USING CONTROLLED WATER TREATMENT ON UNDERSTORY PLANT SPECIES TO DETERMINE THE EFFECTS OF CLIMATE CHANGE ON THE BOREAL FOREST

By

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ABSTRACT

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Climate change poses a big threat to boreal forest managers. We have set out to test how different precipitation levels will affect a number of boreal understory species across the three forest types commonly found in the boreal forest and see if the literature supports our findings. Total species abundance was higher in the Broadleaved stands compared to mixedwood and conifers stands. The Broadleaf composition had significantly more total richness than the mixedwood and conifer. Vascular and nonvascular abundance also followed the similar results as those for total abundance and was higher in broadleaved stands compared to mixedwood and conifer stands. The Broadleaf composition had similar results with vascular plant richness as with the total richness. The non-vascular compositions however, were not significantly different.

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INTRODUCTION AND OBJECTIVE

INTRODUCTION

The boreal forest is the largest biome in the world. It stores about half of the global forest carbon, which makes it an important part of the global carbon cycle and climate regulation (*Gauthier et al. 2015*). Knowing the effect of water or a lack of water has on the boreal forest is important to understand, especially if we expect different precipitation levels in the future (*Gauthier et al. 2015*; *Price et al. 2013)*. We can predict information about the boreal forest in the future by knowing the result of high or low precipitation today.

As a graduating student with a degree in forestry it is in my cohorts' and my own best interest to learn about the potential changes in the environment that we will be working and living in. The most accurate climate data that accounts for current climate trends come from the last 100 years. Using this data and general circulation models (GCMs), scholars can predict how the climate will be in the future. They believe that temperature will increase during the winter over the next 100 years, as well as in the summer in the interior regions by about 5 to 10 centigrade (*Gauthier et al. 2015*; *Price et al. 2013)*. There is a strong agreement among the GCMs studied that annual precipitation will increase across the entire boreal. It is important to note that while there will be an increase in precipitation, there will also be an increase in temperature, which leaves soil moisture to remain the same (*Gauthier et al. 2015*; *Price et al. 2013)*. On that same point there may not be more snowfall due to the same reasons. The boreal plant species that are projected to be the most effected are those found in wetland and permafrost areas, as these areas are the most sensitive to temperature fluctuation and dryness.

Since climate affects boreal ecosystem functions presently, a changing climate will have a serious impact on it and thus is a matter of concern for forest managers (*Price et al. 2013*). Climate change will seriously affect vegetative succession, especially for species that are found in already not ideal climate conditions (*Price et al. 2013*). This is brought about by the changing occurrence of large-scale disturbances like fires, and small-scale disturbances like storms, which will be higher frequency and severity in the future (*Price et al. 2013*). Boreal plant species are adapted to the climate for their particular locations in the forest. With a change in this climate, there is a chance that these plants can become maladapted. Some effects of maladaptation on trees include late bud flush and early dormancy. This discrepancy in timing causes an increase in susceptibility to insect related stress. Firstly the insects that hatch when the bud flush is supposed to occur would die out and then come back, as an insects' speed of adaptation is much higher than a tree's, as well the increased temperature will allow warmer temperature insects' range to enter the boreal forest (*Allen et al. 2010*; *Price et al. 2013*). This will cause a large increase in tree mortality, and therefore succession rate.

An increase in temperature will lead to an increased frequency of drought conditions in the boreal forest except in areas where soil moisture is not a limiting factor. Drought effects are important to understand because growth and CO_2 uptake are constrained the most by drought (*Vicente-Serrano et al. 2013*). The boreal forest is shown to be severely sensitive to drought, as the dominant plant species that make up the boreal forest cannot tolerate even small water deficits. Even a short period of a water deficit on the boreal forest will significantly affect tree growth, plant growth, and vegetation activity (*Vicente-Serrano et al. 2013*). The other effects of droughts include tree mortality, side effects of low moisture like insect infestation and fire frequency, and can hamper the ability for trees to naturally regenerate via seeding (*Price et al. 2013*). Tree mortality has increased by as much as 6% per year since the 1960s, especially in young forest. This can be attributed to the fact that the average drought events happening today are as severe as the highest recorded severity droughts in the 1960s. In fact, young forests are much more susceptible to tree mortality as a side effect of drought conditions from increasing temperatures compared to older forests (*Luo et al. 2013*). As the temperature has increased, so have droughts and pests with it. Since young trees are not as large as older trees, they are more susceptible to warming based mortality. An increase in mortality will cause trees that are less competitive and less adapted to the warmer weather to be outcompeted more frequently (*Luo et al. 2013*). As *Populus balsamifera* as a pioneer species has had the highest increase in mortality, it can be ascertained that the loss of water availability due to regional warming is the reason why trees adapted to moist environments are dying. *Picea mariana* and *Picea glauca* experiences a higher increase in mortality rate when compared to *Populus tremuloides* and *Pinus banksiana*, across both young and old forests. We can expect that the future forest will be dominated by early-successional species if these increases in mortality due to increased warming were to continue (*Luo et al. 2013*).

