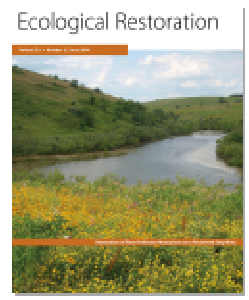
Can Mulch and Fertilizer Alone Rehabilitate Surface-disturbed Subarctic Peatlands?



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Can Mulch and Fertilizer Alone Rehabilitate Surface-disturbed Subarctic Peatlands?

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ABSTRACT

Subarctic peatlands are increasingly faced with disturbances from resource extraction industries. Their rehabilitation is being required through government regulation, and backed by financial guarantees. A three-year field experiment was conducted to test a modification of existing peatland rehabilitation protocols on winter road clearances in subarctic peatlands of the Hudson Bay Lowland. The experiment was conducted on severely disturbed sections of winter roads with extensive cut hummocks. *Sphagnum* fragments were not spread on bare peat surfaces, contrary to existing protocols, because of the close proximity to propagules in vast and adjacent, undisturbed peatlands. Factorial combinations of microclimate amelioration (straw mulch) and phosphorus fertilization were applied, as in existing protocols. Rock phosphate fertilization and straw mulch did not increase the recolonization of *Sphagnum* nor of other bryophytes, lichens or vascular plants. After three years, *Sphagnum* remained almost absent and bare peat was colonized mostly by lichens and bryophytes typical of disturbed peat surfaces. The spreading of fragments on top of severely disturbed surface peats appears to be required in order to rehabilitate peatlands, even when extensive undisturbed peatlands are found nearby.

Keywords: fertilization, microclimate amelioration, peat, *Sphagnum*, winter roads

The Hudson Bay Lowland (HBL), Canada, is a vast peatland that forms the third largest wetland in the world (Abraham and Keddy 2005). It is an important store of terrestrial organic carbon, with discontinuous permafrost (Riley 2011), giving it global significance and vulnerability to climate change. Extensive mining developments are also in operation or are planned in the HBL for diamonds, base metals, and precious metals (Far North Science Advisory Panel 2010). So despite best efforts to avoid and minimize impacts, mining does and will continue to cause diverse disturbances to peatlands. Many of these are linear disturbances, including winter roads, pipelines and all-terrain vehicle trails. Regulatory agencies and local First Nations communities are increasingly requiring that mining proponents rehabilitate mine sites towards sustainable ecosystems dominated by local, native vegetation. Financial guarantees are put in place and held in trust prior to mining to ensure that rehabilitation occurs at mine closure. Sound rehabilitation protocols must therefore be developed for these disturbed subarctic peatlands.

Disturbances in peatlands can create exposed peat surfaces, which can be extreme environments, with moisture deficits, low nutrients, and needle ice (Price et al. 1998, Quinty and Rochefort 2003, Groeneveld, et al. 2007). Detailed rehabilitation protocols already exist for drained, surface-mined *Sphagnum*-dominated peatlands in north-temperate and south-boreal regions of North America, which are exploited for horticultural peat (Quinty and Rochefort 2003). These protocols focus on *Sphagnum* recovery because these mosses are responsible for the majority of peat formation in boreal peatlands (Rochefort 2000). Although the disturbances differ from those associated with mining in the HBL, these protocols do give guidance to rehabilitate subarctic peatlands. Briefly, the top 10 cm of *Sphagnum* moss carpets are collected from an intact peatland and then spread sparsely over a bare peat surface (Quinty and Rochefort 2003). A light dose of rock phosphate fertilizer is added, and then straw mulch is placed over the *Sphagnum* fragments to moderate the microclimate. Because these surface mined peatlands are drained, heavy machinery can be used to scale up the rehabilitation. The water table is then raised to just below the peat surface to improve moisture conditions. Using this protocol, the cover of the *Sphagnum* mosses can return to near typical levels within approximately half a decade and begin peat accumulation again (Lucchese et al. 2010).

