The natural revegetation of winter roads in the Hudson Bay Lowland

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Abstract

In 2006, the construction of Ontario's first diamond mine began in the Hudson Bay Lowlands, one of the largest wetlands in the world. Several winter roads were constructed across these subarctic peatlands to supply the mine. The purpose of this study was to determine if subarctic peatlands damaged by winter roads can naturally return to their pre-disturbance state. We compared five abandoned winter roads of various ages, at three sites each. At each site, we sampled a 19m transect across the winter road and another 19 m transect immediately adjacent to the road. We sampled the pH and conductivity of each site as well as the soil topography along each transect using a laser level and a meter stick. Along each transect we also investigated species diversity, species composition and percent cover of vascular plants, bryophytes and lichens by sampling 50cmx50cm quadrats every 1.5m along the transect. A multivariate analysis of variance showed a significantly lower percent cover of bryophytes and vascular plants on abandoned roads compared to undamaged sites. There was also a significantly lower average species diversity on winter road versus undamaged transects. An analysis of similarity revealed that there was a significant difference in the species composition between the road and undisturbed areas at three of the five abandoned roads. All other variable investigated showed no significant differences. Our results agree with similar studies of natural revegetation in mined peatlands in the Low Boreal region that have showed that natural revegetation is very successful on block-cut peatlands, which have a much higher degree of disturbance than the winter roads we are investigating.

Acknowledgements

I would like to thank my thesis advisor, Dr. Daniel Campbell for his support and guidance during the planning and execution of my fieldwork. I would also like to thank him for the help he provided, particularly with data analysis, while writing my thesis. I would like to thank Angie Charbonneau, who was a great help during my field work and collection of data. Thanks to the De Beers Victor Mine staff who provided transportation, lodging and food, a work space and lab supplies and who always answered any question I had. Finally, I would like to thank NSERC and NOSIM as well as Dr. Daniel Campbell for funding which allowed me to accomplish this project.

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Introduction

Peatlands are a type of wetland where large amounts of water are stored and retained by an accumulation of partially decayed organic material, also known as peat (Smith and Smith 2001). There are two main types of peatlands: ombrotrophic peatlands and minerotrophic peatlands. Ombrotrophic peatlands are fed by precipitation only and as a result they tend to have less mineral cations and a lower pH (Sjors 1959, Sims *et al.* 1982). They are also known as bogs, and generally support a plant population of acidophilus vegetation (Sjors 1959). Minerotrophic peatlands, also known as fens, receive water from precipitation but also from mineral soils and consequently have less acidic condition and support a much more rich vegetation (Sjors 1959).

One of the most important variables in peatlands are their hydrological processes (Ingram 1987). It is the waterlogged situation, which causes anoxia, coupled with cool temperatures, that initiates the accumulation of peat deposits (Gorham 1991). In ombrotrophic peatlands, the accumulated peat deposits consist mainly of *Sphagnum* moss species, which build up over long periods of time (Roberts et al. 1999). Under acidic waterlogged conditions, such as those in bogs, *Sphagnum* growth occurs more quickly than decomposition with an approximate mean accumulation of 0.5mm per year (Robert et al. 1999). Sphagnum species also stimulate peatland development by decreasing the pH and maintaining a high water table (Chirino et al. 2006). Although peatlands are perceived as flat landscapes, they are made up of an undulating micro-topography consisting of hummocks and hollows resulting from the different rates of accumulation of various *Sphagnum* species (Sjors 1959; Gorham 1991).

Peatlands have played an important role in human culture and society for a very long time. They have been used by humans for activities such as food acquisition through the hunting of bog animals and the gathering of wild berries as well as plants for medicinal use (Rochefort 2000). Peatlands also act as buffers against flooding, and as filters against impurities, improving groundwater quality (Rochefort 2000). Additionally, dried out peat from peatlands has been used for soil modification, in gardening, and as fuel for centuries. One of the most important global functions of peatlands is its role in the regulation of atmospheric gases, acting as both a source and a sink for compounds such as CO_2 and methane (Rochefort 2000).

Peat is also mined at large-scales mostly for horticultural use. Since 1989, peat has also been mined and developed into absorbent hygienic products by pharmaceutical companies (Robert et al. 1999). Industrial scale peat mining has often leadto severe and irreversible changes to the peatland ecosystem (Girard et al. 2002).

Other anthropogenic activities that threaten the ecological integrity of peatlands are hydroelectric power developments for water export and the extraction of mineral resources, such as logging and mining. More specifically, some of the most large-scale disturbances caused by these activities are the linear disturbances resulting from oil and gas pipelines, power line and access roads. These types of disturbances are gradually increasing in wetlands across the world, particularly in the vast wetlands of North America.

The Hudson Bay Lowland is the world's third largest wetland and is located south of Hudson Bay and west and south of James Bay in Northern Canada (Abraham and Keddy 2005). This area is characterized by boreal climate consisting of short, cool summers and long, cold winters (Abraham and Keddy 2005). Consequently, it has both continuous and discontinuous permafrost. The Hudson Bay Lowland plays an important hydrological role, supplying water to a dozen major rivers and hundreds of minor rivers. With regards to vegetation, these peatlands support at least 816 known different species of vascular plants and at least 98 species of non-vascular plants (Riley 2003, Abraham and Keddy 2005). Due to its northern distribution, these lowlands have remained in more or less pristine condition with very little industrial activity occurring. This is made obvious by the essentially roadless terrain spanning a distance of 373,700 km^2 (Abraham and Keddy 2005). Despite its relatively pristine condition, both natural disturbances, occurring prior to human appearance, and anthropogenic disturbance, as a result of human activities, threaten the ecological integrity of this vast wetland (Walker and Walker 1991).

The persistence of some anthropogenic disturbances have cumulative effects on peatland substrate and vegetation which often causes loss of biodiversity and a decrease in ecosystem function (Forbes and Jeffries 1999). This concurs with Bealands et al. (1986) who state that minor disturbances can accumulate over the long term and may be highly destructive. Potential effects of disturbances include loss of diversity and a decrease in reproductive success of biota (Forbes and Jeffries 1999). One particular type of disturbance, which when occurring persistently has the potential to cause severe damage to peatlands, is the construction and use of winter roads.

An example of disturbances by winter road activity is occurring as a result of the De Beers Victor Diamond mine, near Attawapiskat, Ontario. In February 2006, construction of this diamond mine was initiated, however this was preceded by advanced exploration activities to locate and assess the diamond-bearing ore body. This activity was supported by the construction of winter roads, which allowed for the transportation of equipment and supplies to the mine site during the winter months (De Beers Canada 2008).

Winter roads near the Victor Mine are constructed usually in mid December to mid January. Once 30-60 cm of snow is on the peatlands, the snow is packed using snowmobiles to reduce the insulation of the snow and allow deep freezing of the peat. When 15 to 25 cm of frost is in the peat, a light, wide-track bulldozer is used to pack the snow further and to drag heavy tires or steel drags back and forth at slow speed. Larger trees are cut by hand or 'shear-bladed' at ground level with a sharp bladed bulldozer or snow-cat after the peat freezes, leaving the tree roots intact in the ground. As the frost depth increases enough to support rubber-tired equipment, a road grader is used to further smooth the surface and either scrape off excess snow to improve frost penetration, or pull snow in from the sides of the road to increase the thickness of the packed snow. Once the road is solid and smooth, trucks water the surface to saturate the snow and thereby create a 10 to 15 cm load-bearing ice cap on top of the packed snow. This ice cap does not extend to the peat surface, which otherwise would allow sunlight to penetrate and melt the road from the bottom up. The use of winter roads often results in repeated disturbances to underlying vegetation as well as surface organic matter. Some of the effects of winter roads and use by vehicles include the crushing and shearing of surface vegetation, which involves the stripping of leaves, flowers and buds from the plants (Rickard and Brown 1974). Compaction of organic material at the surface may also occur in some instances (Rickard and Brown 1974). By removing the vegetation layer from the surface, areas of permafrost may experience thaw to greater depths and may also dry out, increasing the potential for erosion and preventing the establishment of seedlings (Kevan et al. 1995, Bérubé and Lavoie 2000). This occurs due to the increased transfer of heat into the deeper soil layers, resulting from compaction of surface layers (Rickard and Brown 1974). Another effect of winter roads on the surrounding biota, is the noise generated by passing vehicles. Traffic disturbances, as well as visual disturbance and pollutants are believed to cause avoidance of certain species (Forman and Alexander 1993). With respect to the physical effects of winter roads on vegetation and substrate, spontaneous revegetation would allow these systems to return to a more natural state.