Globally, the boreal forest can be considered a humid forest type, and therefore has on average, a higher water surplus than water deficit. In other words, the boreal forest is extremely maladapted to arid conditions, and is severely damaged by drought conditions. The most common condition of drought in the boreal forest is damage to plant tissue and loss in foliar biomass (*Vicente-Serrano et al. 2013*). Since the boreal forest is humid, the plants can bounce back easily after a very damaging but short drought period. It is projected that by 2060 many parts of Canada including the boreal forest will experience droughts that last multiple years due to an increase in sea surface temperature, which will change wind circulation patterns and divert precipitation towards the poles. Since these will be significantly long-term droughts, the boreal forest will not be able to return to its state before the drought occurred. Even now at the southern margins of the boreal forest, tree dieback is occurring and shrub lands and grasslands due to the increase in frequency and severity of drought conditions are replacing the boreal forest (*Allen et al. 2010*; *Gauthier et al. 2015*; *Price et al. 2013*). Understory species make up the majority contributor of biodiversity in the boreal forest and contribute important to important ecosystem functions (*Chen 2018*).

In a study of 1032 understory plant species in 1409 vegetation plots that have been surveyed and then resurveyed, that 33% of the plant species have changed to species that are better adapted to warmer climates. The coldest temperature adapted plants being outcompeted by the slightly warm temperature plants caused the change in species of 33% of the study to occur (*De Frenne et al. 2013*). In some plots, there was actually a net increase in species, due to a higher rate of immigration of warmer adapted species that extirpation of colder adapted species. It was found that canopy cover is the best way to mitigate understory species replacement. Dense crown canopies lower the temperature below them, increase air humidity and shade. This means that the species that were replaces by more competitive warm climate species were light-dependent species. The humid, cool, dark environments these dense canopies create also provide the perfect nursery for herbaceous plants and tree seedlings. Due to how fragmented the modern forest is, using dense forests as buffers may be the way of the future to protect temperate forest diversity (*De Frenne et al. 2013*). On drought prone locations, herbaceous understory vegetation can reduce biomass regeneration in overstory trees by up to 51%. This causes an overstory species shift to more drought tolerant species, which will then alter the understory species (*Thrippleton 2017*). A large influence on understory species richness and cover is overstory type (*Vockenhuber 2011*). Soil resource and light availability for understory plants depends on the overstory type (*Chavez 2012*). Locations with a broadleaf dominated overstory have high understory species richness and cover because of high light availability and the leaf litter is high in nutrients (*Chen 2017*). This is contrasted by conifer dominated overstory areas, which offer low light and poor nutrient leaf litter and therefore a lower species richness, with mixedwood compositions having a species richness between broadleaf and conifer (*Chavez 2012*). Due to the differences in light, moisture, and nutrient availability, the broadleaf overstory has a majority vascular understory, the conifer overstory has a majority non-vascular understory, and the mixedwood understory has a split between the two (*Chen 2018*). This however is not always the case, as stand age also plays an important role in understory composition (*Kumar 2018*).

OBJECTIVE

The objective of this thesis is to determine if an increase or decrease in water will result in a significant difference in the understory species abundance and richness of the boreal forest. This will help determine if we as managers need to be worried about the projected change in climate changing the boreal forest. As an aside, it will also test the efficacy of the water treatment system.

HYPOTHESIS

We expect a higher cover of vascular plants in the broadleaved stand because broadleaf stands have higher light availability and nutrients, which create conditions favourable for various herbs and shrub species (*Chen 2017*). However, we expect the opposite for non-vascular plants and hypothesize that non-vascular plants are higher in the conifer stands because of their preference for the low light, lower temperature and higher humidity that conifer stands offer (*Chavez 2012*). We also expect that there will not be a significant difference with water treatment, due to boreal understory species being unable to tolerate drought conditions (*Luo et al. 2013*), and vegetative activity being inhibited by lower water availability (*Vicente-Serrano et al. 2013*) over a longer period of time than one growing season, in order to take effect.

MATERIALS AND METHODS

STUDY AREA

The sampling areas, of which I have data for nine of each of the three treatments, repeated three times, is found in the boreal forests north of Lake Superior and west of Lake Nipigon in the Black Spruce Forest, located approximately 100 km north of Thunder Bay, Ontario, Canada (49°23'N to 49°36'N, 89°31'W to 89°44'W). The area falls within the Moist Mid-Boreal (MBX) ecoclimatic region (Ecoregions Working Group 1989) and is characterized by warm summers and cold, snow-rich winters. Mean annual temperature is 2.5°C and mean annual precipitation is 712 mm at the closest meteorological station located in Thunder Bay, Ontario (Environment Canada 2016). The overstory is typically dominated by *Pinus banksiana* Lamb., *Populus tremuloides* Michx., *Betula papyrifera* Marsh., *Picea mariana* [Mill.] B.S.P., *Picea glauca* [Moench] Voss and *Abies balsamea* [L]. Mill.This location was chosen because there is conifer dominated, hardwood dominated, and mixed wood forests, which had been clear-cut and then caught on fire, causing them to be in the same age class. These forest types, as well as their geographic location make them ideal candidates for a statistical analysis of the boreal forest.

DATA COLLECTION

The water treatment device was built in the summer of 2017 and it stops rain from entering the water reduction area and deposits it in the water addition area, which is about 15 metres away. The device itself is made out of iron stakes and wire to hold itself together, plastic sheets to prevent water from hitting the ground and move water to the transportation system. The transportation system is a parallel of gutters that move and then deposit the water in the addition area. At each site there is also a control group that is outside of the water device's area of influence. Some photographs of the device are shown here in Figures 1 to 3. I personally attended the research twice during October 2017, where I helped Han Chen's master students (in particular Xinli) collect their data and put away parts for the winter.