We have recently extended this protocol to severely disturbed subarctic peatlands in areas of the HBL that have been disturbed by mining (Corson and Campbell 2013). Once *Sphagnum* fragments are spread and fertilizers applied, mulches do not

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Figure 1. (top) Winter road clearance with adjacent power line corridor in the Hudson Bay Lowland near the Victor Mine. Bright areas on the winter road clearance have more bare peat. (bottom) Cut hummock on a winter road clearance in August 2010, showing bare peat. The area adjacent to the cut hummock is within the road clearance but has more recovering vegetation. Photo credits: K. Garrah and K. Skeries.

appear to be needed to encourage revegetation, unlike in southeastern Canada. Fragments even survive when applied over frozen ground in the winter (Corson and Campbell 2013), potentially allowing the scaling-up of peatland rehabilitation using heavy equipment. This modified protocol is promising for the rehabilitation of severely disturbed peatlands in the HBL and other subarctic regions.

Winter roads are a common disturbance over peatlands in the HBL (Figure 1A). They are narrow (10–25 m), but long (10–100 km), so they are extensive. Winter roads are built by cutting or scraping the vegetation of a peatland in early winter, packing down the snow with snowmobiles and tracked heavy equipment, building up a roadbed of snow and ice with a road grader, then watering it to form an ice cap until the road can support transport trucks (Campbell and Bergeron 2012). This removes most vegetation in the road clearance and can disturb surface peats, leaving much bare peat and scattered remnant vascular plants, mosses and lichens (Haag and Bliss 1974, Adam and Hernandez 1977). After abandonment, most of these road clearances appear to revegetate naturally to similar covers of vascular plants, bryophytes and lichens as in adjacent peatland within approximately seven years, although species composition differs slightly, with lower diversity and slow recovery for certain key groups, such as trees (Campbell and Bergeron 2012). Ice also remains closer to the surface for several years after abandonment (Campbell and Bergeron 2012).

However, the most severely disturbed sections of winter road clearances appear to require intervention. They can occur where the surface preparation of a winter road was deficient, leading to melting of the base layer of snow and rutting or damage to the peat surface. They also occasionally occur where peatlands initially had much microtopography with hummocks, which are cut or scraped off during road preparation, leaving bare peat mostly devoid of vegetation (Figure 1B). We observed 50 m sections of winter roads where approximately half the surface had cut hummocks with bare peat.

Here we asked the question whether the spreading of *Sphagnum* fragments was necessary on severely disturbed sections of winter roads over these subarctic peatlands. Could we simplify these protocols by just ameliorating environmental conditions and not spreading fragments? Several lines of evidence suggest that *Sphagnum* propagules should already be present or can easily disperse into severely disturbed peatlands along winter roads. First, the preparation of the road clearances moves plant material along the winter roads even into severely disturbed sections, so propagules such as seeds, spores or moss fragments should be widely distributed even on severely disturbed sections, where they may survive until road abandonment. Second, *Sphagnum* is frequent on winter roads after abandonment, although less abundant than in adjacent undisturbed peatlands (Campbell and Bergeron 2012). Therefore, abandoned roads may provide propagules for dispersal. Third, winter road clearances are linear and narrow (< 25m), and we observed fruiting *Sphagnum* in adjacent peatlands, so spores or fragments should be able to disperse naturally to winter road clearances. Fourth, *Sphagnum* mosses have been known to form persistent spore banks, especially in hummocks (Clymo and Duckett 1986, Sundberg and Rydin 2000), so viable spores may already be present in cut hummocks.

Other lines of evidence suggest that, if *Sphagnum* propagules occur on cut hummocks, they do not establish because of unfavourable conditions in surface peats. *Sphagnum* requires phosphorus to germinate and establish, but phosphorus is in extremely low concentrations in peatlands (Sundberg and Rydin 2002). Secondly, bare peat can dry out at the surface, even in this subarctic region (Corson and Campbell 2013), and can form surface crusts or cause drought stress to colonizing species, especially *Sphagnum* (Price et al. 1998).

We hypothesized that only phosphorus fertilization and/or microclimate amelioration with mulch should be required to stimulate *Sphagnum* recruitment and rehabilitate severely disturbed sections of winter roads. If so, this would greatly reduce the effort and cost required to rehabilitate winter road clearances over peatlands. We conducted a field experiment to test this hypothesis.

Table 1. ANOVA results of the effects of straw mulch and rock phosphate treatments on overall cover, taxon richness and Simpson's diversity across all plant groups on cut hummocks on the road clearance in August 2010. The road was constructed and used for one winter in 2005–2006. Significant effects are shown in italics ($p < 0.05$).

