FROM BRANCH TO BUG: EXPLORING THE ECOLOGICAL IMPACTS OF WOODY RESIDUALS ON SOIL-DWELLING ARTHROPODS

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ABSTRACT

This study focuses on the effect that coarse woody residuals left on the ground post-forest thinning have on the biodiversity of soil-dwelling arthropods, as measured by the number of arthropod individuals and the presence of different taxonomic groups. Soil arthropods are vital to forest systems in their composition of the soil food web, which significantly contributes to nutrient cycling within the forest ecosystem. To understand the impacts of woody residuals on soil arthropods, soil samples were taken from treated and untreated sites in mixed forest stands in the Northeast. The number of arthropod individuals, as well as taxa present per treatment site, were measured. Arthropods were organized and summed per treatment type, and the mean numbers of arthropods per treatment were calculated. A Kruskal-Wallis test showed a significant difference in the mean number of arthropods by treatment. In general, plots with treetop material on the ground had the highest mean number of individual arthropods. Pairwise comparisons show that plots with treetop material had a significantly higher mean number of individuals than nearby paired plots devoid of treetop material, and all plots within the treatment where whole trees were removed during harvest. These findings have implications for preserving soil arthropod communities during the process of partial tree harvest. This study highlights the benefit of leaving behind woody residuals during harvest in order to maintain abundance within the soil community, contributing to a healthy forest ecosystem..

Key Words: soil biota, tree-thinning, forestry, woody residuals, soil arthropods, arthropod diversity

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Definitions

The following terminology will be used consistently throughout this work. "Soil arthropods" refers to the community assemblage of various arthropod taxa found in the top layers of the soil and leaf litter, as well as individuals of the soil-dwelling community. "Woody residuals" (sometimes known as 'coarse woody residuals', or CWR) are the branches and canopies of trees (or other tree material unsuitable for timber harvest), that are intentionally left on the forest floor post-thinning. For the purposes of this study, 'stand' refers to a whole forest, within which are 'treatments'. Within each treatment is a number of 'plots', which refers to the individual sampling areas.

Introduction

A variety of soil arthropod taxa are vital to forest ecosystems, in that communities of these arthropods compose a complex food web that provides multiple ecosystem services (Barrios et al., 2007). Taxonomic diversity among the soil arthropod community creates a healthier soil system to the benefit of the forest; as such, the biodiversity of soil arthropods is important to maintaining forest health via the soil food web (Marra et. al., 1998). Soil arthropod communities are vital to decomposition and nutrient cycling, seed and spore dispersal, soil mixing and aeration, shaping and maintaining microbial activity and community structures, and mediating soil food-web stability (Moore et al., 1988; Kalisz et al., 2000). The role of the complex soil food web cannot be understated in terms of its importance to forest systems.

Forestry practices, including the thinning and removal of whole trees for timber harvest, can be framed as disturbance events to an ecosystem due to the removal and disruption of dominant tree species, altering the productivity of a forest. Tree removal results in a reduction of organic material that would otherwise aid in nutrient cycling through decomposition within the forest system. In contrast, the retention of organic matter on the forest floor is one of the underlying mechanisms behind community composition and success of soil-dwelling arthropods that in turn allow for decomposition and nutrient cycling. The removal and destruction of organic material via thinning may negatively impact soil arthropod communities and community structure (George et al., 2017; Perry et al., 2018), thereby impacting forest health through the reduction of ecosystem services (Boggs et al., 2020, Grodsky, 2018).

When timber is harvested in the Northeastern United States, the trunk of a tree is utilized while the crown (including branches, leaves, twigs, etc.) is often converted to wood chips, used for firewood, or otherwise repurposed. Removing these residuals can be detrimental to forest ecosystem processes. Studies have shown that woody residuals are a vital component of forest health, functioning as a carbon sink, aiding in nutrient retention, and providing food and habitat for forest organisms (Grodsky, 2018; Marra et. al., 1998). This direct contribution of woody residuals is "thought to enhance the diversity of soil organisms…and may be critical to the maintenance of biological properties of the forest floor" (Marra et. al, 1998). The relationship between soil-dwelling arthropods and woody residuals is well-studied, and research shows that thinning can reduce the abundance and diversity of soil-dwelling arthropods by reducing organic matter and eliminating both food and habitat for these organisms (Marra et. al, 1998).