Revegetation of disturbed peatlands is helpful in that it prevents erosion by stabilizing the surface peat layers. However, many areas damaged by winter roads are left to naturally regenerate, due to challenges in accessing these linear disturbances during the growing season. This natural revegetation may be a slow process, particularly in high latitudinal areas (Rickard and Brown 1974). Studies on the natural revegetation of peatlands damaged by winter road or off-road vehicle activity are often contradictory. York *et al* (1997) studied vehicle trails that had been abandoned for 20 years and found that, in bog type habitats, the effected areas appeared to be permanently altered compared to undisturbed areas. Similarly, a 25-year-old trail in Alaska's North Slope was found to be devoid of vegetation (Hok 1969). However, this same disturbed area was also found to have spontaneously revegetated along other areas of the trail. Studies on disturbance caused by manual peat mining, which is much worse than the damage caused by winter roads, also found that natural revegetation can quickly occur (Lavoie and Rochefort 1996). This contradicting data makes it difficult to predict whether natural revegetation will or will not occur under various circumstances.

The purpose of this study was to determine if it is possible for bog species to spontaneously recolonize abandoned winter roads used for the De Beers Victor Mine project in the Hudson Bay Lowland. In order to test this the topography, the percent cover of bryophytes, vascular plants and lichens, the species diversity and the species composition were compared between disturbed sites on winter roads and sites located in undisturbed areas immediately adjacent to winter roads. Additionally, a comparison was made between winter roads of various ages for all of these variables to determine if there was a difference over time.

I hypothesized that the topography of winter roads will be much less variable than that of undamaged areas. I also predicted that percent cover, species diversity and species composition will be lower on winter roads than in natural areas. With respect to winter road age, I predicted that we would see a difference in recently used roads compared to older abandoned road for all variables.

Materials and Methods

Study Site

The De Beers Victor Mine is located in the Hudson Bay Lowland at 52°48’N, 83°54’W. Surrounding the mine site are multiple abandoned and currently used winter roads, which are used to access the site during the winter. Data regarding topography, pH and conductivity, vegetation cover, species richness and species composition were collected from 5 of these winter roads over the period from June 20th, 2008 to July 20th, 2008. The winter roads were named, based on the small amount of historical information available for the road or the general location of the road. Table 1 describes the five winter roads, which are rated from what we believe to be the most recently damaged road, New road, to the winter road that has been abandoned the longest period of time, South road. The location of the sites can be seen from an aerial photo of the mine site taken in August 2007 (Figure 1). A map illustrating the exact location of each site can be seen in Figure 2 and GPS coordinates for each site can be found in Appendix A.

Table 1. Description of the use and abandonment of winter roads under study.

Winter Road	First use	Use
New	January 2007	Main winter road in winter 2007 and 2008, heavy traffic (several thousand loads incoming)
Esker	After 2006	Used in 2006 and 2007 for sand haul for construction perhaps 100 trucks per winter, some summer use by Argo ATV
One year	January 2006	One winter use only, heavy traffic
Old	Prior to 2003	Several winters for exploration drill rig access
South	As early as 2003	Used intermittently for drill access until 2005; minimal use

Figure 1: Aerial photograph identifying the five winter roads that were studied, where the yellow line indicated the actual location of the winter road.

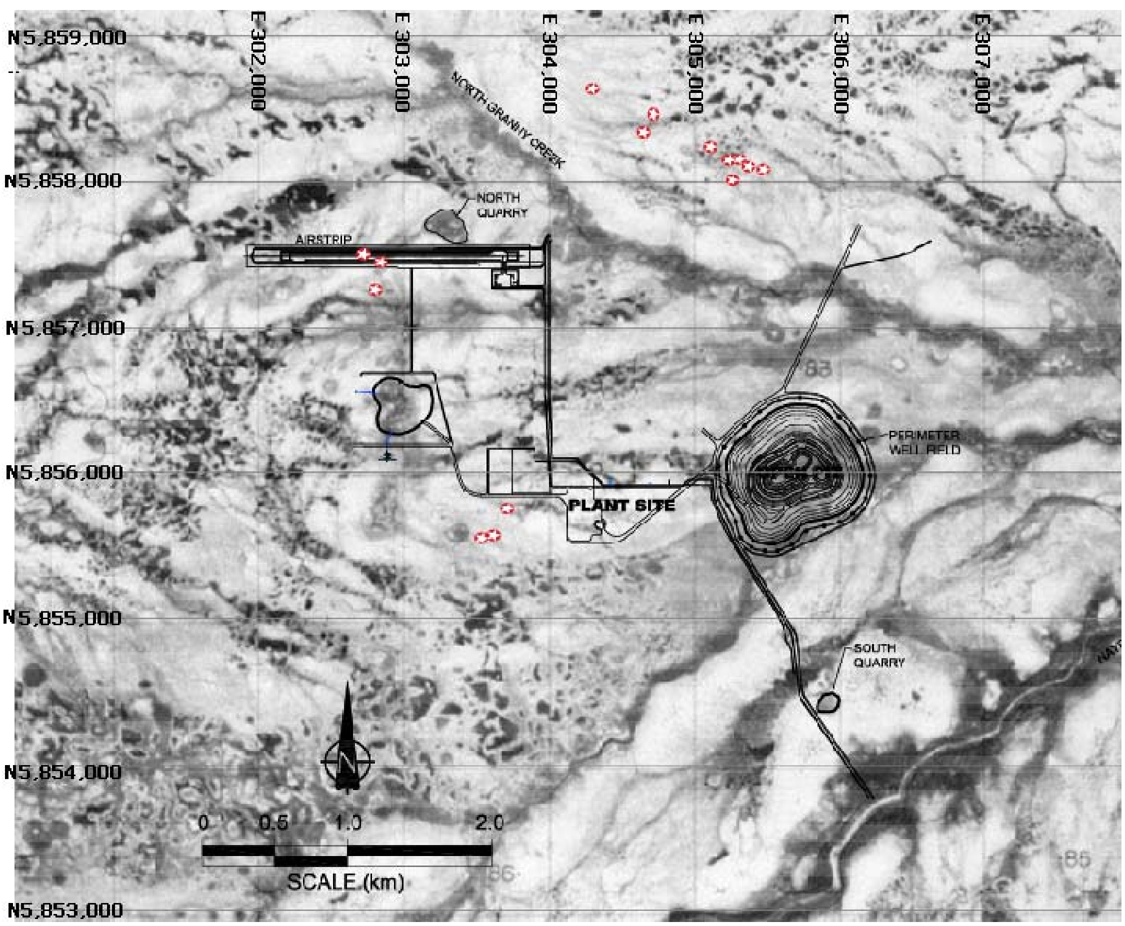

Figure 2. Base map of Victor mine site, prior to construction, with the coordinate location of each site indicated by red stars.

Data collected regarding the pH and conductivity for each site of each winter road indicate that a portion of South road had a high pH and high conductivity, which is indicative of minerotrophic peatlands, or fens. All the other roads had lower conductivity, indicating a lower amount of nutrient typical of ombrotrophic peatlands, or bogs. Some sites from the Esker road and South road had higher pH values, which suggest that these may be approaching a fen environment (Figure 3).

On each road, three sites were selected at random, with a total of 15 sites for this study. Each site consisted of two 19 m transects: one located across the width of the winter road and one located in an adjacent undamaged peatlands (Figure 4).