		Cover			Taxon richness			Simpson's diversity		
Source	df	MS	*F*	*p*	MS	*F*	*p*	MS	*F*	*p*
Block	5	650	1.81	0.147	*52.8*	*3.70*	*0.012*	*0.0057*	*2.95*	*0.031*
Mulch	1	94	0.26	0.613	10.0	0.70	0.410	0.0009	0.44	0.511
PO_4	2	575	1.60	0.221	10.6	0.74	0.487	0.0000	0.00	0.999
Mulch × PO_4	2	198	0.55	0.583	1.4	0.10	0.909	0.0005	0.26	0.776
Error	25	359			14.3			0.0019		

Methods

The study was conducted near the De Beers Victor Diamond Mine in the Hudson Bay Lowland, 110 km west of James Bay, Ontario (52°50.2'N, 83°53.4'W; 82 m elevation). Vast peatlands with fens and bogs cover this coastal limestone plain, bordering Hudson and James Bays (Riley 2011). At the nearest climate station, (Lansdowne House; 52°14'N, 87°53'W; 280 km WSW), mean annual temperature is –1.3°C, with a January mean of –22.3°C and a July mean of 17.2°C (Environment Canada 2013). Mean annual precipitation is 700 mm, over half of which falls from June to September during the growing season.

The experiment was established on a ~200 m by ~19 m section of abandoned winter road, which was constructed and used for one winter in 2005–2006, but received heavy traffic from transport trucks (2337 round trips). Snowmobiles and light tracked vehicles, road graders and water trucks were used to make a winter road surface of ice over packed snow (Campbell and Bergeron 2012). Peat depth below the cut-hummocks could not be determined due to permafrost, but was approximately 2 m at the nearby Victor Mine pit. In August 2008, the average percent cover of vascular plants, bryophytes and lichens in undisturbed peatland adjacent to this road clearance was 18, 67, and 21%, respectively (Campbell and Bergeron 2012). Bog vegetation dominated, with sparse and stunted black spruce (*Picea mariana*; < 5 m tall), ericaceous shrubs (*Chamaedaphne calyculata*, *Vaccinium oxycoccos*, *Kalmia polifolia*, *Ledum groenlandicum,* and *Andromeda polifolia*), peatland herbs (*Maianthemum trifolium*, *Rubus chamaemoru,s* and *Eriophorum vaginatum*), bryophytes (mostly *Sphagnum* species) and lichens (mostly *Cladina* and *Cladonia*; Table A1). In contrast, the winter road clearance had much bare peat, no trees, and an average percent cover of vascular plants, bryophytes and lichens of 6, 46, and 8%, respectively. The most disturbed sections of the winter road consisted of extensive areas of hummocks (~100–300 m² each), which had been cut-off near to ~5–15 cm above the remaining peatland surface, exposing bare peat (Figure 1).

In May 2008, a factorial experiment was set up on these cut hummocks, on the abandoned road clearance, using a complete randomized block design with six blocks. In each block, 2 × 2 m² experimental plots were set up on the surface of the cut hummocks and randomly received factorial combinations of phosphate fertilizer amendments (none, low, high) and straw mulch (without or with). The phosphate fertilizer consisted of rock phosphate (0-2-0, NPK), with a dose of 30 g m^{-2} rock phosphate in the low dose treatment and 90 g m^{-2} in the high dose treatments. The low dose is the same as in successful peatland rehabilitation experiments nearby (Corson and Campbell 2013), and similar to existing peatland rehabilitation protocols in southeastern Canada (Quinty and Rochefort 2003). The fertilizer was

Table 2. Cover, taxon richness, and Simpson's diversity overall and individually for vascular plants, bryophytes, and lichens on cut hummocks on the road clearance in August 2010 (n = 36; mean ± SE). The road was constructed and used in the winter of 2005–2006; treatments were applied in May 2008.

	Overall		Vascular		Bryophyte		Lichens	
	mean	SE	mean	SE	mean	SE	mean	SE
Cover	20.2	3.3	3.8	0.7	14.3	3.0	2.0	0.5
Taxon richness	12.3	0.7	4.6	0.4	4.4	0.4	3.2	0.2
Diversity (1-*D*)	0.106	0.008	0.762	0.040	0.344	0.043	0.116	0.008

applied evenly to the surface of the plots using a 1L container with a perforated cover, resembling a large salt shaker. The mulch consisted of straw attached to a plastic mesh (Terrafix® S31), cut into 2.5 m × 2.5 m squares and pegged into place over plots.