In 2009, Dr. Stephen Morreale and Kristi Sullivan of Cornell University began an experiment to test the ecological impacts of leaving the crowns of harvested trees on the forest floor in loosely consolidated piles. Building off of this experimental design as a framework, the study presented here aims to determine the potential impacts of woody residuals on soil-dwelling arthropods in managed forests. Here, the diversity and abundance of arthropods are compared between different treatment sites in managed and unmanaged forest stands in order to determine potential differences in arthropod abundance relative to the presence of woody residuals on the forest floor.

Methods

Study Sites

Samples were taken from five forest stands: Mount Pleasant Stands 11 (MP11) and 7c (MP7c) located near Mount Pleasant Road in Dryden, NY; Arnot Stands 6-4, and ‘the Boot’, located in the Arnot Teaching and Research Forest in Van Etten, NY; and McGowan woods, located of off Game Farm Road in Ithaca, NY.The Arnot and Mount Pleasant stands were cleared in the late 1800s but later abandoned, leading to their current second-stage growth. The Arnot is primarily composed of hemlock and northern hardwood species, including oak, beech, and maple. Mount Pleasant is primarily composed of beech-maple species. Each of these stands was thinned in 2009 and treatment squares of 1.5 ha were established. These treatments contain transects of loosely consolidated piles of stems, logs, and branches which compose 4-inch and 10-inch piles of woody residual treatments (Fig.1). An additional treatment was made in each stand where whole trees were removed and no woody residuals were left. These treatments are referred to as 4”, 10”, and Whole Tree (WT).

Fig. 1: T plot on the left with woody residuals, O plot on the right with no woody residuals

McGowan Woods is a mixed stand containing species common to Northeast mesophytic forests. There have been no significant harvests since a clear-cut in 1904 and is regarded as unmanaged and uncut. There are no intentionally constructed piles of woody residuals, but due to the unmanaged nature of this stand, natural forest processes have allowed for woody material accumulation. McGowan woods was sampled on the exterior edge of the forest (E), and the interior of the forest (I).

Within each treatment site at the Mount Pleasant and Arnot stands are piles of woody residuals that have been paired with areas of the forest floor containing no downed wood. These gaps between piles on the forest floor were left intentionally post-thinning to create paired plots: those with woody residuals (T plots), and those without (O plots). Samples were taken from the paired plots within each treatment (4" and 10"), as well as from the WT treatments which are not paired. It's important to note that O plots are embedded within treatment sites containing woody residuals– they may lack piles but are within a 5m radius of those that do have consolidated downed wood. Conversely, the WT treatment is not paired, as it was thinned and cleared with no piles left.

Sampling

Sampling occurred from June 2023 to July 2023. Soil samples were collected from five paired plots, for a total of ten soil samples from each treatment within a stand. With three treatments per stand (4-inch and 10-inch woody residuals, and WT removal) in both Mount Pleasant sites and Arnot sites, a total of 25 samples were collected from each. Samples were taken from plots containing woody residuals on the forest floor. Paired samples were then taken nearby at a distance of 5 m from each woody residual pile. The plots were designated with individual numbers, followed by a "T" or "O" to indicate the presence of treetop material, or lack thereof (e.g., within MP11, individual 4" piles were labeled as 100T, 100O, 101T, 101O, and so forth). At McGowan Woods, five samples were taken within 5 m from the edge of the forest paralleling Game Farm Road, 20 m apart from each other (E plots). Paired with these were samples taken 30 m from the edge of the stand along the interior of the forest, also at a distance of 20 m apart (I plots).

Soil samples were collected using a soil cores made from PVC with a 5.5-cm diamteter, to a depth of 6-cm. Leaf litter was not disturbed prior to sampling. Once collected, soil samples were placed in ziplock bags and labeled with their corresponding plot number and T/O type. Samples were kept in cool conditions and efforts were made to mitigate the disturbance of the samples, such that cores stayed as intact as possible while in the field.

