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Authors: Nixon, Laura J., Barnes, Caitlin, Rugh, Anthony, Hott, Christian, Carper, Lee, et al.

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Evaluating materials to serve as removable oviposition substrates for *Lycorma delicatula* (Hemiptera: Fulgoridae) under field conditions

Laura J. Nixon[1,], Caitlin Barnes[1], Anthony Rugh[1], Christian Hott[1], Lee Carper[1], John Cullum[1], Sharon Jones[1], Dalton Ludwick[1,2], Cameron Scorza[1], and Tracy C. Leskey[1]*

Lycorma delicatula White (Hemiptera: Fulgoridae), spotted lanternfly, is an invasive planthopper first detected in Berks County, Pennsylvania, USA, in 2014 that now has spread to an additional 13 states in the US. This invasive pest is univoltine with 4 nymphal instars developing between late spring and early fall to the adult stage. Adult populations feed heavily in the late summer and reproduce throughout fall before succumbing during hard frost events (Barringer et al. 2015; Lee et al. 2019; Liu 2019a). *Lycorma delicatula* is considered a threat to a range of specialty crops and, in particular, grape vine, *Vitis vinifera* L. (Vitaceae), with heavy feeding related to yield reductions and vine death (Leach et al. 2019; Leach & Leach 2020).

Because *L. delicatula* is invasive, there is strong interest in developing a classical biological control program. The egg and nymphal parasitoid species, *Dryinus sinicus* Olmi (Hymenoptera: Dryinidae) and *Anastatus orientalis* Yang & Choi (Hymenoptera: Eupelmidae), respectively, are both from the same native range as *L. delicatula* and currently are being evaluated via host range testing programs (Liu 2019b; Malek et al. 2019; Broadley et al. 2020). If these parasitoids are approved for release in the US, then a classical biological control program will require large numbers of *L. delicatula* eggs and nymphs to be available for rearing these biological control agents. In nature, most egg masses generally harbor less than 50 eggs per mass with large numbers of egg masses recorded on host plants such as *Ailanthus altissima* Mill. (Swingle) (Simaroubaceae) as well as *Prunus* L. (Rosaceae) and *Acer* L. (Sapindaceae) spp. among others (Liu 2019a).

Recently, a rearing procedure for *L. delicatula* was developed. This methodology requires both suitable plant material, namely *A. altissima* plants and logs, and controlled environmental conditions for successful rearing in greenhouses or growth chambers (Nixon et al. 2022). While this approach does generate both egg masses and nymphs, there may be a possibility of using egg masses collected from nature as a source for rearing biological control agents. High densities of egg masses have been recorded in the field (up to 75 egg masses per m^2) on natural host substrates (Liu 2019a; Liu & Hunter 2021). However, removal from these host substrates requires a great deal of time and careful handling (Nixon et al. 2022) because egg masses become brittle as the winter season progresses, with the protective waxy coating flaking away and exposing egg masses to potential damage or dislodgement when removed from the substrate.

One approach to obtaining large numbers of egg masses inexpensively may be to deploy suitable substrates in areas with reproducing *L. delicatula* populations at high densities. Indeed, *L. delicatula* oviposit on human-made objects such as metal fence posts (Liu 2019a), cut stone, cinder blocks, vehicles, and rail cars (Urban 2020). While this behavior may contribute to human-assisted spread (Urban et al. 2021), it also points to the opportunity to use removable substrates to gather egg masses. Here, we evaluated a range of available materials to determine if they were suitable substrates for *L. delicatula* oviposition; when deployed in the field, substrates could be used for detection of reproductive *L. delicatula* populations and as a means for collecting egg masses for research.