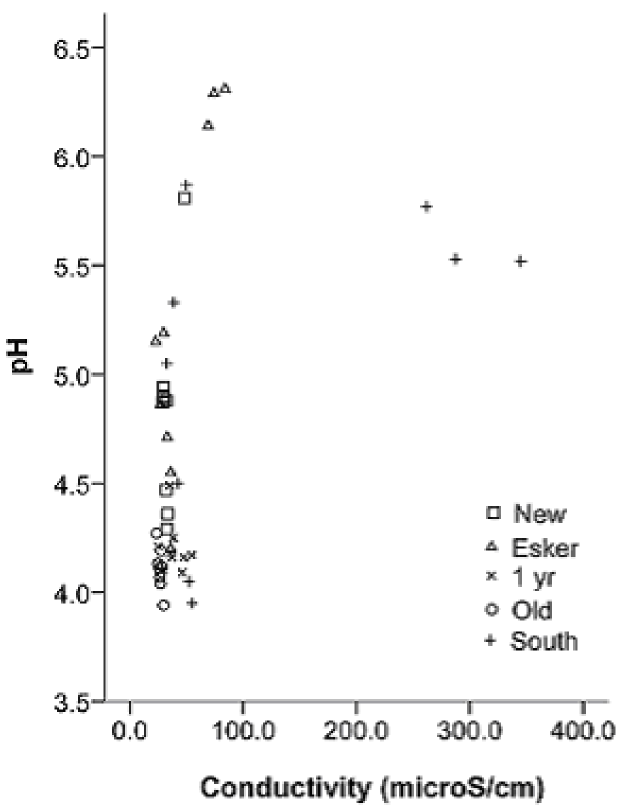

Figure 3. pH and conductivity values for each site of the five winter roads

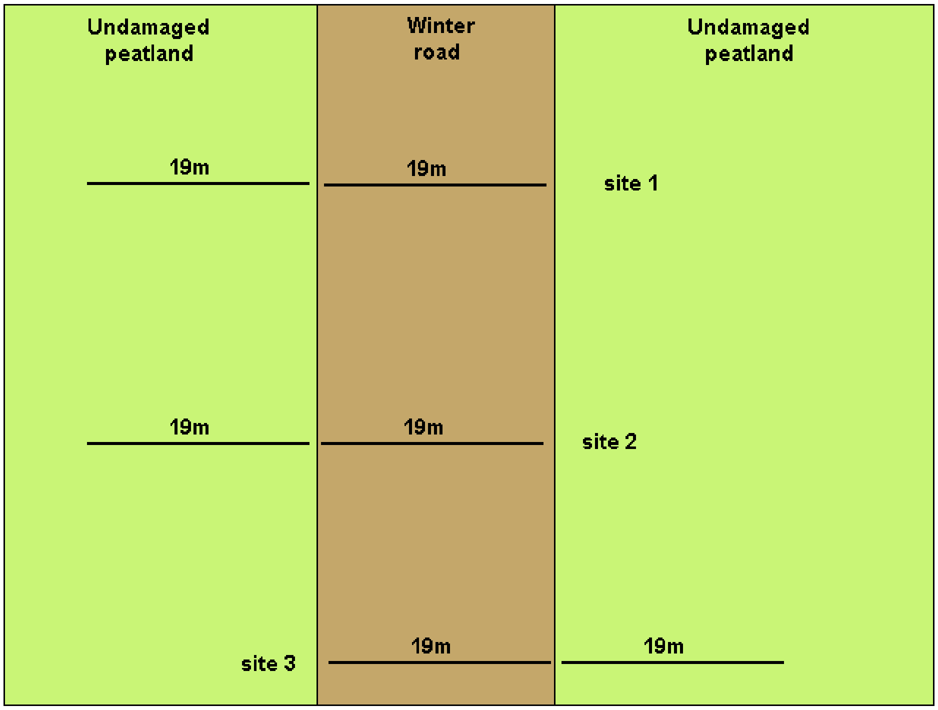

Figure 4. Experimental design of each winter road

Topography

Along each transect topography was sampled. This was done using a laser level attached to a tripod as well as a meter stick. The laser level was set up at the zero mark of the transect, and every 0.5 m, the height at which the laser struck the meter stick, in cm, was recorded. This was done on all 15 sites. Because the laser seldom reached a distance over 10m, I was required to move the laser. When this occurred, I would record the height of the laser on the meter stick before it was moved, and after it was moved, so that we could calibrate the data during analysis. At each site, one water table reading was also taken. This was done when I reached a hollow along the transect that was below the water table. In this instance, I would place the meter stick so that its bottom was touching the water surface, and the height at which the laser struck the meter stick was recorded. Then the meter stick was lowered until it hit the soil below the water, and again the height of the laser beam on the meter stick was recorded. If no water was visible along the entire transect, a hole was dug until the water table was reached, and the same measurements were taken. Since the water table is thought to be a fairly constant variable over a large area, we transformed our topography data so that it was relative to the water table, which had a value of zero. This allowed us to do comparative analysis of the topography among all sites.

pH and Conductivity

On each site, I collected three water samples along the transects. This information was used to characterize the sites and roads. No distinction was made from water samples collected on the winter road or off the winter because winter road damage is not likely to impact pH or conductivity. If there was no surface water along the transect, we dug a hole until we reached the water table and took our sample from there. In the lab, we analyzed the pH using an Accumet BASIC AB15 pH meter from Fisher Scientific, calibrated following standard laboratory practices. For the water conductivity, we used the Orion 4 star pH Conductivity Portable from Thermo Electron Corporation.

Vegetation survey

Vegetation surveys were conducted along each 19m transect to establish if there was a difference in cover, species diversity and species composition between winter roads and unaffected adjacent transects. A 50cm x 50cm quadrat was placed every 1.5m along each transect. In each quadrat, the percent cover of plant species grouped into bryophytes, vascular plants and lichens, was visually estimated. Also, for each quadrat, all plant species present within the quadrats were recorded. Any unknown plants were collected and identified in the lab at a later time.

Data Analysis

Topography

To interpret our topography data we wanted to make comparisons between roads, but mainly between transects on the winter roads and off the winter roads of all sites aggregated. In order to do this, we averaged all our topography values, which were relative to the water table, for each transect. With these mean values, we did a univariate ANOVA to determine if there was a significant difference in the average height of the topography above the water table between damaged winter roads and undamaged transects. We also did a univariate ANOVA for the standard deviation of the topography data to determine if the topography varied between transects on winter roads and off winter roads.

Percent Cover

To analyze our percent cover data, we used average values of each group (bryophyte, vascular plant, lichen) from each transect and conducted a MANOVA with the average cover of bryophytes, vascular plants and lichens as dependant variables and the road, site and area along the transect (on the winter road vs. off the winter road) as independent variables. We also analyzed bryophyte cover, vascular plant cover and lichen cover individually using a univariate ANOVA. An a priori decision was made to only include main effects and an interaction between the road and transect in our MANOVA and ANOVA models. Throughout the entire study, all ANOVA or MANOVA analyses were conducted using SPSS software version 15.0.1.

Species diversity

We used species richness and species evenness as measures of species diversity. Species richness is a measure of the number of different species in a specific area (Magurran 2006). Species evenness is a measure of the variability in species abundance, where a community with all species having approximately the same abundance is rated as very even (Magurran 2006). Species diversity takes into account both richness and evenness as a measure of diversity. To analyze species richness, we conducted a univariate ANOVA of the total number of species of all the quadrat along a transect as well as a second ANOVA for the mean number of species per quadrat for each transect. In order to measure species evenness, we determined the Simpson index ($1-\lambda' = \Sigma(N_i*(N_i-1)/N*(N/1))$) for each transect using SPSS and conducted a univariate ANOVA with this data.

<u>Species Composition</u>

Species composition was analyzed using the statistical program PRIMER version 6.1.11. All the species data was used, where all the species were the column headings and each row was a different quadrat. With this data, a similarity matrix was first produced using the Bray-Curtis similarity measure. Next, we used the similarity matrix to conduct an analysis of similarity (ANOSIM) for all roads together and of each road individually. ANOSIM is a multivariate technique similar to MANOVA but used for species data when normality is not possible. It is based on Monte Carlo simulations. We then produced a non-metric multidimensional scaling (MDS) ordination diagram to compare the similarity between species composition for all quadrats of all roads together as well as all quadrat for each road individually. Outliers were removed from Old and New winter roads in order to better visualize the distribution of points amongst one another. Based on the ANOSIM, roads that had statistically significant results were further analyzed to determine which species accounted for most of the dissimilarity between the transects on and off winter roads. This was done in PRIMER using the SIMPER routine. This is also a Monte Carlo based technique.

Results

Topography

There was no significant difference in average topography between transects on winter roads versus off winter roads (Table 2). However, habitats on the winter road have a slightly higher, although non-significant, average height above the water table (Figure 5). There was also no significant difference for the standard deviation of the topography on versus off winter roads (Table 3). A bar graph of the standard deviation of topography shows that the variation in topography between transects on winter roads and in adjacent undamaged sites is very similar (Figure 6).

Table 2. Analysis of variance on the average height (cm) above the water table between winter roads and undisturbed transects adjacent to winter roads.

Source	d.f.	*F*	*P*
Road	4	0.474	0.755
Site	2	2.155	0.145
Transect	1	0.673	0.423
Road x Transect	4	0.829	0.524
Error	18		
Total	29		

Table 3. Analysis of variance on the average standard deviation (cm) of the topography between winter roads and undisturbed transects adjacent to winter roads.

