Received: 12 April 2019 | Accepted: 21 June 2019
DOI: 10.1111/2041-210X.13258

PRACTICAL TOOLS

Methods in Ecology and Evolution BRITISH ECOLOGICAL SOCIETY

Optimizing sampling of flying insects using a modified window trap

Anna K. Knuff[1] | Nathalie Winiger[2] | Alexandra-Maria Klein[1] | Gernot Segelbacher[2] | Michael Staab[1]

[1]Nature Conservation and Landscape Ecology, University of Freiburg, Freiburg, Germany
[2]Wildlife Ecology & Management, University of Freiburg, Freiburg, Germany

Correspondence
Anna K. Knuff
Email: anna-k.knuff@t-online.de

Funding information
Deutsche Forschungsgemeinschaft, Grant/Award Number: GRK 2123/1TPX

Handling Editor: D. J. (Johan) Kotze

Abstract

1. Insect populations are globally declining but standardized long-term data to evaluate trends and consequences are largely missing. One difficulty among many is the rather narrow taxonomic cover of most conventional trap types, which makes the use of several complementary collection methods necessary to achieve comprehensive coverage. To avoid the effort associated with operating multiple traps, we demonstrate how to modify window traps in a simple and standardizable way to capture a wider range of flying insect taxa.
2. While a typical window trap only has a collection unit below the windows, we added an additional collection unit on top of the windows. We tested this modified trap design in 135 study plots in a temperate forest over 5 months and compared trap catches between top and bottom collection units.
3. The top collection unit captured considerably more individuals of Hymenoptera, Diptera, Lepidoptera, Neuroptera, Auchenorrhyncha and Thysanoptera than the bottom collection unit. In contrast, there were more individuals of Coleoptera, Heteroptera, Sternorrhyncha and Psocoptera in the bottom collection unit. Both collection units captured a highly distinct insect community and patterns were consistent throughout the season.
4. These modified traps are suitable for collecting a broader range of flying insects compared to conventional window traps. The additional top unit is fast and easy to build and the traps require little maintenance while operating in the field. These characteristics make modified window traps with top and bottom collection units a promising tool for standardized and replicable biodiversity studies covering a broad range of insect taxa.

KEYWORDS
arthropod diversity, biodiversity inventory, flight interception trap, insect sampling, monitoring, temperate forest, window trap

1 | INTRODUCTION

Insects are a hyper-diverse taxonomic group taking key roles in ecosystems (Schowalter, Noriega, & Tscharntke, 2018). Yet, their abundances are considerably declining (Hallmann et al., 2017; Shortall et al., 2009) but most long-term assessments are restrained to a few charismatic groups such as butterflies or bees (e.g. van Swaay, 1990; Conrad, Woiwod, Parsons, Fox, & Warren, 2004; Potts et al., 2010). A multi-taxon approach for insect monitoring with standardized trapping methods is, therefore, important to understand the causes and consequences of changes in insect populations (Simons, Weisser, & Gossner, 2016).

To study insect biodiversity, we were looking for a standardized method to catch a broad range of flying insects in forests including saproxylic Coleoptera and parasitic Hymenoptera. Larger or hard-bodied insects like many Coleoptera fall down after collision with a barrier and are, therefore, often collected with window traps (Hines & Heikkenen, 1977; Hyvärinen, Kouki, & Martikainen, 2006). Yet, these traps miss most Hymenoptera and other more soft-bodied insects that tend to orientate upwards after meeting obstacles (Townes, 1972; Wells & Decker, 2006).

Many other traditional trapping methods are also not suitable because they usually only target a particular taxonomic or functional group (Ozanne, 2005; Russo, Stehouwer, Heberling, Shea, & Dearden, 2011) while having limited coverage for others (Staab, Pufal, Tscharntke, & Klein, 2018). When aiming at sampling a broad range of insect taxa, several complementary trapping methods are necessary (Mazón & Bordera, 2008; Russo et al., 2011). However, using several trap types increases costs and workload for building, setting-up and maintaining the traps. Therefore, different trap types have occasionally been combined into a single device (e.g. Wilkening, Foltz, Atkinson, & Connor, 1981; Basset, 1988; Russo et al., 2011).

To extend the range of flying insects captured by conventional window traps (Hines & Heikkenen, 1977), Wilkening et al. (1981) presented a modification of the design by adding a funnel with a collection bottle above the window. Although this design was later adapted by different authors (Gossner & Ammer, 2006; Gossner et al., 2016; Springate & Basset, 1996), its benefits have not yet been tested. Only few studies compare the captured insect taxa among different collection units of traps, albeit with low sample sizes and different trap designs (Basset, 1988; Russo et al., 2011).