Arthropod Extraction

Berlese-Tullgren funnels were constructed for soil arthropod extraction using 1L plastic funnels, ¼” and ½” wire mesh, and wooden frames. The heat and light source for the funnels was 10W incandescent bulbs, contained within a reflector constructed out of a plastic housing and covered in aluminum foil. The reflector functions to concentrate both heat and light into the individual funnels as well as to prevent light leakage into neighboring funnels. Funnels were placed 15 cm apart at the base, with reflectors suspended 4 cm above the rim of each funnel (Fig. 2). This resulted in a gradient between the top and bottom of soil samples placed within the funnels, required for driving soil-dwelling arthropods through the bottom of the funnels (Peterson, 1978; Edgar, 1992). At the bottom of each funnel was a glass jar containing 70% ethanol for arthropod preservation. Samples were placed in Berlese-Tullgren funnels inverted whenever possible, as the literature suggests this aids in arthropod egress (Macfadyen, 1953). Samples stayed in the Berlese-Tullgren funnels for three days before removal and processing, as this was sufficient to fully desiccate the soil and drive out arthropods.

Fig. 2: Berlese-Tullgren funnels with samples

Arthropod Identification

With assistance from four employees of the Cornell University Insect Collection Insect Diagnostic Lab, most arthropods were identified at the family level, with some exceptions that were identified to order (Fig. 3).

date	stand	treatment	Composite	plot	T/O/WT	Total ind	Collembola (entomobryidae) -	Collembola (hypogastruridae / poduridae)	Collembola (Symphypleona)
7/19/2023	Arnot 6-4	10"	70T	70	T	35	8	4	0
7/19/2023	Arnot 6-4	10"	71T	71	T	48	4	6	0
7/19/2023	Arnot 6-4	10"	73T	73	T	28	5	6	0
7/19/2023	Arnot 6-4	10"	74T	74	T	37	0	5	0
7/19/2023	Arnot 6-4	4"	80T	80	T	75	34	15	0

Fig. 3: A sample of the recording method for individual arthropods of different taxa

Analysis

Number of Individuals

The number of individual arthropods was summed for plots with treetops (T), no treetops (O), and whole trees removed (WT) in Mount Pleasant and Arnot stands. The same was done for McGowan's interior (I) and exterior (E). Next, the mean number of individual arthropods found in each treatment was calculated, and the normality of the distribution was assessed using JMP Pro 17. Because the data were not normally distributed, a one-way nonparametric Kruskal-Wallis test was conducted to determine any differences between treatments. A nonparametric pairwise comparison using the Wilcoxon method was then utilized to further understand the distinctions between the mean number of arthropods found within each treatment type.

Diversity of Taxa

To calculate differences in arthropod diversity, Shannon’s Diversity Index was run for the individuals found within each treatment type, and a t-test calculation was used to compare the values of each treatment.

Results

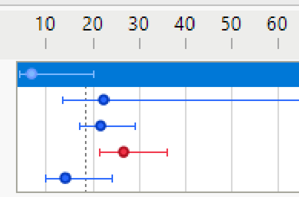
Number of Individuals

A total of 2,724 arthropod specimens were sorted and identified, representing 37 different taxa. Of these, 2,655 individuals were used for analysis. In plots with woody residuals (T plots, N=30), a total of 1,282 individual arthropods were found. In the nearby paired plots (O plots, N=30), a total of 831 individuals were found. In plots where whole trees were removed (WT, N=12), a total of 243 arthropods were found. In McGowan forest interior (I plots, N=5), 176 arthropods were found, and in McGowan forest edge (E plots, N=5) 123 individuals were found.

The highest mean number of individuals were found in T treatments, and the lowest in plots where no woody residuals were left (WT) (Fig. 4). The mean number of arthropods for T plots was 42.7; for O plots the mean was 22.5; and for WT removal the mean was 20.2. For the interior and edge of McGowan, the means were 35.2, and 24.6 respectively.

Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%	Std Dev Lower 95%	Std Dev Upper 95%
E	5	24.6	6.9856997	3.1240999	15.926108	33.273892	4.1853642	20.073797
I	5	35.2	22.487774	10.056838	7.2777401	63.12226	13.473171	64.619871
O	30	27.7	21.71151	3.9639612	19.592789	35.807211	17.291197	29.187112
T	30	42.733333	26.805729	4.8940342	32.723909	52.742757	21.348269	36.035349
WT	12	20.25	14.117204	4.0752858	11.280356	29.219644	10.000559	23.969291



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
E	5	191.500	207.500	38.3000	-0.300
I	5	232.500	207.500	46.5000	0.475
O	30	1064.00	1245.00	35.4667	-1.738
T	30	1578.50	1245.00	52.6167	3.207
WT	12	336.500	498.000	28.0417	-2.113

Kruskal-Wallis Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
12.6142	4	0.0133*

Fig. 4: Chart showing each treatment type (E,I,O,T,WT) and their respective means. "Kruskal-Wallis Test, ChiSquare Approximation" subtable shows that one of the above means is significantly different from the others (P= 0.0133)

Species Richness

Species richness was calculated for each treatment type. T plots had the highest measure of species richness (30); followed by O plots (26); and then WT plots (19).

Wilcoxon/ Kruskal-Wallis Tests

The Kruskal-Wallis analysis showed that there was a significant difference between the mean number of arthropods found in the treatment types (p=0.0133) (Fig. 5).

To further delineate these differences between individual treatments, a Wilcoxon pairwise comparison of the mean numbers of arthropods showed differences between the T and O plots (p=0.006), and the T and WT plots (p=0.0047) (Fig. 4).

Nonparametric Comparisons For Each Pair Using Wilcoxon Method

q*	Alpha
1.95996	0.05

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value	Hodges-Lehmann	Lower CL	Upper CL
T	O	12.3000	4.507495	2.72879	0.0064*	14.0000	4.0000	25.0000
T	E	8.2833	4.946627	1.67454	0.0940	13.0000	-4.0000	35.0000
T	I	2.3333	4.948361	0.47154	0.6373	4.0000	-22.0000	31.0000
I	E	1.0000	1.885618	0.53033	0.5959	14.0000	-19.0000	38.0000
WT	E	-2.4083	2.681340	-0.89818	0.3691	-7.0000	-20.0000	12.0000
O	E	-3.1500	4.943157	-0.63724	0.5240	-2.0000	-14.0000	15.0000
WT	I	-3.8250	2.687936	-1.42302	0.1547	-13.5000	-40.0000	11.0000
WT	O	-4.2000	4.187549	-1.00297	0.3159	-4.0000	-16.0000	5.0000
O	I	-4.2000	4.944892	-0.84936	0.3957	-6.5000	-34.0000	13.0000
WT	T	-11.8417	4.189078	-2.82680	0.0047*	-19.0000	-33.0000	-7.0000

Difference Plot

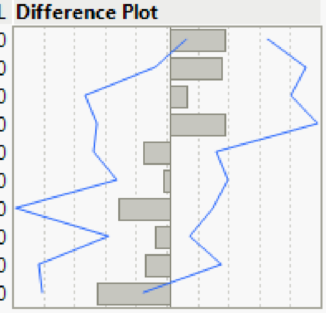


Fig. 5: Nonparametric comparisons between means show that there is a significant difference between the T and O treatments (p = 0.0064) and the T and WT treatments (p =0.0047)

Shannon's Diversity Index

The diversity (H value) for T sites was 2.35, for O sites was 2.35, and for WT was 2.20 (Fig. 6).

