Received: 24 May 2022 | Accepted: 6 September 2022

DOI: 10.1111/2041-210X.13987

Methods in Ecology and Evolution BRITISH ECOLOGICAL SOCIETY

PRACTICAL TOOLS

A cost-effective method to passively sample communities at the forest canopy–aerosphere interface

Michael J. Cunningham-Minnick[1] | H. Patrick Roberts[1] | Brian Kane[1] | Joan Milam[1] | David I. King[2]

[1]Department of Environmental Conservation, University of Massachusetts, Amherst, Massachusetts, USA

[2]U.S. Forest Service Northern Research Station, Amherst, Massachusetts, USA

Correspondence
Michael J. Cunningham-Minnick
Email: mcunninghamm@umass.edu

Funding information
University of Massachusetts

Handling Editor: Nick Isaac

Abstract

1. The ecology of the canopy–aerosphere interface within forested ecosystems remains underexplored largely due to the challenges of physically accessing this zone. Sky bridges, towers and other permanent structures are most commonly used to sample the forest canopy–aerosphere interface, but these methods are costly, challenging to replicate, and often alter and degrade the local environment during construction. Thus, there is a clear need for cost-effective and replicable methods for accessing and passively sampling above the forest canopy.
2. We designed and deployed an inexpensive and lightweight telescopic hanger composed of common materials to sample aerial invertebrates above the forest canopy. Deployment involved climbing into tree crowns and securing our hanger design to vertical branches. We sampled the invertebrate community above forest fragments on the campus of the University of Massachusetts Amherst, USA by suspending blue vane traps from hangers, which were extended to approximately 1 m above the highest terminal bud of the tree, continuously from April through August 2021. We also recorded the microclimate conditions above the canopy at each hanger, including temperature and light intensity.
3. All hangers and traps remained in place and active throughout the study period. In May, we made minor repairs at two locations where the hangers were attached to the trees and, following an intense weather event in July, observed damage to one hanger that did not affect sampling effort. We include cost breakdowns of design components as well as detailed building instructions.
4. This tool offers a durable and inexpensive solution for researchers to access and sample the forest canopy–aerosphere interface that has minimal impacts on the environment and is more easily replicated compared to previous methods. Assembly pitfalls and design alterations are discussed based on our experience with the installation and implementation of the tested design, as well as included prototypes.

KEYWORDS
above forest canopy, aerosphere interface, blue vane trap, hanger design, monitoring, tree climbing

1 | INTRODUCTION

The current body of research addressing the vertical distribution of organisms, particularly invertebrates, within temperate forests is limited, especially with respect to the canopy–aerosphere interface (Bouget et al., 2011; Cannon et al., 2021; Kunz et al., 2008; Lowman et al., 2012; Ozanne et al., 2011; Ulyshen, 2011). The paucity of information is largely due to the challenges of accessing the canopy, particularly its outer reaches where vertical branches support very little weight. Interest in the vertical distribution of invertebrates within forests has spurred the development of standardized methods for sampling into the canopy, yet methods for sampling the canopy–aerosphere interface remain underdeveloped (Cannon et al., 2021; Maguire et al., 2014; Nakamura et al., 2017; Ulyshen, 2011) and often rely on inferences from remote sensing techniques despite the unique interactions documented between invertebrates and the dynamic conditions associated with this zone (Kelly & Stepanian, 2020; Wainwright et al., 2017). Novel methods that grant researchers access beyond the forest ceiling are needed to advance our understanding of the ecological roles of forest communities (Cannon et al., 2021; Nakamura et al., 2017).

Methods to sample the high canopy and canopy–aerosphere interface of forests have been largely restricted to construction cranes (canopy cranes), scaffolding, observation (canopy) towers and ecotourism-associated canopy walkways (Barker & Pinard, 2001; Basset et al., 1997; Cannon et al., 2021; Lowman et al., 2012; Ozanne et al., 2011), which require large monetary investments, need considerable maintenance and have a disturbance footprint during construction (Basset et al., 2003; Jackson, 1996; Lowman, 2020; Lowman et al., 2012; Nakamura et al., 2017; Thiel et al., 2021). Some alternative methods to reach invertebrates within and above tree crowns have greater mobility, such as inflatable rafts that move along the top of the tree canopy, while others also require less infrastructure and monetary investment, such as insecticidal fogging machines hoisted into the canopy, as well as balloons (Erwin, 1982; Gering & Crist, 2000; Hallé & Pascal, 1991; Lowman et al., 1993). Yet, these methods can be imprecise and challenging to replicate both spatially and temporally and to deploy throughout the season when forests are structurally complex. Thus, there is an immediate need for a simple, durable, economic and highly replicable methodology that is also portable and can access the forest canopy–aerosphere interface for extended periods.