Here, we present the design, construction and effectiveness of the modified window trap sensu Wilkening et al. (1981) as, to our knowledge, the great potential of equipping a window trap with a top collection unit has not been documented before. We tested whether top and bottom collection units captured a different range, abundance and composition of insect taxa with 270 traps that operated continuously for 5 months. Additionally, we evaluated whether the expected differences between collection units are seasonally constant. Considering that the long-term monitoring of insects is a pressing issue, we promote this modified window trap as it facilitates consistent and efficient insect sampling with a broad taxonomic coverage and can be adapted for multiple applications.

2 | MATERIALS AND METHODS

2.1 | Trap design

We adopted window traps following Wilkening et al. (1981). Two transparent crossed acrylic glass windows serve as an omni-directional flight barrier and, as with conventional window traps (Hines & Heikkenen, 1977), arthropods that fall down after collision are collected into a container beneath the windows (bottom collection unit). We supplemented this window trap by adding a funnel on top of the windows to also catch insects flying upwards upon collision (Figure 1, see Supporting Information S1 for details on construction).

2.2 | Sampling

In 135 plots in the southern Black Forest (southwest Germany), two traps were installed with a separation of c. 100 m. The traps were attached to a sturdy line fixed between two trees with the lower edge of the windows being approximately 1.50 m above the ground. Understorey vegetation touching traps or lines was removed.

We operated the 270 traps continuously between mid-March and mid-August in 2017. Catches were collected at 4-weekly intervals, resulting in five sampling periods. Arthropods were stored in

FIGURE 1 Modified window trap supplemented with top collection unit. Two transparent crossed windows serve as flight barrier. Funnels beneath and on top of the windows serve as sturdy attachments between windows and collectors and direct arthropods into the collectors. For details see Supporting Information S1

75% ethanol, sorted to order level (with Hemiptera being further separated into Auchenorrhyncha, Sternorrhyncha and Heteroptera). Further details on study area and sampling are given in Supporting Information S2.

2.3 | Data analysis

All non-flying taxa (Isopoda, Arachnida, Collembola, Myriapoda; Table S1), wingless juveniles and insect taxa with less than 500 individuals summed over all catches were excluded from analysis, as they are unlikely to be reliably sampled with window traps (Henderson, 2003). For the remaining 10 taxa, we used the average number of specimens captured per day instead of raw numbers as not all traps were operated for the exact same amount of time.

Analyses were performed in R 3.5.1 (R Core Team, 2018) using the 'vegan' package for all multivariate analyses (Oksanen et al., 2018). To test whether the top and bottom collection units captured different insect communities on order level, we performed a multivariate permutation analysis of variances (ADONIS, 10,000 permutations) using Morisita–Horn dissimilarity. Differences between collection units were visualized with a twodimensional non-metric multidimensional scaling (NMDS, Morisita–Horn dissimilarity). We used paired Wilcoxon rank-sum tests to determine whether numbers of captured individuals differed between top and bottom collection units for each insect taxon. Tests were calculated both for data pooled over all sampling periods and for each sampling period separately.

3 | RESULTS

We collected 230,162 specimens from all locally occurring major arthropod taxa, of which 125,572 were caught in the top collection unit (Table S1).

Coleoptera (40,095 individuals), Sternorrhyncha (29,186) and Diptera (17,140), were the most abundant taxa in the bottom unit and accounted for 83% of all specimens captured in the bottom unit. In the top unit, the most abundant insect taxa were Diptera (79,966), followed by Hymenoptera (19,034) and Coleoptera (14,158) together accounting for 90% of all specimens in this unit. Composition of higher level insect taxa per collection unit was markedly different (ADONIS: $F = 272$, $R^2 = .34$, $p < .001$, $n = 270$), with little overlap between top and bottom (Figure 2).

Individual numbers per collection unit differed significantly for all analysed taxa (paired Wilcoxon-test, $n = 270$ traps, statistical details in Table S2) when pooled over all sampling periods (Figure 3). The top collection unit captured significantly more individuals of Hymenoptera, Diptera, Lepidoptera, Neuroptera, Auchenorrhyncha and Thysanoptera. In contrast, the bottom collection unit captured significantly more Coleoptera, Heteroptera, Psocoptera and Sternorrhyncha. With few exceptions, especially in spring when individual numbers were lower, these patterns were consistent throughout the sampling time (Supporting Information S3).