We evaluated 9 potential substrates including roofing shingles, *Sorbus* spp. L. (Rosaceae) (Ash) bark, roof caps, landscaping fabric, corrugated plastic, mylar bubble wrap, white mesh, vinyl siding, and wooden planks as potential removable oviposition substrates for *L. delicatula*; for sizes and product information of all substrates, see Table 1. Substrates were deployed on 1 Oct 2019. Substrates were deployed directly on *A. altissima* trees with some larger trees hosting multiple treatments at 5 sites within 1.6 km of each other (1 replicate per site with the exception of roof cap and wood treatments, which were deployed only at 4 locations) in Frederick County, Virginia, USA. Rigid substrates (bark, roof caps, corrugated plastic, vinyl siding, and wooden planks) were affixed to tree trunks with 2 screws in the center of the material area; flexible substrates (shingles, landscape fabric, mylar wrap, and white mesh) were wrapped loosely around the tree trunk and stapled into place. Deployment height ranged from 1 to 2 m, and tree diameter ranged from 25 to 60 cm diameter at breast height. Materials were removed and egg masses counted on 16 Dec 2019. In total, 68 *L. delicatula* egg masses were recovered. The number of egg masses per m^2 was calculated for each material; these data followed a non-normal distribution, therefore a non-parametric Kruskal-Wallis Rank Sum Test was performed to compare the number of egg masses per m^2 on each material type with a Steel-Dwass post hoc analysis for all pairs. Data analysis was performed using JMP 16.0 (SAS Institute Inc., Cary, North Carolina, USA). Significantly more egg masses were

[1]USDA-ARS, Appalachian Fruit Research Station, 2217 Wiltshire Road, Kearneysville, West Virginia, USA; E-mail: laura.nixon@usda.gov (L. J. N.), caitlin.barnes@usda.gov (C. B.), anthony.rugh@usda.gov (A. R.), chris.hott@usda.gov (C. H.), lee.carper@usda.gov (L. C.), john.cullum@usda.gov (J. C.), sharon.jones@usda.gov (S. J.), cameron.scorza@usda.gov (C. S.), tracy.leskey@usda.gov (T. C. L.)
[2]Department of Entomology, Texas A&M AgriLife Research & Extension Center, Corpus Christi, Texas, USA; E-mail: dalton.ludwick@ag.tamu.edu (D. L.)
*Corresponding author; E-mail: laura.nixon@usda.gov

Table 1. Sizes (m^2) and product information for all removable substrates deployed for oviposition of *Lycorma delicatula*. Mention of a concept, idea, trade name, or commercial product in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the US Department of Agriculture.

Material	Size m^2	Product information
Corrugated plastic	0.4–0.9	4 mm brown twinwall plastic sheet; Coroplast, Vanceburg, Kentucky
Sorbus spp. (Ash) bark	0.2–0.5	Collected from dead ash trees in the field
Landscaping fabric	0.4–0.6	3 oz woven weed barrier; Vigoro, Lake Forest, Illinois
Mylar bubble wrap	0.3	Double reflective insulation staple tab; Everbilt, Home Depot Product Authority, LLC, Atlanta, Georgia
White mesh	0.2	0.9 oz Noseeum mesh; Ripstop by the Roll LLC, Durham, North Carolina
Roof cap	0.3	Red Ondura premium ridge cap; Onduline, Fredericksburg, Virginia
Roofing shingle	0.3	Royal Sovereign charcoal algae resistant 3-tab roofing shingles; GAF Materials Corp., Troy Hills, New Jersey
Vinyl siding	0.5	Double 4 inch wicker lap vinyl siding; Ply Gem, Martinsburg, West Virginia
Wooden planks	0.4	11/32 in southern yellow pine plywood sheathing; Home Depot Product Authority LLC, Atlanta, Georgia

recovered from roofing shingles, roof caps, and ash bark compared with all other treatments (χ^2 = 26.69; df = 8; *P* = 0.0008) (Fig. 1). Egg masses laid in 2019 on ash bark and roof shingles were cut out using plant pruners; those sections of substrate were stored in Ziploc bags (S. C. Johnson & Son, Racine, Wisconsin, USA) and transported to a quarantine facility in Fort Detrick, Maryland, USA, in accordance with APHIS permit P526P-18-03369. Roof caps with egg masses were sealed in larger bags and transported whole. The 42 egg masses that were laid on the roof shingles and the 7 that were laid on the roof caps were all physically damaged during this process due to the flexibility of the substrate. Thus, we were not able to conduct egg hatch studies for substrates. Egg masses deposited on ash bark fared better, and this substrate has been used previously to acquire field-derived egg masses (Nixon et al. 2022).

