**Introduction**

Temperate forests provide multiple benefits to humanity, including provisioning services, regulating services, and cultural services. Provisioning services include the harvest of trees for lumber and paper, which in the U.S. generates $288 billion annually. Regulating services involve the processes of decomposition, water filtration, crop pollination, and temperature regulation. For example, forest patches within agricultural landscapes can provide nesting habitat for pollinator insects (Ulyshen et al., 2023). Cultural services include recreation and scientific advancement. For example, the study of how white rot fungi decompose woody debris has led to applications in bioremediation to degrade organic pollutants.

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).

Although it is unclear if climate change will alter the frequency and intensity of strong winds (Seidl et al., 2017), it is possible it could still increase the impact of windstorms on trees in the Eastern US. For example, climate change is causing annual precipitation to increase in Ohio (Wilson, 2024), and increased precipitation may reduce the anchorage of trees in soil which can affect the frequency of windthrows (Seidl et al., 2017).

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.

Salvage-logging can have multiple impacts on plants. Previous studies have focused mostly on the impacts for the first five years after salvaging (Thorn et al., 2018). These studies have demonstrated that the species composition of plants changes after salvage-logging (Thorn et al., 2018) but different plant growth forms respond differently (Spicer et al., 2023). For example, at Powdermill Nature Reserve in Pennsylvania, salvage logging a tornado-impacted area increased herbaceous plant diversity in the short term, with species such as American burnweed (*Erechtites hieraciifolius*) being indicative of salvaged area, potentially because the disturbance of the soil by salvaging machinery scarifies seeds, enabling their germination (Slyder et al., 2020). Additionally, salvaging can benefit shrubs such as *Rubus* spp., while altering the seed rain of tree seeds such as blackgum (*Nyssa sylvatica*) and beech (*Fagus grandifolia*) (Curtze et al., 2018). Site-specific factors like fern cover and deer abundance can modulate the effects of salvage logging on plants (Curtze et al., 2018; Spicer et al., 2023).

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. If salvage logging has impacts on the forest ecosystem, these may be detectable by studying ground-dwelling invertebrates.

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 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).

The study of functional traits can give insights into how environmental changes can impact an organism’s fitness. A functional trait is any characteristic of an organism that impacts its fitness by affecting reproduction, growth, or survival (Fountain-Jones et al., 2015). In ground beetles,

One important trait of ground beetles is wing reduction. Ground beetle species can either be macropterous, meaning fully winged, brachypterous, meaning the wings are reduced to stubs, or dimorphic, meaning some individuals of a species are fully winged while others have reduced wings. Wing reduction has a long history of study in ground beetles, and it is important because it relates to environmental conditions such as habitat stability, flood frequency, latitude, and others. When an isolated patch of disturbed habitat is colonized by a ground beetle species, it is often (but not always) macropterous individuals which are able to disperse to the patch. However, if a habitat remains stable for many years, brachypterous individuals may have higher fitness than macropterous individuals of the same species, due to increased fecundity (Venn, 2016). Thus, wing reduction is highly relevant in the context of forest disturbance.

An interesting feature of ground beetles (Carabidae) is that the trochanter of the hind leg is enlarged. This bean-shaped hind trochanter is a relatively reliable character for Carabidae, but its length relative to the length of the hind femur can vary. The purpose of the enlarged hind trochanter is to allow for a form of locomotion called “wedge pushing” which allows for locomotion between flattened layers of bark, litter, or soil. The muscle within the trochanter allows the ground beetle to create a force in the dorsal direction, which enlarges the space and allows the beetle to move through constricted areas. Depending on a ground beetle species’ predominate manner or locomotion, and what substrate it inhabits, the hind trochanter can vary in length relative to the femur.

**Methods**

Statistical analysis

Because pitfall traps preferentially collect insects that are more active and mobile, 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 (Swenson, 2014). The

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

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