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Research article

Vegetation community composition in wetlands created following oil sand mining in Alberta, Canada

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ABSTRACT

Reclaiming wetlands following open pit mining for industrial oil sand extraction is challenging due to the physical and chemical conditions of the post-mined landscape. The aim of our study was to examine and compare the influence of oil sands process water (OSPW) and material (fine fluid tails or FFT) on the plant community composition of created wetlands. Compared to created-unamended and natural wetlands, the created wetlands amended with OSPW and/or FFT (created-tailings wetlands) had significantly higher water salinity, conductivity, dissolved oxygen concentration and lower oxidative-reductive potential. Water chemistry parameters of created-unamended did not differ significantly from those of natural wetlands. The sediment of created wetlands had significantly less moisture, total nitrogen, and organic content than the natural wetlands. The application of OSPW/FFT in created wetlands will likely lead to initial vegetation composition atypical of natural regional wetlands. For the objective of reclaiming vegetation composition to the status of natural regional wetlands, unamended wetlands were the best reclamation option, based on the physical and chemical parameters measured. Despite being the favored reclamation option, created-unamended wetlands' physical and chemical characteristics remain atypical of natural wetlands. Most significantly, the basin morphometry of created wetlands was significantly different from that of naturally-formed wetlands in the region, and this appears to partly explain difference in vegetation composition. We also demonstrate that species richness alone is not a useful measure in wetland monitoring. Instead, plant community composition is a better indicator of wetland conditions.

1. Introduction

The province of Alberta is known for its oil sands deposits and associated extraction activities. The Oil Sands Administrative Area (OSAA) covers 142,200 km^2 of northern and eastern Alberta (Vitt and Bhatti, 2012). It is estimated that ultimately, approximately 3,000 km^2 of oil sands post-mined landscape will need to be reclaimed of which approximately 660 km^2 will be returned to wetlands (Rooney et al., 2012).

Reclaiming wetlands is challenging due to the physical and chemical characteristics of the post-mined landscape. Oil sands industries use an open pit mining technique that entails the complete removal of the earth's surface layers, to a depth of 70 m in some areas, to provide access to the subsurface bitumen deposits (Alberta Environment, 2011). This newly exposed layer of soil creates challenging conditions for effective reclamation due to its elevated salinity, a relic of ancient inland sea beds, limited amounts of organic matter and an absence of viable propagules (Larney and Angers, 2012).

Water is used to separate bitumen from its sand and clay matrix. Due to Alberta's no-net- discharge policy, the water used to extract bitumen is recycled numerous times, increasing its salinity, before being stored in settling basins (also called tailings ponds). Sodium hydroxide is occasionally added to the separation water to improve the efficiency of bitumen extraction, which additionally increases the water salinity (Allen, 2008). Such extraction methods produced approximately 262,000 m^3 of tailings per day in 2010. Water

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storage in settling basins and the tailings ponds' management constitutes one of the main environmental challenges facing the oil sands industry (Alberta Environment, 2011; Schindler, 2014). Forecasted expansion of oil sands mining is expected to produce tailings volumes that will exceed 1.1 billion m^3 by 2020 (Pembina Institute, 2013; Schindler, 2014). Fluid Fine Tailings (FFT) are slurries of process-water, tailings sand, silt, clay and soluble compounds such as salts, naphthenic acids (NAs) and polycyclic aromatic hydrocarbons (Schramm et al., 2000; Fedorak et al., 2003; BGC, 2010). NAs are acutely toxic to aquatic biota (Headley and McMartin, 2004). Tailings constituents are divided into two broad categories representing 1) the solid phase in oil sands process material (FFT) resulting from the sedimentation and consolidation of fine tailings in settling basins (see Fedorak et al., 2003 for more details) and 2) the liquid phase in oil sands process water (OSPW)) resulting from the waters released from tailings sediments during consolidation (Alberta Environment, 2011).

To understand the potential effects of different amendments, such as FFT on biota, the mining companies constructed pilot wetlands, shallow open waters and ponds. Additionally, created-tailings wetlands result directly or indirectly from runoff or tailings pond seepage and are often amended with FFT as substrate. In other words, the created-tailings wetlands are either built on FFT substrates or are filled with OSPW. Other pilot wetlands are referred as created-unamended. Created-unamended wetlands rest on the native mineral substrate, contain fresh surface water, and have not received FFT or OSPW.