Source	d.f.	*F*	*P*
Road	4	0.474	0.755
Site	2	2.155	0.145
Transect	1	0.673	0.423
Road x Transect	4	0.829	0.524
Error	18		
Total	29		

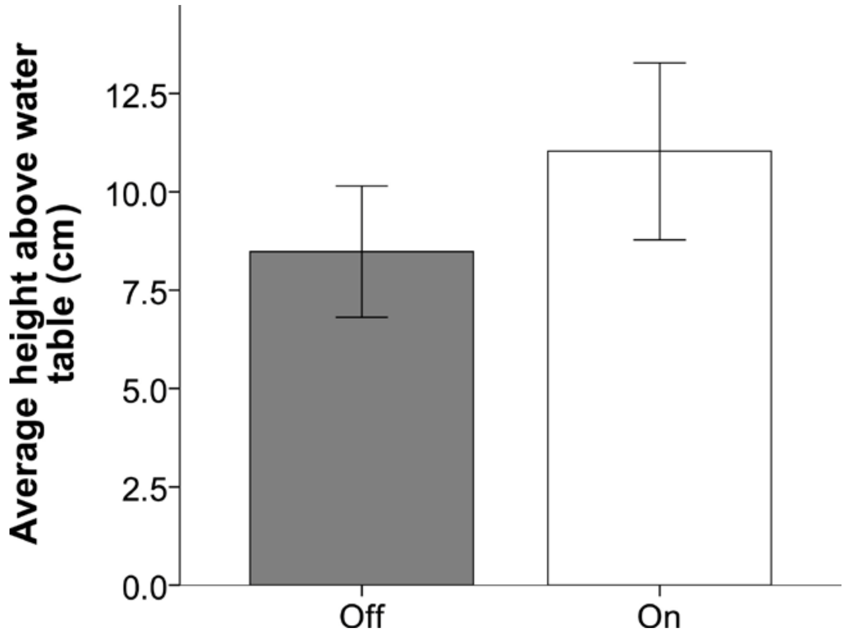

Figure 5. Mean height of the peat surface above the water table (+/- 1 S.E.) of transects located in undamaged areas (grey) and of transects directly on winter roads.

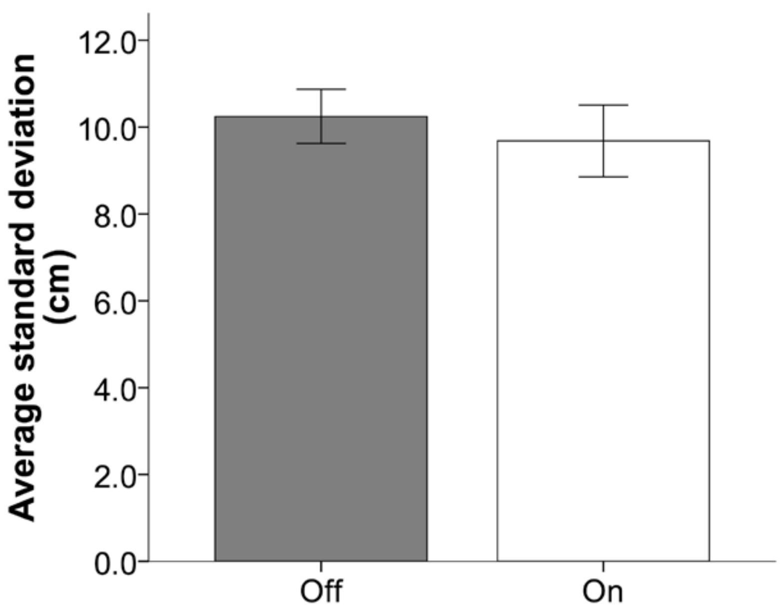

Figure 6. Standard deviation of topography (+/- 1 S.E.) along transects located in undamaged areas (grey) and of transects directly on winter roads.

Percent Cover

Cover data needed to be fourth square root transformed to achieve homogeneity of variances. The results of our MANOVA demonstrated there was a significant difference in percent cover between roads and between transects on winter roads versus off winter roads (Table 4). We also found that there was a significant interaction between the winter road and control sites and the roads (Table 4), which tells us that the cover differences did not occur on all the roads.

Table 4. Multivariate analysis of variance of the 4^{th} square root of percent cover for bryophytes, vascular plants and lichens, using Pillai's Trace statistic.

Source	d.f.	*F*	*P*
Road	4	4.053	0.000
Site	2	1.687	0.647
Transect	1	37.026	0.000
Road x Transect	4	1.660	0.620
Error	17		
Total	28		

By analyzing the individual ANOVAs for each plant group, we found that bryophyte cover showed significant differences between roads as well as between transects on and off winter roads, with transects on damaged winter roads having a lower percent cover than the undisturbed sites (Table 5, Figure 7). For vascular plants, we found that there was also a significantly higher percent cover in the undisturbed areas compared to the winter roads transect. There was also a significant difference between winter roads of different ages (Table 6, Figure 7). Additionally, we found a significant interaction between the roads and the transects for both bryophytes and vascular plants (Table 5 and 6). Both bryophyte and vascular plant cover on Old and South winter roads, which are believed to be the older winter roads, showed the least amount of variation when comparing values on the winter road and value in natural areas adjacent to the winter roads (Figure 8). For lichen cover, there was only significance when comparing the different winter roads (Table 7). Bar graphs of the average percent cover values for each cover group better illustrate the differences described above (Figure 7).

Table 5: Analysis of variance of the 4th square root of percent cover for bryophytes

Source	d.f.	*F*	*P*
Road	4	6.569	0.003
Site	2	1.228	0.202
Transect	1	18.803	0.005
Road x Transect	4	3.637	0.026
Error	17		
Total	28		

Table 6: Analysis of variance of the 4th square root of percent cover for vascular plants

Source	d.f.	*F*	*P*
Road	4	11.210	0.000
Site	2	0.053	0.931
Transect	1	22.474	0.000
Road x Transect	4	2.244	0.031
Error	17		
Total	28		

Table 7: Analysis of variance of the 4th square root of percent cover for lichens

Source	d.f.	*F*	*P*
Road	4	4.017	0.019
Site	2	2.188	0.858
Transect	1	2.168	0.423
Road x Transect	4	0.262	0.907
Error	17		
Total	28		

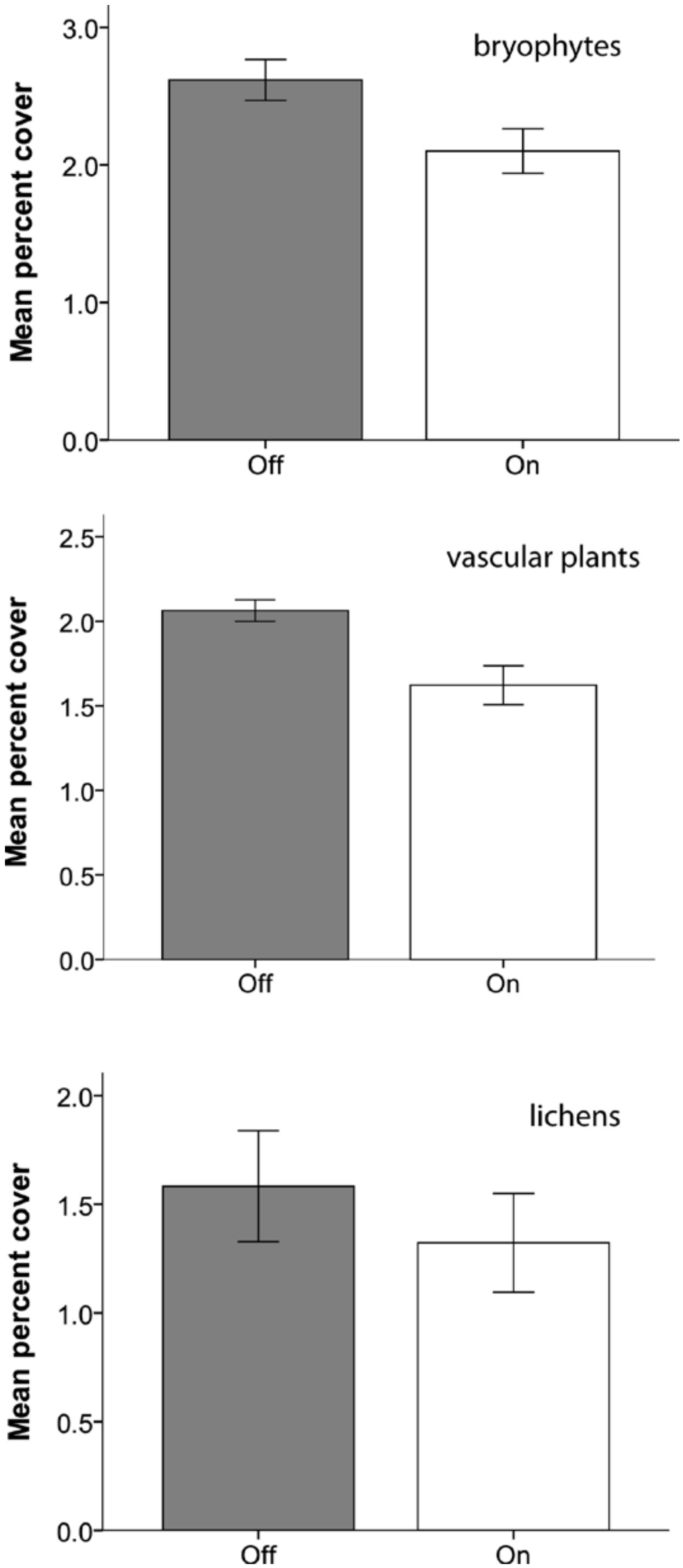

Figure 7. Mean bryophyte, vascular plant and lichen cover (4th square root +/- 1 S.E.) of transects located in undamaged areas (grey) and of transects directly on winter roads.

