Journal of Environmental Management 197 (2017) 258–264

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Re-establishment of hummock topography promotes tree regeneration on highly disturbed moderate-rich fens

Victor J. Lieffers [a, *], Richard T. Caners [a, b], Hangfei Ge [a]

[a] Department of Renewable Resources, University of Alberta, Edmonton, AB T6G 2H1, Canada
[b] Royal Alberta Museum, Edmonton, AB, Canada

ARTICLE INFO

Article history:
Received 14 December 2016
Received in revised form
22 March 2017
Accepted 1 April 2017

Keywords:
Peatland
Restoration
Microtopography
Mounding
Conifer
Erosion

ABSTRACT

Winter exploration of oil sands deposits underlying wooded fens mostly eliminates the hummock-hollow topography on drilling pads and the ice roads leading to them, after their abandonment in spring. Recovery of black spruce (*Picea mariana* (P. Mill.) B.S.P.) and tamarack (*Larix laricina* (Du Roi) K. Koch) on these disturbed peatlands is thought to depend on the recovery of hummock topography. In late winter, numerous large blocks of frozen peat (1.5 × 1.5 m) were lifted out of the flattened drilling pads and positioned beside their excavated hollows; this was done on six temporary pads. Four years later, the condition of the mounds and the regeneration of conifers from natural seed dispersal were assessed on these elevated mounds compared to adjacent flattened areas of the pads. Then, conifer seedling density was more than five times higher on elevated spots than the mostly flat, flood-prone areas between them, and seedling density was positively related to mound height and strength of seed source. Higher mounds tended to have larger seedlings. Mounds on some of the pads were heavily eroded down; these pads had peat with higher humification, and operationally these pads were also treated in late winter when peat was thawing and fractured into pieces during mound construction. Developing a large volume of elevated substrate that persists until natural hummock-forming mosses can establish is thought necessary for tree recruitment and the recovery of the habitat for the threatened woodland caribou of this region.

1. Introduction

Canada has 1.24×10^6 km^2 of peatlands and much of the northern half of Alberta is covered by peatland (Vitt et al., 1997). In many regions, fens blanket half of the landscape and have developed over the last 7000 years from pond loci and then by paludification and lateral expansion (Halsey et al., 2000; Bauer et al., 2003). Wooded moderate-rich (WMR) fens are the most common peatland type in this area and are characterized in part by hummock-hollow microtopography (Vitt, 1994), where hummocks, formed by mosses such as *Sphagnum fuscum* (Schimp.) Klinggr., are 30–50 cm above the usual water table and the hollows usually have standing water. These fens have a tree layer that is dominated by black spruce (*Picea mariana* (P. Mill.) B.S.P.) and tamarack (*Larix laricina* (Du Roi) K. Koch) and their roots are confined to positions above the usual water table (Lieffers and Rothwell, 1987).

Alberta has large tracts of deeply buried bitumen reserves that underlie 142,000 km^2 of Alberta (Government of Alberta, 2016). The exploration of the oil sands deposits by *in situ* methods places oils sands exploration (OSE) drilling pads at a density of up to five pads per km^2, even across wooded fens. In exploration areas across peatlands, a network of temporary OSE ice drilling pads, and associated winter ice roads for access, are established (see details below). Caners and Lieffers (2014) surveyed 10-year old abandoned OSE pads that were formed by this freezing-in processes and showed that most pads lose the hummock-hollow microtopography typical of WMR fens. The highest surfaces on most abandoned pads are usually within 8 cm of the water table and the dominant vegetation is aquatic sedges. As roots of northern conifers such as black spruce and tamarack cannot tolerate extended periods of anaerobic conditions (Conlin and Lieffers, 1993), trees germinating close to the water table height will experience periods of anaerobic rooting conditions. Thus, restoration treatments to produce acceptable growing sites for conifer seedlings on such heavily disturbed peatland pads will likely need substrate positions to be well above the water level (Pearson et al., 2011). This needs

* Corresponding author.
E-mail address: victor.lieffers@ualberta.ca (V.J. Lieffers).

http://dx.doi.org/10.1016/j.jenvman.2017.04.002
0301-4797/

testing.

In general, most of the literature on the recovery of fen ecosystems after disturbance has focussed on re-establishment of peatland vegetation following drainage for forestry (Laine et al., 2011) or drainage plus peat removal and its resulting shifts in peatland chemistry and prolonged loss of peatland vegetation (see reviews by Grand-Clement et al., 2015; Lamers et al., 2015). Here the application of donor plant diaspores is often used to establish peatland mosses and other vegetation on the base substrates in mined-out areas (Graf and Rochefort, 2008; Pouliot et al., 2011). Redevelopment of microtopography has been identified (Triisberg et al., 2014) as important in restoration of peatland vegetation. Recovery of frozen-in OSE pads and roads on fens, however, has a different starting point than most other disturbed fens; lack of microtropography and flooding might be the critical factors for species re-establishment, instead of lack of propagules and changes in peatland chemistry in highly disturbed drained fens.

The woody vegetation on these WMR fens provides key habitat characteristics for the threatened Woodland Caribou (*Rangifer tarandus caribou*) of this region (Species at Risk Act, Schedule 1; Environment Canada, 2012). Coniferous trees are thought to slow the movements of people (Pigeon et al., 2016) and predators into these habitats, and trees provide substrate for arboreal lichens, a food source for caribou (Environment Canada, 2012); thus trees are a focus of recovery efforts for OSE pads and the thousands of kilometers of seismic exploration lines across peatlands (van Rensen et al., 2015). Recovery of trees on such disturbed fens, however, is slow (Lee and Boutin, 2006; van Rensen et al., 2015). The natural recovery of conifers on peatlands is promoted by minor disturbance to substrates and more elevated microsites (Morris et al., 2009) and the amount of seed cast (Groot and Adams, 2005). Seed of tamarack and spruce may readily spread 70 m into disturbed areas from living trees on the edges (Greene and Johnson, 2000), but it is not clear if this would be the case with the smaller trees of peatlands. As these peatlands are remote and access for planters during summer months can be treacherous, natural regeneration as opposed to planted trees would be desirable.

