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Effect of Snowpack on Species Composition, Biomass, Soil Composition and Microbial Activity in Restored Prairies in Southeastern Minnesota

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Abstract

Dramatic weather fluctuations, such as reduced snow cover and duration, are predicted for northern temperate and arctic ecosystems in the next century. Snow depth and melt timing affects a number of interrelated environmental processes, including microbial activity and biomass production (Brown and Mote 2009, Fornara et al. 2009). This study aimed to quantify the affects of two winters (2008-2010) of snow removal in four plots in a restored southeastern Minnesota prairie. Of the four plots with snow removed, two were in prairie that was restored from agricultural land in 1993 and two were in a prairie that was restored in 1998. Each snow removal plot had a corresponding control plot which did not have its snowpack altered. In a continuation of the previous year's study, in the fall 2010, above ground biomass, below ground biomass, CO_2 flux, soil moisture, and soil organic matter in the snow removal and covered (control) plots were measured. Data collected in the fall 2010 were compared to data collected in fall 2009. In the 1993 restored prairie the control plots tended to have more above ground biomass than the snow removal plots, while in the 1998 restored prairie this trend was reversed. There tended to be less above ground forb biomass and less below ground biomass in snow removal plots compared to their paired control plots, however this trend did not hold true for all sites. The affects of snow removal on the plots should continue to be quantified, as more long-term data will help illuminate the effects of snow removal for the carbon debt in restored prairie ecosystems.

Introduction

Global temperatures are predicted to increase between 1.5 and 5 degrees Celsius by the year 2100, largely due to anthropogenic increases in greenhouse gas emissions (IPCC 2007). As a result of increased warming, snowpack depth is predicted to decrease and spring snowmelt to occur earlier (Brown and Mote 2009). These changes are expected to alter plant community composition and productivity (IPCC 2007). Soil microbial communities and activity constantly change with environmental conditions and are particularly sensitive to the timing and duration of soil thaw. The processes that take place within soil microbial communities during freeze-thaw in winter determine the nutrient composition of the soil, and thus the whole system, for the following growing season (Edwards et al. 2007).

Plant species composition has been shown to change over time in arctic tundra environments in response to changes in snowpack depth and passive warming treatments (Wahren et al. 2005, Arft et al. 1999). It is reasonable to assume, then, that in a prairie ecosystem, long-term snowpack depth manipulation experiments may change plant species composition.

The St. Olaf College Natural Lands contain a 150 acre area of prairie that was restored from conventional agricultural land starting in 1989. More sections of land have been converted back to prairie every few years since then and have been maintained with periodic controlled fire disturbance (Smith 2008). Conventional agricultural practices strip soil of organic matter (carbon) while inundating the soil with nitrogen-based synthetic fertilizers, altering microbial communities and soil composition. Prairie restoration projects, like the one on the St. Olaf College Natural Lands, intend to return marginalized agricultural land to native grassland. However, regaining previous soil quality can take anywhere from 55 to 75 years for some components such as organic matter (McLauchlan et al. 2006).

While snowpack depth may have an effect on soil composition, microbial communities, and biomass production, the number of years since prairie restoration may also have an effect. Average CO_2 flux, microbial biomass and plant C:N ratios have been found to increase with increasing years since prairie restoration, while aboveground biomass tends to be reduced in older restored prairies (Manning et al. 2008).

In order to better understand how anthropogenic greenhouse gas emissions will affect ecosystems, it is important to simulate and study the predicted effects of climate warming. This study examined plant species composition, above and below ground biomass, soil composition, and CO_2 flux between snow removal and control plots and between the 1993 and 1998 restored prairies on the St. Olaf College Natural Lands.

Methods

This study was conducted on the St. Olaf College Natural Lands in southeastern Minnesota, and combines data from fall 2009 to fall 2010. The land was formerly used for agriculture, but was restored to back prairie in 1993 and 1998 for the two areas in this study. The seeds used to plant the prairie grasses and forbs were from Prairie Restoration Inc., a company that sells prairie seeds native to the area. The prairies have been managed with periodic fire disturbance. The 1993 prairie was last burned in 2006, and the 1998 prairie last burned in 2005 (Smith, 2008).

