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Effects of organic matter removal, soil compaction, and vegetation control on Collembolan populations

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Summary

Collembola can be among the most numerous meso-invertebrates in the forest floor and, through their interaction with primary decomposers in the decomposition food web, may affect litter decomposition and consequently site productivity. This study was conducted to determine whether Collembolan abundance could be impacted by organic matter removal, compaction, and vegetation control on a loblolly pine (*Pinus taeda* L.) plantation. Monthly soil and litter samples were taken over 2 years and the fauna extracted from them using modified Tulgren funnels. Organic matter removal and vegetation control generally caused a significant decrease in Collembolan populations, while compaction did not significantly affect Collembolan populations. These results indicate that habitat was the primary influence on population abundance in this experiment, possibly via its influence on desiccation. Sensitivity of collembolan populations to habitat changes caused by organic matter removal indicates a potential effect on long-term site productivity.

Introduction

In many biomes, Collembola play an important role in decomposition and, along with mites, are often the most abundant invertebrates in warm temperate forest floor material (Wallwork, 1970; Swift et al., 1979; Joosse, 1981). They can directly affect decomposition rates (McBrayer et al., 1977; Abbott and Crossley, 1982; Cragg and Bardgett, 2001) and plant growth by mobilizing nitrogen and other nutrients from plant or fungal tissue through grazing (Anderson et al., 1983; Faber and Verhoff, 1991), feces (Finlay, 1985; Tueban and Roelofsma, 1990), or from their own tissue when they molt or die (Anderson et al., 1983). Conversely, Collembola may hinder plant growth by eating plant tissue,

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especially roots, creating sites for secondary infection (Brown, 1985) or spreading pathogens through the soil as they migrate. Their relatively large population size and potential influence in nutrient mobilization make Collembola an important component in site productivity and forest system processes.

The Long-term Soil Productivity study (LTSP) is an international study including sites in the United States and Canada. The core study is designed to examine the effects of soil compaction, organic matter removal, and competition control on various soil properties affecting forest soil productivity. Three levels of both soil compaction and organic matter removal were chosen to represent a range of disturbance from minimal to extreme and the competition control treatment was included to provide information about plant growth potential on the site. Investigating the effects of these factors on Collembola population levels may provide insights to understanding differences in site productivity, decomposition rates, and related nutrient fluxes.

The objective of this experiment was to determine impacts of organic matter removal, soil compaction, and competition control on Collembola abundance over time.

Methods

Site

The study site is located on the Croatan National Forest in eastern North Carolina, at approximately longitude 76°48′W and latitude 34°55′N. This region is part of the lower coastal plain and typically has cool winters and hot, humid summers (Goodwin, 1989). Remnants of tar kilns on the site and pre-harvest site examination suggest that the site had supported a predominantly longleaf pine (*Pinus palustris* M.) or mixed longleaf and loblolly pine (*Pinus taeda* L.) forest since at least the early 1800s until the early 1900s. Vegetation on the site at the time of study installation was a mixed pine-hardwood forest with loblolly pines making up the majority of dominant and co-dominant trees approximately 64 years old. The soil in Block 1 is classified as predominantly Goldsboro (fine-loamy, siliceous, thermic, Aquic Paleudults) and the soil in Blocks 2 and 3 as Lynchburg (fine-loamy, siliceous, thermic, Aeric Paleaquults) with inclusions of Norfolk, Onslow, and Rains. Average annual precipitation is 1303 mm with 60% occurring between April and September (Goodwin, 1989).

Experimental design

The LTSP study was installed in 1992 beginning in March and ending in September. The overall study is a 3×3 factorial, split-plot in three complete randomized blocks. Main effect treatments were organic matter removal (bole only (BO), whole tree (WT), whole tree and 100% forest floor removal (WTFF)) and soil compaction (none, moderate, severe). Each main treatment plot was split in two, with the split-plot treatments being complete vegetation control (H1) and no vegetation control (H0). One additional whole plot per block was treated with WT removal and moderate compaction, and was bedded, planted, and broadcast fertilized at 224 kg/ha with triple super phosphate after planting to represent local harvesting techniques and post-harvest ameliorative treatments.

