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On the use of mulching to mitigate permafrost thaw due to linear disturbances in sub-arctic peatlands

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ABSTRACT

The presence or absence of permafrost strongly influences the hydrology and ecology of northern watersheds. Resource exploration activities are currently having profound effects on hydrological and ecological processes in sub-arctic peatlands. In wetland-dominated zones of discontinuous permafrost, permafrost occurs below tree-covered peat plateaus where the tree-canopy and vadose zone act to insulate and preserve permafrost below. Linear disturbances such as seismic lines result in removal of the canopy, and cause permafrost thaw, which results in increased soil moisture, land subsidence, and deforestation. This contributes to land-cover transformation, habitat and vegetation loss, and changes to basin hydrologic cycles. The resultant permafrost-degraded corridors comprise large portions of the drainage density of sub-arctic basins, and alter the region's water and energy balances. Mulching over disturbances, with the removed tree canopy, has been proposed as a best management practice to help reduce this environmental impact. Here we present climate chamber and numerical modeling results which quantify the effects of mulching and its ability to limit permafrost thaw and alterations to the ground thermal regime. Overall, the thermal buffering ability of the mulch had beneficial effects on slowing thaw, due to its low thermal conductivity, which decouples the subsurface from meteorological forcing and impedes heat conduction. Results indicate that mulching is an effective technique to reduce permafrost thaw and provides a scientific basis to assess the mitigation measure on its ability to slow permafrost degradation. This study will provide guidance as to how northern exploration may be performed in a more environmentally sustainable manner.

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1. Introduction

Hydrological and ecological processes in northern latitudes are strongly coupled and influenced by the distribution of permafrost and peatlands (Woo and Winter, 1993). When present, the spatial characteristics of permafrost controls watershed hydrology by creating barriers and channels in the subsurface, directing water movement during summer months and modulating the ground's temperatures and energy balance (Woo, 1986). Peatlands cover approximately 12% of Canada's land surface (Tarnocai, 2006), of which approximately 30% is underlain by permafrost (Aylsworth et al., 1993; Zoltai, 1993). Exploration practices resulting in tree canopy removal have led to widespread permafrost degradation in northern peatlands (Quinton et al., 2009; Williams et al., 2013). Linear disturbances are increasing occurrences in northern Canada; pipelines, winter roads and seismic lines now account for large portions of the drainage density of watersheds in the Canadian sub-arctic (Quinton et al., 2011). The most common types of linear disturbances are seismic lines, created during oil and gas exploration. In the zone of discontinuous permafrost, these disturbances have led to a suite of environmental impacts on the hydrologic and ecological functioning of these sensitive ecosystems. Impacts include changes in the basin hydrology, vegetation growth, habitat destruction and entire land-cover change, including permafrost thaw, ground surface subsidence, and inundation (Beilman and