In 2020, 3 replicates of 7 of these materials were deployed with the same protocol; roof caps and ash bark were not evaluated in 2020 due to a lack of availability. Substrates were deployed on 1 Oct 2020 and removed for counting on 18 Dec 2020. A total of 9 egg masses across 3 substrate items were recorded: 7 on a single roofing shingle and 2 on vinyl siding treatments each receiving 1 egg mass. Additionally, in 2020, we evaluated the most effective substrate from 2019, roof shingles, either in direct contact with the vertical tree trunk or suspended horizontally between trees. Three replicates of the direct and suspended shingles were deployed on 1 Oct 2020 at 3 sites (1 replicate

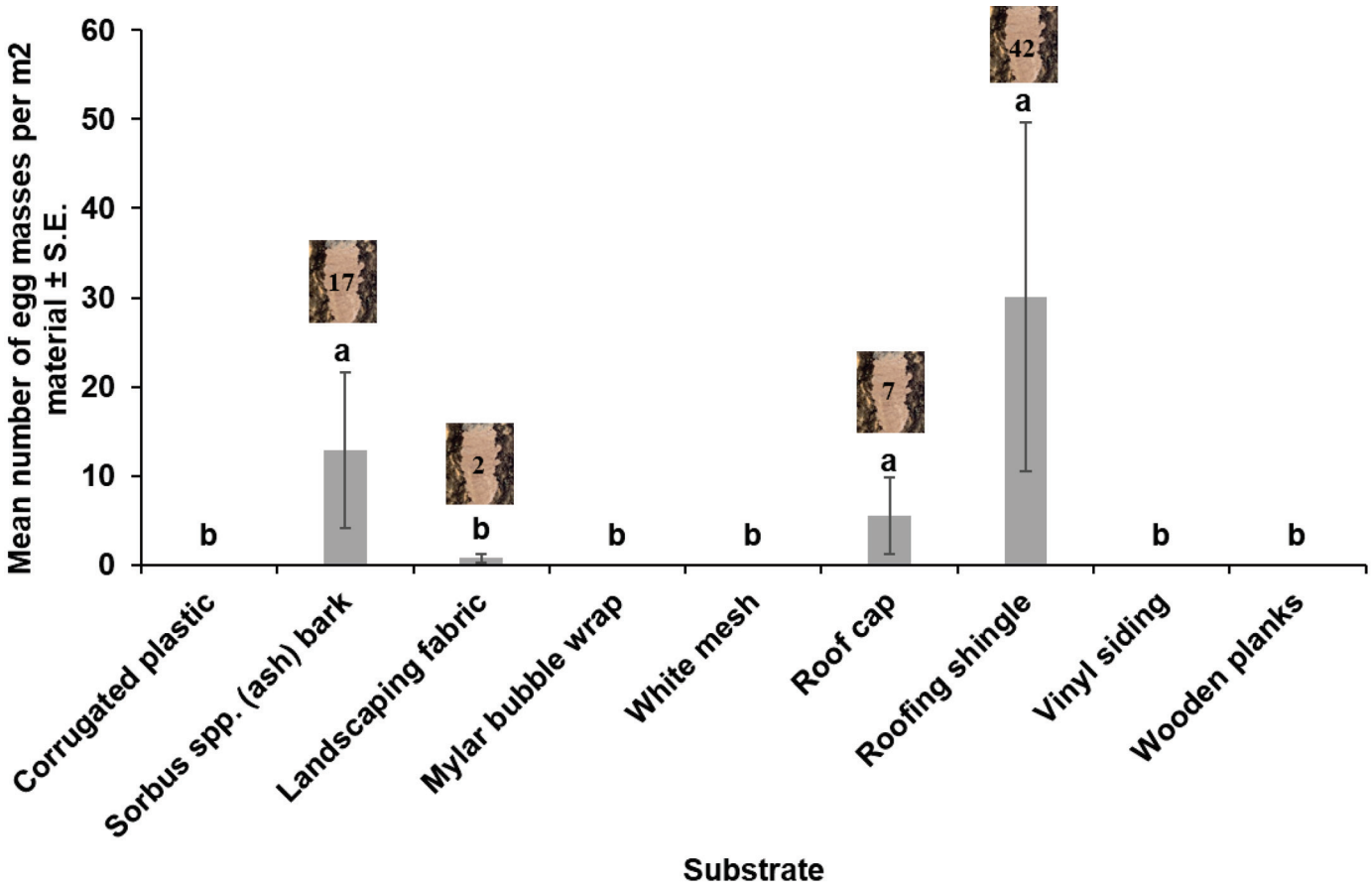

Fig. 1. Egg masses deposited per m^2 of removable substrates deployed in direct contact with *Ailanthus altissima* in 2019. Kruskal-Wallis analysis with Steel-Dwass post hoc applied: bars (means ± SE) sharing a letter were not significantly different from each other. Total egg masses collected from each substrate type is specified above each bar.

per site) within 1.6 km of each other in Frederick County, Virginia, USA. Direct contact shingles were attached vertically to *A. altissima* trees 1 m from the ground as described above, and suspended shingles were folded lengthwise and the long edges affixed to either side of a 5 × 5 cm wooden post. This wooden post was then suspended in a level horizontal orientation at either end to 2 *A. altissima* trees 1 m from the ground. These shingles were removed on 1 Mar 2021 and the number of egg masses on each recorded. A total of 7 *L. delicatula* egg masses were laid on direct contact shingles (1, 1, 5) and 1 was laid on the suspended shingles (0, 0, 1). In general, *L. delicatula* relative densities were much lower in 2020 compared with 2019, leading to deposition of far fewer egg masses.

Based on these results, it is possible to gather egg masses using removable oviposition substrates under field conditions. Roofing shingles, roof caps, and ash bark resulted in *L. delicatula* oviposition when in direct contact with *A. altissima* trees. However, care must be taken in handling flexible materials like roofing shingles to ensure egg masses are not damaged or dislodged. Additionally, this same approach may provide an opportunity for monitoring *L. delicatula* oviposition in newly invaded regions, because egg masses are cryptically colored, and may be more easily observed on removable substrates.