Gravimetric water content of surface peat was determined in August 2008 using a short cylindrical sampler, 5 cm in diameter by 0.5 cm deep, weighing the peat fresh, drying it at 105°C for 24 hours and then reweighing it. Active layer thickness was measured at the same time by inserting a 1.5 cm diameter steel rod into the surface of every experimental plot until it hit frozen peat.

The abundance of *Sphagnum* and other plant species was determined in May and August 2008 and again in August 2010 by randomly placing ten 12.5 cm × 12.5 cm quadrats over the surface of each plot and tallying the presence of taxa. Bryophyte and lichen taxa were mostly identified to genus. This provided an abundance score by plot of 0 to 10 for each taxon. This method was preferred over visual estimates of cover because of the extremely low cover abundances early in the study. It provided an objective score of abundance, but cannot be related to percent cover of species in plots. In August 2010, total plant cover and covers of total vascular plants, total bryophytes and total lichens was also determined in each quadrat and averaged by plot.

Taxon richness and Simpson's diversity index (1–*D*) were determined from this abundance data for each plot. Data from gravimetric water content, active layer thickness, plant cover, taxon richness, and Simpson's diversity were analyzed separately using univariate ANOVA. Mulch and fertiliser were considered fixed treatment effects and block was considered as a random effect. Interactions with the block term were not included in the statistical model. Square-root transformed *Sphagnum* abundance data was analyzed over the three sampling dates using repeated measures analysis. Residuals were analyzed to verify homogeneity of variance and normality. These analyses were performed with Statistica® version 10 (StatSoft, Inc., Tulsa, OK, USA). The type I error rate was set at 5% for all analyses.

The effects of treatments on species assemblages over the three sampling dates were tested using the multivariate statistical software PRIMER-E® version 6.1.11 (PRIMER-E Ltd, Ivybridge, U.K.) and PERMANOVA+® version 1.0.1 (PRIMER-E Ltd, Ivybridge, U.K.). A similarity matrix between plots was first calculated using a Bray-Curtis similarity coefficient calculated from raw data. The effects of treatments were then tested with a repeated measures design using permutational multivariate analysis of variance (PERMANOVA procedure), a Monte Carlo procedure akin to a multivariate ANOVA. The homogeneity of multivariate dispersion was assessed using the PERMDISP procedure. Significant effects were illustrated using non-metric multidimensional scaling. Species that differed among treatments or dates were identified using the SIMPER procedure. Significance was determined based on 9999 random permutations.

Results

Mulch cover did not affect gravimetric water content of surface peats on these cut hummocks in August 2008 during a dry spell ($F_{1,25} = 0.2$, $p = 0.63$); water content remained high (89.0 ± 0.5 %; mean ± SE). Neither did the mulch affect the thickness of the active layer in August 2008 ($F_{1,25} = 0.3$, $p = 0.57$; mean ± SE: 43.1 ± 1.6 cm).

Straw mulch and fertilizer treatments had no effect on cover, taxon richness or Simpson's diversity, either overall or looking at lichens, bryophytes or vascular plants separately (Table 1). Cut hummocks only had 20% cover across all treatments and all plant groups after three years, mostly with bryophytes (Table 2).

Sphagnum abundance also remained low across all plots (mean ± SE: 8 ± 2% of quadrats). *Sphagnum* was not affected by fertilizer ($F_{2,25} = 0.46$, $p = 0.64$), nor by mulch ($F_{1,25} = 0.19$, $p = 0.66$). The lack of a fertilizer effect was also independent of the mulch treatment ($p = 0.94$). However, *Sphagnum* abundance did change slightly but significantly over time ($F_{2,50} = 3.6$, $p = 0.035$), with a drop from May to August 2008 of 11 to 5% of quadrats, and a rebound by August 2010 to 9% of quadrats.