All trees were directionally felled into their respective plots. The BO treatment was implemented by limbing the trees in the plot and removing the bole, either by skidder in the severe compaction treatment plots or by crane residing adjacent to the plot in the no compaction plots. The WTFF treatments were implemented by removing the entire tree by skidder or crane, again depending on the compaction treatment. The remaining branches and limbs were removed by hand and the entire plot was raked by a bulldozer-mounted shearing blade on the severe compaction treatment and by hand on the no compaction treatment. The severe compaction treatment plots were further compacted using a smooth drum vibratory roller with full vibration for two passes over the entire plot, the no compaction plots had no machinery on them during the harvesting and installation process. Mean bulk density was 1.22 g/cm^3 in the no compaction plots versus 1.45 g/cm^3 in the severe compaction plots. Vegetation control was implemented by spot use of herbicide (Accord™ and Arsenal™[1]) and by brush saw as needed to remove all non-planted vegetation on the complete control treatment plots. No control was implemented on the no control treatment plots.

In this study, we investigated only the effects of the extreme treatments on Collembolan population levels. This study's design was a factorial combination of the two organic matter removal and two compaction treatments (BO and WTFF removal, no and severe compaction), maintaining the split-plot component.

[1]The use of trade marks is for the convenience of the readers and does not imply endorsement by the USDA Forest Service.

Measurements

Samples were collected monthly from February through November 1993 and from March through October 1994, usually in the first week of the month. Litter samples from three randomly located points per plot were collected using a shovel. The target sample point area was 625 cm^2, however if less than 600 cm^3 of forest floor was collected from a sample point, additional material was gathered immediately adjacent to the point to total 600 cm^3 per collection. Samples were composited by plot and a 600 cm^3 subsample of each was removed for processing. Faunae were extracted by drying the samples under a 15-W light placed over modified Tulgren funnels for 6 days. Extracted faunae were stored in a 70% aqueous ethanol solution and Collembola separated out and counted.

As part of the LTSP design, an Omnidata 800 series weather monitoring station was installed in a cleared area adjacent to block one and used to record climatic variables and soil temperature. Sensors were automatically read every 5 min and averaged for each hour. Soil temperature and time were recorded at each sample point at the time of collection. For each treatment, plot soil temperature and weather station soil temperature at sample time t were used to create a regression. Differences between treatment parameters were tested for significance at the $P = 0.05$ level.

Analysis

Due to extremely low population counts in the mineral soil samples, analysis was only conducted on the forest floor data. Tests for treatment significance on Collembola population levels were performed: (1) over the entire sample period using sample date as a class variable, (2) for each sample date, and (3) each year using sample date as a class variable. The null hypothesis was that there were no treatment effects on Collembolan population levels during the experiment. Analysis of variance (ANOVA) of abundance was performed using SAS® for Windows, version 6.10 (SAS, 1994). Analysis of the Collembola populations by treatment showed that the standard deviations were proportional to the means and the data were normalized using a $\log_{10} + 1$ transformation (Steele and Torrie, 1980).

Average forest floor depth on each sampled treatment plot was estimated in July 1995 from three randomly selected points per plot using a frame with sampling area of 929 cm^2. The depths were measured at the four corners and the center of the frame and the volume was calculated on a treatment plot basis.

Although analysis was done on transformed data, the graphs and error bars in the results were constructed using the untransformed data. In some instances this causes a discrepancy between the effects listed as significant and the appearance of significance on the graphs.

Results

The BO plots had almost five times more organic matter volume than did the WTFF plots. Both compaction treatment levels had approximately the same volume of organic matter, and the H0 plots had almost twice the volume of organic matter compared to the H1 plots (Table 1).

Organic matter removal had a strong effect on Collembolan population levels in this experiment (Table 2), with the BO treatment having one-third more Collembola had the WTFF (43–31/600 cm^3). The greatest difference in Collembolan abundance occurred from collections taken in June, July, and August in both years (Fig. 1). The compaction treatments did not have a significant effect on Collembola population levels in any analysis (Fig. 2) and no trends were identified. Collembolan populations were significantly higher in the H0 treatment over the entire experiment, and the H1 treatment seemed to have had a greater negative effect on Collembolan populations in 1994 than in 1993 (Fig. 3).

Organic matter removal and vegetation control affected soil temperature (Figs. 4 and 5) while the compaction treatment did not (data not shown). The slope of the estimated temperature was steeper in both the WTFF removal (Fig. 4) and H1 treatments (Fig. 5) than in the BO and H0 treatments.