Climbing trees to deploy sampling devices represents a relatively simple strategy for surveying the canopy, but the inability of climbers to safely reach the upper limits of the crown prevents the canopy–aerosphere interface from being included (Barker & Pinard, 2001; Lowman et al., 2012). Researchers interested in sampling above trees have addressed this issue by removing the highest portion of the crown that lacks the structural integrity to support significant weight, then mounting a hanger above the cut portion of the tree (Müller et al., 2013; Seibold et al., 2018). While effective for certain studies, this methodology modifies the canopy environment by changing the physical structure of the focal tree and thus altering the microclimate and resource availability (e.g. food, nesting substrates). Moreover, removing a portion of the canopy adversely affects tree health (Fini et al., 2015), leading to decay (Dahle, Holt, Chaney, Whalen, Grabosky, et al., 2006) and weakly attached re-growth (Dahle, Holt, Chaney, Whalen, Cassens, et al., 2006), which ultimately increases the likelihood of tree failure, making it unsafe for further climbing and hazardous if the area is heavily trafficked by people. Thus, an effective design of an apparatus that facilitates sampling at the forest canopy–aerosphere interface also needs to avoid damaging the crown or compromising tree health.

We designed, built and tested a novel and cost-effective telescopic hanger that allowed us to position an invertebrate sampling device above the forest canopy for extended periods without altering the canopy structure or damaging the tree or forest floor. We tested the durability of the hanger in the field continuously from April through August in temperate forest fragments. We present detailed findings on the invertebrate community elsewhere and focus here on durability of the hanger design.

2 | MATERIALS AND METHODS

2.1 | Assembly

Hangers were built with common and inexpensive materials and hardware readily found at home improvement stores for a cost of $US 52 per hanger; a cost that includes all design modifications and recommendations discussed in the remaining sections (Figure 1).

No.	Item	Quantity	Total Price (US Dollars)
1	3-m x 50-mm SCH40 PVC Pipe	10	113
2	3-m x 38-mm SCH40 PVC Pipe	10	80
3	3-m x 13-mm SCH40 PVC Pipe	2	19
4	0.35-L Foam Insulation	2	11
5	0.91-m x 50-mm VELCRO straps	2/pk x 15 pk	121
6	Industrial Strength Cable Ties	1 pk	8
7	Polystyrene Rope	305 m	110
8	Braided Nylon Rope	305 m	19
9	10-mm hex bolts	40	28
10	10-mm washers	80	10
11	10-mm hex nuts	40	4
	GRAND TOTAL	**10 HANGERS**	**$523**

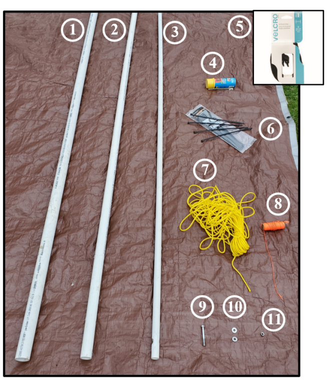

FIGURE 1 Complete list of products and costs needed for the assembly and installation of 10 hangers. Products and prices were based on availability at a local hardware store in Amherst, Massachusetts, USA as of March 2021. Products are listed in metric measurements. Standard equivalents in which products were sold are presented in Appendix A (Figure A1).

Hangers were constructed with polyvinyl chloride (PVC) pipes to provide a flexible but sturdy structure that sheathed a polystyrene rope which held a blue vane trap with approximately 0.6 L of diluted propylene glycol as preservative (Figure 2). Overlapping pipes allow for the telescopic feature. By drilling holes through overlapping pipes in 0.3-m (1-ft) increments, the hanger could be contracted to minimal length (3.35 m or 11 ft) for transportation and expanded in the field up to 5.79 m (19 ft). We recommend using a hand drill

Assembly and Deployment Instructions

Tools Needed: Drill, Marker, Tape measurer, 13-mm & 25-mm hole saws, 10-mm & 6-mm drill bits, clamp or vice, appropriate Personal Protective Equipment (PPE)

1) Make a 25-mm hole through the 38-mm PVC pipe centered exactly 50 mm from an end (Terminus A).
2) Insert the 38-mm PVC pipe into the 50-mm PVC pipe. Ensure 0.28 meters of the 38-mm pipe, including Terminus A, is exposed and then clamp the pipes together.
3) Measure 0.46 m from Terminus B and drill a 10-mm hole through the pipes. Place bolt in hole with a washer on both sides of 50-mm pipe, then secure with hex nut. Do not overtighten!
4) Measure and drill another eight 10-mm holes equally spaced 0.3 meters apart and in the same orientation (aligned exactly) with the bolt. Remove clamps.
5) Cut the 3.05-m x 25-mm PVC pipe into 0.38-m lengths (n = 8). One piece will be used for each hanger.
6) Cut a 13-mm hole into one face of the 25-mm pipe 50 millimeters from an end. To avoid debris clogs in the field, do not cut all the way through both sides of the pipe. At the same end, drill a 6-mm hole centered 13 millimeters from the end such that the hole is perpendicular to the 13-mm hole.
7) Tie the thinner cord (pull-down assist cord) to a washer or nut and thread through pipes. Insert in Terminus B, lift, and feed until it exits Terminus A. Reinsert into Terminus A and pull out the 25-mm hole (either side). Remove washer/nut and continue to thread cord into 13-mm hole of 25-mm pipe and out the opposite end of the pipe. Keep tension on the cord and fit the 25-mm pipe into the 25-mm hole of the 38-mm pipe until the 6-mm holes are visible on the other side. Make sure the 13-mm hole is perpendicularly facing Terminus B. The cord should now move freely throughout the hanger.
8) Prevent the elbow from moving by inserting a cable tie through the 6-mm holes in the backside of the elbow and attach to (encircle) the 38-mm PVC pipe beneath the elbow. (Alternatively, drill another set of 6-mm holes in frontside of elbow, then place cable tie through all four holes).
9) Tie the free end of the pull-down assist cord at Terminus A to the thicker cord and thread through the hanger by pulling the free end of the pull-down assist cord at Terminus B. Tie an appropriate loop/knot needed for your purposes. Make sure the knot is wider than the width of the elbow.
10) Fully secure the elbow with an expanding foam insulation being careful not to inhibit movement of the polystyrene cord (Apply only to the outside of the 38-mm pipe). Allow time to dry.