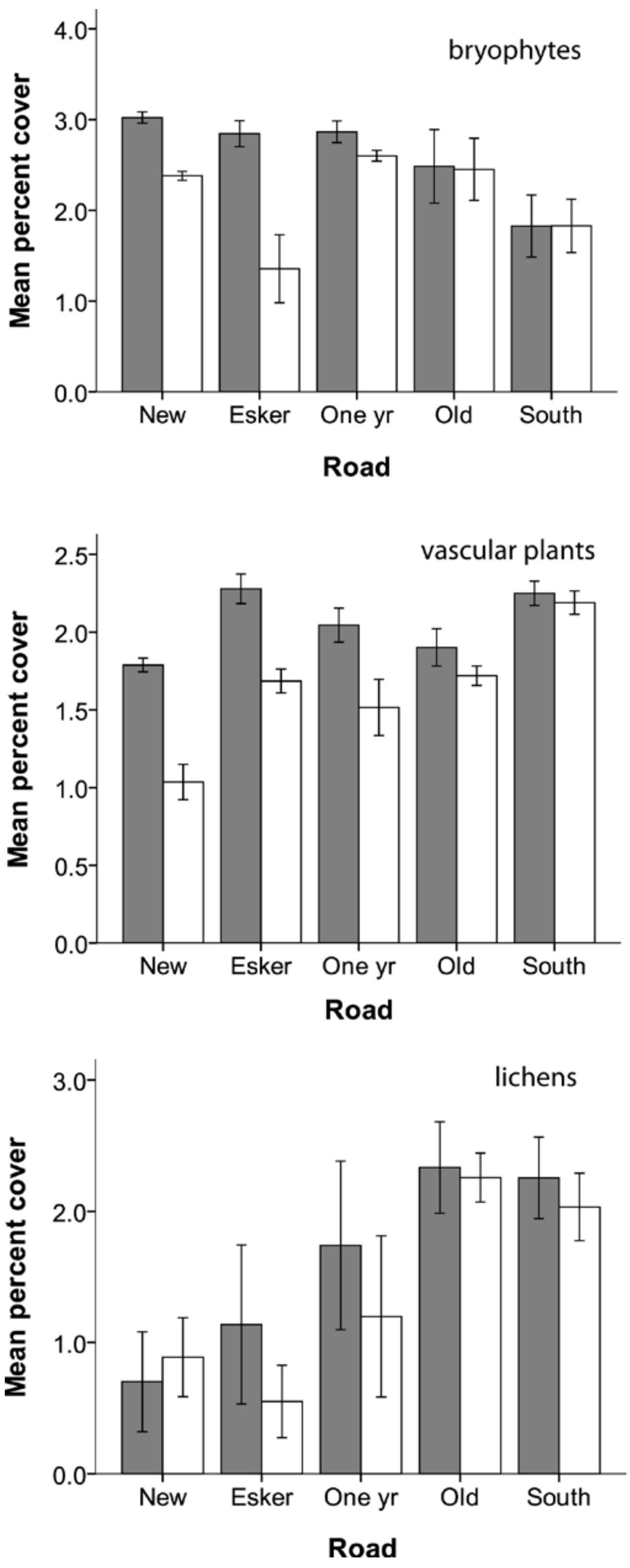

Figure 8. The mean percent cover (4th square root +/- 1 S.E.) of bryophyte, vascular plant and lichen cover of transects located in undamaged areas (grey) and of transects directly on winter roads.

Species diversity

There was a significant difference in average species richness between transects on versus off winter roads but there was no road or site differences and no interactions (Table 8). For total species richness (Table 9) and species evenness (Table 10) we found no significant difference between roads, sites and transects as well as no significant interaction between roads and transects. By comparing the bar graphs of average species richness (Figure 9), total species richness (Figure 10) and species evenness (Figure 11), we can clearly see that the greatest difference occurs when comparing average species richness of quadrats along winter roads transects and off winter roads.

Table 8. Analysis of variance of the average species richness per transect.

Source	d.f.	*F*	*P*
Road	4	3.758	0.022
Site	2	0.039	0.961
Transect	1	20.831	0.000
Road x Transect	4	1.964	0.143
Error	18		
Total	29		

Table 9. Analysis of variance of the total species richness per transect.

Source	d.f.	*F*	*P*
Road	4	0.472	0.756
Site	2	0.245	0.785
Transect	1	0.867	0.364
Road x Transect	4	0.736	0.580
Error	18		
Total	29		

Table 10: Analysis of variance of the species evenness (Simpson's evenness index) of winter roads and adjacent undamaged sites transects

Source	d.f.	*F*	*P*
Road	4	0.830	0.524
Site	2	0.124	0.884
Transect	1	1.438	0.246
Road x Transect	4	0.803	5.39
Error	18		
Total	29		

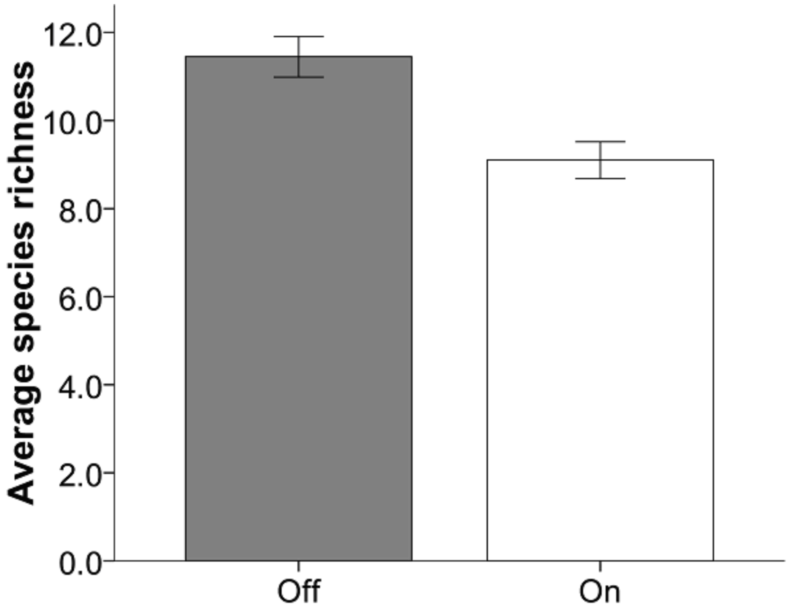

Figure 9. Average species richness (+/- 1 S.E.) of transects in undamaged areas (grey) versus transects on winter roads (white).

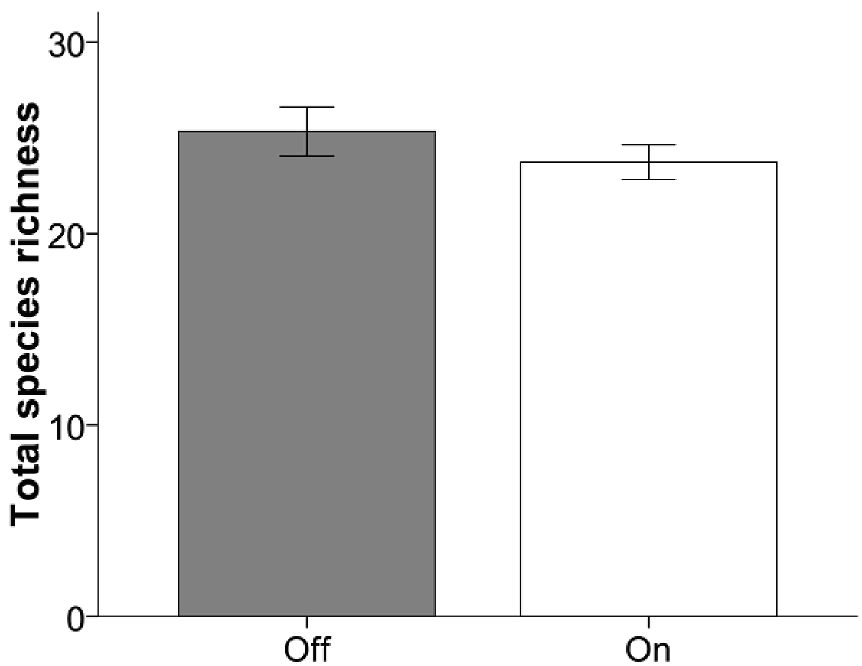

Figure 10. Total species richness (+/- 1 S.E.) of transects in undamaged peatlands (grey) versus transects on winter roads (white)

