The effects of Garlon application to remove buckthorn (*Rhamnus cathartica*) on soil quality and macroinvertebrate diversity

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Abstract

The presence of buckthorn (*Rhamnus cathartica*) and the application of Garlon herbicide can have adverse effects on ecosystem health. In order to understand how Garlon application affects soil quality, soil samples were collected from plots with Garlon application and without Garlon application. The percentage of moisture, percentage of organic matter, and bulk density were calculated for these samples and two-way analysis of variance tests were run for all three soil quality variables. Macroinvertebrate diversity was also measured at these same plots by identifying and quantifying macroinvertebrates, calculating Shannon and Simpson diversity indices, and running pairwise comparisons between the Simpson indices. The results showed that soil moisture and soil bulk density were only significantly different between sites, while organic matter was not significantly different between sites or between the plots with or without Garlon. There were no significant differences between sites or plots in macroinvertebrate diversity. These results suggest that Garlon can be used in buckthorn management in the concentration and amount that it was used in this study without having any significant effects on soil quality or macroinvertebrate diversity.

Key Words: buckthorn management, Garlon, soil moisture, soil organic matter, soil bulk density, terrestrial macroinvertebrate diversity, chemical dissipation, herbicide application, management of invasive species

Introduction

Common buckthorn (*Rhamnus cathartica*) is a large shrub or small tree that is non-native in North America and can have detrimental effects on forest ecosystems. These effects include outcompeting and inhibiting the growth of native plants, changing habitat and food sources for animals, altering soil N, and reducing leaf litter (Knight et al. 2007). Buckthorn's potential to inhibit plants is enhanced by its ability to chemically attack other plants, and these chemicals are most effective where buckthorn is non-native (Warren et al. 2017). Buckthorn can also reduce the potential of a forest to store carbon. This is because buckthorn never grows much larger than a small tree, so it is preventing other tree species that would grow larger and store more carbon from growing (Mascaro and Schnitzer 2011).

Buckthorn can also change soil quality and macroinvertebrate abundance. The presence of buckthorn has been shown to cause an increase in the percentage of N (Heneghan et al. 2006) and an increase in the percentage of C, pH, and moisture in the soil (Heneghan et al. 2004). Areas with buckthorn have also been found to have a greater number of Psocidae (barklice) present when compared to areas with native trees (Hansen 2006). In addition to this, oribatida (mites) were more common in the buckthorn plots compared to plots with native trees (Hansen 2006).

Awareness of how the presence of buckthorn alters native ecosystems has led to efforts to remove buckthorn. This has been challenging because buckthorn is very dominant in many ecosystems and can be highly resistant to removal efforts. This ability to dominate comes from buckthorn's ability to thrive in many different habitats (Kurylo et al. 2007). This is enabled by buckthorn's potential to build resistance to chemical inhibitors from other plants (Callaway et al. 2005), and its tolerance of flooding, a wide range of soil moistures (Kurylo et al. 2015), and harsh winters (Stewart et al. 2006).

Due to these persistent characteristics of buckthorn, eliminating or significantly reducing buckthorn populations can be challenging. Three of the main methods that are used to reduce buckthorn are physical removal of the plant and its belowground biomass (by hand pulling, weed wrench, or brush saw), cutting the plant and applying herbicide, and herbicide application on the stem without cutting (Roth 2015). All of these approaches to buckthorn removal were found to be similarly effective, but they would probably not be as effective in most management situations when there is less potential for controlled and skilled work (Roth 2015). This suggests that herbicide application can be a useful tool in buckthorn management and is commonly used for this purpose.

One herbicide that is commonly applied to buckthorn and other forest vegetation is Garlon, which contains 3, 5, 6 trichloro-2-pyridinyloxy-acetic acid, with triclopyr as its active chemical ingredient (El-Khodary et al. 1998). The two main types of Garlon herbicide are Garlon-3 and Garlon-4. Garlon-3 has a lower concentration of triclopyr compared to Garlon-4, and Garlon-3 contains butoxyethyl ester while Garlon-4 contains triethylamine salt (Forestry Distributing 2021). Garlon-4 has been effective at substantially reducing buckthorn seed production (Delanoy and Archibold 2007). Garlon-3 has been similarly effective at removing buckthorn, especially when applied multiple times and in combination with other removal strategies (Bisikwa et al. 2020).