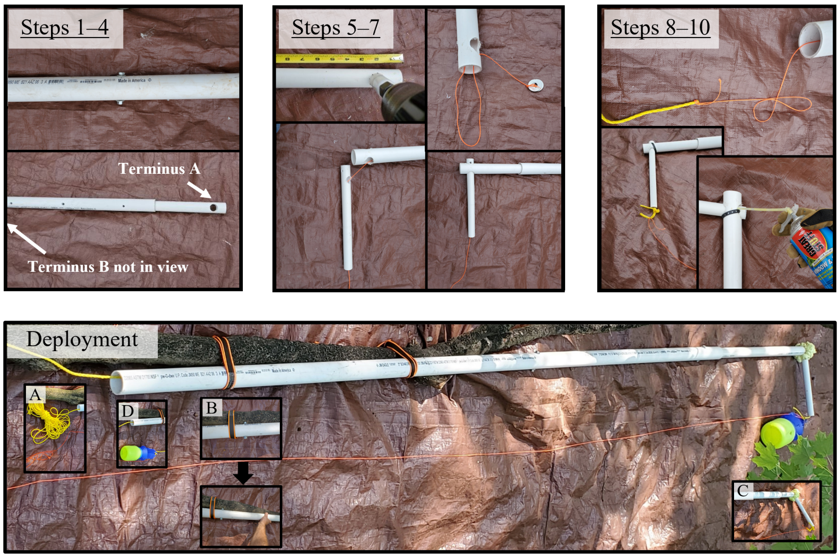

FIGURE 2 Assembly instructions in metric measurements with visual aids for assembly and deployment of the telescoping hanger design. Instructions in standard units can be found in Appendix A. Deployment: Once climber is secured within the tree, allow 3 m of polystyrene cord to be free. Do not untie the bundle of cord; this is a failsafe to stop the outer pipe from falling when the bolt is removed (a). Then pre-fit the hanger in fully contracted position. Loosely attach lower strap while pressing the pipe above to the tree with one hand while manipulating the hanger into a secure position with the crossbar directly above the fewest branches with the other hand (b). Next, estimate the height of the canopy ceiling relative to the pre-fit positioning of the hanger. Remove the bolt holding the two pipes together and lower the hanger. Hold the outer pipe with one hand and pull the inner pipe to extend it to the appropriate height and secure the bolt in the hole nearest Terminus A (c). Refit the hanger as before (b). Once the crossbar is at the height of the canopy ceiling, lower the hanger once more and extend the hanger 1 m. Refit the hanger, tighten the lower strap and secure a second strap at the highest reachable contact point between the target branch and the hanger. Finally, untie the bundled polystyrene cord and pull on the nylon cord until the polystyrene cord from Terminus A is in hand. Attach the trap or device. Raise the trap by pulling the polystyrene cord from Terminus B, then raise and lower the trap to ensure it will penetrate the canopy ceiling (d). Lastly, descend to the ground while providing an unobstructed path for both cords to the forest floor.

with the aid of a level and clamp or a press for the placement of the incremental holes. If the holes are not uniform in interval, exactly aligned, and exactly 180 degrees from opposing holes, the bolt securing the overlapping PVC pipes will not be able to properly lock. This design ensured a minimum 0.30 m (1 ft) of overlapping pipes for stability when the structure was fully extended. Hangers were constructed with components made in the United States, which uses the Standard system of measurements (Figures A1 and A2). Thus, component sizes (e.g. PVC pipes) and building instructions may need to be adapted to local product availability in other countries (Figure 2).

2.2 | Deployment

Four hangers were installed by MC-M and BK on one branch each in the crown of one *Quercus rubra* L. (Northern red oak) and a paired *Acer rubrum* L. (Red maple) within each of two forest fragments (42.39877°N, −72.2123°W; 42.39286°N, −72.52206°W) on the campus of the University of Massachusetts in Amherst, Mass., USA, which is in USDA Hardiness Zone 5a. Permission from the University of Massachusetts to conduct the experiment on University property was acquired prior to site selection. *Acer rubrum* and *Q. rubra* trees were chosen for their large size (diameter at breast height: *A. rubrum*—73.2 and 56.4 cm, *Q. rubra*—89.2 and 51.6 cm) and evaluated for climbing safety by BK, an International Society of Arboriculture (ISA) Certified Arborist, according to the most recent edition (at the time of data collection) of the consensus arboricultural safety standard in the USA (Anderson et al., 2015; ANSI, 2017). Branches were chosen for their vertical orientation (~90° relative to the ground), maximum ceiling height and safe access (i.e. central location in the crown and stem diameter large enough to bear expected loads associated with ascending, work positioning to install the telescopic hanger, and descending).