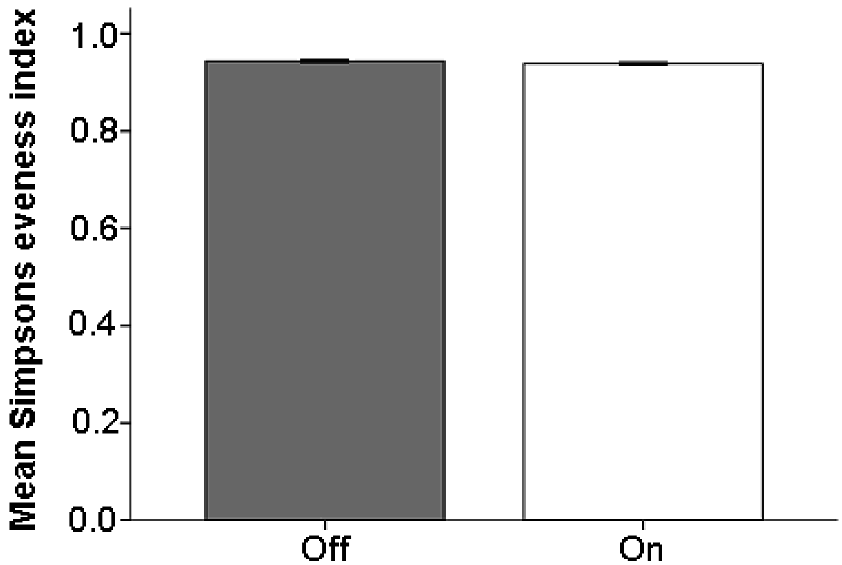

Figure 11. Species evenness (+/- 1 S.E.) of transects in undamaged peatlands (grey) versus transects on winter roads (white)

Species composition

An ANOSIM of all winter roads together, indicated that there was a significant difference in species composition between on and off transects (Table 11). The individual ANOSIMs, indicated that significant differences in species composition occurred between New road, Esker road and One year (Table 11).

By examining the non-metric MDS ordination diagrams of each road, we can see that there seems to be dissimilarity between on and off quadrats most obviously for New road and Esker roads, but also for One year road (Figure 12). This is evident by the spatial separation and distribution of species from quadrats on the winter roads (circles) and off the winter roads (squares). We did not include the non-metric multidimensional scaling plot of all the winter roads together because the large number of data points made it very uninformative.

Table 11: Individual analysis of similarity (ANOSIM) results for the species composition between transects on winter roads and adjacent undamaged transect of each winter road and of all the winter roads combined.

Road	*R*	*P*
New	0.221	0.00001
Esker	0.153	0.00001
1 year	0.234	0.00001
Old	0.011	0.18400
South	0.010	0.19200
All	0.0058	0.01

For New, Esker and One year roads, as well as all the winter roads together, we conducted an analysis to determine which species were contributing to 60% of the total dissimilarity between the damaged winter roads and the undamaged adjacent transects. In most cases, species of plants were found to be more prevalent off winter roads compared to on winter roads. For the analysis of all roads together, we found that the common sundew *(Drosera rotundifolia*) had the highest average dissimilarity of 3.03 between winter roads and undisturbed sites, accounting for

5.29% of the total dissimilarity. Other species, such as *Kalmia polifolia*, *Ledum groenlandium*, *Rubus chamaemorus*, *Sphagnum fuscum and Sphagnum angustifolium* also had dissimilarity values ranging from 2.77 to 2.95 and their contribution to the total dissimilarity of the treatments (on versus off) ranged from 4.84% to 4.96% (Table 12).

For the New road, Labrador tea (*Ledum groenlandicum*) had the highest dissimilarity value of 3.96 and accounted for 7.20% of all the dissimilarity (Table 13). Esker winter road had Black spruce (*Picea marinara*) as its most dissimilar species found on the winter road compared to off the winter road. Black spruce had an average dissimilarity of 2.77 accounting for 6.16% of the dissimilarity of this winter road (Table 14). Finally, the common sundew (*Drosera rotundifolia*) was the most dissimilar species on One-year winter road, with an average dissimilarity of 3.63, contributing to 6.25 % of the dissimilarity (Table 15)

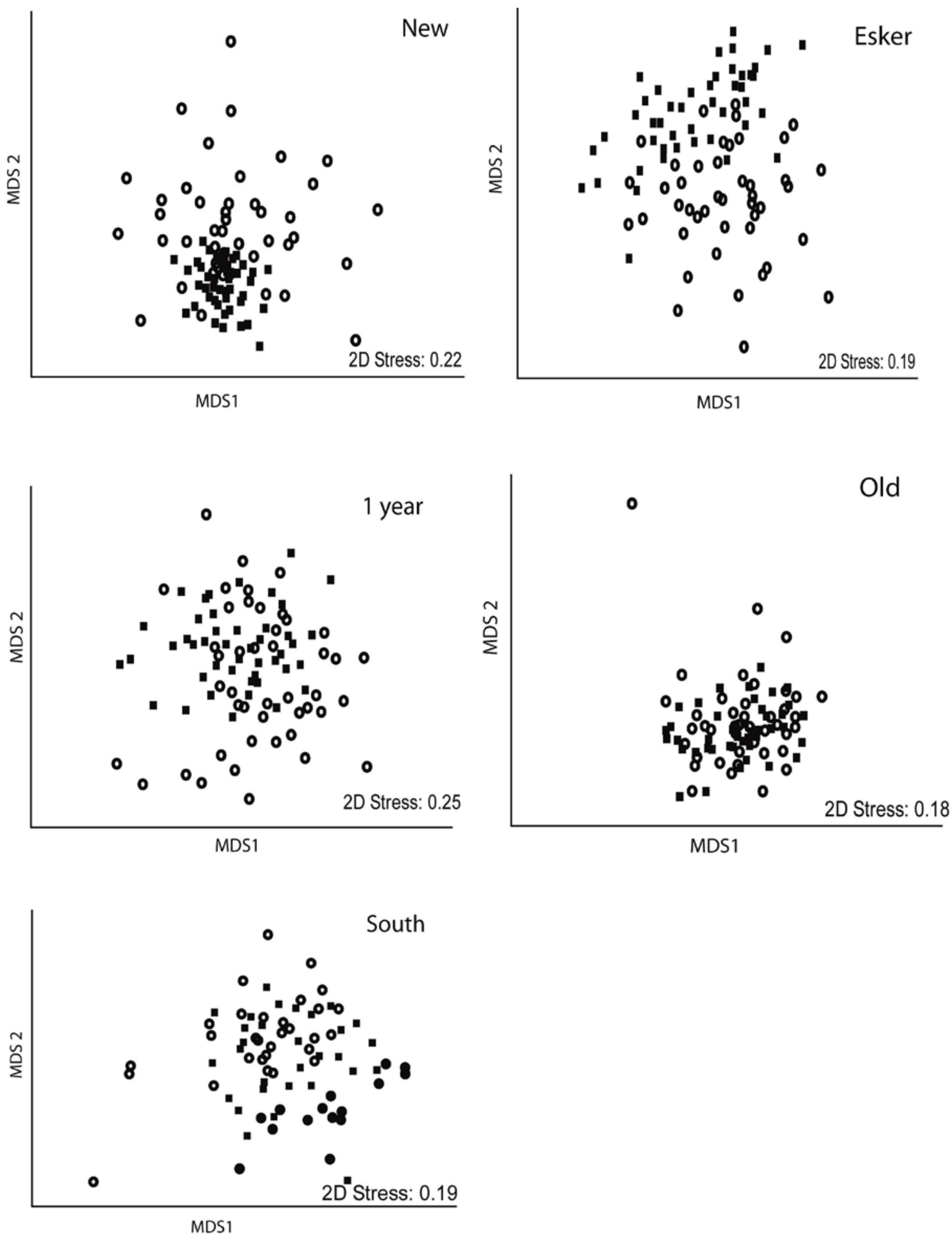

Figure 12. Non-metric multidimentional scaling ordination diagrams illustrating the species assemblages of each winter road, where black squares represent quadrats along undamaged transects and white circles represent quadrats along winter road transects.

Table 12: The average dissimilarities of species and their contribution to the total dissimilarity between sites of all winter roads and their adjacent undamaged sites (N=15).