Despite these benefits of using Garlon in buckthorn management, these herbicides can have negative impacts on other organisms in the ecosystem. Garlon herbicides can leak into aquatic environments where they are toxic to fish (Guilherme et al. 2013), duckweed, and freshwater green algae (Tajnaiova et al. 2020). Garlon can also be ingested by browsing wildlife when these animals consume vegetation that was sprayed with Garlon. This method of Garlon ingestion has been found to reach a level of risk for chronic toxicity that is unacceptable for long-term browsing moose (Voinorosky and Stewart 2020). Garlon ingestion by small mammals through browsing can also result in chronic health issues for these small mammals (Voinorosky 2020).

Soil quality and macroinvertebrate health have also been shown to be affected by Garlon. One example of this is that areas that were treated with Garlon showed reduced enzymatic activity in soil (Tajnaiova et al. 2020). Garlon application has also been shown to significantly increase earthworm mortality rates (Durkin 2011). This suggests that application of Garlon can have adverse ecological effects on both soil quality and macroinvertebrate health, so these impacts must be considered when deciding to use Garlon as an herbicide to manage buckthorn.

These buckthorn management considerations are relevant to Minnesota ecosystems because buckthorn is dominant in many locations in Minnesota where it contributes to regeneration failure of native trees and vegetation (Wyckoff et al. 2005). This significant and problematic buckthorn presence in Minnesota has led to substantial buckthorn management efforts, including the use of herbicides to reduce buckthorn populations (Moriarty 2005). One of the herbicides that has been used to manage buckthorn in the St. Olaf College Natural Lands in southeastern Minnesota is Garlon 3 herbicide. Studying the effects of this herbicide in this location will lead to a better understanding of how Minnesota ecosystems react to Garlon. This information can be used to weigh the benefits of buckthorn removal with the potential adverse effects of Garlon application.

Understanding the effects of Garlon on soil quality and macroinvertebrates is important because these effects must be considered when making buckthorn management decisions. In order to gain a better understanding of these relationships, the soil quality and macroinvertebrate diversity will be compared between plots where Garlon is present and absent. One hypothesis is that there will be significant differences in the soil quality (percentage of moisture, percentage of organic matter, and bulk density) between paired plots that differ in application/no application of Garlon. Another hypothesis is that there will be significant differences between the diversity of macroinvertebrates in the paired plots that differ in application/no application of Garlon. A third hypothesis is that there will be significant differences between the soil quality or macroinvertebrate diversity between plots from the two site locations. Specific objectives to test these hypotheses were to: 1) compare the percentage of soil moisture, percentage of organic matter, and bulk density of soil samples from Garlon presence/absence plots, and 2) identify and quantify macroinvertebrates from Garlon presence/absence plots.

This study will inform buckthorn management practices by showing if there are adverse effects on soil quality or macroinvertebrates from using Garlon for buckthorn removal. In this way, the results of this study will help forest managers make holistic and informed decisions about buckthorn removal and how to effectively remove buckthorn without causing harm to the ecosystem.

Methods

Site Description

I studied two sites in the St. Olaf College Natural Lands in southeastern Minnesota. The Forest Restoration Loop two site was at a latitude of 44°27’32’’N and a longitude of -93°11’27’’W with an elevation of 307m. This hardwood forest was planted in 2005. The plots at this site were located in small patches of this hardwood forest and surrounded by a small wetland. The second site is in Heath Creek at a latitude of 44°26’57’’N and a longitude of -93°11’22’’W and an elevation of 285m. This hardwood forest was not planted as part of St. Olaf College restoration efforts. The plots at this site were located in hardwood forests next to Heath Creek. Buckthorn management is similar at both of these sites. The primary approach to buckthorn removal is cutting the buckthorn down and treating the stump with Garlon 3 herbicide. This herbicide is applied at a concentration of 5 fluid ounces for every 4 gallons of water.