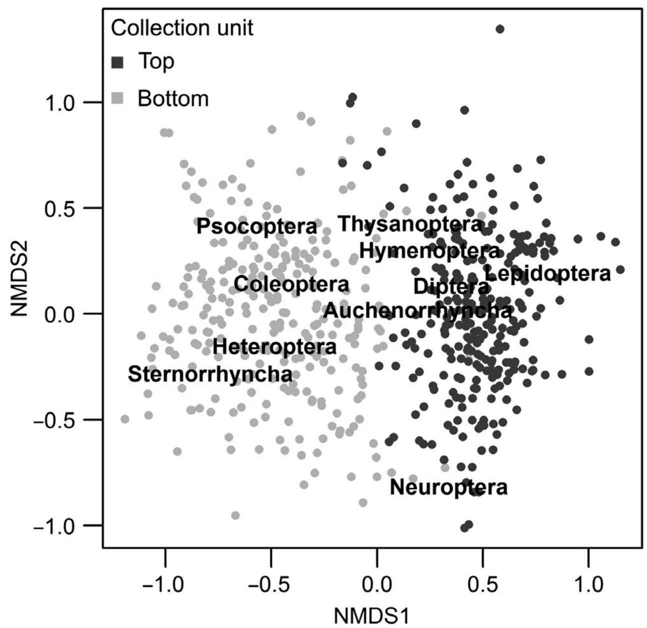

FIGURE 2 NMDS ordination (stress = 0.19) of insect numbers pooled over all sampling periods. Shown are the scores of the top (dark grey) and bottom (light grey dots) collection units, that is, collectors with similar composition of taxa are situated close to each other. Scores of insect taxa are shown as labels at the centroid of the positions of the respective taxa in the ordination space

4 | DISCUSSION

We show that a window trap equipped with an additional collection unit above the windows indeed collects several taxa more efficiently than a conventional window trap. Although specimens of all taxa were present in both collection units, the top unit captured considerably more individuals of multiple insect taxa such as Diptera and Hymenoptera.

The top sampling unit successfully exploits the behaviour of certain insects to orient upwards in a similar way as Malaise traps do (Malaise, 1937; Noyes, 1989; Townes, 1972). Similar combinations of different trap types have effectively expanded the range of insects captured also in other contexts, climates and habitats (Basset, 1988; Russo et al., 2011). For example, congruent with our findings, the bottom units of window traps in rainforests predominantly captured Coleoptera while the top sampling units captured predominately Diptera and Hymenoptera (Basset, 1988; Lamarre, Molto, Fine, & Baraloto, 2012).

Assessing the status of insect populations across geographical areas and ecosystems is of particular importance with respect to the globally discussed insect decline. To understand its extent and drivers, we need standardizable and inexpensive traps that capture a large range of insects and that are suitable for long-term monitoring (Noriega et al., 2018). Based on our results, we can recommend the modified window trap for biodiversity assessments (Lindenmayer et al., 2012).

By sampling complementary communities in each collection unit, modified window traps enable more comprehensive sampling

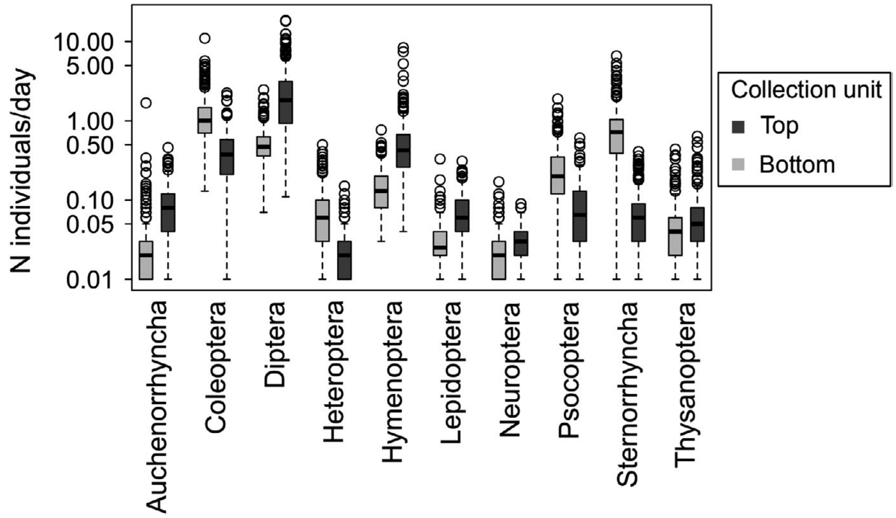

FIGURE 3 Taxon-wise number of individuals captured per day by each collection unit pooled over all sampling periods. Paired Wilcoxon-test: all pairwise comparisons were significantly different at $p < .01$, $n = 270$ traps. See Supporting Information Table S2 for test statistics. Y-axis is on logarithmic scale