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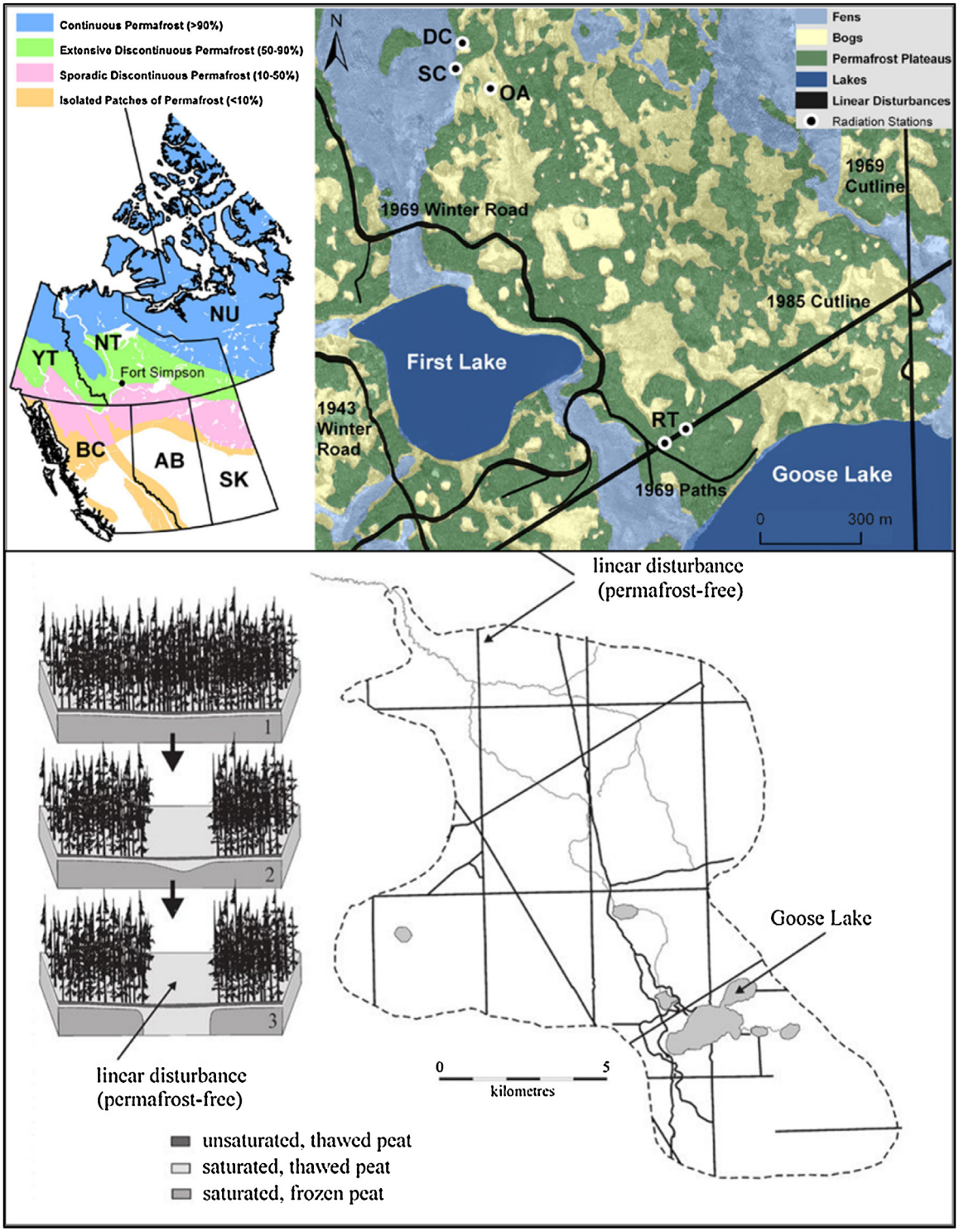

Fig. 1. Location of Scotty Creek near Fort Simpson, Northwest Territories within the zone of discontinuous permafrost and a plan view of the patterned peatland landscape (GSC, 2002). Lower images show plan schematic of linear disturbances at Scotty Creek along with a conceptual of permafrost thaw once the tree canopy has been removed (adapted from Quinton et al. (2009) and Williams and Quinton (2013)).

Robinson, 2003; Jorgenson et al., 2010; Williams et al., 2013). Seismic exploration involves the removal of the tree canopy and the compression of the ground surface, both of which decrease the thermal insulation of the active layer and permafrost (Wright et al., 2009). As a result, seismic lines typically represent lines of preferential permafrost thaw and ground surface subsidence.

In the wetland-dominated zone of discontinuous permafrost, permafrost occurs below tree-covered peat plateaus that rise 1–2 m above surrounding treeless wetlands composed of flat bogs and channel fens (Wright et al., 2008). The presence and distribution of permafrost is correlated to mean annual air temperatures (MAAT) (Shur and Jorgenson, 2007), although peat plateaus and other organic soil-covered terrains in the southern margin of permafrost are highly effective at insulating permafrost so that permafrost can persist in areas of relatively high MAAT. Permafrost thickness ranges between 10 and 20 m and ground ice can constitute

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