ball positive for adelgid wool, with several streaks of wool present on the ball. See text for details.

total number of attempts, out of 10, that successfully captured wool, and the total time to complete the 10 attempts. The time to first positive was estimated by dividing the total time by 10 and then multiplying this by the number of attempts to detect first wool. To evaluate the probability of detecting wool with increasing sample attempts, we created ranked datasets for each tree. For the first dataset, we coded the first sampling attempt that detected wool and all attempts thereafter as a

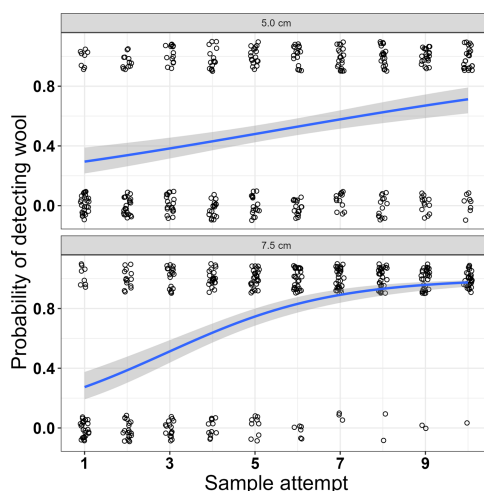


Figure 3. Influence of ball diameter and sample attempt on detectability of *Adelges tsugae* wool in the canopy of *Tsuga canadensis* in southwestern Nova Scotia, Canada. Circles are raw data offset for visualisation.

“1” (infested); we coded sampling attempts before this occurrence as a “0” (uninfested). For the second dataset, we ranked the detection of wool by sampling attempt. Here, we considered a rank of “10” as the detection of wool on the first attempt, a rank of “9” as the detection of wool on the second attempt, and so on, until a rank of “0”, which was no wool detected after 10 attempts. However, when analysing the detection of wool, we did not include trees where both ball sizes failed to detect *A. tsugae*.

We fit generalised linear mixed-effect models to describe the probability of trapping wool on the ball as the response variable and ball size and number of attempts as the predictor variables, with tree as a random effect in the model. We also fit generalised linear mixed-effect models for the other response variables. We fit separate models for the ranked number of samples until the first positive sample, time-to-first-wool detection, total time to complete all 10 samples, and the number of woolly samples out of 10 attempts as the response variables, with ball size as the predictor variable and tree as a random effect. Model fitting was done in the R statistical computing environment, version 4.3.0 (R Core Team; <https://www.R-project.org/>). Models were fitted using functions in the *lme4* package (Bates *et al.* 2015). Differences among levels of the predictor variables were examined using functions in the *emmeans* package (Lenth 2017). We examined the dispersion parameters and residual plots after running these models (Zuur *et al.* 2009).

The probability of trapping wool on the ball increased with each successive attempt, increasing faster for the 7.5-cm ball than for the 5.0-cm ball and resulting in a significant interaction between ball size and number of attempts ($D = 19.64$, $df = 1$, 672, $P < 0.0001$; Fig. 3). After 10 attempts, detectability of wool was significantly higher for the 7.5-cm ball ($P[\text{detection}] = 0.97 \pm 0.03$) than for the 5.0-cm ball ($P[\text{detection}] = 0.75 \pm 0.08$; $D = 7.09$, $df = 1$, 62, $P = 0.008$; Fig. 2). Of note, detectability by the 5-cm ball was similar to that by the 5.6-cm ball used in earlier studies (Fidgen *et al.* 2021). The resultant gain in detectability by the larger ball was likely due to the larger surface area of Velcro on the ball and to the increased mass of the ball resisting deflection when hitting branch tips.

The rank out of a maximum score of 10 for the first positive attempt was significantly higher for the 7.5-cm ball than for the 5-cm ball (Table 1). The 7.5-cm ball detected wool after 2–3 sampling attempts as compared to 4–6 attempts for the 5.0-cm ball. The time to the first sampling attempt to detect adelgid wool was similar for both ball sizes (Table 1). However, the total time to complete 10 sampling attempts was significantly higher for the 7.5-cm ball than for the 5.0-cm ball. Both

Table 1. Various comparisons of 5.0- and 7.5-cm-diameter balls as sampling devices to detect the wool of *Adelges tsugae* in the canopy of *Tsuga canadensis* in southwestern Nova Scotia, Canada

Test	5.0-cm ball mean $\pm$ standard error	7.5-cm ball mean $\pm$ standard error	P-value
Rank of first attempt to detect wool	5.03 $\pm$ 0.73	7.15 $\pm$ 0.46	0.0004 [†]
Time to first attempt to detect wool	319 $\pm$ 41 seconds	325 $\pm$ 48 seconds	0.93*
Total time to complete 10 attempts	490 $\pm$ 26 seconds	619 $\pm$ 41 seconds	0.0006 [†]
Total number of attempts with wool out of 10	2.1 $\pm$ 0.4	2.4 $\pm$ 0.3	0.56*

[†]Ordination and Multivariate Analysis for Ecology generalised linear mixed-effect negative binomial model.