Species	Average Abundance Undamaged	Average Abundance Winter road	Average Dissimilarity	Contribution (%)	Cumulative Contribution (%)
Drosera rotundifolia	0.59	0.27	3.03	5.29	5.29
Kalmia polifolia	0.67	0.47	2.95	5.16	10.46
Ledum groenlandium	0.61	0.46	2.94	5.14	15.60
Rubus chamaemorus	0.64	0.48	2.90	5.07	20.67
Sphagnum fuscum	0.73	0.57	2.77	4.85	25.52
Sphagnum agustifolium	0.49	0.40	2.77	4.84	30.36
Maianthemum canadensis	0.62	0.63	2.76	4.82	35.18
Mylia anomala	0.48	0.32	2.70	4.72	39.90
Picea mariana	0.46	0.18	2.68	4.68	44.58
Cladonia rangiferina	0.38	0.26	2.56	4.47	49.05
Cladonia Stellaris	0.34	0.28	2.50	4.37	53.42
Vaccinum oxycoccus	0.81	0.71	2.33	4.06	57.49
Dicranum scoparium	0.21	0.28	1.96	3.43	60.92
Total			57.20		

Table 13: The average dissimilarities of species and their contribution to the total dissimilarity between sites of the New winter road and their adjacent undamaged sites (N=3).

Species	Average Abundance Undamaged	Average Abundance Winter road	Average Dissimilarity	Contribution (%)	Cumulative Contribution (%)
Ledum groenlandium	0.71	0.09	3.96	7.20	7.20
Kalmia polifolia	0.80	0.36	3.57	6.50	13.70
Rubus chamaemorus	0.71	0.33	3.37	6.12	19.82
Drosera rotundifolia	0.62	0.16	3.35	6.08	25.90
Mylia anomala	0.53	0.24	2.97	5.39	31.30
Sphagnum angustifolium	0.71	0.60	2.77	5.03	36.33
Geocaulon lividum	0.40	0.27	2.60	4.73	41.06
Maianthemum canadensis	0.96	0.62	2.43	4.42	45.47
Picea mariana	0.40	0.11	2.41	4.38	49.86
Vaccinium oxycoccus	0.89	0.64	2.39	4.35	54.21
Chamaedaphne calyculata	0.93	0.69	2.23	4.05	58.25
Andromeda polifolia	0.07	0.09	1.82	3.31	61.56
Total			55.01		

Table 14: The average dissimilarities of species and their contribution to the total dissimilarity between sites of the Esker winter road and their adjacent undamaged sites (N=3).

Species	Average Abundance	Average Abundance	Average Dissimilarity	Contribution (%)	Cumulative Contribution (%)
	Undamaged	Winter road			
Picea mariana	0.60	0.00	2.77	6.16	6.16
Rubus chamaemorus	0.71	0.33	2.62	5.83	11.98
Kalmia polifolia	0.84	0.49	2.41	5.36	17.34
Ledum groenlandium	0.64	0.44	2.38	5.30	22.64
Drosera rotundifolia	0.51	0.24	2.32	5.16	27.80
Mylia anomala	0.67	0.51	2.31	5.15	32.95
Dicranum scoparium	0.33	0.51	2.30	5.12	38.07
Cladonia rangiferina	0.44	0.27	2.20	4.90	42.97
Eriophorum vaginatum	0.38	0.38	2.16	4.81	47.78
Sphagnum angustifolium	0.71	0.76	1.90	4.23	52.00
Sphagnum russowii	0.38	0.20	1.88	4.19	56.19
Sphagnum magellanicum	0.38	0.13	1.79	3.98	60.17
Total			44.95		

Table 15: The average dissimilarities of species and their contribution to the total dissimilarity between sites of the 1 year winter road and their adjacent undamaged sites (N=3).

Species	Average Abundance	Average Abundance	Average Dissimilarity	Contribution (%)	Cumulative Contribution (%)
	Undamaged	Winter road			
Drosera rotundifolia	0.73	0.22	3.63	6.25	6.25
Sphagnum fuscum	0.82	0.36	3.45	5.93	12.17
Kalmia polifolia	0.67	0.40	3.03	5.21	17.38
Sphagnum angustifolium	0.53	0.27	2.83	4.86	22.24
Ledum groenlandium	0.51	0.53	2.82	4.85	27.09
Rubus chamaemorus	0.53	0.56	2.81	4.83	31.92
Andromeda polifolia	0.49	0.31	2.73	4.69	36.61
Maianthemum canadensis	0.62	0.80	2.58	4.43	41.04
Picea mariana	0.42	0.09	2.50	4.29	45.34
Mylia anomala	0.42	0.09	2.43	4.18	49.52
Equisetum palustre	0.38	0.16	2.16	3.71	53.23
Sphagnum magellanicum	0.40	0.09	2.16	3.71	56.94
Dicranum scoparium	0.27	0.27	2.08	3.58	60.52
Total			58.16		

Discussion

Topography

The microtropography of hummocks and hollows did not differ significantly between winter road sites and undamaged adjacent peatlands. This was an unexpected result, because in order to create the winter roads the surface vegetation appears to have been removed and the topography seems to have been flattened by lopping off the tops of the hummocks and filling in the hollows, however the exact mechanism is not known. Perhaps there was no difference because the flattening process was not as disturbing as I predicted it would be. Another potential explanation for this would be differences in the water table between sites. Some of the winter roads were located closer to the open pit, where water is pumped out of the area, which may have differential affects on the water table of surrounding areas. As a result, it may not have been appropriate to compare the topography of each road relative to the water table.

Percent Cover

The determination of percent cover for bryophytes, vascular plants and lichens was one of my first steps in determining if there was a difference in vegetation between the damaged winter road transects and the undamaged natural transects. Overall, I found that there was a difference between vegetation percent cover. Graf *et al* (2008), who investigated vegetation cover on bulldozed sites, which may be more disturbed, but comparable to winter road damage, found that vegetation cover on these sites was only 70% while undisturbed sites had close to 100% cover of vegetation. We also found significant differences between some of our cover groups.

For bryophytes, we found that there was a difference in their percent cover, with winter roads supporting less bryophytes than natural areas. We also found that this difference is stronger in the newer and more heavily used roads (New, One year, Esker) compared to the older roads

(Old, South). This suggests that natural recolonization of bryophytes, mainly *Sphagnum,* is occurring over time on the older abandoned winter roads. Because *Sphagnum* mosses were the most abundant bryophytes in our study areas, this discussion will focus on them. Similar findings were found by many studies investigating natural revegetation of disturbed peatlands, most of which had a much higher degree of disturbance in comparison to winter roads. For instance, block-cut peatlands are peat harvesting operations involving the creation of trenches to drain the bog, the clearing of all surface vegetation and the manual removal of peat blocks forming a system of baulks and trenches (Robert et al. 1999). Many studies investigating the natural revegetation of these abandoned block-cut mines, found that *Sphagnum* cover did return spontaneously, without human restoration techniques (Robert et al. 1999, Bérubé and Lavoie 2000, Poulin et al. 2005). Robert *et al* (1999) found that *Sphagnum* re-established naturally on residual peat deposits of abandoned block-cut peatlands, but not to the extent of those in natural conditions in the Cacouna Bog. Similar results were found in Sweden, where block cut bogs had successful *Sphagnum* regeneration (54%), although coverage was still lower than unmined areas having a cover of 74% (Soro *et al* 1999). The success of naturally regenerating *Sphagnum* species in my study areas may be a result of the high water table. Van Seters and Price (2001) found that water level was the main factor related to revegetation with large section of the area having no *Sphagnum* cover, even after 30 years of abandonment, due to the drainage ditches that were still functioning. Because the winter road activity in this area does not seem to affect the water table and *Sphagnum* thrive in peat with high humidity and a high water table, I would predict that *Sphagnum* species should not have too much difficulty recolonizing the winter roads (Rochefort 2000).

Vascular plant cover had similar results, with a significantly lower percent cover occurring on the winter roads, compared to the undamaged peatlands. However, again, this difference seems to decrease on the older winter roads (Old road and South road). A study on block-cut mined peatlands in Southern Quebec, found that ericaceous shrubs were quick to recolonize these damaged sites, covering 90% of the surface after only 5 years (Lavoie and Rochefort 1996). In the Bas-Saint-Laurent region, near the Hudson Bay Lowlands, mined peat lands also showed an increase in ericaceous shrub cover (Gauthier and Grandtner 1975). Perhaps it is the quick recolonization of vascular plants that allow the *Sphagnum* species to return. Rochefort (2000) suggests that vascular plants may act as nursing plants thus providing a better environment for *Sphagnum* establishment. The success of plant revegetation on South road in particular, may be a result of its higher minerals and less acidic environment producing a more fen-like habitat. Famous et al. (1991) found that fens disturbed by peat mining revegetated faster than bogs, with a vegetation cover of 75% within seven years of abandonment.

