**Introduction**

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Wind disturbance from hurricanes, derechos, and tornados, is a dominant natural disturbance in forests of the eastern United States (Fischer et al., 2013). When canopy trees are thrown by wind, multiple effects can occur. These include increased sunlight in the understory, reduction in leaf litter depth, deposition of woody debris in the form of trunks and branches which are broken or bent, and soil mixing because of trees being uprooted (Perry and Herms, 2019). However, during wind disturbance events, the wind does not destroy all living organisms in the affected area, but rather leaves “biological legacies” such as surviving canopy trees and surviving understory plants. After a wind event, any pre-existing advance regeneration (immature trees which were in the understory) usually benefit immensely from the disturbance. Additionally, trees which are strongly rooted may benefit when early successional trees with weaker root systems are removed by a wind event (Fischer et al., 2013).

The harvesting of fallen trees, which is called salvage logging, is a common response to windthrow events in forests. The removal of trees may be aimed at reducing the fuel load to prevent large-scale fires (Gandhi et al., 2008), or it may be motivated by the economic value of the fallen trees. During a tree harvest, machines such as \_\_\_\_\_, \_\_\_\_\_\_, and \_\_\_\_\_\_ are used to remove trees. There are varying intensities of salvage-logging operations, where varying proportions of the windthrow area are logged. Another important factor is whether slash (\_\_\_\_\_) is removed or left on the ground. Salvage-logging changes the biological legacies left by natural wind disturbance because it often removes the understory plants and removes much of the woody debris.

In addition to plants, studies of ground-dwelling invertebrates can give another perspective on how salvage logging after wind disturbance impacts forest life. Multiple feeding guilds of invertebrates can be found on the forest floor, including detritivores, fungivores, herbivores, granivores, predators, and parasites/parasitoids. These animals are adapted to utilize the food resources present on the forest floor, such as leaf litter, seeds and fruits, carrion, scat, woody debris, roots, fungal mycelium and fruiting bodies, slime molds, understory herbaceous vegetation and tree seedlings, and moss. Invertebrates, in partnership with microbes and fungi, are responsible for cycling nutrients by converting complex organic molecules from dead organisms back into forms available for plant uptake. Ground-dwelling predators, such as ground beetles like *Calasoma frigidum*, can also help control outbreaks of forest pests. Finally, ground-dwelling invertebrates provide cultural services to humans, for instance, the study of Appalachian forest cockroaches has contributed to an understanding of the evolution of social systems. Studying the ground dwelling invertebrate community thus gives insights into the ecosystem services provided by the forest.

One invertebrate group in particular, the ground beetles (Coleoptera: Carabidae), are particularly well suited as indicators of forest health. These beetles are easy to sample, taxonomically diverse and yet well known, and sensitive to environmental change. Environmental conditions can influence ground beetles because many species are adapted to specific light levels, moisture levels, soil compositions, dominant tree species (Werner and Raffa, 2000), ground cover types, and food sources (although many are also generalists).

**Methods**

Statistical analysis

Because

pitfall traps preferentially collect insects that are more active and mobile (ref), the number of ground beetles caught in pitfalls is reported as activity-abundance, which emphasizes that insect sampling methods have inherent biases towards certain taxa.

Before analyzing activity-abundance data, we standardized the counts to account for occasional trap loss due to animal disturbance. For each year, and for each plot, we divided the trap catch by the number of days that the trap was operational for that year (Sklodowski and Garbalinska, 2011).

To verify if our sampling effort was sufficient to make estimates of species richness, we used species accumulation curves (Chao and Chiu 2016). We created species accumulation curves for each treatment and year using the rarefaction method, which accumulates individuals rather than sites. This was implemented in R (R Core Team, 2024) using the package ‘vegan’ (Oksanen et al., 2024).

We calculated species richness at each plot, and for each year, as the number of unique ground beetle species captured. We calculated Simpson diversity using the inverse Simpson index, which ranges from 1 to the species richness, depending on the degree to which species abundances are equal. We calculated Simpson evenness as the inverse Simpson index divided by species richness. These calculations were implemented in R (R Core Team, 2024) using the packages ‘hillR’ (Li, 2018) and ‘chemodiv’ (Petren et al., 2023).

To estimate the number of undetected species and thus estimate the true species richness of ground beetles across all the plots within a forest management treatment, we used an asymptotic approach (Chao and Chiu, 2016). We calculated the Chao1 estimator, which is a nonparametric estimator that gives a lower bound on the true species richness. This estimator incorporates the number of singletons and doubletons to estimate the number of undetected species and was implemented using the function “ChaoSpecies” using the R package “SpadeR” (Chao et al., 2016).

To analyze functional traits of ground beetles, we used community-weighted means (CWMs). This metric is a mean trait value weighted by the relative abundances of each species in a sample. Because traits are not independent, but rather occur together in syndromes, we used a principal component analysis to find

For each ecomorphological trait (Table \_\_\_\_), we calculated a community-weighted mean trait value.

Anne Chao, Ma, K.H., Hsieh, T.C., Chiu, C., 2016. SpadeR: Species-Richness Prediction and Diversity Estimation with R.