Figure 1. Water reduction treatment area.

Figure 2. Water addition treatment area.

Figure 3. Water control treatment area.

STATISTICAL DESIGN

In The data that I received is a list in the form of an excel spreadsheet of 43 boreal understory plant species, their average heights, the sites and treatments they are present in, the overstory forest type and the percentage of coverage they have at each site and treatment. Species abundance was evaluated as the sum of individual species percent cover on each plot and species richness was treated as the total number of species recorded on each plot. Total vegetation cover was treated as the sum of species-specific cover values on each plot. To test for Treatment and overstory composition effects on species abundance and species richness we used two-way analysis of variance. We used

Shapiro–Wilk's test to check the assumptions of normality. For species richness, we specified distribution as Poisson. We also used permutation multivariate analysis of variance (perMANOVA) to examine the effect of treatment and overstory compositions, on understory species composition. PerMANOVA is a nonparametric, multivariate analysis that uses permutation techniques to test for compositional differences between more than one factor (Anderson 2005). To examine trends in the composition data, we used nonmetric multidimensional scaling (NMDS), which is a robust ordination technique for community data that are non-normal or evaluated on ordinal scales (McCune and Grace 2002).

RESULTS

We found that total understory species abundance varied significantly only with overstory composition types, whereas treatment did not have any effect on total understory abundance (Table 1). Total species abundance was higher in the Broadleaved stands compared to mixedwood and conifers stands (Figure.4). Vascular and nonvascular cover also followed the similar results as those for total cover (Table 1) and was also higher in broadleaved stands compared to mixedwood and conifer stands (Figures 5 and 6).

We also found that there is a significant difference in total and vascular species richness depending on overstory composition, with no significant difference when looking at non-vascular plants, the different treatments or the interaction of treatment and overstory type (Table 2). The Broadleaf composition had significantly more total richness than the mixedwood and conifer composition (Figure 7). The Broadleaf composition had similar results with vascular plant richness as with the total richness (Figure 8). The non-vascular compositions however, were not significantly different.

Additionally we found that on the perMANOVA results (Table 3) there was no effect of treatment on understory species composition but overstory composition had a significant effect on understory species composition. When we visualize this table, we found that broadleaved stands had a different species composition than conifers stands whereas mixed wood stands have understory species common to broadleaved and conifers stands (Table 9).

Table 1. Effects of treatment and fixed effect of overstory composition and their interactions on understorey total, vascular, and non-vascular abundance. Bold fonts indicates statistical significance (α = 0.05).

Attribute	Source	df	MS	F	P
Total abundance	Treatment	2	423	0.88	0.431
	Composition	2	4925	10.26	**0.001**
	T × C	4	327		0.614
Vascular abundance	Treatment	2	257.9	1.91	0.176
	Composition	2	1837.4	13.63	**0.001**
	T × C	4	95.3	0.71	0.598
Non-vascular abundance	Treatment	2	27.8	0.15	0.857
	Composition	2	801.8	4.47	**0.027**
	T × C	4	85.3	0.48	0.753