Fertilizer did not significantly change the species assemblages on cut hummocks across any dates, as determined from PERMANOVA analyses (Table 3). The addition of a mulch had a borderline effect on species assemblages ($p = 0.06$), but only in May 2008, when there was more leatherleaf (*Chamaedaphne calyculata*) and small cranberry (*Vaccinium oxycoccos*) on the un-mulched plots; this differences disappeared by August 2008 ($p = 0.30$). Species assemblages did however change over time, with significant differences between May and August 2008 ($p = 0.0001$) and between August 2008 and August 2010 ($p = 0.0001$, Table 3, Figure 2). This shift was due to increases in bryophytes (*Pohlia nutans*, small Dicranaceae, *Polytrichum strictum*, and *Dicranum* species), lichens (*Cladonia* and *Cladina* species) and certain vascular plants (*Vaccinium oxycoccus*, *Ledum groenlandicum*, *Kalmia polifolia* and *Rubus chamaemorus*; Table A1). Assemblages in different treatments were also more dispersed in May 2008 (p < 0.04, 9999 permutations), and decreased by August 2008 and again by August 2010, meaning that species assemblages were becoming less variable with time.

Overall assemblages on cut hummocks remained quite different from the rest of the winter road and the adjacent undisturbed peatlands (Table A1). Cut hummocks had lower abundances of vascular plants, especially black spruce (*Picea mariana*) and sundew (*Drosera rotundifolia*), and different bryophyte species, in striking contrast to the adjacent peatlands.

Discussion

We modified environmental conditions on cut hummocks on winter road clearances using straw mulch covers and mild phosphorus fertilization, both of which have been found to help establish *Sphagnum* fragments in disturbed peatlands in southeastern Canada (Quinty and Rochefort 2003). We expected that they would enhance the establishment of *Sphagnum*, without the need to introduce additional propagules. However, these treatments had no impact on *Sphagnum* recovery. *Sphagnum* remained almost absent from cut hummocks after three years.

Viable spores or propagules of *Sphagnum* may be absent from cut hummocks or have difficulty dispersing there. However, this would be surprising, given the narrow, linear nature of these winter road clearances and the vast size of adjacent peatlands with abundant *Sphagnum*. Although *Sphagnum* sporophytes were observed in adjacent peatlands, we acknowledge that their abundance was not quantified, nor the dispersal of spores to road clearances.

Table 3. Repeated measures PERMANOVA on the effects of straw mulch and rock phosphate treatments on species assemblages on cut hummocks in winter road clearances between May 2008, August 2008 and August 2010. The road was constructed and used for one winter in 2005–2006. Significant effects are shown in italics (p < 0.05).

Source	df	MS	Pseudo-F	p
Block	5	*2400*	*2.9*	*0.0001*
Mulch	1	1220	1.5	0.164
PO4	2	731	0.9	0.610
Mulch × PO_4	2	625	0.7	0.776
Error a	25	837		
Date	2	*33614*	*16.5*	*0.0001*
Mulch × date	2	3148	1.5	0.060
PO_4 × date	4	1995	1.0	0.504
Mulch × PO_4 × Date	4	1957	1.0	0.540
Error b	56	2036		
Total	103			

Alternatively, our attempts to enhance environmental conditions through phosphate fertilization and microclimate amelioration were insufficient to encourage *Sphagnum* re-establishment, at least from available spores or small vegetative propagules. *Sphagnum* readily recolonizes in these subarctic peatlands from large fragments with capitula (Corson and Campbell 2013), however spores or small fragments generally have a lower ability to establish (Rochefort 2000, Rochefort et al. 2003).

We were also surprised that our fertilizer and mulch treatments did not have any impact on the recovery of other bryophytes, lichens or even vascular plants. In fact, limited vegetation returned to these cut hummocks within three years, in contrast to the remainder of the winter road