Chao, A., Chiu, C., 2016. Species Richness: Estimation and Comparison, in: Kenett, R.S., Longford, N.T., Piegorsch, W.W., Ruggeri, F. (Eds.), Wiley StatsRef: Statistics Reference Online. Wiley, pp. 1–26. https://doi.org/10.1002/9781118445112.stat03432.pub2

Curtze, A.C., Carlo, T.A., Wenzel, J.W., 2018. The Effects of a Tornado Disturbance and a Salvaged Timber Extraction on the Seed-Rain and Recruitment Community of an Eastern Temperate Deciduous Forest. Northeastern Naturalist 25, 627. https://doi.org/10.1656/045.025.0408

Fischer, A., Marshall, P., Camp, A., 2013. Disturbances in deciduous temperate forest ecosystems of the northern hemisphere: their effects on both recent and future forest development. Biodivers Conserv 22, 1863–1893. https://doi.org/10.1007/s10531-013-0525-1

Gandhi, K.J.K., Gilmore, D.W., Katovich, S.A., Mattson, W.J., Zasada, J.C., Seybold, S.J., 2008. Catastrophic windstorm and fuel-reduction treatments alter ground beetle (Coleoptera: Carabidae) assemblages in a North American sub-boreal forest. Forest Ecology and Management 256, 1104–1123. https://doi.org/10.1016/j.foreco.2008.06.011

Li, D., 2018. hillR: taxonomic, functional, and phylogenetic diversity and similarity through Hill Numbers. JOSS 3, 1041. https://doi.org/10.21105/joss.01041

Oksanen, J., R, Legendre P, Minchin P, O’Hara R, Solymos P, Stevens M, Szoecs E, Wagner, H, Barbour M, Bedward M, Bolker B, Borcard D, Carvalho G, Chirico M, De, Caceres M, Durand S, Evangelista H, FitzJohn R, Friendly M, Furneaux B, Hannigan G, Hill M, Lahti L, McGlinn D, Ouellette M, Ribeiro Cunha E, Smith T, Stier A, Ter Braak C, Weedon J, Simpson G, Blanchet F, Kindt, 2024. \_vegan: Community Ecology Package\_.

Perry, K., Herms, D., 2019. Dynamic Responses of Ground-Dwelling Invertebrate Communities to Disturbance in Forest Ecosystems. Insects 10, 61. https://doi.org/10.3390/insects10030061

Petren, H., Kollner, T.G., Junker, R.R., 2023. Quantifying chemodiversity considering biochemical and structural properties of compounds with the R package chemodiv. New Phytologist 237, 2478–2492.

R Core Team, 2024. R: A Language and Environment for Statistical Computing.

Seidl, R., Thom, D., Kautz, M., Martin-Benito, D., Peltoniemi, M., Vacchiano, G., Wild, J., Ascoli, D., Petr, M., Honkaniemi, J., Lexer, M.J., Trotsiuk, V., Mairota, P., Svoboda, M., Fabrika, M., Nagel, T.A., Reyer, C.P.O., 2017. Forest disturbances under climate change. Nature Clim Change 7, 395–402. https://doi.org/10.1038/nclimate3303

Sklodowski, J., Garbalinska, P., 2011. Ground beetle (Coleoptera, Carabidae) assemblages inhabiting Scots pine stands of Puszcza Piska Forest: six-year responses to a tornado impact. ZK 100, 371–392. https://doi.org/10.3897/zookeys.100.1360

Slyder, J.B., Wenzel, J.W., Royo, A.A., Spicer, M.E., Carson, W.P., 2020. Post-windthrow salvage logging increases seedling and understory diversity with little impact on composition immediately after logging. New Forests 51, 409–420. https://doi.org/10.1007/s11056-019-09740-x

Spicer, M.E., Royo, A.A., Wenzel, J.W., Carson, W.P., 2023. Understory plant growth forms respond independently to combined natural and anthropogenic disturbances. Forest Ecology and Management 543, 121077. https://doi.org/10.1016/j.foreco.2023.121077

Thorn, S., Bässler, C., Brandl, R., Burton, P.J., Cahall, R., Campbell, J.L., Castro, J., Choi, C.-Y., Cobb, T., Donato, D.C., Durska, E., Fontaine, J.B., Gauthier, S., Hebert, C., Hothorn, T., Hutto, R.L., Lee, E.-J., Leverkus, A.B., Lindenmayer, D.B., Obrist, M.K., Rost, J., Seibold, S., Seidl, R., Thom, D., Waldron, K., Wermelinger, B., Winter, M.-B., Zmihorski, M., Müller, J., 2018. Impacts of salvage logging on biodiversity: A meta-analysis. Journal of Applied Ecology 55, 279–289. https://doi.org/10.1111/1365-2664.12945

Ulyshen, M., Urban‐Mead, K.R., Dorey, J.B., Rivers, J.W., 2023. Forests are critically important to global pollinator diversity and enhance pollination in adjacent crops. Biological Reviews 98, 1118–1141. https://doi.org/10.1111/brv.12947

Werner, S.M., Raffa, K.F., 2000. Effects of forest management practices on the diversity of ground-occurring beetles in mixed northern hardwood forests of the Great Lakes Region. Forest Ecology and Management.

Wilson, A., 2024. Impacts of Climate Change on Woodlands and Wildlife.