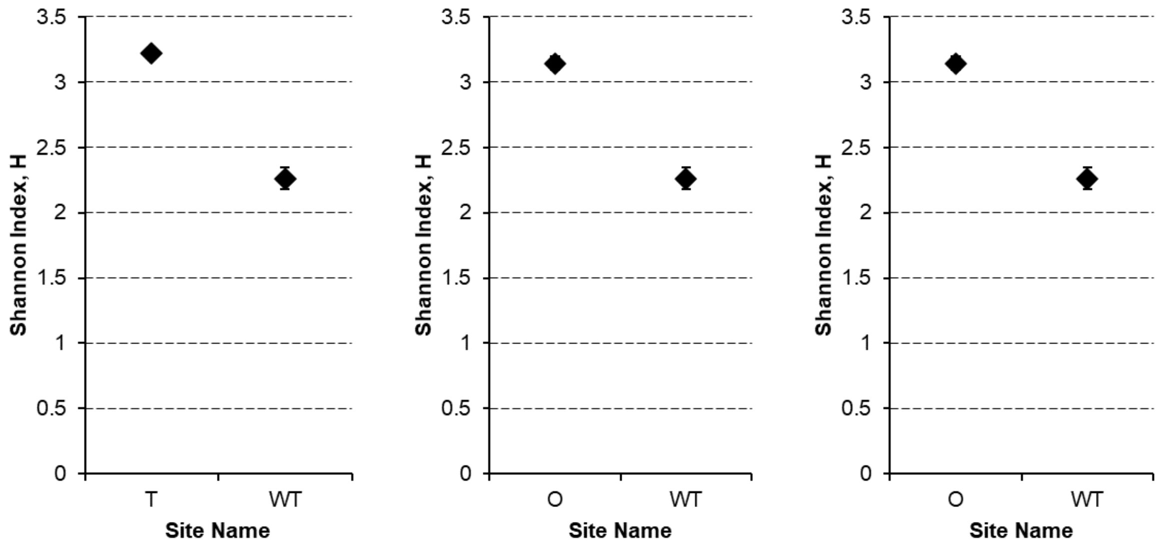


Fig 6: H comparison between T (H= 3.2), O (H= 3.1), and WT (H= 2.2) treatments

Discussion

This study shows that the number of soil-dwelling arthropods increases with the presence of woody material in the form of treetops and branches left behind during a partial harvest. Plots containing treetops left on the ground post-thinning (T) had the highest mean number of soil-dwelling arthropods and the highest richness of taxa (Fig. 7). In contrast, plots where whole trees were removed during harvest (WT) had the lowest number of arthropods and lowest richness of taxa. Plots embedded in treatments containing woody residuals, but lacking piles themselves (O) had an intermediate mean number of arthropods—with values falling between T and WT plots. Similarly, O plots had an intermediate richness value between T and WT plots. The difference in the mean number of arthropods between T and O sites, as well as T and WT sites is significant, providing evidence that leaving woody residuals post-thinning has a positive impact on soil arthropod numbers. In turn, the number of soil arthropods positively impacts the forest community by providing food resources for other organisms and changing organic matter into base components through decomposition– a process that is integral to a healthy forest. This research supports the previously documented importance of leaving woody residuals post-thinning as a boon to soil arthropod communities.