There are two snow removal plots in each prairie, with a paired control plot that remained covered with snow, for a total of eight plots (Figure 1). The plots were established in 2008. Each snow removal plot has been shoveled off within 24 hours after a snowfall event starting in the 2008-2009 winter. As snow was shoveled to the east of each snow removal plot, control plots have been established to the west of each snow removal plot.

<u>*Biomass Analysis*</u>

In order to assess biomass accumulation, one 0.25 m^2 quadrat was sampled in each plot, making for eight biomass samples total. Above ground biomass was harvested with large shears to cut down all of the biomass that had roots within the quadrat.

Biomass was cut at approximately 4-6 inches above the ground and placed into marked paper bags. Once brought back to lab the biomass was air dried.

Biomass samples were then sorted into grasses, legumes, and non-legume forbs, and were treated as separate samples for the remainder of analyses. All biomass samples were massed in pre-weighed aluminum boats to obtain a total air-dried weight. A subset of each biomass sample was then massed in an aluminum boat and placed in a drying oven at 70 degrees Celsius for 48 hours. The subset samples were massed again after the drying period. A total oven-dried mass for each biomass sample was calculated using the following equation:

Total oven-dried biomass = (Sample subset post-oven mass/Sample subset pre-oven mass)* Total air dried mass

Belowground root biomass samples were collected using a bulb planter with a 0.00246 m^2 surface area. One sample was taken per plot for a total of 8 samples, and placed in labeled zip-lock bags. Soil was washed from the root biomass samples according to the procedure in Shea's lab manual (2010). Root biomass samples were then placed in pre-massed aluminum boats and dried for 48 hours at 105 degrees Celsius in a drying oven. The samples were massed again after drying. The sample masses were converted to represent below-ground biomass for a 0.25 m^2 quadrat to match the quadrat size for the above-ground biomass samples. The equation used for that conversion was:

Oven-dried belowground biomass for 0.25 m^2 quadrat size = (Oven dried root mass for 0.00246 m^2 sample * 0.25 m^2)/ 0.00246 m^2

Soil Analysis

Soil quality data collection was a collaborative effort with a student from the Biology/Environmental Studies 350: Biogeochemistry class. In order to assess soil quality, three soil cores were taken from the exposed and covered areas of each plot, on two sampling days (one in the beginning of October and one in early November), resulting in six soil cores for each plot and 48 samples total. Soil core samples were placed in pre-massed labeled tins and massed for a fresh weight. Samples were then put in a drying oven at 105 degrees Celsius for 48 hours. After the drying period, samples were massed for a dry weight. Percent soil moisture was calculated using the following equation:

$$\% \text{ Moisture} = [(\text{Fresh weight} - \text{Dry weight})/\text{Dry weight}] \times 100$$

A 10-20 g soil sample was taken from the dried portion, crushed until it was the consistency of sand, and poured through a 1.19 mm sieve. The sample was then placed in a pre-weighed crucible and placed in a muffle furnace at 500 degrees Celsius for 4 hours. The soil and crucible were then massed to calculate percent soil organic matter using the following equation:

$$\% \text{ Soil Organic Matter} = [(\text{Dry mass} - \text{Ashed mass})/\text{Dry mass}] \times 100$$

CO_2 Flux

CO_2 flux data collection was also done in collaboration with a Biogeochemistry student. Data were measured using a LICOR LI-6400 Portable Photosynthesis System, and measurements were made according to the model's handbook instructions. Measurements were taken on two separate days, in early and mid-November. Readings were taken inside the snow removal plots and in the control plots. In the exposed area the four readings were taken approx. 0.5-1 meter away from the center, in the four corners of the quadrat. In the covered area the four readings were taken approx. 1 meter from the exposed area, on the four sides of the square.

Long-Term Data

Biomass, soil composition, and CO_2 flux data from this study were also compared to data collected by Blank in 2009 to examine trends in data over time.