of flying insects than conventional window or Malaise traps alone (Juillet, 1963; Lamarre et al., 2012). Additionally, they seem ideal for long-term monitoring as our successful study in the challenging terrain of the Black Forest indicates. Once in place, they require little maintenance. They were sturdy enough to withstand all occurring weather conditions including storms and frost. During the 5 months of continuous operation, we did not lose a single trap due to weather or wildlife, and they are still in good condition for more field seasons.

Despite the advantages of modified window traps over other flight-interception traps, they share some limitations as they all rather provide a measure of flight activity than abundance (Evans & Owen, 1965). Thus, standardized trap placement is crucial (Kowalski et al., 2011; Sverdrup-Thygeson & Birkemoe, 2009) because factors such as installation height or vegetation structure may influence catches (Floren & Schmidl, 2008; Juillet, 1964). Because of the stable and slender design presented herein, the traps can be operated in different vegetation types and at all heights, including tree crowns (Basset, Springate, Aberlene, & Delvare, 1997).

Although we showed that the modified window trap is ideal for sampling a broad range of insect taxa, more specific traps may be advisable depending on the study purpose (Missa et al., 2009). However, slight alterations to the modified window trap can further increase its range of applications: coloured strips on the windows may enhance sampling effectiveness for flower visitors (Campbell & Hanula, 2007) and the addition of baits increases capture of specific target groups (Hyvärinen et al., 2006). When suitable collection fluids are used (Gossner et al., 2016), the captured bulk insect samples can be used for metabarcoding, which is a fast-developing method facilitating rapid quantification of insect diversity through DNA sequencing and thus allowing the processing of large numbers of samples (Ritter et al., 2019).

5 | CONCLUSIONS

As insects increasingly come into the focus of biodiversity research, it is necessary to employ sampling methods that collect a large range of taxa and that are easily standardizable to allow comparisons among future studies. The presented trap type fulfils these requirements and its utilization is feasible even with restricted budgets and timeframes. Thus, the modified window trap may be well suited for the collection of various taxa to monitor insect diversity and population trends.

ACKNOWLEDGEMENTS

We thank the nature conservation authorities for collection permits and all foresters who supported research in their forest stands. Numerous technical and student assistants helped with assembling traps, conducting fieldwork and sorting insects. We thank the ConFoBi team for setting up the infrastructure and for logistical support. This study was funded by the German Research Foundation within the Research Training Group ConFoBi (grant number GRK 2123/1 TPX).

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

A.K.K. and M.S. conceived the idea; A.K.K. and N.W. collected the data; A.K.K. and M.S. analysed the data; A.K.K. and N.W. wrote the manuscript with input from M.S., A.-M.K. and G.S. All authors gave approval for publication.

DATA AVAILABILITY STATEMENT

Data deposited in the Dryad Digital Repository, https://doi.org/10.5061/dryad.q2f55kf (Knuff, Winiger, Klein, Segelbacher, & Staab, 2019).

ORCID

Anna K. Knuff https://orcid.org/0000-0002-3573-7729
Michael Staab https://orcid.org/0000-0003-0894-7576

REFERENCES

Basset, Y. (1988). A composite interception trap for sampling arthropods in tree canopies. *Australian Journal of Entomology*, *27*, 213–219. https://doi.org/10.1111/j.1440-6055.1988.tb01527.x

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

Campbell, J. W., & Hanula, J. L. (2007). Efficiency of Malaise traps and colored pan traps for collecting flower visiting insects from three forested ecosystems. *Journal of Insect Conservation*, *11*(4), 399–408. https://doi.org/10.1007/s10841-006-9055-4

Conrad, K. F., Woiwod, I. P., Parsons, M., Fox, R., & Warren, M. S. (2004). Long-term population trends in widespread British moths. *Journal of Insect Conservation*, *8*, 119–136. https://doi.org/10.1023/B:JICO.0000045810.36433.c6

Evans, F. C., & Owen, D. F. (1965). Measuring insect flight activity with a Malaise trap. *Papers of the Michigan Academy of Science, Arts and Letters*, *1*, 89–94.