Each telescopic hanger (Figure 3a) without a trap was 6.2 kg (13.6 lbs) and was easy to lift into the canopy once the climber verified the structural integrity of the target branch for hanger attachment and was situated in a secured position. Hangers were extended 79%–95% of the full capability of the design (total length of 4.58–5.50 m). Once in place, each hanger was secured to a branch at three locations such that the diameter of the branch at the base of the hanger ranged from 7.9 to 15.2 cm (3.1–6.0 in). Three hangers were secured using duct tape over cable ties while the fourth was secured using duct tape over 5-cm (2-in) Velcro straps (see Figure 1 for local prices for producing 10 hangers and Figure 2 for a detailed protocol for hanger installation).

One blue vane trap was attached to the polystyrene rope that extended from the top of each hanger at heights ranging from 28.9 to 31.2 m (95–102 ft; Figure 3b,c). Blue vane traps were 38 cm tall when fully assembled and a single trap ranged from 0.23 kg (0.5 lbs) when empty to 1.63 kg (3.6 lbs) when filled with rainwater up to the factory-designed overflow holes. Further details on the original trap design can be found on the website of the manufacturer at www.bluevanetraps.com. Traps on prototype hangers (Figure A3) often detached from the rope during storms. To ensure that each trap remained assembled and attached throughout the study period we added security to the traps (Figure A4). We also secured one Onset HOBO® Pendant data logger (Part AU-002-64) shielded by two sheets of 15 × 15-cm corrugated polypropylene sheets separated by ~1 cm to each polystyrene cord directly above the trap to measure temperature and light intensity at the forest canopy–aerosphere interface (Figure A4). Precipitation and wind speed were extracted from a nearby weather station (ID: CW5324) through the publicly

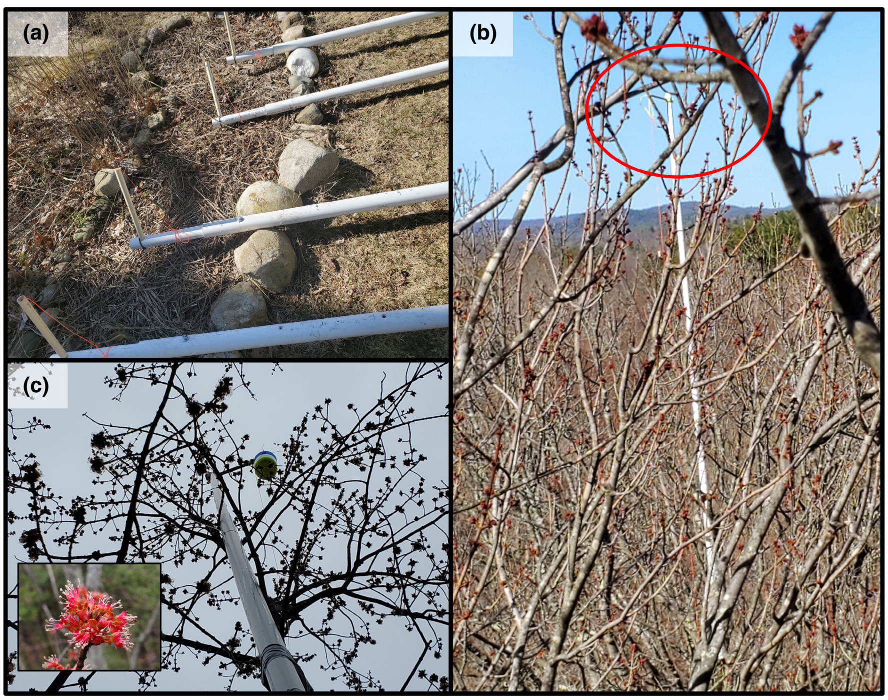

FIGURE 3 Assembled hangers were retracted for mobilization into the field (a) where they were installed such that the attachment point for traps was 1 m above the canopy ceiling and on average 30.3 m above the ground in *Acer rubrum* (b) and *Quercus rubra* trees. Traps were deployed above the canopy before leaf-out in early April during the flowering period of *A. rubrum* (c); *Q. rubra* flowered in May.

available MesoWest database to provide a basis for storm events (Horel et al., 2002). Finally, a nylon cord of smaller diameter than the polystyrene cord was tied to the attachment point of the trap as a means of assistance for lowering the trap. The free ends of both cords were secured to the tree ~10 m (33 ft) above the forest floor to minimize tampering from pedestrians at this publicly accessible site. However, this meant that the tree had to be climbed to collect the sample. At sites where tampering risk is low, securing the cords near the ground would obviate the need to climb trees and facilitate the collection of samples. For example, it took us 45 min once at a site to collect a sample and redeploy the trap due to the time required to put on climbing gear, assemble equipment and get the climbing rope into position; in contrast, lowering the trap with a rope, collecting the sample and redeploying it with new preservative required only 10–15 min. Samples were collected from traps and redeployed every 1–3 weeks. Hangers were removed from trees 8 September 2021. Each hanger and its branch attachment points were evaluated for damage on 12 May and 8 September.