Statistical Analysis

Stata version 9.0 was used for all statistical analyses (StataCorp 2005). Two-way ANOVA tests were used to determine relationship significance between each of the two independent variables (prairie age and snowpack treatment) and the measured dependent variables: total oven-dried above ground biomass, oven-dried grass biomass, oven-dried forb biomass, oven-dried root biomass, percent soil moisture, percent soil organic matter, and CO_2 flux. A P value of 0.05 determined significance. Mean values of variables were used for comparisons.

Results

Biomass parameters

There were no significant relationships between total aboveground, grass, forb, or belowground oven-dried biomass for prairie age, snowpack treatment, or collection period (Tables 1, 2). However, there was a trend looking at the mean forb masses that there was greater biomass in the control as opposed to the snow removal plots, though this relationship was not significant ($P = 0.1709$) (Table 1). There was a similar trend for the belowground biomass sample means, though again it was not significant ($P = 0.1757$) (Table 1).

Soil parameters

There were no significant differences between percent soil organic matter or percent soil moisture for either prairie age or snowpack treatment for the 2010 data collection (Table 1). However, the percent soil moisture was significantly higher in the 1998 plots than in the 1993 plots for the composite data ($P= 0.0385$) (Table 2).

CO_2 Flux

For the 2010 data collection, mean CO_2 Flux was significantly higher in the 1993 plots than in the 1998 plots ($P< 0.0001$) (Table 3). This shows a relationship between age of prairie and CO_2 flux, a proxy for microbial activity, and is consistent with data from the previous year (Table 5). Mean CO_2 flux was also significantly higher in the area of each plot that had snow removed during the previous winter than in the control area ($P< 0.0001$) (Table 4). This is the opposite effect that was seen in data collected in fall 2009 (Table 6).

Discussion

Prairie age and soil quality

Modern agriculture has degraded soils over the past century to such an extent that it takes years before restored prairie land has nutrient-rich soil once again. Soil carbon increases at a constant rate for the first 40 years after it is converted from agricultural land to grassland (McLauchlan et al., 2006). When comparing prairies that have recently been converted to those that have been established for a longer time, soil microbial C and N biomass has been found to increase by 141% and 33%, respectively (Baer et al., 2000). Another study found total C, microbial biomass C, and C mineralization to increase as a function of time in a 12-year time horizon (Baer et al., 2002). These results follow previous research in the Natural Lands where average CO_2 flux was found to be higher in older prairies (Manning et al., 2008).

Percent soil organic content has been shown to not be significant between prairie age or snowpack treatment on the Natural Lands (Blank 2009, Smith 2008). This is likely due to the fact that the St. Olaf prairies are fairly close in age and have been restored relatively recently. Restored prairies can take 55 to 75 years to regain former levels of organic content after agricultural marginalization, so significant differences might not be detectable for decades more (McLauchlan et al. 2006).

The percent soil moisture difference between the two prairies from the composite data is difficult to explain. However, given that there was no difference found in the 2010 data collection, it is likely that this is due to carryover from the Blank study (2009). She hypothesized that there could be a connection between soil moisture and biomass, as she also found higher biomass in the 1998 prairie. Since plants require water for growth, higher moisture in the 1998 prairie could explain the higher production in the 1998 prairie. The biomass trend follows the results of Smith (2008) where biomass was negatively related to prairie age. Also, the 1993 prairie was burned more recently, in 2006, than the 1998 prairie, burned in 2005. Previous studies have found biomass to be reduced in more recently burned prairies (Manning et al. 2008, Smith, 2008).

Snowpack, nitrogen availability, and microbial activity

Previous analysis on soil N processes during the winter of 2008-2009 found the covered soil to have negative rates of N mineralization and increased rates of nitrification, resulting in immobilization of nitrogen in the predominate ammonium form under soil covered in snow (Carpenter et al., 2009). In the exposed soil the processes were just the opposite with positive rates of N mineralization and decreased rates of nitrification, resulting in mobilization of N in the nitrate form. The higher mineralization of N in the exposed soil allowed for more nitrogen availability in the spring (Carpenter et al, 2009). This could have been predicted to show higher biomass production in the exposed sites, but that was not found in this study. Another study found that a reduction in N availability in soil (as was found in the covered plots) did not result in a decrease in net productivity and attributed this to shifts in nitrogen-use efficiency and functional group composition. More specifically, it was hypothesized that there were more C4 grasses with better nutrient-use efficiency in the less nutrient soils (Baer and Blair, 2008).