*Generalised linear negative binomial model.

sampling devices detected wool the same number of times out of 10, on average (Table 1). Overall, this analysis supports using a larger ball for the detection of *A. tsugae* wool from the upper canopy of *T. canadensis*. Of note when encountering trees with undetectable or no infestation of *A. tsugae*, sampling with the larger ball will take 1.25 times longer to complete than using the smaller ball.

There is one major limitation to the adoption of a larger device when sampling more than just a few trees: the slingshot. We suspect an improved launching device will address these problems. For example, the BigShot has poor accuracy compared to the HyperDog, and users became fatigued after 30–40 attempts (J. Fidgen and G. Forbes, unpublished data). These issues could be remedied by the development of a pneumatic launching system. Once developed, we recommend re-assessing the 7.5-cm ball on trees with a range of adelgid population levels as was done for the 5.6-cm-diameter sampling device (Fidgen *et al.* 2021). We suspect surveyors will continue to use unsanctioned tools to ball sample for *A. tsugae* wool. This note serves as a reminder that adaptations to the ball sampling technique must be vigorously tested and a method optimised before integrating it into an operational setting.

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References

- Bates, D., Maechler, M., Bolker, B., and Walker, S. 2015. Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, **67**: 1–48. <https://doi.org/10.18637/jss.v067.i01>.
- Canadian Food Inspection Agency. 2017. Hemlock woolly adelgid – *Adelges tsugae* (Annand): Detections: Southwestern Nova Scotia. [online]. Canadian Food Inspection Agency, Ottawa, Ontario, Canada. Available from <https://inspection.canada.ca/en/plant-health/invasive-species/insects/hemlock-woolly-adelgid> [accessed 22 August 2023].
- Cornelson, C.T., MacQuarrie, C.J.K., and Lee, S.-I. 2024. Modelling the distribution of hemlock woolly adelgid under several climate change scenarios. *Canadian Journal of Forest Research*, **54**: 1458–1470. <https://doi.org/10.1139/cjfr-2023-0275>.
- Derry, V., DiGaspero, M., MacQuarrie, C.J.K., and Sturba, M. 2024. Guide for managing hemlock woolly adelgid (*Adelges tsugae*): An invasive insect threatening eastern hemlock (*Tsuga canadensis*) in Canada. Invasive Species Centre, Sault Ste. Marie, Ontario, Canada. Available