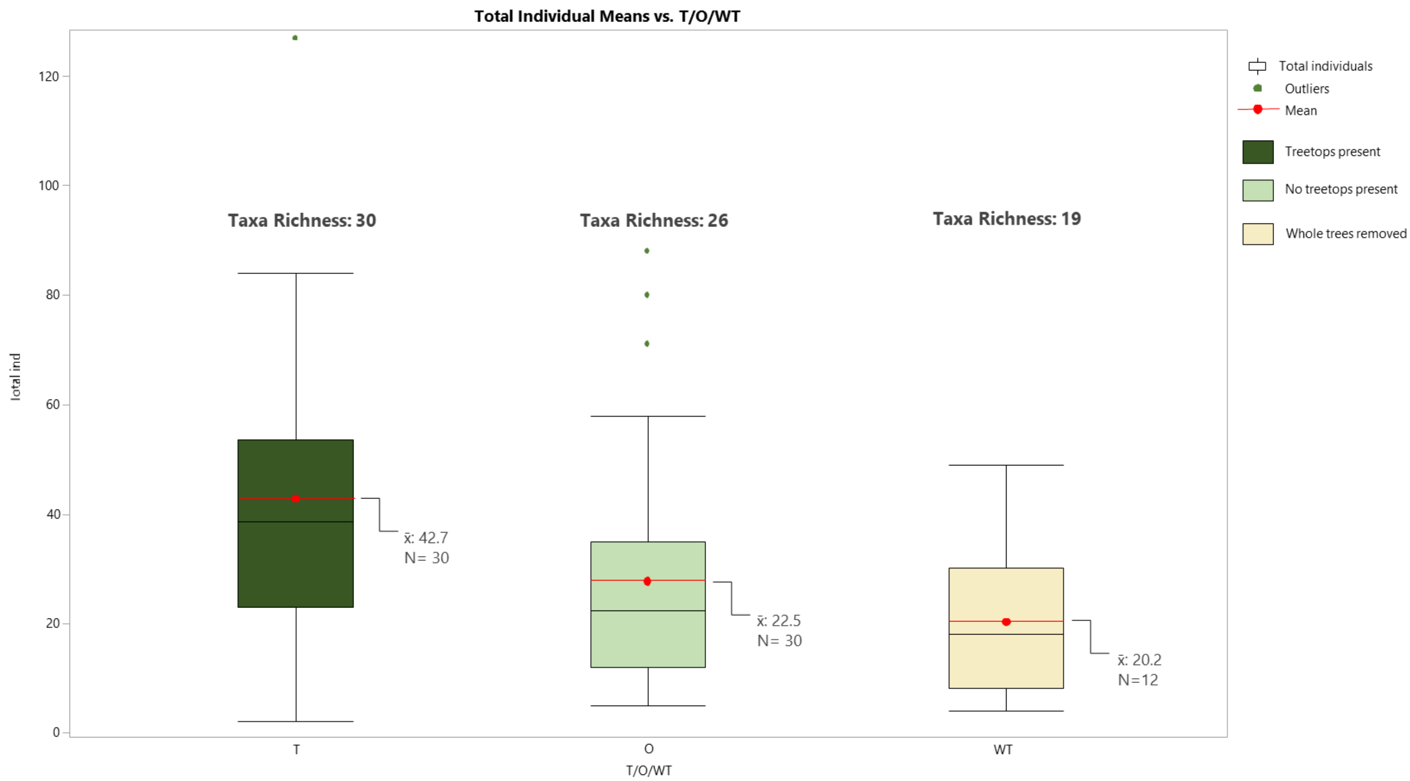


Fig. 7: Mean individuals for T, O, and WT treatments

While the Shannon's diversity values are similar, it is still evident that there is a difference in community composition between treatments containing woody residuals and those without. It is both the number and diversity of soil arthropods that is beneficial to forest systems, as a myriad of taxa provide different ecosystem services. These include saproxylic taxa converting downed woody material into carbon and nitrogen, pollinator species using it as nesting material, and woody material providing refugia for a number of other taxa that also serve as an important food source for predators (Boggs et al., 2020). These results follow the trend of other research that has shown that woody residuals have a positive impact on invertebrate biodiversity (see: Herrera-Alvarez et al., 2020, Boggs et al., 2020, Grodsky et al., 2018).

The mean number of soil-dwelling arthropods for sites with woody residuals present (T plots) within the harvested Mount Pleasant and Arnot stands is comparable to the interior sites (I plots) of McGowan Woods– a stand unmanaged for over a century ($\bar{x}$= 42.7 and 35.2 respectively) (Fig. 8). Despite the anthropogenic disturbance that the managed stands have undergone, the presence of woody residuals has mitigated the loss of soil-dwelling arthropods. Interestingly, the mean number of arthropods for McGowan plots sampled within 5 m from the road (E plots) is only slightly higher than that plots where whole trees were removed (WT): ($\bar{x}$= 24.6 and 20.2 respectively). E plots are exposed to harsher environmental conditions than I plots– such as wind and snow– due to the lack of protection from full canopy cover. They are also more subject to anthropogenic use than the interior of the stand, from people driving on the nearby road and entering the forest through the perimiter. The similarity in means between E and WT plots shows that the removal of whole trees combined with the lack of woody residuals has a similar effect on arthropod numbers as a frequently disturbed area of the forest exposed to harsher environmental conditions.