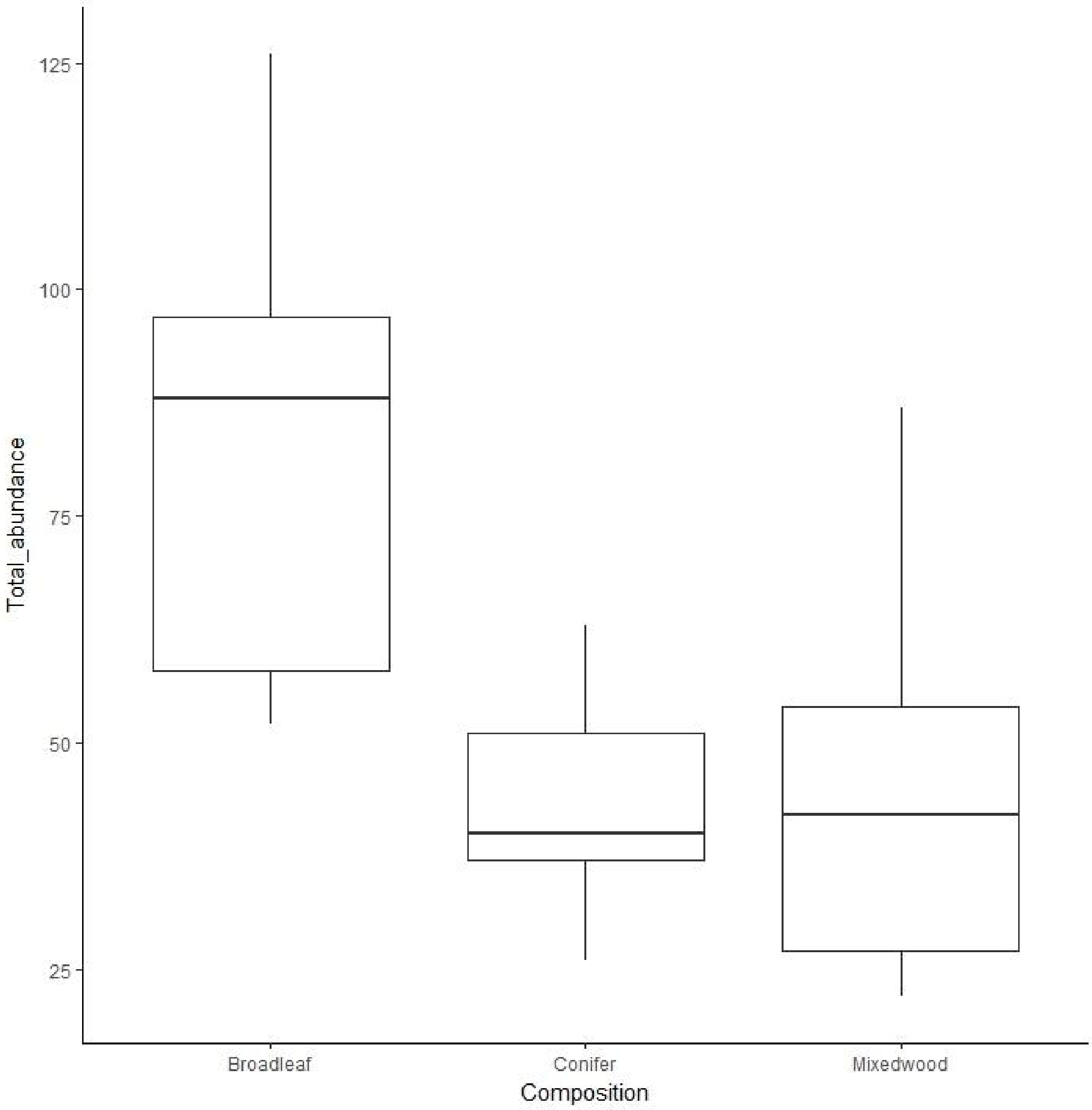

Figure 4.Total abundance box and whisker plot comparing the three overstory compositions.

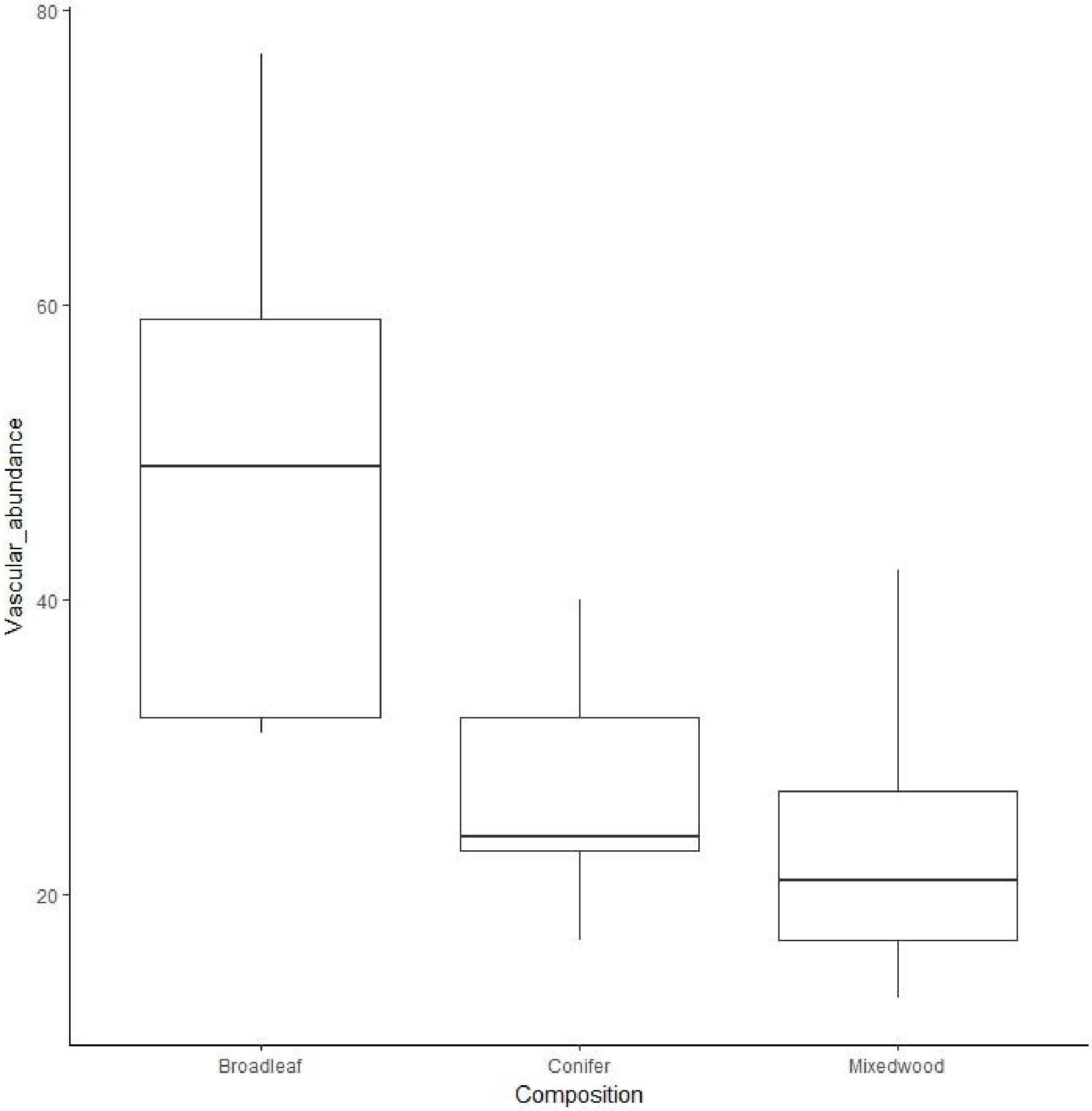

Figure 5. Vascular plant abundance box and whisker plot comparing the three overstory compositions.