Instead of increased biomass in exposed plots, higher N content was found in the grass in these sites. Microbial immobilization has been found to be the most important process leading to reduction in N uptake by plants (Vitousek and Matson, 1984). The grasses with higher N content also had a lower C:N, following results of previous studies (Pastor et al., 1984; Wedin and Tilman, 1996).

Microbial activity determines the C and N cycling in the soil, setting the soil nutrients before plants begin to grow in the spring (Edwards et al., 2007). The previous winter had shown higher CO_2 flux values in the covered sites in the March data, but once the snow had melted in April the snowpack treatment had hardly any effect on CO_2 flux values. I found higher CO_2 flux values in this study for the previously covered sites and there had been no snowpack on the ground since the previous winter. The lack of a relationship between CO_2 flux and snowpack treatment from April and the presence of one in the autumn could be representing different microbial communities depending on the climate conditions and the time of year. Microbial activity is extremely sensitive to soil thaw timing and duration (Edwards et al., 2007). In the spring the soil was rapidly thawing and waterlogged, and the microbial communities that thrived in the frozen soil could have been dying out as new species grew in numbers. The CO_2 flux was in a transition phase, not as stable as the communities became throughout the summer and into the fall. The stable conditions in the fall made it easier to see the effect of snowpack effect on microbial activity.

Since CO_2 flux is a proxy for microbial activity, I hypothesize that there may be a relationship between increased soil N availability and decreased microbial activity. Wallenstein et al. (2006) found decreased organic soil microbial biomass in hardwood and pine stands with high N fertilization. One hypothesis for this result is that soil C:N will decrease with increased soil N and bacteria with a smaller C:N than fungi will be able to use organic substrates with lower C:N. Another hypothesis proposed was soil acidification from increased soil nitrification resulting in nitrate leaching.

Implications for future ecosystem shifts due to climate change

It is widely known, based on predicted and observed data, that snow cover will decrease in amount and duration with increasing global temperatures (Brown and Mote 2009, IPCC 2007). Data from snow removal sites on the prairie provides a look at what future ecosystem changes may occur in restored prairie ecosystems due to climate warming.

Negative trends have been found between N availability in soils and plant diversity, hinting that long-term increases in soil N availability, as was seen in exposed winter soils, will decrease biodiversity (Baer and Blair, 2008). Supporting this hypothesis is the similarity in effects from increased N deposition and N availability in soil.

Increased soil nitrogen deposition has been shown to decrease plant diversity, decrease native grass species (C4 grasses), increase non-native grass species (C3 grasses), decrease the C:N ratio in prairie biomass, and increase soil nitrate and mineralization rates. A decrease in plant diversity is also a decrease in the capacity of carbon sequestration, resulting in a positive feedback for climate change (Fornara and Tilman, 2008).

The increase in soil nitrate decreases total N retention in soil (Wedin and Tilman, 1996). Faster rates of N cycling makes a more active N pool, which ultimately allows the soil to remain productive with increasing C and N deposition. Since the added nutrients will be taken up by the plant biomass instead of in the soil in this more active system, less carbon will be sequestered (Fornara et al., 2009).

One hypothesis for the effects of high N loss from soils due to increased mineralization could result in higher N concentrations in runoff and thus nutrient additions to nearby water bodies, which could ultimately result in eutrophication (Vitousek and Matson, 1984). A second hypothesis is that increased soil nitrate could likely result in higher denitrification rates, especially during spring snowmelt when soil water content is high and oxygen is limited. Increased microbial activity also contributes to increased nitrous oxide flux. Therefore, the exposed soil could produce nitrous oxide from denitrification, but the covered soil will produce nitrous oxide with increased microbial activity (Filippa et al., 2009). More work should be done to quantify the denitrification rates and thus nitrous oxide emissions from both the covered and exposed soil, during winter and throughout the following year. While nitrous oxide is an important part of the nitrogen cycle, it is a greenhouse gas (Filippa et al., 2009).