- from https://www.invasivespeciescentre.ca/wp-content/uploads/2024/04/HWAManagementGuide_FINAL_April2024_WEB.pdf [accessed 18 April 2025].
- Emilson, C.E. and Stastny, M. 2019. Decision framework for hemlock woolly adelgid management: review of the most suitable strategies and tactics for eastern Canada. *Forest Ecology and Management*, **444**: 327–343. <https://doi.org/10.1016/j.foreco.2019.04.056>.
- Entomological Society of America. 2019. Little, fuzzy, but not so cute: the hemlock woolly adelgid [online]. *Entomology Today*, 7 February 2019. Entomological Society of America, Annapolis, Maryland, United States of America. Available from <https://entomologytoday.org/2019/02/07/little-fuzzy-not-cute-hemlock-woolly-adelgid/> [accessed 9 December 2024].
- Evans, A.M. and Gregoire, T.G. 2007. The tree crown distribution of hemlock woolly adelgid, *Adelges tsugae* (Hem., Adelgidae), from randomised branch sampling. *Journal of Applied Entomology*, **131**: 26–33. <https://doi.org/10.1111/j.1439-0418.2006.01121.x>.
- Fidgen, J.G., Fournier, R.E., Whitmore, M.C., MacQuarrie, C.J.K., and Turgeon, J.J. 2019. Factors affecting Velcro-covered balls when used as a sampling device for wool of *Adelges tsugae* (Hemiptera: Adelgidae). *The Canadian Entomologist*, **151**: 101–114. <https://doi.org/10.4039/tce.2018.50>.
- Fidgen, J.G., Whitmore, M.C., MacQuarrie, C.J.K., and Turgeon, J.J. 2021. Detection of *Adelges tsugae* (Hemiptera: Adelgidae) using Velcro-covered balls. *The Canadian Entomologist*, **153**: 640–650. <https://doi.org/10.4039/tce.2021.24>.
- Fidgen, J.G., Whitmore, M.C., and Turgeon, J.J. 2015. Detection of hemlock woolly adelgid (Hemiptera: Adelgidae) infestations with sticky traps. *Great Lakes Entomologist*, **48**: 125–131.
- Fidgen, J.G., Whitmore, M.C., and Turgeon, J.J. 2016. Ball sampling: a novel method to detect *Adelges tsugae* (Hemiptera: Adelgidae) in hemlock (Pinaceae). *The Canadian Entomologist*, **148**: 118–121. <https://doi.org/10.4039/tce.2015.29>.
- Ford, R. 2023. Using slingshots to battle invasives? *Cottage Life*, 30 March 2020 [online]. Available from <https://cottage.life.com/outdoors/using-slingshots-to-battle-invasives/> [accessed 22 August 2024].
- Havill, N., Montgomery, M., Yu, G., Shiyake, S., and Caccone, A. 2006. Mitochondrial DNA from hemlock woolly adelgid (Hemiptera: Adelgidae) suggests cryptic speciation and pinpoints the source of the introduction to eastern North America. *Annals of the Entomological Society of America*, **99**: 195–203. [https://doi.org/10.1603/0013-8746\(2006\)099\[0195:MDFHWA\]2.0.CO;2](https://doi.org/10.1603/0013-8746(2006)099[0195:MDFHWA]2.0.CO;2).
- Kirtane, A., Dietschler, N.J., Bittner, T.D., Lefebvre, M.B., Celis, S., O'Connor, K., *et al.* 2022. Sensitive environmental DNA (eDNA) methods to detect hemlock woolly adelgid and its biological control predators *Leucotaraxis* silver flies and a *Laricobius* beetle. *Environmental DNA*, **4**: 1136–1149. <https://doi.org/10.1002/edn3.317>.
- Lenth, R. 2017. Emmeans: estimated marginal means, aka least-squares means [online]. Available from <https://CRAN.R-project.org/package=emmeans> [accessed 11 July 2024].
- Limbu, S., Keena, M.A., and Whitmore, M.C. 2018. Hemlock woolly adelgid (Hemiptera: Adelgidae): a non-native pest of hemlock in eastern North America. *Journal of Integrated Pest Management*, **9**: 018. <https://doi.org/10.1093/jipm/pmy018>.
- MacQuarrie, C.J.K., Fidgen, J.G., and Turgeon, J.J. 2021. Ground and stem sampling as potential detection tools for the wool of *Adelges tsugae* (Hemiptera: Adelgidae). *Journal of Economic Entomology*, **114**: 1622–1630. <https://doi.org/10.1093/jee/toab082>.
- Maine Department of Agriculture, Conservation and Forestry. 2024. Hemlock woolly adelgid overview [online]. Maine Department of Agriculture, Conservation and Forestry, Augusta, Maine, United States of America. Available from https://www.maine.gov/dacf/mfs/forest_health/insects/hemlock_woolly_adelgid_overview.htm [accessed 11 July 2024].
- McClure, M.S. 1990. Role of wind, birds, deer, and humans in the dispersal of hemlock woolly adelgid (Homoptera: Adelgidae). *Environmental Entomology*, **19**: 36–43. <https://doi.org/10.1093/ee/19.1.36>.

- North American Plant Protection Organization. 2012. Detection and eradication of hemlock woolly adelgid (*Adelges tsugae* Annand) in Etobicoke, Ontario [online]. North American Plant Protection Organization, Raleigh, North Carolina, United States of America. Available from <https://www.pestalerts.org/nappo/official-pest-reports/774/> [accessed 22 August 2024].
- Prince Edward Island Invasive Species Council. 2022. Woodlot management in the face of hemlock woolly adelgid: a simplified survey protocol for woodlot owners [online]. Available from <https://peiinvasives.com/hemlock-woolly-adelgid/> [accessed 22 August 2024].
- Sanders, M., Tardani, R., Locher, A., Geller, K., and Partridge, C.G. 2023. Development of novel early detection technology for hemlock woolly adelgid, *Adelges tsugae* (Hemiptera: Adelgidae). *Journal of Economic Entomology*, **116**: 168–180. <https://doi.org/10.1093/jee/toac175>.
- Stoetzel, M.B. 2002. History of the introduction of *Adelges tsugae* based on voucher specimens in the Smithsonian Institute National Collection of Insects. In *Proceedings: Hemlock Woolly Adelgid in the Eastern United States Symposium*, 5–7 February 2002, East Brunswick, New Jersey. Edited by B. Onken, R. Reardon, and J. Lashomb. New Jersey Agricultural Experiment Station and Rutgers University, New Brunswick, New Jersey, United States of America. P. 12.
- Venette, R.C., Ambourn, A., Aukema, B.H., Jetton, R.M., and Petrice, T.R. 2024. Hosts and impacts of elongate hemlock scale (Hemiptera: Diaspididae): a critical review. *Frontiers in Insect Science*, **4**: 1356036. <https://doi.org/10.3389/finsc.2024.1356036>.
- Zuur, A.F., Ieno, E.N., Walker, N.J., Saveliev, A.A., and Smith, G.M. 2009. *Mixed Effects Models and Extensions in Ecology with R*. Springer, New York, New York, United States of America. <https://doi.org/10.1007/978-0-387-87458-6>.

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