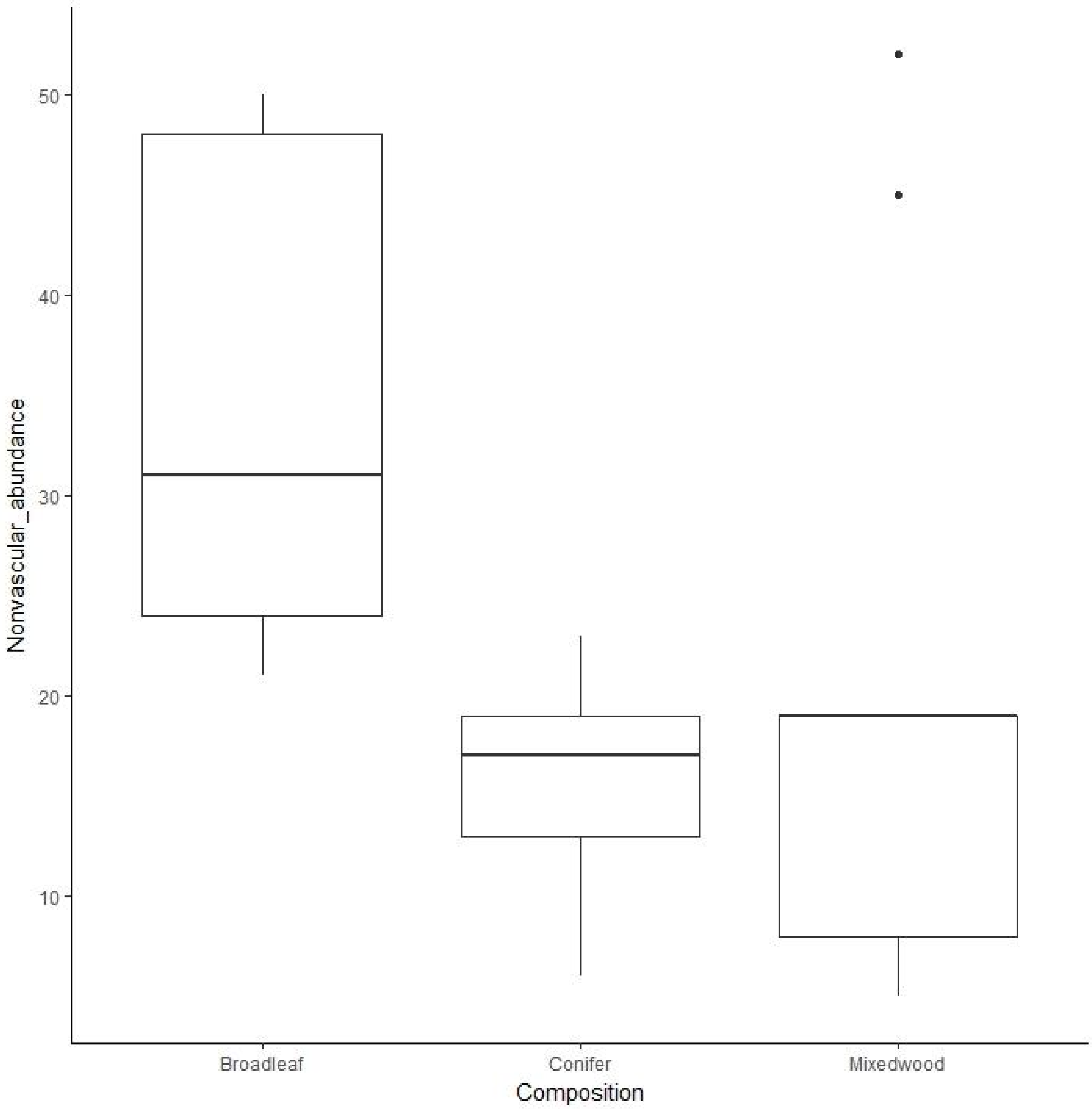

Figure 6. Non-vascular plant abundance box and whisker plot comparing the three overstory compositions.

Table 2. Results of generalized linear model showing the effects of treatment and overstory composition types and their interactions on understory total, vascular and non-vascular species richness. Bold fonts indicates statistical significance (α = 0.05).

