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Using tree ring analysis to determine impacts of a road on a boreal peatland

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ABSTRACT

Linear disturbances such as roads are common in areas of intensive resource development. When roads cross peatlands, they can interrupt natural hydrologic processes and alter vegetation composition and structure. Hydrological changes to a poor fen impacted by a road in northeastern Alberta were evaluated using tree rings of living and dead black spruce trees. All trees that were less than 83.5 cm above the road's single culvert died in 1989. The temporal uniformity of dieback suggested that a single inundation event caused the trees to drown. The inundation likely was caused by a culvert blocked by beavers, and indicates the critical role of hydrologic patterns and processes for controlling vegetation composition, including tree growth patterns and mortality. The disturbance of peatlands by roads could be reduced or eliminated by improving road designs to include multiple culverts that cannot easily be blocked by debris or beavers, or underdrain systems that create more natural surface and ground water flow patterns. In addition, regular inspection and maintenance could limit the negative effects of blocked point locations that can be dammed by beavers.

1. Introduction

Linear disturbances such as seismic lines, roads, pipelines and power-line rights-of-way are common features in regions with intensive resource extraction (Lee and Boutin, 2006). Roads, ranging from highways to small tracks, create edges that deplete interior forest habitats, and open the remaining land to greater light infiltration, changes in temperature, predation of sensitive interior species by edge-tolerant species, increased exposure to wind, dust and debris from roadsides and invasion of exotic species (Findlay and Bourdages, 2000; James and Stuart-Smith, 2000; Laurance, 2000; Laurance et al., 2007; Dubé et al., 2011).

Linear features can also fragment the landscape and alter local vegetation and hydrologic regimes, especially in wetlands (Williams et al., 2013). When a road bisects a wetland it can alter hydrologic processes and its connectivity to downstream areas on a local or landscape scale (Neilsen et al., 2012). Alteration of the hydrologic regime may change site water table depth and dynamics that affect trees growing in the wetland that may be evident in their annual ring width patterns (Dang and Lieffers, 1989; Freléchoux et al., 2000; Linderholm et al., 2002; Cedro and Lamentowicz, 2011). Examining the response of a wetland's biota to hydrologic alterations caused by roads can provide insight into the processes of vegetation change.

Roads that cross wetlands with thick peat soils are typically constructed using a mineral soil roadbed, with culverts placed at the elevation of the former ground surface to allow surface water to flow beneath the road. Road-building techniques in certain regions have improved in the last several decades with permeable road base materials or multiple culverts used to help maintain a more natural hydrologic regime (Graf, 2009; Ducks Unlimited Canada, 2014). However, a culvert placed too high, or one that is too small to handle larger flows, or a culvert blocked by debris or a beaver dam can result in water levels rising up-gradient of the road, and the channelized water that exits the culvert may lower the water table below the road (Stoeckeler, 1967; Phillips, 1997). The depth of standing water and depth to the water table are critical environmental variables influencing plant species composition (Andersen et al., 2011; Kapfer et al., 2011), peatland type (Asada, 2002; Pellerin et al., 2009) and tree growth (Lieffers and Rothwell, 1986; Cedro and Lamentowicz, 2011). In addition, mineral rich sediment run-off from a road's surface into a peatland can alter local ion concentrations and change water and soil pH and the site vegetation composition, especially in acidic and ion poor peatlands such as poor fens (Wood, 2007).

A water level increase up-gradient of roads can cause tree death in forested peatlands (Jeglum, 1975) because it reduces soil aeration, substrate temperature and nutrient availability (MacDonald and Yin, 1999). Peatland trees including black spruce (*Picea mariana*) and tamarack (*Larix laricina*) form shallow or adventitious roots to access aerobic soils, but if the soil is inundated for long duration, tree death can occur (Schwintzer, 1978; Reddoch and Reddoch, 2005; Rydin and

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Jeglum, 2006; Calvo-Polanco et al., 2012). Tree dieback up-gradient of a road crossing is common in peatland habitats, and has been studied throughout northern environments including in northern Ontario (Jeglum, 1975), Minnesota (Stoeckeler, 1967; Phillips, 1997), northern Europe (Stoeckeler, 1965), the Boreal Plains (Graf, 2009; Ducks Unlimited Canada, 2014) and the Maritime provinces (Mader, 2014). During the course of this research, authors observed other instances of road-impacted peatlands where tree dieback had occurred.

Dendrochronology uses tree rings as a proxy for environmental changes through time (Fritts, 1976). Tree rings are useful indicators of change when one variable limits tree growth. For example, in arid regions, precipitation typically limits tree growth, whereas in cold regions, temperature during the growing season is critical (e.g. Stokes and Smiley, 1968). Several studies have used tree rings as proxies for hydrological variables such as water table depth (Ferguson and St. George, 2003; Perez-Valdivia and Sauchyn, 2011), lake levels (Bégin, 1999; Meko, 2006) or streamflow (Case and MacDonald, 2003). In peatlands, where trees are generally stunted and slow-growing due to oxygen deficient root zones, depth to water table is the most important factor limiting tree growth (Lieffers and Rothwell, 1987; Linderholm et al., 2002; Moir et al., 2011). In impacted peatlands tree ring analysis can be used to identify the year when changes occurred, and the effects of these changes on tree growth and survival (Cedro and Lamentowicz, 2011).