Data Collection

In order to study the relationship between Garlon and soil quality, I sampled soil at four sites in Heath Creek and four sites at the Loop site (Figure 1). For each site, these plots were divided into two sets of paired plots. For each paired plot, one of the plots had buckthorn stumps that had been treated with Garlon 3 about six months ago, while in the other plot Garlon 3 had not been applied and buckthorn was present. I used a soil corer to collect three soil samples at each plot for a total of 24 soil samples.

I analyzed the percentage of moisture, soil bulk density, and percentage of organic matter in these samples. I measured the percentage of moisture by oven-drying the samples for 24 hours at 105°C and massing them to compare the masses before and after drying the samples. I determined the percentage of organic matter using the samples that were oven-dried for 24 hours at 105°C and sieving the soil. I then divided the samples into 4.5 - 9.0g samples and dried these samples in the oven at 105°C for 24 hours. After these samples cooled, I placed them in the muffle furnace at 500°C for 4 hours and massed them after they had cooled enough to be handled.

To quantify the biodiversity of macroinvertebrates, I established 25cm^2 plots in each of the plots where I sampled soil, leading to a total of 8 plots. I dug 12 inches deep in each of these plots and identified all macroinvertebrates to the level of the order.

Data Analysis

I calculated the percentage of moisture in the soil by dividing the weight of the fresh sample by the weight of the dry sample (Brower and vonEnde 1998). I calculated the percentage of organic matter by dividing the weight after drying the sample at 105°C, minus the weight after drying the sample at 500°C, by the weight after drying the sample at 105°C (Brower and vonEnde 1998). I determined the soil bulk density by dividing the dry weight of the soil by the volume of the sample, which was calculated from the dimensions of the soil corer.

I used version 3.3.1 of RCommander to perform two-way ANOVA tests between the two explanatory variables of site location and Garlon presence/absence with a response variable of either soil moisture, bulk density, or organic matter. For macroinvertebrate data analysis, I calculated the Shannon and Simpson diversity indices for four groups: the Heath Creek location with and without Garlon application, and the Loop location with and without Garlon application. I also ran Simpson pairwise comparison tests between these groups.

Results

Soil Results

For the percentage of moisture in the soil, significant differences were only found between Heath Creek plots and Loop plots ($p < 0.01$, Table 1). The mean percentage of moisture in the soil was significantly higher in the Loop site compared to Heath Creek. There were no significant differences in soil moisture between plots with and without Garlon (Table 1). For the bulk density of the soil, significant differences were found between Heath Creek and Loop plots ($p < 0.01$, Table 1). The bulk density was higher at Heath Creek plots than in the Loop plots (Table 1). There were no significant differences in bulk density between plots with and without Garlon (Table 1). For the percentage of organic matter in the soil, there were no significant differences between site or presence/absence of Garlon (Table 1).

Macroinvertebrate Results

A total of 56 macroinvertebrates from six different taxon orders were found between all plots (Table 2). The species richness value, Shannon index, and Simpson index were greatest for the Loop plots without Garlon, and second greatest for the Heath Creek plots without Garlon (Table 3). No significant differences were found between Simpson index comparisons between plots comparing sites and presence/absence of Garlon (Table 3).

Discussion

Soil Moisture

The differences between percentages of soil moisture between plots that varied in Garlon presence/absence were not significant (Table 1). This can be explained by how the concentration of Garlon that was applied to the soil was probably very low. This seems probable considering a study by Jimmo et al. (2018) that found that chemical residue from Garlon application was present in soils as long as 365 days after the Garlon application, but after only 30 days this presence was not high enough to significantly impact the soil quality. This suggests that the rapid dissipation of Garlon concentration in soil prevented Garlon application from significantly altering the soil moisture when it was measured six months after Garlon application. This result has positive implications as it suggests that Garlon can continue to be used to kill buckthorn in the St. Olaf Natural Lands without significantly altering soil moisture.