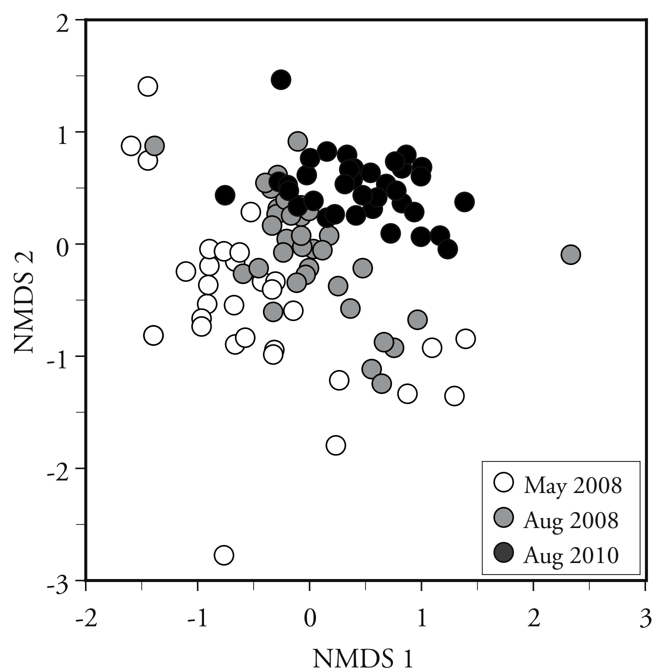

Figure 2. Non-metric multidimensional scaling of the change in species assemblage from May 2008 through to August 2010, based on vascular plants, bryophytes and lichens (stress = 0.20). The road was constructed and used in the winter 2005–2006.

clearance (Campbell and Bergeron 2012). What did return was dominated by bryophytes and lichens. Most of the colonizing bryophyte taxa were not observed in adjacent peatlands. These species commonly colonize bare peat in vacuum-harvested peatlands in southeastern Canada (Poulin, et al. 2005, Graf, et al. 2008); their dominance reflects a shift away from conditions conducive for *Sphagnum* recolonization. A similar condition appears to be occurring here. The vascular plants that did recover were mostly creeping (*Vaccinium oxycoccus*) or rhizomatous species (*Chamaedaphne calyculata*, *Ledum groenlandicum*, *Kalmia polifolia*, *Rubus chamaemorus*, *Maianthemum trifolium*); they appear to have mostly recovered through vegetative means from the cut hummocks or from adjacent hollows. *Eriophorum vaginatum* was the only vascular plant species that evidently germinated; it is tufted, so with limited ability to spread vegetatively, and the few that we observed were mostly seedlings. This species commonly recolonizes disturbances in boreal peatlands (Poulin, et al. 2005) and arctic organic tundra (Chapin and Chapin 1980), so its low abundance by August 2010 (5% of quadrats) underlines the slow colonization of these cut hummocks. The overall shift in species assemblages over time towards sparse communities atypical of peatlands and the decreasing dispersion of the assemblage suggests that species assemblages are reaching an alternative and perhaps stable state, away from typical peatland communities.

Why was the recolonization of *Sphagnum* and other plants so poor, even given our rehabilitation attempts? It is possible that nutrient levels in surface peats were insufficient to support plant colonization, even with higher rock phosphate fertilization. Phosphorus content of these peats is quite low (bioavailable phosphorus < 0.03 mg/kg, n = 5; Campbell, unpubl. data), and microbial decomposition of peat or uptake by other plants may also be competing for added nutrients (Silvola 1988, Pouliot et al. 2009). Bryophytes in arctic peatlands are known to absorb nitrogen and phosphorus and increase plant nutrient content, without a corresponding effect on growth (Pouliot et al. 2009), so colonizing bryophytes might absorb phosphorus, without exhibiting any growth effect.

The top ~5 mm of the cut hummocks had relatively high moisture contents (89%), even during a dry period, and surprisingly was not affected by mulch. Large *Sphagnum* fragments are quite sensitive to drought conditions (Price et al. 1998), so spores or small fragments may be more so. These cut hummocks also had some surface crusting within the top few millimeters, so a strong moisture gradient was likely present; moisture conditions at the peat surface may not have been conducive for spores or small vegetative fragments.

Ice is present closer to the surface over winter road clearances as compared to adjacent undisturbed peatland (43 cm under cut hummocks in August 2008, 45 cm in centre of road clearances, and 115 cm in undisturbed peatland in August 2010, Campbell and Bergeron 2012). The ice content and low temperature in the peats may limit plant growth, at least for vascular plant species. The high ice content may also be related to the water content of the surface peats and the lack of a mulch effect. Furthermore, because of the lack of vegetation on winter roads and the slightly raised microtopography of cut hummocks, they should be repeatedly exposed to harsh winter conditions (Arseneault and Payette 1992). This could be maintaining the ice in cut hummocks and could affect the successful establishment of any plant species.

We acknowledge that we only conducted the study on one winter road, but this was in six blocks spread over 200 m of the road. As such, we believe that our results are generally representative of what could be expected to occur on other severely disturbed sections of winter roads in the Hudson Bay Lowland.