Table 1. Estimated mean volume of organic matter/1000 cm^2 by treatment

Treatment	Mean volume (cm^3) $\pm$ std. err.
Bole only removal	2792 ± 263^a
Whole tree + 100% forest floor	582 ± 181^a
No compaction	1679 ± 334
Severe compaction	1695 ± 246
No herbicide	2121 ± 309
Herbicide	1253 ± 257

[a]Significantly different at $Pr > F = 0.05$.

Post-experiment comparison of the forest floor volume between the treatments indicated that the quantity of forest floor increased in the H0 plots. Changes in the quality or quantity of forest floor in the treatment could affect Collembola population levels, and additional analysis by year was done to examine possible inconsistent treatment effects as a result of vegetation control treatment.

Some ANOVA showed a significant vegetation control effect on Collembola abundance either as a single factor (Fig. 3) or with a date interaction (Table 2).

Table 2. Response of Collembola to organic matter removal (OM), compaction (C), competition control (H), and time (S)

Treatment	Pr > *F*
OM removal (OM)	0.0023[a]
Compaction (C)	0.2079
OM × C	0.9382
Vegetation control (H)	0.0020
OM × H	0.3223
C × H	0.0606
OM × C × H	0.0804
Sample date (S)	0.0001[a]
OM × S	0.0001[a]
C × S	0.8025
OM × C × S	0.9209
H × S	0.0134[a]
OM × H × S	0.1393
C × H × S	0.9866
OM × C × H × S	0.1488

Data analyzed were number of Collembola 600/cm^3 collected during the experiment.
[a]Significance is at $Pr > F = 0.05$ on $\log_{10}(Y + 1)$ transformed data.

Discussion

Organic matter removal generally had a negative impact on Collembolan population densities, either alone or as part of a temporal interaction. Because organic matter on the forest floor provides an insulating layer that moderates temperature changes, these data suggest that the difference in temperature is the result of the thickness of the organic matter. Due to the higher soil temperatures in the WTFF treatment plots during summer, the forest floor in these plots may dry more quickly than the forest floor in the BO removal plots. The drier conditions could result in lower population levels, either by causing higher mortality or migration in the WTFF treatment plots. Newell (1984) reported an increase in Collembola density from 16% to 22% over the control when a polyethylene sheet was used to artificially create the insulating benefits of a litter layer. Conversely, in the winter months the small relatively thin patches of forest floor on the WTFF removal plots, although initially cooler in the early part of the day, would warm more quickly than the fairly contiguous layer in the BO removal plot. Soil faunae, including Collembola, would become active earlier and be active for longer periods of time on these plots, possibly explaining the observed peaks of

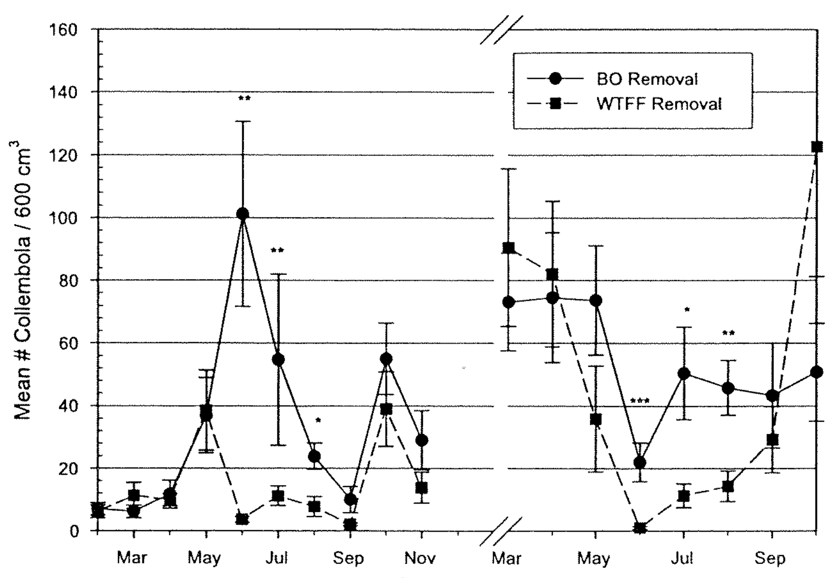

Figure 1. Mean (±SE) Collembola population response to bole only removal (BO) and whole tree and forest floor removal (WTFF). *,**,***Indicate significance at $P = 0.05, 0.01$, and 0.001 levels. Each point is the average of 12 samples.