In this study, we examined the effectiveness of artificial mound formation to promote the natural regeneration of trees on highly disturbed fens. Assessments were made four to five years after mounding, on six OSE drilling pads on WMR fens. We linked regeneration success to the height of mounds, the density and size of adjacent seed trees and peat characteristics among pads. As peat surfaces without living mosses and vascular plants are subject to erosion (Parry et al., 2014; Shuttleworth et al., 2015), we also assessed if artificial mounds were sustained over time.

2. Methods

This study was conducted in a large fen complex, *ca.* 40 km southeast of Conklin, Alberta (central study drilling pad 2-32: 55° 26′ 52.3″ N, 110° 53′ 23.9″ W), within the Central Mixedwood Natural Subregion of the Boreal Forest Natural Region (Natural Regions Committee, 2006). This peatland complex is characterized by aeolian sand outcrops, and variation in peatland type (Grootjans et al., 2012); elevational changes and water flow patterns are easily visible from aerial and global mapping (see attachment). Sites were categorized as wooded moderate-rich fens based upon surface water pH 5.5 to 7, moderate alkalinity (Table 1) and indicator bryophytes, including minerotrophic *Sphagnum* species, *Tomentypnum nitens* (Hedw.) Loeske, *Hamatocaulis vernicosus* (Mitt.) Hedenas, and *Brachythecium mildeanum* (Schimp.) Schimp. ex Milde (Vitt, 1994; National Wetlands Working Group, 1997). Climate is continental: mean daily temperature is 2.1 °C and mean total annual precipitation is 421 mm (Environment Canada, Cold Lake A meteorological station; http://climate.weather.gc.ca/climate_normals/index_e.html).

We examined six temporary drilling pads (up to 10 km apart, each approximately 0.7 ha) that were constructed by Devon Energy Corporation in winter 2011/2012 in their regular operations to assess the depth and quality of bitumen reserves. Starting in early winter, trees were cut and either mulched, or pushed (windrowed) to the side of the pad. Using freezing-in techniques, the snow and remaining vegetation including tree stumps and most of the root systems were smoothed, compacted and some had water added to allow greater penetration of frost into wet peat. The pads, and roads leading to them, became strong enough to support heavy machinery and drilling rigs; rigs were removed soon after drilling.

After rig removal, the frozen surface peat was sliced 70 cm deep in a grid pattern (1.5 × 1.5 m squares) with a single tooth shank ripper mounted on a bulldozer (D6 Caterpillar). A tracked excavator (Komatsu PC200LC) fitted with a standard bucket and thumb lifted out the frozen squares (35–60 cm thick) and repositioned these on the surface adjacent to their excavated holes with the original upper peat layer upright (Fig. 1a). One of the pads (6–5; numbers relate to a contraction of the mapping description) was mounded on February 4, 2012. In this colder period, large blocks of peat were lifted out intact (Fig. 1a). The remainder of the pads were mounded in early to mid March (Table 1). At this later time, there was some thawing and peat usually fractured into pieces during mound formation, except at 8–28 (Appendix 1). The mounds were left to regenerate naturally from tree seed dispersed by wind from adjacent stands (Fig. 1).

In either the fourth or fifth growing season, we sampled 10 mounds selected systematically across each of the six pads. Circular plots with a radius of 1.78 m (10 m^2) centred on mounds; the 10 m^2 plot size is used in the regulatory surveys used for assessing regeneration. Near each mounded plot a second non-mounded plot was established in the adjacent area. In each of these 20 plots per pad, the number of seedlings of each tree species was counted and the height of tallest seedlings of each tree species. At each pad, peat samples were collected from 10 cm below the upper surface near the edge of four mounds. The degree of decomposition/humification of each peat sample was assessed using a visual analysis of the peat water and the textural state of the plant material forming the peat. This information was used to scale humification (H) using the von Post classification, graded from 1 to 10 (Hobbs, 1986), where H_1 meant that the moss and plant material was mostly intact and H_{10} it was highly decomposed. We visually assessed the average height of the canopy conifer trees on four edges of the pad using a Biltmore stick and the density of seed trees in a 20 m ring around the pad was estimated visually by tree counts from 10 × 10 m virtual plots on aerial photographs (scaled by known dimensions). Using these quick estimates we ranked pads in terms of their potential seed supply; the mean rank of tree density and the mean height of the trees were averaged to obtain pad rank – analogous to strength of seed source assessed by basal area by Greene and Johnson (2000). Seed crops of tamarack and black spruce appeared to be small to moderate in the years from 2012 to 2015. In each mounded plot, the height of the mound above the substrate of the average surrounding area was measured using a horizontal bar and vertical ruler, set perpendicular to each other by a hand level. Pads 6–5 and 3–33 were assessed in late July of 2015, and pads 8–28, 7–32, 2–32 and 15–29 in late June of 2016. To standardize the presentation of seedling height, in 2016 seedlings were measured at the bud scale scar formed in 2015, i.e., at four years growth.

Water samples were obtained from these six sites, collected from natural pools near the centre of pads in 1 L Nalgene bottles. These were refrigerated within a few hours of collection and then frozen prior to analysis by the Natural Resources Analytical Laboratory (NRAL) at the University of Alberta, for pH, electrical