CO_2 emissions due to soil respiration are greater from deeper snowpacks, due to the increased microbial activity (Edwards et al., 2007). Although exposed soils will provide a smaller carbon sink, they might be a smaller carbon source as well. Quantifying the carbon processes in exposed as compared to covered soils could help settle the debate on which snowpack treatment would produce the most carbon debt.

Decreased snow cover will certainly change soil nutrients, microbial activity, and biomass species composition, even in the short-term time frame.

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Tables and Figures

Table 1. Biomass and soil composition data from fall 2010 collection period, separated by year of prairie restoration and snowpack treatment. Biomass data is in mean g/0.25 m^2, while soil composition data is in mean percentages.

	1993		**1998**		**P Values**	
Fall 2010 Data	**Snow Removal**	**Control**	**Snow Removal**	**Control**	**Between Prairie**	**Between Snowpack**
Biomass (g/0.25 m^2)						
Above Ground Total	61.3760	126.7270	127.3130	108.1025	0.4751	0.4853
Grass	53.1310	112.3020	114.3730	81.1675	0.6597	0.7031
Forb	8.2450	14.4250	12.9400	26.9350	0.2283	0.1709
Below Ground	297.3998	330.8954	232.4388	481.6253	0.7844	0.1757
Soil Composition						
Organic Matter (%)	4.3901	4.3316	4.3013	4.5490	0.8741	0.8157
Moisture (%)	19.7296	18.0955	17.8980	18.2981	0.6071	0.6964

Table 2. Composite biomass and soil composition data from fall 2010 and fall 2009 collection periods, separated by year of prairie restoration and snowpack treatment. Biomass data is in mean g/0.25 m^2, while soil composition data is in mean percentages.

	1993		**1998**		**P Values**	
Composite Data	**Snow Removal**	**Control**	**Snow Removal**	**Control**	**Between Prairie**	**Between Snowpack**

Biomass (g/0.25 m^2)						
Above Ground Total	66.081	89.5295	105.8963	102.5896	0.0618	0.4597
Grass	55.057	71.1106	89.3175	80.3493	0.1279	0.7985
Forb	11.024	18.4191	16.5788	22.2403	0.4965	0.3463
Soil Composition						
Organic Matter (%)	5.5410	5.2927	5.3133	5.2199	0.6616	0.6187
Moisture (%)	17.8286	19.0462	20.5176	21.0846	0.0385	0.4282

Table 3. A comparison of mean CO_2 flux values from the soil of prairies restored in 1993 and 1998 in the St. Olaf College Natural Lands, data collected fall 2010.

Prairie	Mean CO_2 flux (g CO_2/m2/hr)	Std. Dev.	Frequency	P value
1993	1.456	0.266	708	<0.0001
1998	1.021	0.095	612	
Total	1.254	0.319	1320	

Table 4. A comparison of mean CO_2 flux values from the soil of prairies in the St. Olaf College Natural Lands that either were covered in snowpack (control) or exposed (snow removal) during the winter from 2008-2010, data collected fall 2010.

Snowpack	Mean CO_2 flux (g CO_2/m2/hr)	Std. Dev.	Frequency	P value
Snow Removal	1.399	0.314	572	<0.0001
Control	1.144	0.276	748	
Total	1.254	0.319	1320	

Table 5. A comparison of mean CO_2 flux values from the soil of prairies restored in 1993 and 1998 in the St. Olaf College Natural Lands, data collected fall 2009 (Blank 2009).

Prairie	Mean CO_2 flux (g CO_2/m2/hr)	Std. Dev.	Frequency	P value
1993	0.295	0.103	32	0.0269
1998	0.234	0.095	25	
Total	0.268	0.104	57	

Table 6. A comparison of mean CO_2 flux values from the soil of prairies in the St. Olaf College Natural Lands that either were covered in snowpack (control) or exposed (snow removal) during the winter of 2008-2009, data collected fall 2009 (Blank 2009).