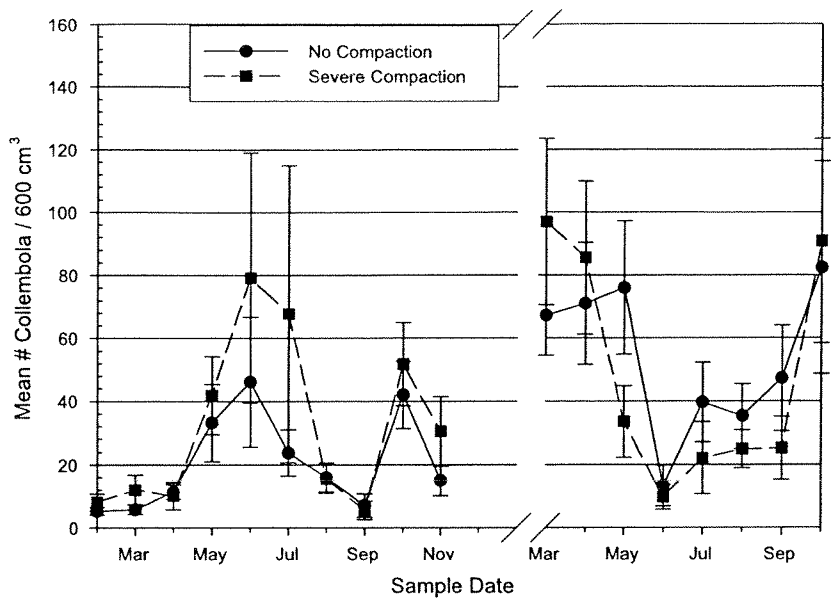

Figure 2. Mean (±SE) Collembola population response to severe and no compaction. *,**,*** Indicate significance at $P = 0.05$, 0.01, and 0.001 levels. Each point is the average of 12 samples.

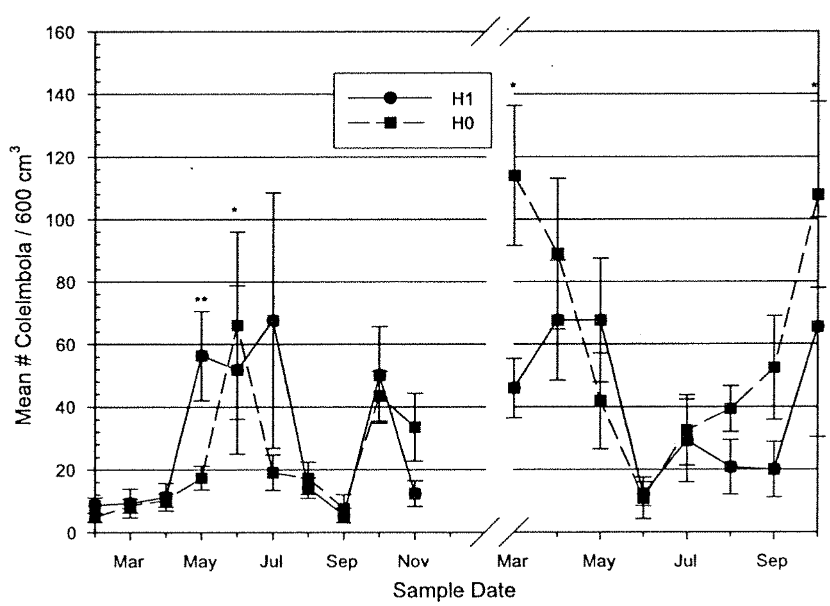

Figure 3. Mean (±SE) Collembola population response to total and no competition control. *,**,*** Indicate significance at $P = 0.05$, 0.01, and 0.001 levels. Each point is the average of 12 samples.

Collembolan populations in the March 1994 samples. Hopkin (1997) and Ferguson and Joly (2002) concluded that Colembola reproduction is probably temperature- and soil-moisture dependent.

Comparison of the number of Collembola per unit volume (Fig. 1) with the reduction of organic matter on the WTFF plots compared to the BO plots (Table 1) indicates that the composition of the organic matter may also be an important determinant of Collembolan abundance. McBrayer et al. (1977) describes the L layer as a dry zone of undecomposed material, the F layer as a zone of active decomposition, and the H layer as a zone of highly decomposed material of low nutritional value (for oribatid mites). They concluded that the H layer became a zone of refuge in the driest part of the year due to its ability to remain moist. Although not measured, it was assumed that the forest floor remained relatively undisturbed in the BO treatment plots whereas it was nearly totally