3 | RESULTS AND DISCUSSION

We deployed our novel telescopic hanger design for 171 days from 21 March 21 to 8 September, which provided uninterrupted sampling of the invertebrate community at the canopy–aerosphere interface of every tree from 2 April to 21 August. Traps above the canopy yielded bees and beetles as two prominent taxa within the canopy–aerosphere interface, including 167 bees of 28 species and more than 4300 beetles of multiple functional guilds that will be published elsewhere. During deployment, hangers were subjected to a wide range of conditions throughout the season including wind events and fluctuations in temperature and light exposure (Figures A5 and A6), yet neither the traps nor the cords used to lower the traps ever detached from the polystyrene cords. Finally, there was no evidence of wildlife tampering with the traps, cords, hangers or hanger–tree attachment points.

Given the broad range of possible tree structures of different forest types, future studies planning to use this design may find that the specifications outlined above (Figure 2) are too risky to safely climb to a location in the crown that permits safe installation of the hanger to reach above the canopy (e.g. tree species with more slender vertical branches). To address this issue, the length of the hanger could be extended by adding another telescoping pipe. However, this modification will add the weight of another pipe to the design, which will require the climber to use greater force and more leverage to appropriately extend the hanger, hold it in place and attach it to the tree. To do this safely, the climber would need to be positioned lower within the canopy where the diameter and strength of the supporting branches are greater. Once the hanger was installed, the additional weight of the added pipe must be supported by the vertical branch; therefore, the climber would likely need to install it even lower, offsetting to some extent the additional height gained by adding another telescoping pole. Since it would not be possible a priori to optimize the installation location because of the inherent variability in crown architecture and branch slenderness, the climber would need to make these decisions while within the canopy.

Evaluation of the hanger–tree attachment points showed only minor damage to the duct tape mid-season (12 May), but more extensive damage was observed at the end of the sampling period, including worn duct tape at nearly all locations and a broken cable tie at one attachment point per hanger. There was also a band of discoloration on the bark where the duct tape was in direct contact with the branch, which may be indicative of minor tree damage (Figure 4). Compared to cable ties, VEL straps demonstrated greater durability and were not associated with any visible alterations to the tree; therefore, we recommend the use of Velcro straps without duct tape, despite their added monetary costs (Figure 1), though less expensive alternatives with similar strength may also be effective. Otherwise, tree damage at the attachment points was limited to small terminal twigs that likely got caught in the actual trap during sample collection or storm events.

We observed that the crossbar at the elbow of one hanger (Figure 4c) broke following a weather event lasting 27–29 July; however, the hanger remained functional throughout the remainder of the study period without repairs. The crossbar failure demonstrated that, while the hanger–tree attachment mechanism was sufficient, the crossbar piece was not strong enough to support a trap full of water (approximately 1.6 kg, or 3.6 lb) during these storms. It was not possible to replicate the dynamic loading during the storms that induced crossbar failure. Instead, we performed quasi-static load tests to approximate the load-bearing capacity of the hanger (Figure A7). The forest floor at the location of this hangar was often windy due to it being atop a west-facing slope of the forest fragment with a 17° pitch. Given the height of the trap, this means that the slope between the exposed ground 100 meters (Euclidean distance) away at the edge of the fragment and the trap was actually 31°, and that it was likely much windier at the trap than the forest floor. Another contributing factor to the observed failure may have been tension in the nylon cord used to pull the trap down. Swaying of the tree due to wind will be of greatest magnitude farthest from the trunk and thus at the crossbar. Since greater wind speeds would result in increased velocity of the swaying hanger, a sudden stop due to a tightening of the nylon cord would greatly increase the force applied to the crossbar, suggesting that future studies should ensure that the tension of the nylon cord can account for this situation. The fact that only one hanger broke throughout the study period suggests that our design is sufficient to sample during spring/summer weather characteristic of southern New England. Nevertheless, we recommend replacing the 19-mm (0.75-in) OD pipe with a 25-mm (1.00-in) pipe as directed in the building instructions, which increased maximum load-bearing capacity of the crossbar (Figure A7). We also recommend thoughtful consideration of the type of trap to be deployed and local climate conditions to decide whether modifications to the hanger may be needed to accommodate greater loads.

Our telescopic hanger design represents a simple, affordable tool that will allow researchers to passively conduct surveys at the tree