Attribute	Source	df	LR Chisq	P
Total richness	Treatment	2	4.62	0.99
	Composition	2	18.26	**0.001**
	T × C	4	2.47	0.649
Vascular richness	Treatment	2	1.3	0.521
	Composition	2	16.07	**0.001**
	T × C	4	2.39	0.664
Nonvascular richness	Treatment	2	5.08	0.079
	Composition	2	4.35	0.114
	T × C	4	1.59	0.81

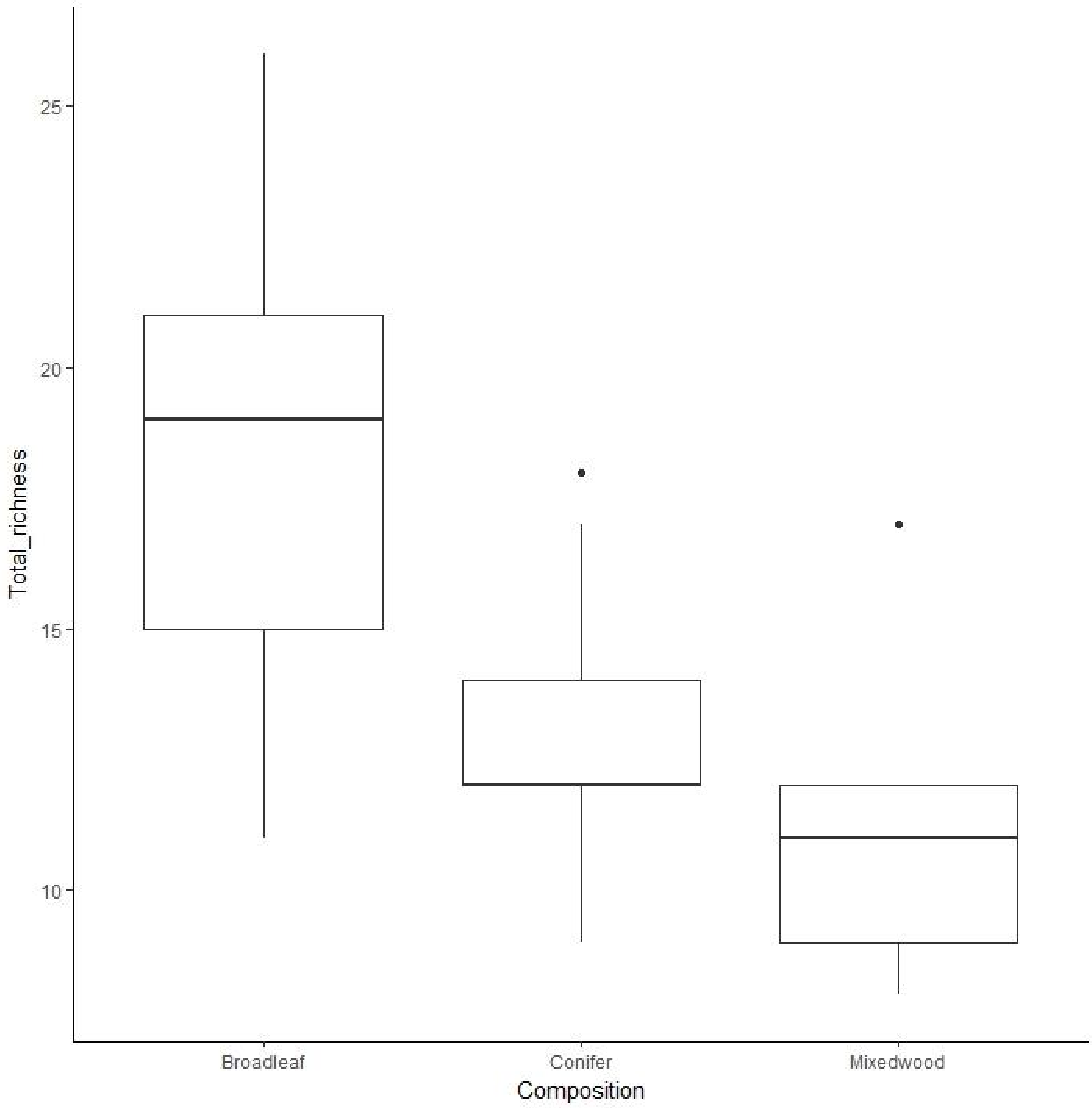

Figure 7. Total richness box and whisker plot comparing the three overstory compositions.