Lichen cover was not found to be significantly different between winter roads and natural sites. These results concurs with Poulin *et al* (2005), who found that lichens often covered less than 10% of abandoned mined peatlands, however their distribution in unmined sites were also limited, although slightly higher.

<u>Species diversity</u>

Species richness and evenness were studied in order to help determine if there was a difference in the species diversity of the damaged winter road sites and undamaged adjacent sites. Although the results for total species richness and species evenness of the sites were insignificant, I did find a significant difference when comparing the average species richness of transects. Kevan *et al* (1995), who studied the effect of off-road vehicles on tundra terrain, found that there were small differences in species abundance on damaged sites, which they believe to be persistent for 20 years. This difference in species richness may be due to alterations in the topography of the winter roads. Vascular plant richness was found to be dependant on the number of microtopographical habitats occurring in a bog (i.e. pools, hollow, hummocks) (Glaser 1992, Fontaine et al, 2007). The same was found for bryophyte diversity, which was generally correlated with habitat diversity (Vitt et al. 1992).

<u>Species composition</u>

Species composition was quantified using analysis of similarity (ANOSIM), which indicated that overall, damaged transects supported a significantly dissimilar composition of species than undamaged transects. However, only the most recently used roads (New, One year and Esker roads) were statistically different regarding species composition. The dissimilarity of species on these roads compared to the undamaged peatlands is evident in the ordination plots.

The difference in species composition may have to do with the resistance of certain species or groups of species to the damages caused by winter road activity. For instance, trees tend to be more resistant than flowering woody plants, such as ericaceous shrubs, which are more resistant than thallophytes (lichens and some mosses) (York *et al.*, 1997). A study done in the Arctic on a snow-packed winter road site indicated that there was a more than 100% increase in the number of new plants in one season, which mostly consisted of vascular plants (Lambert 1972). In abandoned mine trenches, ericaceous shrubs were the first to recolonize the area, followed later by *Sphagnum* species (Smart et al. 1989). These findings are further supported by our analysis of the species accounting for the majority of the dissimilarity between winter roads and natural sites. Most of the species accounting for these differences were vascular plants such as the tree *Picea mariana* and many ericaceous shrubs. In mined peatlands, the most common ericaceous shrubs to recolonized abandoned sites, which were also found on the winter roads included *Kalmia polifolia, Ledum groenlandcium* and *Chamedaphne calyculata* (Poulin *et al* 2005). Lambert (1972) who studied the revegetation of plants on a previously snow-packed winter road in Alaska, found that species such as *Eriophorum vaginatum*, *Ledum decumbens, Rubus chamaemorus* and *Vaccinium vitis-idaea* were present after only one season. All of these species are either present or relative to species accounting for dissimilarities on our site. It is important to note that, although some trees may be more resistant to disturbance as a plant type, it is visually apparent that taller trees are unable to recolonize due to traffice on roads still in use.

The large difference in *Drosera rotundifolia* on winter roads versus off winter roads may be a function of the number of pools on the site. This species occurrence was found to be much higher around pools in a study done by Fontaine et al. (2007). Non-*Sphagnum* mosses, such as *Dicranum scoparium* also accounted for dissimilarity between damaged and undamaged sites. The presence of non-*Sphagnum* mosses may play a role in the primary successional stage on winter roads by stabilizing the soil surface, thus facilitating the establishment of vascular plants and *Sphagnum* colonies (Groenveld and Rochefort 2002). As for *Spahgnum* species, the main species that initially recolonized an abandoned block-cut peatland were *Sphagnum rubellum*, *Sphagnum magellanicum, Sphagnum fallas, Sphagnum fuscum, Sphagnum russowi* and *Sphagnum angustifolium* (Poulin et al. 2005). Most of these species also accounted for the dissimilarity between winter roads and undamaged site in this study.

All plants found on undisturbed peatlands were also found along the winter road transects, but to a lesser degree. As expected, the lower average abundance of most species on winter roads, is most likely a result of the crushing and sheering experienced by plants during winter road construction and use.

Overall, we saw that vegetation was significantly different on sites damaged by winter road activity compared to natural sites for many of our measured variables. The percent cover of bryophytes and vascular plants was higher on natural sites compared to winter roads. However, there seemed to be less of a difference as the age of the road increased. We also found a significant difference in the species richness of all quadrats between the sites on the winter road and off the winter road. As for species composition, the three most recently used roads had the most dissimilarity between species while the two oldest roads had a much more similar species composition. Most of the dissimilarity between the recent winter roads were accounted for by vascular plants. These results strongly suggest that natural revegetation is possible on peatlands damaged by winter road activity and that it is actually occurring on roads that have been abandoned for a longer period of time.

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Appendix A: GPS coordinates of sites

Table 12: GPS coordinates of each of the three sites on all five of the winter roads.

Road	Site	Northing	Westing
New	1	52-50'16.8"	083-53'26.0"
	2	52-50'16.1"	083-53'23.0"
	3	52-50'14.9	083-53'17.9"
Esker	1	52-49'47.4"	083-55'35.2"
	2	52-49'47.7"	083-55'34.9"
	3	52-49'47.7"	083-55'43.3"
One Year	1	52-50'11.9"	083-53'25.5"
	2	52-50'11.9"	083-53'21.6"
	3	52-50'19.1"	083-53'48.8"
Old	1	52-50'24.8"	083-54'04.7"
	2	52-50'26.3"	083-54'06.7"
	3	52-50'30.2"	083-54'16.0"
South	1	52-48'58.7"	083-54'46.3"
	2	52-48'54.8"	083-54'50.4"
	3	52-48'54.5"	083-54'50.7"

Appendix B: Species list

Bryophytes

Campylium stellatum (Lindb.) Perss.
Dicranum fluitans
Dicranum scoparium Hedw.
Drepanocladus fluitans (Hedw.) Warnst.
Gymnocladia sp.
Mylia anomala (Hook.) A. Gray
Pohlia nutans (Hedw.) Lindb.
Polytrichum commune Hedw.
Sphagnum angustifolium (C.E.O. Jensen ex Russow) C.E.O Jensen
Sphagnum capillifolium (Ehrh).Hedw.
Sphagnum controtum Schultz
Sphagnum cuspidatum Ehrh. ex Hoffm
Sphagnum fallax (Klingrr.) Klingrr
Sphagnum flexuosom Dozy and Molk
Sphagnum fuscum (Schimp.) Klingrr
Sphagnum girgensohnii Russow
Sphagnum lindbergii Schimp.
Sphagnum magellanicum Brid.
Sphagnum majus (Russow) C.E.O. Jensen
Sphagnum papillosum Lindb.
Sphagnum ripariuum Angstr.
Sphagnum rubellum Wilson
Sphagnum russowii Wanst.
Sphagnum subsecundum Nees

Vascular plants

Andromeda polifolia L.
Betula pumila L.
Carex aquatilis Wahlenb.
Carex chordorrhiza Ehrh. ex L. f.
Carex limosa L.
Carex magellanica Lam.
Carex pauciflora Lightf.
Chamaedaphne calyculata (L.) Moench
Drosera linearis Goldie
Drosera rotundifolia L.
Empetrum nigrum L.
Equisetum fluviatile L.
Equisetum palustre L.

Eriophorum angustifolium Honck.
Eriophorum vaginatum L.
Geocaulon lividum (Richardson) Fernald
Kalmia angustifolia L.
Kalmia polifolia Wangenh.
Larix laricina (Du Roi) K. Koch
Ledum groenlandicum Oeder.
Maianthemum canadense Desf.
Menyanthes trifoliata L.
Picea mariana (Mill.) Britton, Sterns & Poggenb.
Rubus chamaemorus L.
Sarracenia purpurea L.
Scirpus cespitosus L.
Triglochin maritime L.
Vaccinium myrtelloides Michx.
Vaccinium oxycoccus L.
Vaccinium uliginosum L.

Lichens

Cladonia mitis (Sandst.) Hustich
Cladina rangiferina (L.) Nyl.
Cladina stellaris (Opiz) Brodo
Cladonia cenotea (Ach.) Schaerer
Cladonia chlorophaea (Flörke ex Sommerf.) Spreng.
Cladonia crispata (Ach.) Flotow
Cladonia cristatella Tuck.
Cladonia deformis (L.) Hoffm.
Cladonia fimbriata (L.) Fr.
Cladonia gracilis (L.) Willd. ssp. *elongata* (Jacq.) Vain.
Cladonia gracilis (L.) Willd. ssp. *turbinata* (Ach.) Ahti
Cladonia pleurota (Flörke) Schaerer
Cladonia pyxidata (L.) Hoffm.
Cladonia rei Schaerer
Icmadophila ericetorum (L.) Zahlbr.