Floren, A., & Schmidl, J. (2008). Introduction: Canopy arthropod research in Europe. In A. Floren, & J. Schmidl (Eds.), *Canopy arthropod research in Europe* (pp. 13–20). Nürnberg, Germany: Bioform Entomology.

Gossner, M. M., & Ammer, U. (2006). The effects of Douglas-fir on tree-specific arthropod communities in mixed species stands with European beech and Norway spruce. *European Journal of Forest Research*, *125*(3), 221–235. https://doi.org/10.1007/s10342-006-0113-y

Gossner, M. M., Struwe, J.-F., Sturm, S., Max, S., McCutcheon, M., Weisser, W. W., & Zytynska, S. E. (2016). Searching for the optimal sampling solution: Variation in invertebrate communities, sample condition and DNA quality. *PLoS ONE*, *11*(2), e0148247. https://doi.org/10.1371/journal.pone.0148247

Hallmann, C. A., Sorg, M., Jongejans, E., Siepel, H., Hofland, N., Schwan, H., … de Kroon, H. (2017). More than 75 percent decline over 27 years in total flying insect biomass in protected areas. *PLoS ONE*, *12*(10), e0185809. https://doi.org/10.1371/journal.pone.0185809

Henderson, P. A. (2003). *Practical methods in ecology* (1st ed.). Malden, MA: Blackwell Publishing.

Hines, J. W., & Heikkenen, H. J. (1977). Beetles attracted to severed Virginia Pine (*Pinus virginiana* Mill.). *Environmental Entomology*, *6*(1), 123–127. https://doi.org/10.1093/ee/6.1.123

Hyvärinen, E., Kouki, J., & Martikainen, P. (2006). A comparison of three trapping methods used to survey forest-dwelling Coleoptera. *European Journal of Entomology*, *103*, 397–407. https://doi.org/10.14411/eje.2006.054

Juillet, J. A. (1963). A comparison of four types of traps used for capturing flying insects. *Canadian Journal of Zoology*, *41*(2), 219–223. https://doi.org/10.1139/z63-023

Juillet, J. A. (1964). Influence of weather on flight activity of parasitic Hymenoptera. *Canadian Journal of Zoology*, *42*, 1133–1141. https://doi.org/10.1139/z64-110

Knuff, A., Winiger, N., Klein, A., Segelbacher, G., & Staab, M. (2019). Data from: Optimising sampling of flying insects using a modified window trap. *Dryad Digital Repository*. https://doi.org/10.5061/dryad.q2f55kf

Kowalski, E., Gossner, M. M., Türke, M., Lange, M., Veddeler, D., Hessenmöller, D., … Weisser, W. W. (2011). The use of forest inventory data for placing flight-interception traps in the forest canopy. *Entomologia Experimentalis Et Applicata*, *140*(1), 35–44. https://doi.org/10.1111/j.1570-7458.2011.01134.x

Lamarre, G. P. A., Molto, Q., Fine, P. V. A., & Baraloto, C. (2012). A comparison of two common flight interception traps to survey tropical arthropods. *ZooKeys*, *216*, 43–55. https://doi.org/10.3897/zookeys.216.3332

Lindenmayer, D. B., Gibbons, P., Bourke, M., Burgman, M., Dickman, C. R., Ferrier, S., … Zerger, A. (2012). Improving biodiversity monitoring. *Austral Ecology*, *37*(3), 285–294. https://doi.org/10.1111/j.1442-9993.2011.02314.x

Malaise, R. (1937). A new insect-trap. *Entomologisk Tidskrift*, *58*, 148–160.

Mazón, M., & Bordera, S. (2008). Effectiveness of two sampling methods used for collecting Ichneumonidae (Hymenoptera) in the Cabañeros National Park (Spain). *European Journal of Entomology*, *105*, 879–888. https://doi.org/10.14411/eje.2008.116

Missa, O., Basset, Y., Alonso, A., Miller, S. E., Curletti, G., De Meyer, M., … Wagner, T. (2009). Monitoring arthropods in a tropical landscape: Relative effects of sampling methods and habitat types on trap catches. *Journal of Insect Conservation*, *13*(1), 103–118. https://doi.org/10.1007/s10841-007-9130-5

Noriega, J. A., Hortal, J., Azcárate, F. M., Berg, M. P., Bonada, N., Briones, M. J. I., … Santos, A. M. C. (2018). Research trends in ecosystem services provided by insects. *Basic and Applied Ecology*, *26*, 8–23. https://doi.org/10.1016/j.baae.2017.09.006

Noyes, J. S. (1989). A study of five methods of sampling Hymenoptera (Insecta) in a tropical rainforest, with special reference to Parasitica. *Journal of Natural History*, *23*, 285–298. https://doi.org/10.1080/00222938900770181

Oksanen, J., Blanchet, F. G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., & … Wagner, H. (2018). Vegan: Community ecology package. R package version 2.5-2. Retrieved from https://CRAN.Rproject.org/package=vegan

Ozanne, C. M. P. (2005). Methods for forest understory vegetation. In S. R. Leather (Ed.), *Insect sampling in forest ecosystems* (pp. 58–76). Malden, MA, Oxford: Blackwell.