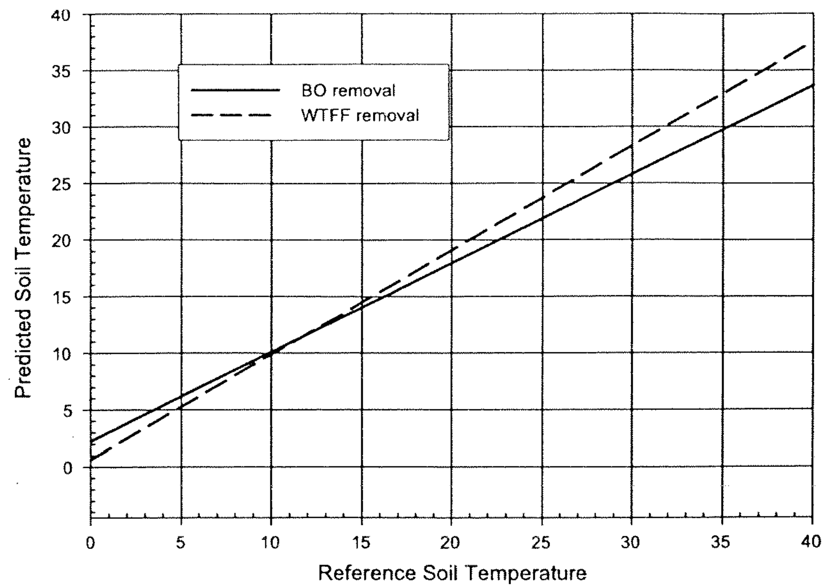

Figure 4. Predicted soil temperatures by forest floor removal treatment.

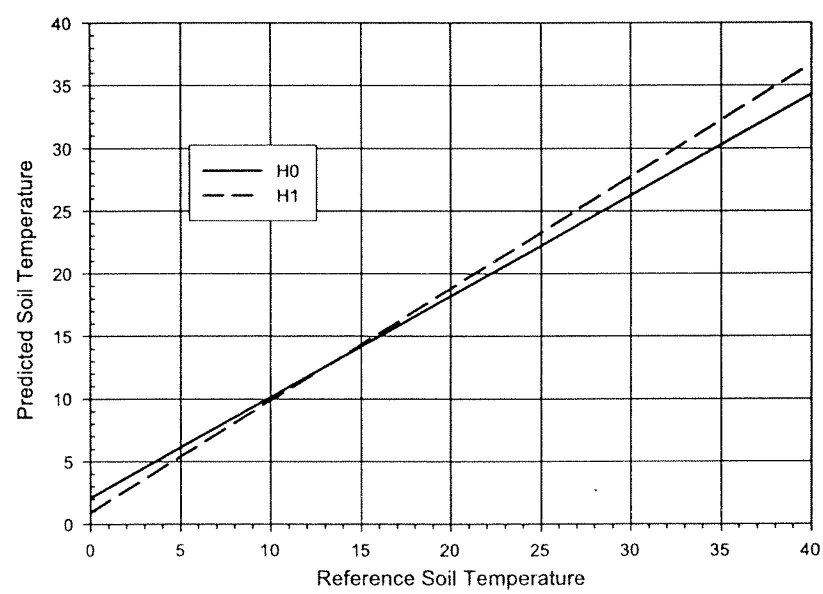

Figure 5. Predicted soil temperatures by herbicide treatment.

removed in the WTFF treatment plots. The 3 years from plot installation to the commencement of sampling may not have been enough time to allow newly accumulated organic matter on the WTFF plots to decompose and form a protective H layer. Subsequent research will attempt to determine if declines in Collembolan populations were due solely to OM removal or in addition to the disturbance of the organic matter layer.

There were no significant compaction treatment effects in Collembolan population levels (Table 2). Since the majority of the Collembola found in this study occurred in the forest floor, the compaction treatment, applied through the forest floor, probably had minimal effect on the forest floor and thus on Collembola abundance. Also, even though the severely compacted treatment plots experienced slightly warmer temperatures in the summer and slightly cooler ones in the winter than the no compaction treatment plots (data not shown), the differences may have been too small to affect Collembolan populations.