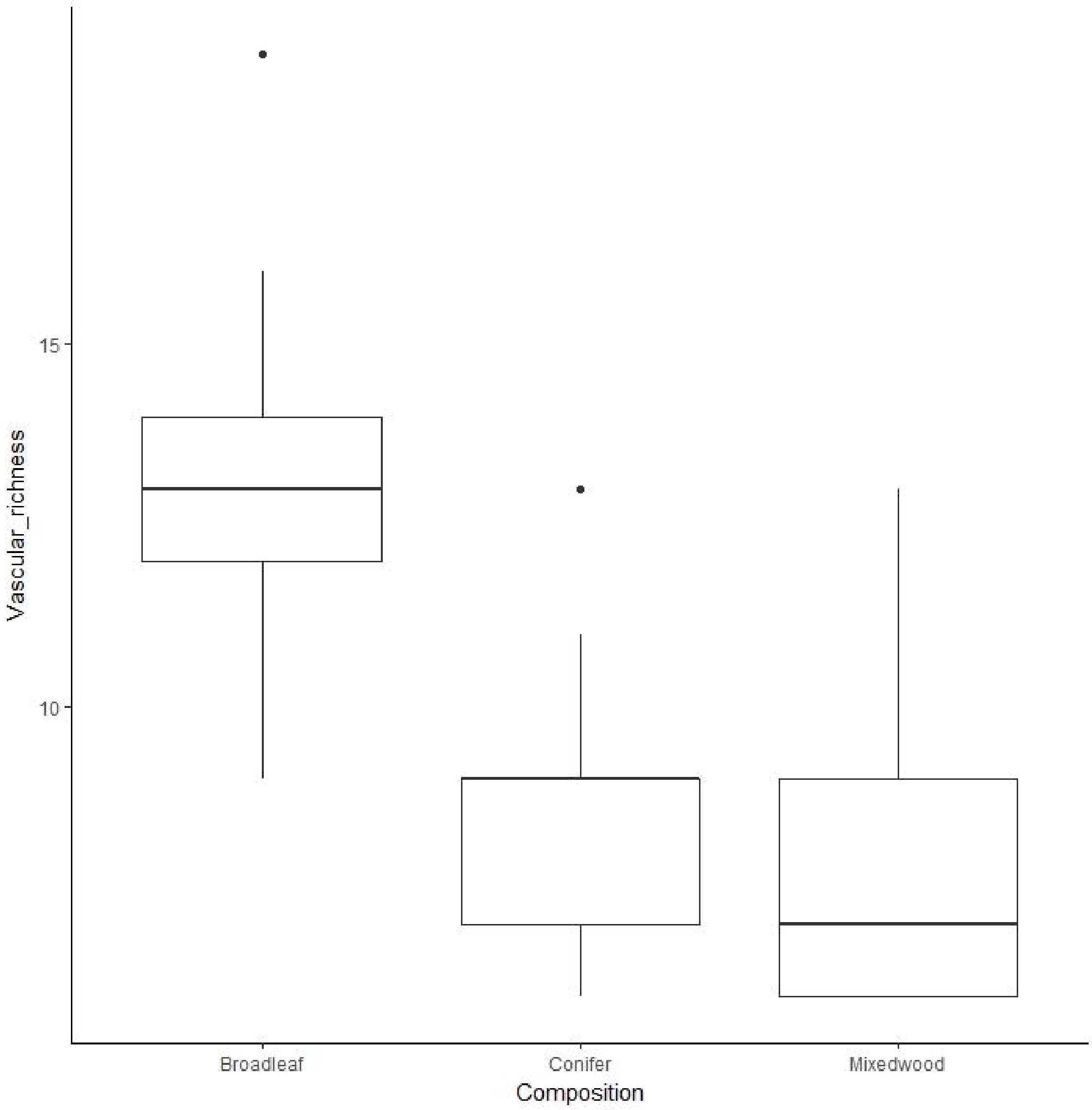

Figure 8. Vascular richness box and whisker plot comparing the three overstory compositions.

Table 3. Results of permutation multivariate analysis of variance (perMANOVA) testing the effects of treatment (T) and overstory compositions (C) on understory species composition. Bold fonts indicates statistical significance (α = 0.05).

Source	df	MS	F	P	Partial R^2
T	2	0.09	0.52	0.96	0.04
C	2	0.5	2.89	**0.001**	0.22
T × C	4	0.06	0.37	1	0.06
Residuals	18	0.17			0.68

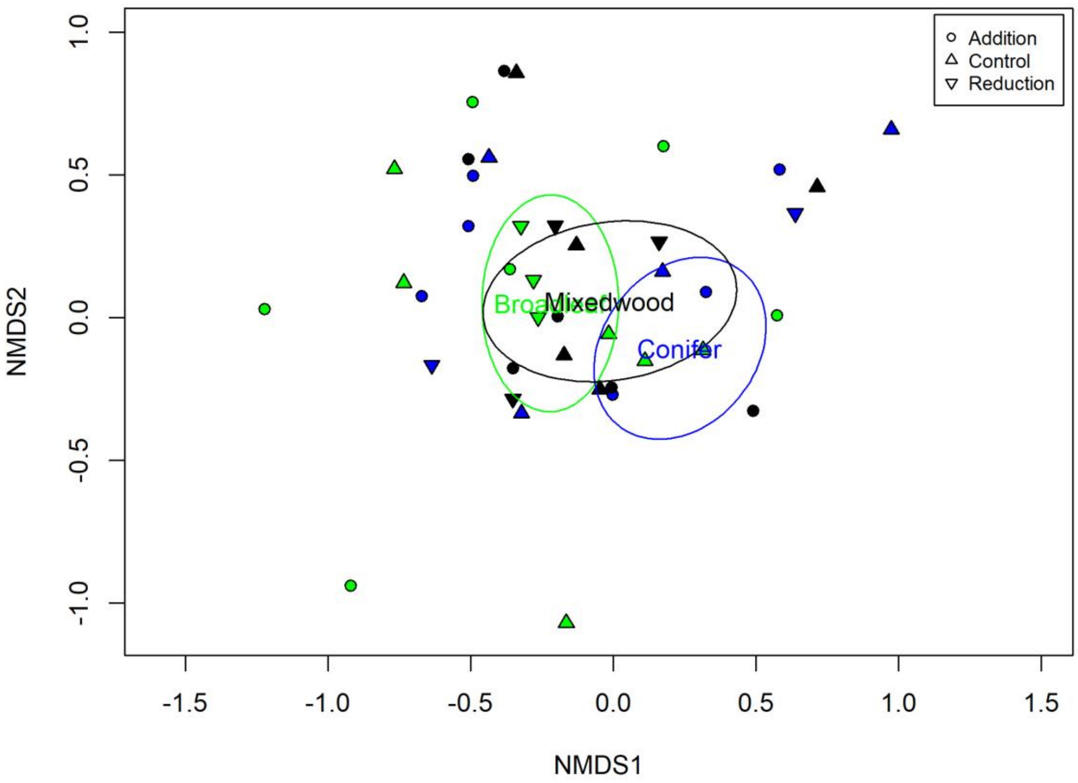

Figure 9. Nonmetric multidimensional scaling data depicting treatment, overstory type, and the interaction between them, with each data point representing a unique understory plant species. This is a visual depiction of (Table 3).