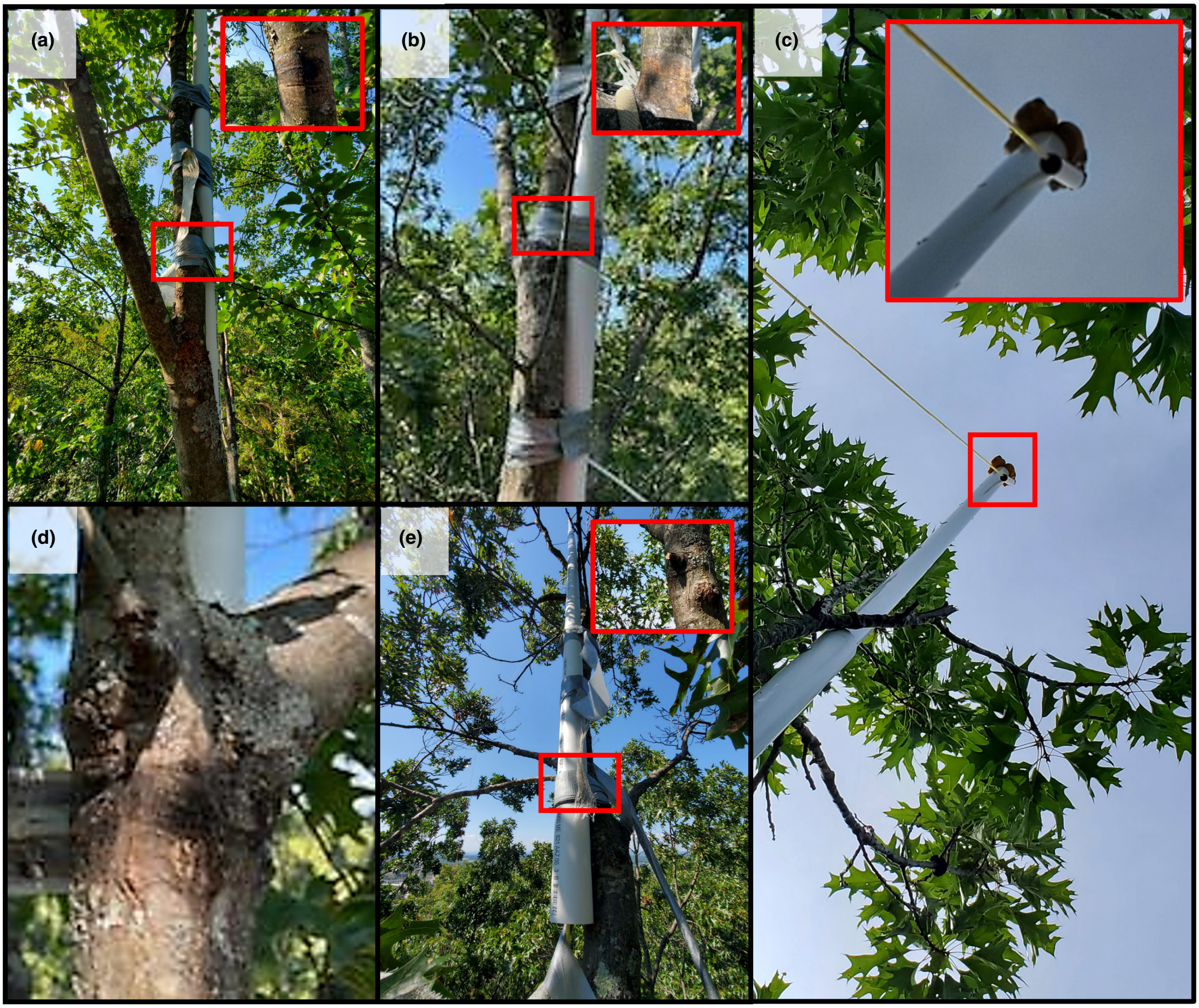

FIGURE 4 Visible discoloration on bark of *Acer rubrum* (a, d) and *Quercus rubra* (b, e) limbs at attachment points of hangers where cable ties and duct tape were used (a, b, d) but not where Velcro straps were deployed (e) on 8 September 2021. Structural failure on hanger elbow occurred in late July after deployment in the field for 135 days (c). Location of the break was on the crossbar of the elbow before the contact point with the vertical shaft.

canopy–aerosphere interface. We successfully monitored weather conditions and sampled invertebrates throughout spring and summer with a trap that experiences fluctuations in weight (during periods of rain and evaporation), suggesting that other sampling devices (e.g. other trap types, platforms, cameras, audio recording devices) would require minimal modifications if securely fastened to the polystyrene cord. For example, a very small trap 10 cm in height and less than 20 cm in width could be deployed using a shorter crossbar of 10 cm to reduce contact with the inner telescoping pipe during wind events, or if contact with the shaft needs to be avoided, then the crossbar could be cut such that it extends from the inner telescoping pipe more than 10 cm. Alternatively, a malaise trap 1 m in height, width and length would require a crossbar more than 1 m in length to avoid contact with the shaft. For lightweight traps and equipment, no other modifications would be needed to the design, though the total extension length needed of the hanger may change.

We allowed for more than 0.5 m of growth in leaves, flowers, fruit and terminal twigs throughout the year to ensure that our trap remained above the canopy ceiling throughout the study period, which was sufficient in our system. In other climates, it may be necessary to allow for greater growth. Smaller traps may need less extension length while taller traps may need more. For instance, the malaise trap would require an extension of five holes (1.5 m, or 5 ft) to allow 0.5 m of growth while the smaller vane trap would only require an extension of two holes. In the absence of excessive wind, our experience suggests that a hanger extended to 92% of full length would support a mass of 13.7 kg (30.2 lbs) but note that dynamic loading associated with windy conditions will increase the likelihood of hanger failure (Figure A7). Therefore, some traps that use heavy batteries (e.g. light traps) may require additional modifications. Shorter crossbars will generally have a higher maximum load-bearing capacity than longer crossbars because of reduced leverage. Crossbars or other pipe components with larger diameters will increase the load-bearing capacity of that particular component, but a balance between the weight of the trap, length and diameter of the crossbar, and extension of the hanger will need to be achieved to successfully maintain any trap above the canopy ceiling (Figure A7).