There were inconsistent treatment effects on Collembolan population levels between the two

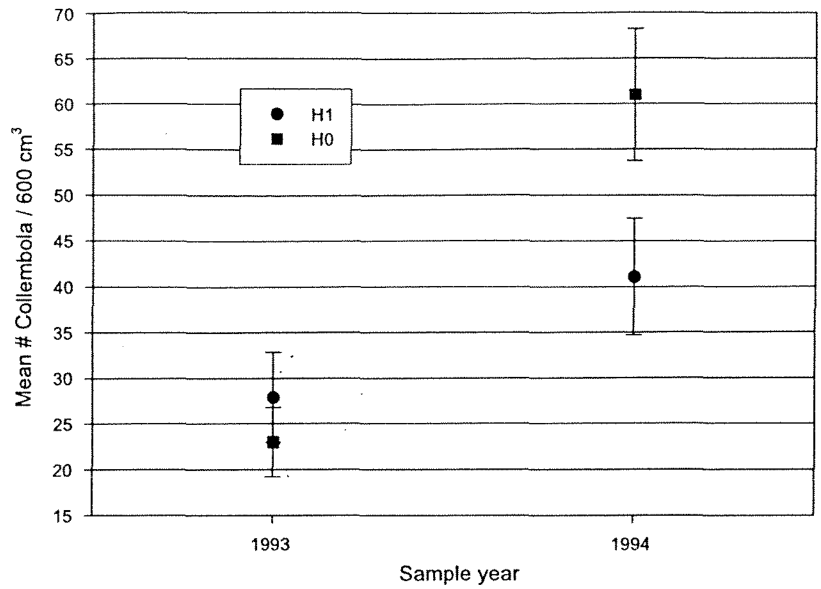

Figure 6. Collembola population response to herbicide treatment by year.

years of the sampling period for the vegetation control treatments (Fig. 6). The milder summer temperatures on the H0 plots (Fig. 5) may be from the understory which provides shade and additional litter to insulate the ground. These effects would moderate the litter temperature and reduce evaporation in the forest floor layer, again providing better habitat for Collembola. Butterfield (1999) reported similar seasonal results in Collembolan populations and suggested an increase in drying rate on the exposed sites as the cause. Bird and Chatarpaul (1986) found significantly higher moisture contents in the forest floor layer of uncut and conventionally harvested plots than in whole tree harvested plots, presumably due to the differences in canopy cover. Similarly, from their study in the northern Rocky Mountains, Hungerford and Babbitt (1987) concluded that understory regrowth on some of their treatment plots provided enough cover to moderate soil temperatures.

Vegetation control can also affect Collembola populations by altering vegetative abundance and diversity on the treatment plots. Quality and quantity of detritus have been shown to affect microarthropod densities (Seastedt, 1984; Takeda, 1987). Although the nutritional quality of the forest floor was not measured, the litter was more diverse in the H0 plots due to the greater variety of herbaceous material in these plots. In addition, a comparison of litter volume in 1995 indicated that the H0 plots were accumulating litter more quickly than the H1 plots (Table 1). The lack of significant vegetative control treatment differences in 1993 could indicate that there were no differences in quality or quantity in accumulated litterfall between H1 and H0 plots after the initial two growing seasons but after a third growing season, litter differences were substantial enough to affect Collembola population densities. It is also possible that plant mortality and leaf drop in September was a factor for the higher Collembola population levels in the October 1994 H0 plots. Although this event would create a new food source on both of the treatment plots, the greater diversity and abundance of litter on the no vegetative control treatment plot could be responsible for a greater diversity and abundance of decomposer organisms (McBrayer et al., 1977) and the animals that feed on them.

Conclusions

Results from population analysis suggest that Collembola are sensitive to disturbances in the organic matter layer. These disturbances may be direct, such as the removal of the organic matter layer, or indirect, such as the changes in microclimate and reduction of quality or quantity of litter, that may occur as a result of vegetation control. It is reasonable to speculate that even a "light" disturbance of the F layer may significantly alter the microsite in ways to cause a significant decrease in Collembola and fungal abundance. The most dramatic effects on the Collembola population in this study occurred in the treatments that likely had the greatest impact on humidity and temperature, i.e. organic matter removal and vegetation control. Both treatments can adversely affect Collembolan populations by decreasing or removing the habitat and increasing the variation of litter temperatures, which affects the moisture levels in the litter layer. Although the level of vegetation control used in this study was much higher than in an average operational situation, results indicate that there may be secondary, indirect effects on Collembola abundance when the vegetation is controlled. Compaction did not significantly affect Collembolan abundance in this study because it primarily affects the mineral soil and not the litter layer where most of the Collembola were found. Additional research will include more treatments to further explore the links between site disturbance, Collembolan populations, and site productivity.

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