Snowpack	Mean CO_2 flux (g CO_2/m2/hr)	Std. Dev.	Frequency	P value
Snow Removal	0.236	0.067	28	0.0114
Control	0.305	0.122	28	
Total	0.27	0.104	56	

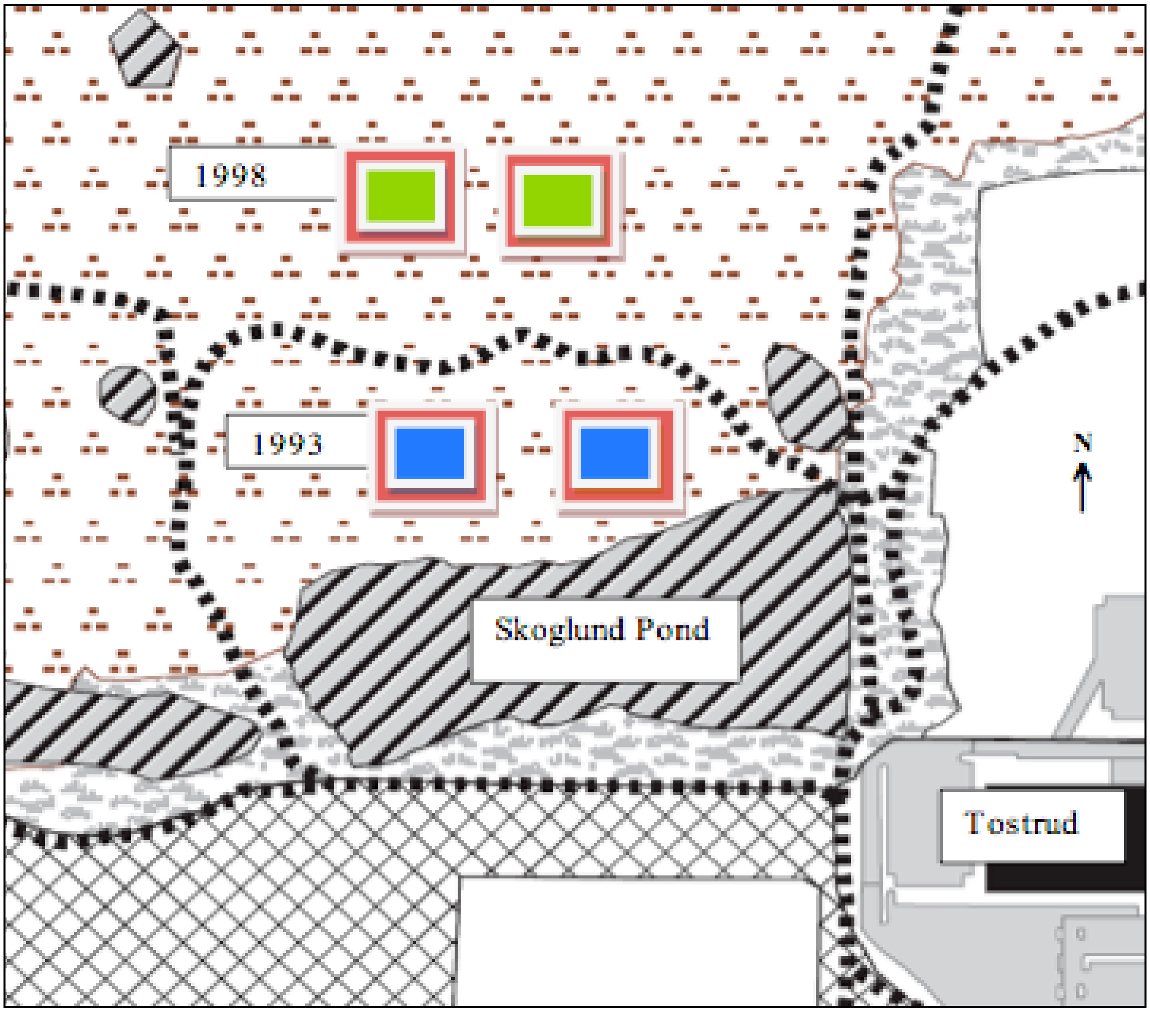

Figure 1. Locations of four plots in the St. Olaf College natural lands from two prairies restored in 1993 and 1998. The plots were established in 2008, and snow has been removed from the interior of each plot beginning in the winter of 2008-2009. The exterior part of each plot was covered in snow cover during that winter.