Our design is quick to instal and requires less than 2 h to put on climbing gear, ascend into the crown, install the hanger, descend and clean up the site. The primary limitation of this method is that hanger installment requires the gear and skills needed to climb trees and should be done in consultation with a certified arborist to ensure safe decisions regarding tree selection and climbing. Researchers that instead rely on canopy walkways and cranes can circumvent some of these limitations and may have easier access to the higher canopy, though we do not recommend the diameter of branches at attachment points of hangers to be less than 7.6 cm (3.0 in) due to a greater risk of branch failure from the load of the hanger and trap. Overall, the simplicity and cost-effectiveness of our design recommend it as a useful method for accessing the canopy–aerosphere interface, an important yet understudied feature of forests.

AUTHOR CONTRIBUTIONS

Michael J. Cunningham-Minnick and Brian Kane conceived the idea and designed the methodology; Michael J. Cunningham-Minnick, Joan Milam, Brian Kane, H. Patrick Roberts and David I. King collected the data. Michael J. Cunningham-Minnick and H. Patrick Roberts led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

ACKNOWLEDGEMENTS

We thank University of Massachusetts—Amherst, as well as Todd Courneyer, campus grounds manager, and Brady Yacek, campus arborist, for their support and permission to use woodlots on campus. We also thank Jacob Edwards for brainstorming design ideas.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

PEER REVIEW

The peer review history for this article is available at https://publons.com/publon/10.1111/2041-210X.13987.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in ScholarWorks, *Data and Datasets* at https://doi.org/10.7275/dq2n-gz77, reference number 153.

ORCID

Michael J. Cunningham-Minnick https://orcid.org/0000-0002-4478-4113
H. Patrick Roberts https://orcid.org/0000-0001-7846-6335
Brian Kane https://orcid.org/0000-0002-2814-0801
Joan Milam https://orcid.org/0000-0002-8056-1304
David I. King https://orcid.org/0000-0001-6827-0398

REFERENCES

Anderson, D. L., Koomijian, W., French, B., Altenhoff, S. R., & Luce, J. (2015). Review of rope-based access methods for the forest canopy: Safe and unsafe practices in published information sources and a summary of current methods. *Methods in Ecology and Evolution*, *6*, 865–872. https://doi.org/10.1111/2041X.12393

ANSI. (2017). *American National Standard for arboricultural operations - safety requirements*. American National Standards Institute.

Barker, M. G., & Pinard, M. A. (2001). Forest canopy research: Sampling problems, and some solutions. *Plant Ecology*, *153*, 23–38. https://doi.org/10.1023/A:1017584130692

Basset, Y., Horlyck, V., & Wright, S. J. (2003). *Studying forest canopies from above: The international canopy crane network*. Smithsonian Tropical Research Institute and UNEP. ISBN 9962-614-05-8.

Basset, Y., Springate, N. D., Aberlenc, H. P., & Delvare, G. (1997). A review of methods for sampling arthropods in tree canopies. In N. E. Stork, J. A. Adis, & R. K. Didham (Eds.), *Canopy arthropods* (pp. 27–52). Chapman and Hall.

Bouget, C., Brin, A., & Brustel, H. (2011). Exploring the "last biotic frontier": Are temperate forest canopies special for saproxylic beetles? *Forest Ecology and Management*, *261*(2), 211–220. https://doi.org/10.1016/j.foreco.2010.10.007

Cannon, C. H., Borchetta, C., Anderson, D. L., Arellano, G., Barker, M., Charron, G., LaMontagne, J. M., Richards, J. H., Abercrombie, E., Banin, L. F., Casapia, X. T., Chen, X., Degtjarenko, P., Dell, J. E., Durden, D., Andino, J. E. G., Hernández-Gutiérrez, R., Hirons, A. D., Kua, C., … Spenko, M. (2021). Extending our scientific reach in arboreal ecosystems for research and management. *Frontiers in Forests and Global Change*, *4*, 712165. https://doi.org/10.3389/ffgc.2021.712165

Dahle, G. A., Holt, H. H., Chaney, W. R., Whalen, T. M., Cassens, D. L., Gazo, R., & McKenzie, R. L. (2006). Branch strength loss implications for silver maple (*Acer saccharinum*) converted from roundover to V-trim. *Arboriculture and Urban Forestry*, *32*(4), 148–154. https://doi.org/10.48044/jauf.2006.020

Dahle, G. A., Holt, H. H., Chaney, W. R., Whalen, T. M., Grabosky, J., Cassens, D. L., Gazo, R., McKenzie, R. L., & Santini, J. B. (2006). Decay patterns in silver maple (*Acer saccharinum*) trees converted from roundovers to V-trims. *Arboriculture and Urban Forestry*, *32*(6), 260–264. https://doi.org/10.48044/jauf.2006.032

Erwin, T. L. (1982). Tropical forests: Their richness in coleoptera and other arthropod species. *The Coleopterists Bulletin*, *36*(1), 74–75. http://www.jstor.org/stable/4007977

Fini, A., Frangi, P., Faoro, M., Piatti, R., Amoroso, G., & Ferrini, F. (2015). Effects of different pruning methods on an urban tree species: A four-year-experiment scaling down from the whole tree to the chloroplasts. *Urban Forestry & Urban Greening*, *14*(3), 664–674. https://doi.org/10.1016/j.ufug.2015.06.011

Gering, J. C., & Crist, T. O. (2000). Patterns of beetle (coleoptera) diversity in crowns of representative tree species in an old-growth temperate deciduous forest. *Selbyana*, *21*(12), 38–47. https://www.jstor.org/stable/41760051

Hallé, F. & Pascal, O. (1991). Biologie D'une Canopée de Forét Equatoriale – II. Rapport de Mission Radeau Des Cimes, Réserve de Campo, Cameroun. Avec Le Parrainage Du Ministére de la Recherche et de lay Technologie.