Potts, S. G., Biesmeijer, J. C., Kremen, C., Neumann, P., Schweiger, O., & Kunin, W. E. (2010). Global pollinator declines: Trends, impacts and drivers. *Trends in Ecology & Evolution*, *25*(6), 345–353. https://doi.org/10.1016/j.tree.2010.01.007

R Core Team. (2018). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing.

Ritter, C. D., Häggqvist, S., Karlsson, D., Sääksjärvi, I. E., Muasya, A. M., Nilsson, R. H., & Antonelli, A. (2019). Biodiversity assessments in the 21st century: The potential of insect traps to complement environmental samples for estimating eukaryotic and prokaryotic diversity using high-throughput DNA metabarcoding. *Genome*, *1–13*, https://doi.org/10.1139/gen-2018-0096

Russo, L., Stehouwer, R., Heberling, J. M., Shea, K., & Dearden, P. K. (2011). The composite insect trap: An innovative combination trap for biologically diverse sampling. *PLoS ONE*, *6*(6), e21079. https://doi.org/10.1371/journal.pone.0021079

Schowalter, T. D., Noriega, J. A., & Tscharntke, T. (2018). Insect effects on ecosystem services—Introduction. *Basic and Applied Ecology*, *26*, 1–7. https://doi.org/10.1016/j.baae.2017.09.011

Shortall, C. R., Moore, A., Smith, E., Hall, M. J., Woiwod, I. P., & Harrington, R. (2009). Long-term changes in the abundance of flying insects. *Insect Conservation and Diversity*, *2*(4), 251–260. https://doi.org/10.1111/j.1752-4598.2009.00062.x

Simons, N. K., Weisser, W. W., & Gossner, M. M. (2016). Multi-taxa approach shows consistent shifts in arthropod functional traits along grassland land-use intensity gradient. *Ecology*, *97*(3), 754–764. https://doi.org/10.1890/15-0616.1

Springate, N. D., & Basset, Y. (1996). Diel activity of arboreal arthropods associated with Papua New Guinean trees. *Journal of Natural History*, *30*(1), 101–112. https://doi.org/10.1080/00222939600770061

Staab, M., Pufal, G., Tscharntke, T., & Klein, A.-M. (2018). Trap nests for bees and wasps to analyse trophic interactions in changing environments—A systematic overview and user guide. *Methods in Ecology and Evolution*, *9*(11), 2226–2239. https://doi.org/10.1111/2041-210X.13070

Sverdrup-Thygeson, A., & Birkemoe, T. (2009). What window traps can tell us: Effect of placement, forest openness and beetle reproduction in retention trees. *Journal of Insect Conservation*, *13*(2), 183–191. https://doi.org/10.1007/s10841-008-9141-x

Townes, H. (1972). A light-weight Malaise Trap. *Entomological News*, *83*, 239–247.

van Swaay, C. A. M. (1990). An assessment of the changes in butterfly abundance in The Netherlands during the 20th Century. *Biological Conservation*, *52*(4), 287–302. https://doi.org/10.1016/0006-3207(90)90073-X

Wells, W., & Decker, T. (2006). A comparison of three types of insect traps for collecting non-Formicidae Hymenoptera on the island of Domenica. *Southwestern Entomologist*, *31*(1), 59–68.

Wilkening, A. J., Foltz, J. L., Atkinson, T. H., & Connor, M. D. (1981). An omnidirectional flight trap for ascending and descending insects. *The Canadian Entomologist*, *113*, 453–455. https://doi.org/10.4039/Ent113453-5

SUPPORTING INFORMATION

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

How to cite this article: Knuff AK, Winiger N, Klein A-M, Segelbacher G, Staab M. Optimizing sampling of flying insects using a modified window trap. *Methods Ecol Evol*. 2019;10:1820–1825. https://doi.org/10.1111/2041-210X.13258