Previous research has shown that peatland trees are not ideal for dendroclimatic analysis, but could be well-suited for dendrohydrology that uses tree rings to reconstruct hydrologic regimes based on the strong relationship between water levels and variation in tree growth (Fritts, 1976; Watson and Luckman, 2006; Cedro and Lamentowicz, 2008; Linderholm, 1999; Smiljanic et al., 2014). Since the water table in peatlands is typically close to the soil surface, minor disturbances can have a large effect on the water table depth and mask climate signals (Smiljanic et al., 2014). For example, if water levels change due to drainage, or due to inundation such as caused by a plugged culvert, tree growth will change regardless of the climate (Wilmking and Myers-Smith, 2008). Also, climate conditions such as drought that can limit growth in upland trees, will not impact peatland trees in the same manner, because water availability remains high in the root zone (Pepin et al., 2002). In contrast, during drought periods tree growth in peatlands may increase as tree roots have access to a larger unsaturated zone (Dang and Lieffers, 1989). Consequently, it can be difficult to cross-date peatland trees using nearby upland tree chronologies that may be climate-limited. Since a water table near the soil surface in peatlands can limit tree growth (Lieffers and Rothwell, 1986), a narrow tree ring will form when the water table is higher than average, whereas a wide growth ring should form in a year when the water table is lower than average. Tree death can follow sustained periods of inundation (Jeglum, 1975).

This research evaluated the spatial and temporal patterns of water level change in a peatland crossed by a single road in northeastern Alberta. This is a regionally important problem because there is a dense network of roads used to access resource development infrastructure such as steam-assisted gravity drainage oil recovery systems in the oil sands region (Turetsky and St. Louis, 2006; Dunne and Quinn, 2009). Using the principles and techniques of dendrohydrology, tree rings were used as a proxy for water table changes in a poor fen. The objectives of this study were to (1) construct a chronology of living and dead trees in the peatland and (2) use this tree ring analysis to reconstruct the spatial and temporal patterns of hydrological change in the peatland.

2. Site description

The study site is an 8 ha acid fen on a highland, Stony Mountain at ~740 masl, 45 km south of Fort McMurray, Alberta, Canada (56°22′30″N, 111°14′05″W) (Fig. 1). The region has an average annual temperature of 1 °C, and for the period 1945–2007 received an average of 437 mm of precipitation annually (Environment Canada 2014; www.climate.weather.gc.ca). The driest year on record was 1998 with 242 mm of precipitation, and the wettest was 1973 with 675 mm. The average annual temperature was 0.3 °C, the warmest year was 1987 at 3.2 °C, and the coldest 1951 at −2.7 °C. During the period of data collection at the fen (2011–2014), precipitation was higher, and temperatures cooler than the averages for the Fort McMurray airport (Table 1).

The study site, called Pauciflora fen, has a maximum peat thickness of 11 m, a median thickness of 1.6 m, and the groundwater has an average pH of 4.5. The ground is covered by mosses, particularly *Sphagnum angustifolium, S. capillifolium* and *S. magellanicum*. The shrubs *Chamaedaphne calyculata, Rhododendron groenlandicum, Vaccinium vitis-idaea* and *Andromeda polifolia,* as well as *Carex aquatilis* and *Eriophorum* spp., *Smilacina trifolia* and *Equisetum* spp. are abundant. Tree cover is discontinuous and dominated by stunted black spruce and some *Larix laricina*, with tree densities ranging from 0.16 to 2.30 trees/m^2. More than 80% of trees within 220 m up-gradient of the road are dead.

Construction of Range Road 90A, that crosses the fen perpendicular to the direction of water flow, began in 1977 to access a communications tower built just east of the fen. A single culvert 0.92 m in diameter was installed under the road on the west side of the fen, 2 m below the road surface and approximately 0.5 m below the current peatland surface. A perennial pool occurs up-gradient of the culvert in a depression likely excavated during road construction. Material from this excavation was placed immediately up-gradient of the road and adjacent to the pool, forming a mound that is vegetated by plants characteristic of the surrounding upland. Vegetation down-gradient of the road follows a hydrological and topographic gradient from dry in the east, with a dense cover of *R. groenlandicum*, *Chamaedaphne calyculata* and *Rubus chamaemorus* on the shrub level, with *Sphagnum angustifolium* the dominant ground cover, and some dense stands of black spruce in the margin, to low and wet near the culvert in the west with high cover of *Carex aquatilis, C. canescens* and *Betula pumila*. Tree density down-gradient of the road range from 2.48 trees/m^2 on the eastern side to 0.18 trees/m^2 near the culvert. A small area down-stream of the culvert opening is inundated during spring snow melt, and is vegetated by *Typha latifolia*. During wet periods, outflow is visible as a stream that continues north from the fen and down Stony Mountain.

3. Methods

3.1. Field and lab methods

Living and dead black spruce trees were sampled in the peatland, up- and down-gradient of the road. Trees at least 2 m apart from adjacent trees were chosen to avoid intraspecific competition. Where possible, larger and presumably older trees were targeted to get longer growth increment records and increase the length of the chronology.

Trees were cut down to collect a full cross sections for analysis. At each tree, the sample number, species, GPS coordinates, height, diameter at base, mortality, general physical characteristics, depth to water table at the nearest groundwater well, substrate type and understory vegetation were noted (Speer, 2010). Fifty-two trees were sampled, including 32 dead and 20 living trees. During sample analysis, several samples had to be discarded due to wood rot. Forty-two trees, 23 dead and 19 living, were used in the final analysis.

After a period of air-drying, the discs were dried in an oven at 105 °C for 24 h. The sanded samples were digitally scanned at 1200–4800 dpi using an Epson Expression 10000 XL scanner. Ring widths were measured on a computer using the program CooRecorder (version 7.7). This program creates a ring width file for the program CDendro (version 7.7) (Cybis Elektronik, 2013).