The percentages of soil moisture were significantly different between Heath Creek plots and Loop plots with the percentage of moisture higher in the Loop site (p-value < 0.01, Table 1). This could be explained by differences in elevation between the sites. This is because all of the plots in both of the sites are near a water source (a wetland in the Loop site and a creek in the Heath Creek site), but in Heath Creek the plots are uphill from the creek while in the Loop site the plots are at about the same elevation as the wetland. Based on this information, it is probable that water from the wetland travels to the soil in the plots at the Loop site and this increases the percentage of moisture in that soil. But water from the creek cannot travel uphill to the soil in the plots at Heath Creek, so the percentage of moisture is lower in those plots. This reasoning is supported by a study that found that differences between forest soil plots in characteristics such as slope could account for a lot of variation in soil moisture (Baldrian et al. 2010). This suggests that the significant differences in soil moisture in the present study can be explained by variations of slope in relation to water sources between the sites.

The significant difference in soil moisture between sites is important to understand because this site variation could alter buckthorn growth, making this information applicable to buckthorn management.

This is because soil moisture has been found to be positively correlated with buckthorn growth (Knight et al. 2007). Soil moisture has also been shown to support buckthorn seed germination when moisture levels are high but not too high (Knight et al. 2007). This means that buckthorn has a greater potential to thrive at the Loop site due to the higher percentage of moisture at this site, so buckthorn management efforts could be focused more on this location considering that the buckthorn are more likely to thrive and become more dominant at this site. But these management prioritization decisions must also consider other aspects that influence buckthorn growth and variations in the ecological importance of buckthorn removal at different locations.

Another result from the soil moisture data is that all of the mean percentages of soil moisture are above 20% (Table 1) which means that they can all be considered to be healthy moisture levels that can support the growth of most plants (Helgerson and Miller 2008). This suggests that the buckthorn that was present in all of the plots (even though it had been cut in the plots that had Garlon) did not alter the soil moisture levels to be at an unhealthy level for plant success. But the percentages of soil moisture are in the lower range of healthy soil moisture, which could pose a challenge for forest restoration efforts, particularly in the Heath Creek site which had lower soil moisture. This could be a challenge because sugar maples (*Acer saccharum*) are an important tree species in southeastern Minnesota hardwood forests and these trees are most successful with soil moisture levels that are not too high or too low (Horsley et al. 2002). So the soil moisture levels found in both sites (but particularly in Heath Creek) might not provide the ideal soil conditions for sugar maple success.

Soil Bulk Density

None of the differences in bulk density between plots with and without Garlon were significant (Table 1). This is somewhat surprising considering that plots that were treated with herbicides containing triclopyr have been found to have substantially higher soil bulk density as long as five years after herbicide application (Yildiz et al. 2010). But the lack of significant differences in soil bulk density in plots with and without Garlon in the present study could be explained by differences in the amount of

Garlon that was applied. This is supported by the study that found that Garlon concentrations in soil dissipated rapidly (Jimmo et al. 2018), suggesting that the Garlon concentration in the present study could have dissipated quickly which could have prevented it from affecting soil bulk density. The different results between the present study and the Yildiz et al. (2010) study could also be explained by differences in other factors that affect bulk density, such as the amount of soil disruption that occured (USDA Bulk Density/Moisture/Aeration). Similarly to soil moisture, the lack of an effect of Garlon on soil density is a positive result as it suggests that Garlon can continue to be used in buckthorn management in the St. Olaf Natural Lands without significantly altering soil bulk density.

Another result is that the bulk densities are significantly different between Heath Creek and Loop plots with the bulk density higher at Heath Creek plots (p-value <0.01, Table 1). This is consistent with the significant differences in soil moisture between these sites because as bulk density increases the total pore volume decreases, which reduces the soil's ability to hold water (USDA Bulk Density/Moisture/Aeration). So considering that the soil moistures are significantly different between the sites it makes sense that the bulk density is also significantly different between the sites. Differences in soil type between the sites could also explain differences in soil bulk density because different soil types alter the density of the pore spaces which influences soil bulk density. The Heath Creek site had predominantly sandy soil, while the Loop site had predominantly silty soil based on observations of soil characteristics at the sites. This could lead to significant differences in bulk density because sand has smaller spaces between pores compared to silt and these small spaces lead to a high bulk density (USDA Bulk Density/Moisture/Aeration).