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Summary

Lycorma delicatula White (Hemiptera: Fulgoridae), spotted lanternfly, is an invasive planthopper now present in over a dozen states in the eastern US. Developing protocols to rear *L. delicatula* has been a high priority for potential classical biological control programs and controlled experiments. Here, we evaluated 9 different materials to serve as potential removable oviposition substrates to enable large numbers of egg masses to be collected in the field. We found that roofing shingles, roof caps, and ash bark were all acceptable substrates for *L. delicatula*, but that care must be taken in handling to ensure egg masses are not damaged or dislodged.

Key Words: invasive species, spotted lanternfly, classical biological control

Sumario

Lycorma delicatula White (Hemiptera: Fulgoridae), la mosca linterna manchada, es una saltahoja invasor que ahora está presente en más de una docena de los estados del este de los EE. UU. El desarrollo de protocolos para criar *L. delicatula* ha sido una alta prioridad para los posibles programas de control biológico clásico y experimentos controlados. Aquí, evaluamos 9 materiales diferentes para que sirvan como posibles sustratos de oviposición removibles para permitir la recolección de grandes cantidades de masas de huevos en el campo. Descubrimos que las tejas para techos, las tapas de los techos y la corteza de fresno eran sustratos aceptables para *L. delicatula*, pero se debe tener cuidado en el manejo para garantizar que las masas de huevos no se dañen o se desprendan.

Palabras Clave: especies invasoras; mosca linterna manchada; control biológico clásico

Author Contribution Statement

Authors LJN, CB, AR, CH, LC, JC, SJ, DL, CS, and TCL all contributed to the selection of treatments, experimental design, study deployment, and data collection. LJN and TCL analyzed data and wrote manuscript; all authors reviewed manuscript.

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