In addition to chemical conditions present in the reclaimed landscape, physical conditions such as hydrology and basin morphology must be finely tuned to support the biological and ecological requirements of aquatic plants (Olson and Barker, 1979; Olson, 1981; Rumble, 1989; Raab and Bayley, 2012; Rooney and Bayley, 2011). The steep basin slopes observed in many oil sands created wetlands represent a physical characteristic that may lead to compromised stands of aquatic vegetation (Raab and Bayley, 2012). Wetlands created with steep basin slopes usually had restricted littoral zones with little or no dewatered period (Rumble et al., 1985; Zampella and Laidig, 2003). Water depth and its permanence within the zone of wetland vegetation influences light penetration and oxygen availability, which in turn influences, for example, the photosynthetic capability of submerged vegetation, and the rate of organic matter accumulation and decomposition (Olson, 1981).

The aim of this study is to examine whether the vegetation of created wetlands is depauperate relative to the natural wetlands of the region thereby clarifying the need for benchmarks to determine acceptable reclamation endpoints. More specifically, this study's objectives were to 1) characterise and compare sediment, water chemistry and physical characteristics of the two created wetland types relative to natural wetlands, 2) define vegetation patterns in each wetland zone (i.e. submersed aquatic vegetation (SAVZ), emergent (EZ) and wet-meadow (WMZ) zones), 3) determine how vegetation composition differs among wetland types, and 4) correlate differences in community composition to water and sediment differences among wetland types.

2. Methods

2.1. Research site

This study was conducted in the Fort McMurray region of northeastern Alberta on and around the mining leases of Syncrude Canada Ltd. and Suncor Energy, Inc (Fig. 1). The oil sands region of Alberta is located in the north-west part of the boreal region of Canada (see Brandt (2009) for an overview of the North American boreal zone). A total of 51 wetlands were selected of which 16 were natural, 16 were created-tailings, and 19 were created-unamended. Natural and created wetlands were randomly selected in approximate proportion to their relative abundances throughout the study area. Distances between the selected wetlands were maximised to minimise spatial autocorrelation and exchange of biota or abiotic influences.

The natural wetlands selected were typical of the marsh-like shallow, open water wetlands found in the boreal plain ecozone (see Locky et al., 2005 for more details). Shallow, open water wetlands are characterised at their deepest portion by a continuous and unshaded open water zone supporting submersed and floating aquatic vegetation (ESRD, 2015). Wetlands were defined as "natural" if they met three criteria: 1) origins were independent of anthropogenic intervention, 2) past and present internal and surrounding conditions showed no major evidence of anthropogenic disturbance, and 3) they were permanent and contained at least three vegetative zones (i.e. SAVZ, EZ and WMZ). All natural wetlands selected exhibited evidence of past or present beaver activities.

The created wetlands selected were shallow, open water wetlands and ponds. Ponds are small waterbodies (less than 200,000 m^2) and were distinguished from other shallow open waters by being more than 2 m deep (ESRD, 2015). A created-unamended wetland was defined by: 1) anthropogenic origins, 2) no direct or indirect addition of OSPW and or FFT, 3) supporting the three vegetative zones described above for natural wetlands.

Created-tailings wetlands differed from created-unamended wetlands by 1) the direct or indirect addition of OSPW and or FFT during their creation and 2) being located solely within the post-mined landscape.

With the exception of one 7-year old wetland, all created wetlands were over 15 years old. Although natural wetlands ages were unknown, most were believed to be >1000 years old (Raab and Bayley, 2012). The examination of historical aerial photos ensured that all natural wetlands studied were present on the landscape in 1957. Mean annual precipitation in the Fort-McMurray region is 456 mm, with an average temperature of 13.2 °C in summer and −13.5 °C in winter (Strong and Leggat, 1992).

2.2. Data collection

Field data were collected during the period of peak aboveground standing crop from mid to late August in 2008–2012. To capture all the vegetation and environmental variables' variation, each sampled wetland was visually classified into three zones: 1) SAVZ, 2) EZ, and 3) WMZ. In this study, the SAVZ was composed of the open water area with a maximum depth of 2 m and qualified by the presence of only submerged and/or floating vegetation. The EZ was characterised by having submersed and emergent vegetation concentrically distributed in a fringe around the SAVZ. The WMZ was characterised as having water-saturated (hydric) soil and very shallow (<2 cm) water depth.

Prior to sampling, reference to an aerial photograph of each wetland was used to divide each wetland into four quadrants of approximately equal size. We positioned six transects radiating outward from the centre of each wetland following a stratified random design. Within each of the four quadrants we randomly positioned one or two transects such that each transect crossed the three wetland zones perpendicularly. We measured zone width along each transect.

2.2.1. Vascular plant data

Along each transect and within each zone, we assessed vegetation in one randomly-positioned one-m^2 plot. In total, we