Another result from the soil bulk density data is that all of the bulk density values are relatively low. This is based on the general guideline that a moderately textured soil would have a bulk density of about 1.33 g/cm^3 (USDA Soil Quality Indicators) and the mean soil bulk densities in the present study ranged from 0.54 g/cm^3 - 0.67g/cm^3 (Table 1). Low bulk density is generally less concerning than soil compaction (high soil bulk density), but low bulk density can still be problematic if the soil is so loose that it has no ability to restrict water movement (USDA Soil Quality Indicators). This could alter root growth/success and the availability of plant nutrients (USDA Bulk Density/Moisture/Aeration). These factors can all determine or influence the success of many different plants in the ecosystem making soil bulk density an important indicator of how successful potential restoration or management efforts will be in altering plant composition. But since the soil bulk density was not significantly different between plots with Garlon and without Garlon, this variable is probably not the cause of the low bulk density, so Garlon application can not be attributed to this result. The fact that buckthorn was present in all of the plots that were sampled could however contribute to the low values of soil bulk density. This is because soil in areas with buckthorn have been found to have significantly lower bulk densities compared to soils where buckthorn is absent (Lauko et al. 2013). This pattern can be explained by how the areas with buckthorn had more leaf litter from the buckthorn which holds moisture in the soil and this corresponds to a decrease in soil bulk density. So removing buckthorn with Garlon application could actually lead to an increase in soil bulk density, and this could increase the quality of the soil.

Organic Matter

There were no significant differences in the percentage of organic matter between plots where Garlon was applied and plots where Garlon was not applied. A probable explanation for this lack of an effect by Garlon is that the Garlon dissipated in the soil, so its concentration was not high enough to alter organic matter. This dissipation of Garlon in soil has been seen before in a study by Jimmo et al. (2018) which suggests that it is a viable explanation for the lack of significant difference in organic matter between plots with and without Garlon application. This result is important because organic matter plays a key role in shaping ecosystem health and can be greatly modified by forest management practices (Freedman et al. 2011). So the lack of effect on organic matter by Garlon suggests that Garlon can continue to be applied without causing any significant changes to this important measurement of soil quality.

Another result is that there were no significant differences between sites for the percentage of organic matter in the soil (Table 1). This is surprising considering that there were significant differences between sites in both soil moisture and soil bulk density. These are both factors that are affected by organic matter which would suggest that organic matter would also be significantly different between the sites, but this is not what the results show. The percentage of organic matter is however greater in the Loop sites (but not significantly greater) compared to Heath Creek (Table 1). This makes sense because the Loop site has lower soil bulk density and a higher percentage of moisture, both of which are associated with a higher percentage of organic matter (USDA Bulk Density/Moisture/Aeration).

Overall, the percentages of organic matter in the soil in both sites and in plots with Garlon and without Garlon are high. This is based on the guideline that forest mineral soils typically have an organic matter percentage of 1-5% by weight (Osman 2013) and the range of mean percentages of organic matter was 9.43-11.43% in the present study (Table 1). This could be due to many different factors including the type and amount of roots, vegetation, microorganisms, and animals, and the amount of microbial decomposition, type of soil, climate, topography, and mineral composition (Osman 2013). Land management practices can also significantly alter organic matter as tillage leads to a loss of organic matter (USDA Soil Quality Indicators). So one factor that was probably contributing to the high organic matter levels was that none of the plots sampled appeared to have been subjected to tillage or significant disturbance.

Another factor that could be altering the organic matter in all of the plots is the presence of buckthorn. This is because buckthorn leaves have been shown to decompose faster than most other leaf litter which can lead to changes in soil organic matter (Heneghan et al. 2004). Another variable that could further complicate the relationship between organic matter and buckthorn presence is that earthworms increase buckthorn growth (Roth et al. 2015). This suggests that all of the plots sampled could have had high numbers of earthworms because all of the plots had buckthorn and buckthorn is more likely to be found where earthworm abundance is high (Roth et al. 2015). This could impact organic matter because earthworms can alter the quality of organic matter (Lavelle et al. 2010). But overall, the values for the percentages of organic matter are not of concern when considering the ability of the soil to support plant growth. Also, Garlon application is not significantly altering the soil organic matter, so there are no implications for Garlon application based on this soil quality variable.