DISCUSSION

We found that total understory species abundance and richness varied significantly only with overstory composition types, like in (*De Frenne et al. 2013*; *Vockenhuber 2011*). We expected this because the forest that was sampled is relatively young, so the understory species that would be established there will be colonizer species, primarily, who are better adapted to the high light, high temperature, nutrient rich broadleaf forests (*Kumar 2018*). Total species abundance and richness was higher in the Broadleaved stands compared to mixedwood and conifers stands. This is consistent with previous studies (*Chen 2017*; *Chavez 2012*; *Chen 2018*). The broadleaf overstory is more hospitable for more species than conifer or mixedwood forests, which is why it appears to have a higher richness and abundance than those compositions.

Vascular and nonvascular abundance and vascular richness also followed the similar results as those for total abundance and richness and was higher in broadleaved stands compared to mixedwood and conifer stands. However, non-vascular richness was not significant. This is due to stand age again, as the species that are strongly adapted to live in conifer stands will not be present yet. Since the plants that are missing are mostly non-vascular, late successional species, their lack of presence has resulted in the richness to be the same as the broadleaf and mixedwood stands, which do not ordinarily host these species. We expected conifer stands to have higher non-vascular species richness than broadleaf and mixedwood stands since they are better adapted to conifer stands (*Chen 2018*). Since the results dispute this we believe the reasoning is because either most non-vascular species have not established due to stand age (*Kumar 2018*) or that the naturally low understory richness of conifer stands has lead all composition types to have a similar amount of non-vascular species present (*Chavez 2012*).

We hoped that at least the water reduction treatment might be significantly different like with (*Luo et al. 2013*; *Vicente-Serrano et al. 2013*), however this was not the case. We believe that this is due to the amount of time the project has been in operation. Where most studies on water treatment simulate conditions on a minimum 50-year scale (*Allen et al. 2010; Gauthier et al. 2015*; *Price et al. 2013*), this experiment has only taken place over the course of one growing season. This is not enough time for the water treatments to have a significant impact on the understory plant species, thus there naturally is no significant difference. The perMANOVA results easily show that there was no effect of treatment on understory species composition, as the treatments have no correlations in the figure (Figure 9) but overstory composition did have a significant effect on understory species composition. We found that broadleaved stands had a different species composition than conifers stands whereas mixed wood stands have understory species common to broadleaved and conifers stands, as expected (*Chen 2018*). If the water treatment tests were to occur for the next 50 years, we can hope to expect results similar to (*Allen et al. 2010*; *Luo et al. 2013; Price et al. 2013; Thrippleton 2017*; *Vicente-Serrano et al. 2013*).

We hypothesized that there would be a higher cover of vascular plants in the broadleaved stand because broadleaf stands have higher light availability and nutrients, which create conditions favourable for various herbs and shrub species (*Chen 2017*), which was confirmed. We also expected the opposite for non-vascular plants and that non-vascular plants have higher abundance and richness in the conifer stands because of their preference for the low light, lower temperature and higher humidity that conifer stands offer (*Chavez 2012*) this turned out to be false. This is due to the even stand age and the understory species composition being made up primarily of colonizer species. We also expect that there will not be a significant difference with water treatment, due to boreal understory species being unable to tolerate drought conditions (*Luo et al. 2013*), and vegetative activity being inhibited by lower water availability (*Vicente-Serrano et al. 2013*) over a longer period of time than one growing season, in order to take effect. This was also the case, as the water treatment was not significant. With these results, we believe that we can accept our hypothesis, as the broadleaf overstory had the highest total and vascular abundance and richness among the compositions, the water treatments were not significantly different, and the non-vascular understory results are explained by stand age and the natural low richness and abundance of conifer stands.

CONCLUSION

It is unfortunate that we could not find a significant difference due to water treatment, but that was to be expected. The test had only just begun in the 2017 growing season, and the plants did not have enough time in order to be affected by the different water treatments. We did however confirm that the broadleaf overstory had the most amounts of abundance and richness, across the board, which agrees with (*Chen 2017*; *Chavez 2012*; *Chen 2018*). However, we also learned that non-vascular abundance was also the highest in the broadleaf overstory, and non-vascular richness was not affected by overstory composition. We postulate that this is due mainly to stand age, which would agree with (*Kumar 2018*) or that the naturally low understory richness of conifer stands has led to all composition types to have a similar amount of non-vascular species present (*Chavez 2012*). The stands that were sampled are the same age, where the compositions can be generalized to early, middle, and late stage succession, as broadleaf, mixedwood, and conifer respectively. Since they are all at the early age of succession, the understory species that would be present in the conifer understory have not been established yet, as they have not had the time they require to establish. Compound that with the fact that broadleaf stands have more light and more nutrient rich leaf litter (*Chen 2017*) it is clear why the broadleaf overstory have significantly more species abundance and richness than the conifer overstory.

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