Many winter roads recolonize well naturally (Campbell and Bergeron 2012), so active intervention should only be required for severely disturbed sections of winter road clearances, such as sections with many cut hummocks. We have already demonstrated that other severely disturbed peat surfaces in the HBL can be successfully revegetated if *Sphagnum* fragments are spread, with light fertilization but no mulch (Corson and Campbell 2013). *Sphagnum* fragments even survive extreme winter conditions, giving hope that they could be spread once the ground is frozen. We acknowledge however that cut hummocks may be especially recalcitrant to restoration. Further work is needed to refine restoration protocols for hummocks and to scale-up protocols for use in remote sites.

In conclusion, techniques such as phosphorus fertilization and microclimate moderation alone are ineffective to rehabilitate subarctic peatlands with severe surface-disturbances despite the proximity of undisturbed peatland. Cut hummocks on winter road clearances appear to be especially recalcitrant to recolonization by *Sphagnum* and typical assemblages of peatlands plants. More intensive restoration techniques, such as harvesting larger *Sphagnum* fragments with capitula and spreading them over severely disturbed bare peat substrates (Quinty and Rochefort 2003, Corson and Campbell 2013) will have to be considered so that severely disturbed bare peat substrates can be recolonized in subarctic peatlands, even when extensive undisturbed peatlands are nearby.

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Table A1. Average abundance of vascular plant, bryophyte and lichen taxa encountered on cut hummocks on the road clearance in May 2008 to August 2010, as compared to the rest of this road clearance and to adjacent undisturbed peatlands, as sampled in 2008 (unpublished data; methods in (Campbell and Bergeron 2012). Abundance scores were calculated as the percent of quadrats in which a species is found, based on 12.5 × 12.5 cm quadrats on cut hummocks (*n* = 360) and on 50 × 50 cm quadrats in the rest of the winter road and in the adjacent undisturbed peatlands (*n* = 45 each). Because of the different sized quadrats on hummocks versus the rest of the road and undisturbed peatlands, comparisons should be made with some care. Only taxa with abundances ≥ 5% of quadrats are shown and are ordered by abundance on cut hummocks in August 2010, as determined by the SIMPER procedure.

Group	Taxon	Common name	May 2008 hummocks	Aug 2008 hummocks	Aug 2010 hummocks	Road clearance	Adjacent peatland
Vascular plants	*Vaccinium oxycoccos*	small cranberry	6	26	33	84	89
	Chamedaphne calyculata	leatherleaf	22	26	26	96	100
	Ledum groenlandicum	Labrador tea	3	9	13	44	64
	Kalmia polifolia	bog laurel	0	5	12	49	84
	Rubus chamaemorus	cloudberry	4	12	12	33	71
	Maianthemum trifolium	three-leaf false lily of the valley	0	6	9	100	93
	Eriophorum vaginatum	tussock cottongrass	0	0	5	38	38
	Andromeda polifolia	bog rosemary	2	4	5	29	27
	Carex limosa	mud sedge	0	0	1	16	11
	Picea mariana	black spruce	0	0	0	0	60
	Drosera rotundifolia	round-leaved sundew	0	0	0	24	51
	Geocaulon lividum	false toadflax	0	0	0	2	11
	Trichophorum cespitosum	tufted bulrush	0	0	0	29	11
	Vaccinium uliginosum	bog blueberry	0	0	0	16	4
Bryophytes	Dicranaceae small	-	0	30	42	0	0
	Pohlia sp.	pohlia moss	0	0	39	0	0
	Polytrichum strictum	polytrichum moss	4	7	30	7	0
	Cladopodiella fluitans	-	0	0	11	7	13
	Mylia anomala	-	0	0	1	51	67
	Dicranum scoparium	dicranum moss	0	1	24	51	33
	Sphagnum sp.	sphagnum moss	5	11	9	93	96
	Marchantia polymorpha	common liverwort	0	0	6	0	0
Lichens	*Cladonia gracilis*	cup lichen	3	5	21	7	7
	Cladina sp.	reindeer lichen	2	4	21	49	49
	Cladonia sp.	cup lichen	0	0	19	11	20
	Peltigera sp.	dog lichen	0	0	13	4	2
	Cladonia chlorophaea	cup lichen	0	3	7	7	2