Macroinvertebrates

There were no significant differences between macroinvertebrate diversity between plots with and without Garlon application (Table 3). This is somewhat surprising considering that Garlon application has been found to significantly influence earthworm health (Durkin 2011). This could however be explained by differences in the concentration of Garlon and length of time since Garlon application. This once again relates to the study by Jimmo et al. (2018) which showed that there was significant dissipation of Garlon in soil to levels that did not significantly impact macroinvertebrates. This suggests that Garlon can continue to be used to control buckthorn populations in the St. Olaf Natural Lands without significantly altering macroinvertebrate diversity.

There were also no significant differences between macroinvertebrate diversity between sites (Table 3). This is interesting because there were significant differences between both soil moisture and soil bulk density between sites (Table 1). So this suggests that significant differences in these soil quality variables do not affect macroinvertebrate diversity. This is interesting considering that soil moisture has been found to strongly influence macroinvertebrates (Sylvain 2013). But there are so many factors influencing macroinvertebrate health between the sites that it would not be accurate to claim that the differences in either soil moisture or soil bulk density are not significantly changing macroinvertebrate diversity. There are just many factors at play that have the potential to interact with each other in altering macroinvertebrate diversity.

Conclusion

Differences in percent soil moisture, soil bulk density, and percent organic matter were not found to be significant when comparing these soil quality measurements between plots with and without Garlon.

Differences in macroinvertebrate diversity between plots with and without Garlon were similarly not significant. This suggests that the current method of reducing buckthorn in the St. Olaf Natural Lands by applying Garlon to buckthorn stumps does not have any significant effects on soil moisture, bulk density, organic matter, or macroinvertebrate diversity. Differences in percent soil moisture and soil bulk density were significantly different between sites with the soil moisture higher in the Loop site and the bulk density lower in the Loop site. These differences are primarily attributed to variation in the elevation of the sites in relation to their nearest water source which affects soil moisture and therefore also affects soil bulk density. There were no significant differences between sites for organic matter or macroinvertebrate diversity.

The finding that Garlon application does not significantly alter soil quality and macroinvertebrate diversity is however somewhat limited in that these results only apply to situations in which the same amount, concentration, and type of Garlon is applied, and the length of time after application is at least six months. So the results of this study should be considered to be highly situational considering that changing factors of Garlon application could significantly alter its effect on the ecosystem. The results can instead be seen as evidence that six months after Garlon application there was no evidence that the Garlon significantly altered soil quality or macroinvertebrate diversity. This suggests that use of Garlon in the St. Olaf Natural Lands is having an overall positive effect on the ecosystem as it is reducing buckthorn populations with no adverse impacts. This proposes that Garlon is a safe herbicide to use in forest management as it can aid in reducing harmful plant populations to increase the health and resiliency of forest ecosystems.

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Table 1: A comparison of the mean percentage of soil moisture, soil bulk density, and percentage of soil organic matter between Heath Creek and the Loop site, and between plots with and without Garlon application. Standard deviations are shown in parentheses. No significant differences were found from a two-way ANOVA test between plots with and without Garlon for either percent moisture, bulk density, or percent organic matter. There were significant differences in the percentage of soil moisture between Heath Creek and the Loop site (p-value = 0.01083, df = 1,20 f-value = 7.8934). There were also significant differences in the soil bulk density between Heath Creek and the Loop site (p-value = 0.001454, df = 1,20 f-value = 13.7077). There were no significant differences between the percentage of organic matter between sites.