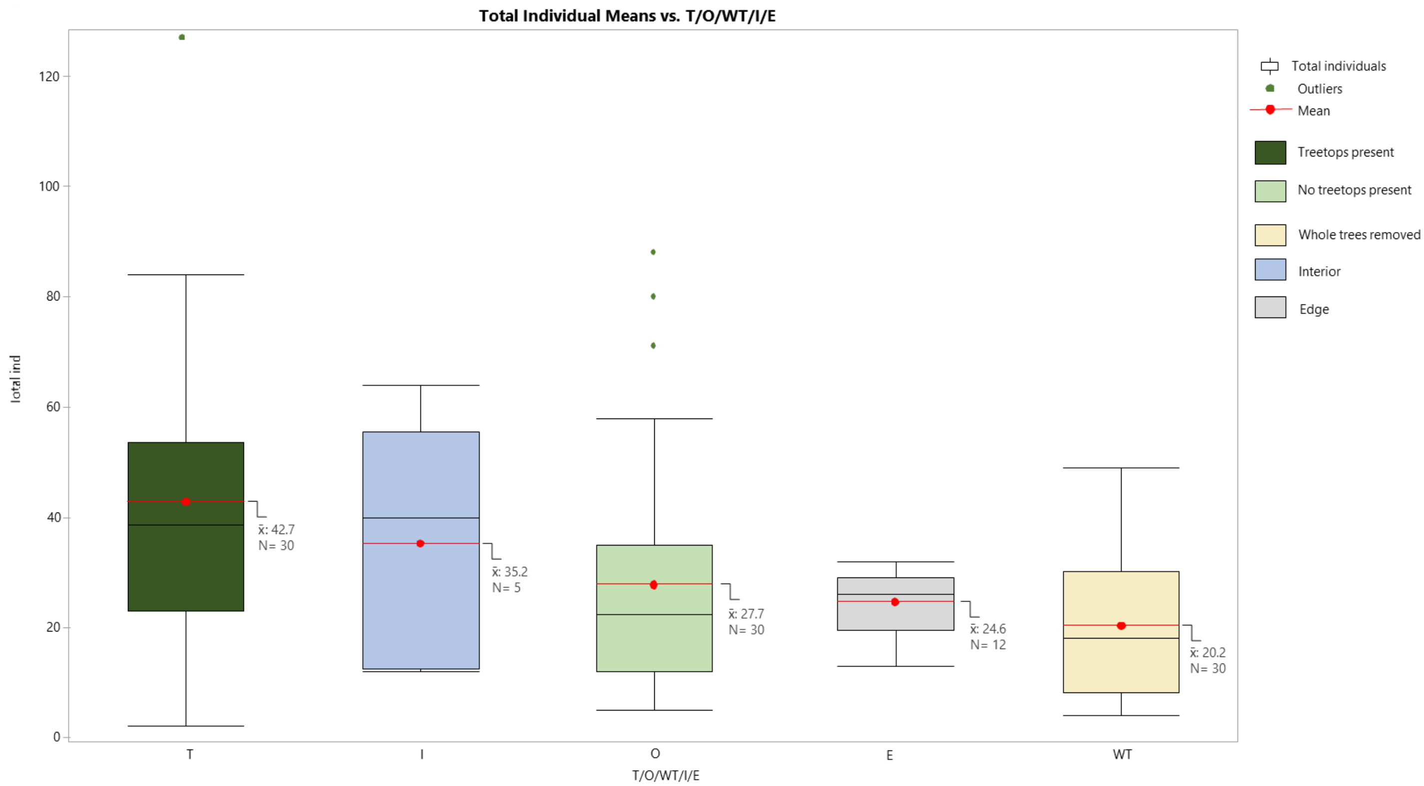


Fig. 8: Mean individuals compared between all treatments. The highest numbers of individuals were found in plots with woody residuals (T) and plots found in the interior of an unmanaged forest stand (I), making their means comparable. The lowest numbers of individuals were found in plots where trees were removed and no residuals were left (WT), and the frequently used edge of an unmanaged forest stand (E).

This is far from the only study that shows the benefits of leaving woody residuals after thinning. It has been shown that woody residuals benefit not only soil arthropod communities, but also those of small mammals, birds, and pollinators (Sullivan et al., 2015, Carrillo-Rubio et al., 2014, Rodríguez et al., 2016). The effects of leaving woody residuals on the soil invertebrate community are beneficial, and long-lasting (Perry et al., 2017). Leaving treetops and branches on the forest floor in during partial harvests of managed forests can be implemented as a sustainable strategy to mitigate the effects of anthropogenic disturbance events on forest systems, promoting biodiversity, and maintaining healthier forest systems as a whole.

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