Horel, J., Splitt, M., Dunn, L., Pechmann, J., White, B., Ciliberti, C., Lazarus, S., Slemmer, J., Zaff, D., & Burks, J. (2002). MesoWest: Cooperative mesonets in the western United States. *Bulletin of the American Meteorological Society*, *83*, 211–225. https://doi.org/10.1175/1520-0477(2002)083<0211:MCMITW>2.3.CO;2

Jackson, R. V. (1996). A new technique for accessing tree canopies to measure insect herbivory. *Australian Journal of Entomology*, *35*, 93–95. https://doi.org/10.1111/j.1440-6055.1996.tb01368.x

Kelly, J. F., & Stepanian, P. M. (2020). Radar aeroecology. *Remote Sensing*, *12*(11), 1768. https://doi.org/10.3390/rs12111768

Kunz, T. H., Gauthreaux, S. A., Hristov, N. I., Horn, J. I., Jones, G., Kalko, E. K. V., Larkin, R. P., McCracken, G. F., Swartz, S. M., Srygley, R. B., Dudley, R., Westbrook, J. K., & Wikelski, M. (2008). Aeroecology: Probing and modeling the aerosphere. *Integrative and Comparative Biology*, *48*(1), 1–11. https://doi.org/10.1093/icb/icn037

Lowman, M. (2020). Life in the treetops–an overview of forest canopy science and its future directions. *Plants People Planet*, *3*, 16–21. https://doi.org/10.1002/ppp3.10125

Lowman, M., Moffett, M., & Rinker, H. B. (1993). A new technique for taxonomic and ecological sampling in rain forest canopies. *Selbyana*, *14*, 75–79. https://www.jstor.org/stable/417601420

Lowman, M. D., Schowalter, T., & Franklin, J. (2012). *Methods in forest canopy research*. University of California Press.

Maguire, D. Y., Robert, K., Brochu, K., Larrivée, M., Buddle, C. M., & Wheeler, T. A. (2014). Vertical stratification of beetles (coleoptera) and flies (Diptera) in temperate forest canopies. *Environmental Entomology*, *43*(1), 9–17. https://doi.org/10.1603/EN13056

Müller, J., Brandl, R., Buchner, J., Pretzsch, H., Seifert, S., Strätz, C., Veith, M., & Fenton, B. (2013). From ground to above canopy–bat activity in mature forests is driven by vegetation density and height. *Forest Ecology and Management*, *306*, 179–184. https://doi.org/10.1016/j.foreco.2013.06.043

Nakamura, A., Kitching, R. L., Cao, M., Creedy, T. J., Fayle, T. M., Freiberg, M., Hewitt, C. N., Itioka, T., Koh, L. P., Ma, K., Malhi, Y., Mitchell, A., Novotny, V., Ozanne, C. M. P., Song, L., Wang, H., & Ashton, L. A. (2017). Forests and their canopies: Achievements and horizons in canopy science. *Trends in Ecology & Evolution*, *32*(6), 438–451. https://doi.org/10.1016/j.tree.2017.02.020

Ozanne, C. M. P., Anhuf, D., Boulter, S. L., Keller, M., Kitching, R. L., Körner, C., Meinzer, F. C., Mitchell, A. W., Nakashizuka, T., Silva Dias, P. L., Stork, N. E., Wright, S. J., & Yoshimura, M. (2011). Biodiversity meets the atmosphere: A global view of forest canopies. *Science*, *301*(5630), 183–186. https://doi.org/10.1126/science.1084507

Seibold, S., Hagge, J., Müller, J., Gruppe, A., Brandl, R., Bässler, C., & Thorn, S. (2018). Experiments with dead wood reveal the importance of dead branches in the canopy for saproxylic beetle conservation. *Forest Ecology and Management*, *409*, 564–570. https://doi.org/10.1016/j.foreco.2017.11.052

Thiel, S., Tschapka, M., Heymann, E. W., & Heer, K. (2021). Vertical stratification of seed-dispersing vertebrate communities and their interactions with plants in tropical forests. *Biological Reviews*, *96*, 454–469. https://doi.org/10.1111/brv.12664

Ulyshen, M. D. (2011). Arthropod vertical stratification in temperate deciduous forests: Implications for conservation-oriented management. *Forest Ecology and Management*, *261*, 1479–1489. https://doi.org/10.1016/j.foreco.2011.01.033

Wainwright, C. E., Stepanian, P. M., Reynolds, D. R., & Reynolds, A. M. (2017). The movement of small insects in the convective boundary layer: Linking patterns to processes. *Scientific Reports*, *7*, 5438. https://doi.org/10.1038/s41598-017-04503-0

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Cunningham-Minnick, M. J., Roberts, H. P., Kane, B., Milam, J., & King, D. I. (2022). A cost-effective method to passively sample communities at the forest canopy–aerosphere interface. *Methods in Ecology and Evolution*, *13*, 2389–2396. https://doi.org/10.1111/2041-210X.13987