Site Description	**Percent Moisture**	**Bulk Density (g/cm^3)**	**Percent Organic Matter**
Heath Creek			
With Garlon	28.44 (3.65)	0.62 (0.67)	10.18 (5.78)
Without Garlon	21.23 (3.35)	0.67 (0.098)	9.43 (4.59)
Loop			
With Garlon	33.31 (10.11)	0.54 (0.048)	11.43 (1.67)
Without Garlon	32.20 (7.99)	0.57 (0.042)	10.89 (3.17)

Table 2: All macroinvertebrates found identified to the level of the taxon order. Macroinvertebrate counts are divided between plots in Heath Creek with Garlon, plots in Heath Creek without Garlon, plots at the Loop site with Garlon, and plots at the Loop site without Garlon.

Taxon Order	**Heath Creek with Garlon**	**Heath Creek without Garlon**	**Loop with Garlon**	**Loop without Garlon**
Isopoda	1	5		4
Haplotaxida	7	6	4	2
Araneae				1
Stylommatophor				1
Lepidoptera		1		1
Spirobolida	1	11	2	9
Total	9	23	6	18

Table 3: Richness, Shannon (H') and Simpson (Ds) diversity indices for macroinvertebrate counts divided between plots in Heath Creek with Garlon, plots in Heath Creek without Garlon, plots at the Loop site with Garlon, and plots at the Loop site without Garlon. No significant differences were found between sites or plots with and without Garlon from Simpson pairwise comparisons.

	Heath Creek with Garlon	**Heath Creek without Garlon**	**Loop with Garlon**	**Loop without Garlon**
Richness	3	4	2	6
Shannon (H')	0.30	0.51	0.28	0.61
Simpson (Ds)	0.42	0.68	0.53	0.72

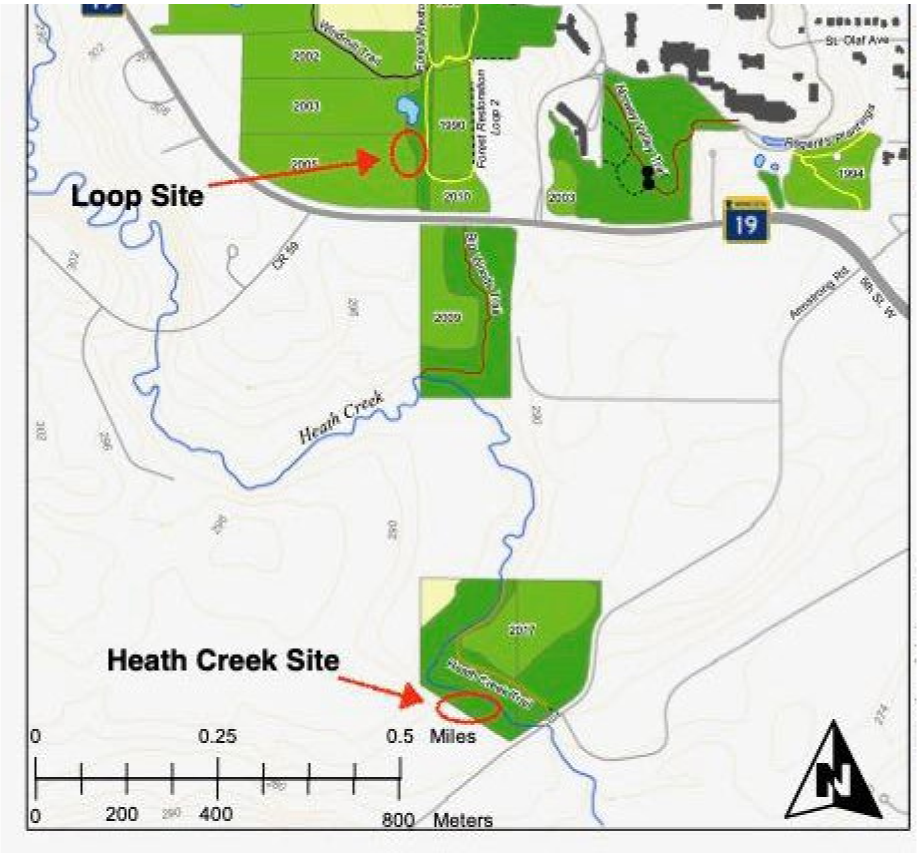

Figure 1: St. Olaf College Natural Lands map showing the Loop and Heath Creek sampling sites.