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Impacts of oil sands process water on fen plants: Implications for plant selection in required reclamation projects

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ABSTRACT

Fen plant growth in peat contaminated with groundwater discharges of oil sands process water (OSPW) was assessed in a greenhouse over two growing seasons. Three treatments (non-diluted OSPW, diluted OSPW and rainwater) were tested on five vascular plants and four mosses. All vascular plants tested can grow in salinity and naphthenic acids levels currently produced by oil sands activity in northwestern Canada. No stress sign was observed after both seasons. Because of plant characteristics, *Carex* species (*C. atherodes* and *C. utriculata*) and *Triglochin maritima* would be more useful for rapidly restoring vegetation and creating a new peat-accumulating system. Groundwater discharge of OSPW proved detrimental to mosses under dry conditions and ensuring adequate water levels would be crucial in fen creation following oil sands exploitation. *Campylium stellatum* would be the best choice to grow in contaminated areas and *Bryum pseudotriquetrum* might be interesting as it has spontaneously regenerated in all treatments.

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1. Introduction

An unprecedented expansion of oil sands extraction has been underway in northwestern Canada over the past two decades. Open pit mining completely removes large parts of the landscape that was originally made up of 50% wetlands (of which 90% were peatlands; Vitt et al., 1996). In the province of Alberta alone, more than 600 km^2 have been disturbed by open pit mining activities (Government of Alberta, 2011). During the extraction process large volumes of wet process-affected tailings are produced. They contain oil sands process water (OSPW) with sand, slits and clays in suspension as well as soluble organic chemicals such as naphthenic acids (NAs), ammonia, heavy metals and salts (Bott, 2010). The material that cannot be recycled must be stored in tailings ponds (more than one billion m^3 in the province of Alberta; Han et al., 2008). Oil companies are legally bound to reclaim post-mined landscapes to an improved or equivalent capacity of the original ecosystem (OSWWG, 2000) and a part has to be reclaimed back to wetlands.

Until recently, marshes have been the focus of reclamation projects as they are able to develop spontaneously in poorly drained sections of disturbed landscapes and hydrology is easier to manage than peatlands (Harris, 2007). However, peat-forming wetlands are recognized to be a keystone ecosystem for the retention and regulation of water in boreal plains of northern Alberta (Ferone and Devito, 2004). Because of the low hydraulic conductivity, the thermal isolative properties, and the diplotelmic structure of peat in most cases (acrotelm/catotelm), boreal peatlands increase water storage across the landscape by remaining wet throughout the year (Fraser et al., 2001; Price et al., 2003). Boreal peatlands are an important component of the carbon cycle. These constantly saturated, cold conditions are ideal for sequestration and long-term storage of carbon (Strack, 2008). As fen peatlands are the dominant wetlands of northwestern Canada, fen reclamation is now required. So far, the creation of fens within landscapes dominated by tailings sand structures and influenced by OSPW is an untested concept (Price et al., 2010).

Salts and NAs concentrations in OSPW may adversely affect the ecology of species of the system to be reclaimed as they could increase water stress and be toxic for organisms (Apostol et al., 2004). Soil water salinity in oil sands reclaimed wetlands is extremely variable (335–2881 mg L^{-1}; Purdy et al., 2005; Renault et al., 1998; Trites and Bayley, 2009), which covers the large range between non-saline (<1340 mg L^{-1}) and slightly saline landscapes (<3350 mg L^{-1}; Purdy et al., 2005). Soil salinity of >2680 mg L^{-1} is

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believed to be detrimental to plants (Close, 2007; Renault et al., 1998). NAs are naturally found in surface waters of the north-eastern Alberta oil sands region (up to 4 mg L^{-1}), but they are found in much higher concentrations in OSPW after oil extraction (around 40–120 mg L^{-1}; Herman et al., 1994). NAs in OSPW are recalcitrant and degrade slowly (half life of 44–240 days; Han et al., 2008) and they disrupt respiration by altering the external membranes of living organisms (Armstrong et al., 2008). In addition, combined effects of salinity and NAs could be greater than the sum of the effects of each one alone (i.e. potentiation; Walker et al., 2006). Attenuation, degradation and transport of sodium and NAs in peat are still not well known. However, studies have shown that these contaminants are strongly adsorbed by organic matter (Janfada et al., 2006) and their transport through peat is delayed by sorption and by diffusion into water immobilized in peat matrix (Rezanezhad et al., in press).

Responses of boreal forest and marsh species to OSPW have been relatively well studied (Apostol et al., 2004; Bendell-Young et al., 2000; Crowe et al., 2001; Renault et al., 1998), but studies which examine the effects of OSPW on fen vascular plant and moss growth are rare. Results from wetland species are encouraging. Oil sands reclamation wetlands can support healthy aquatic plant communities, even if plant assemblages are dissimilar to reference natural wetlands (Rooney and Bayley, 2011). OSPW increased photosynthetic rates compared to fresh water treatment for *Typha latifolia* L. and *Trifolium hybridum* L. and similar growth rates were observed for *T. latifolia* and *Phalaris arundinacea* L. (Bendell-Young et al., 2000; Crowe et al., 2001). In addition, biomass of *T. latifolia* was greater when growing in reclaimed wetlands with tailings materials than in wetlands with fresh water and peat (Foote and Hornung, 2007). Similarly, whole transplants of common species in fen (*Carex aquatilis* Wahlenb., *Carex atherodes* Spreng., *Schoenoplectus maritimus* (L.) Lye and *Triglochin maritima* L.) had relatively good survival rates in wetlands influenced by tailings materials (Trites and Bayley, 2008). However, germination rates are negatively affected by OSPW and that could be a cause for the diminution of biodiversity found in wetlands receiving OSPW (Crowe et al., 2002). Gramineae and Cyperaceae do possess some mechanisms to counteract salinity effect (Albert and Popp, 1977; Cooper, 1982; Gorham et al., 1980). But, both salts (osmotic stress) and NAs (adhesion to plant roots) present in OSPW can interfere with water relations within plants (Armstrong et al., 2008; Kamaluddin and Zwiazek, 2002; Munns and Termaat, 1986). To our knowledge, no study has directly examined the moss responses when influenced by OSPW. Acquiring this information is crucial as mosses play an important role in peat formation.

Understanding salinity and NAs effect on the different key fen species is essential for the selection of tolerant native species before implementation of fen creation in a post-disturbed landscape. We conducted a greenhouse experiment over two growing seasons to test the capacity of five vascular plants and four mosses to grow in peat contaminated with OSPW. This study simulated a realistic scenario of contaminated groundwater discharge and watering regime of uncontaminated rainwater. As wetlands species are able to tolerate OSPW, it was hypothesized that fen vascular plants would tolerate a certain degree of contamination, but that mosses would be especially sensitive to contamination.

2. Materials and methods

2.1. Greenhouse installation

Mosses and vascular plants were grown in peat substrate over two growing seasons in greenhouse complexes of Laval University (Quebec City, Canada). A randomized block design testing three different treatments of OSPW was replicated five times. Treatments were the following: a) non-diluted OSPW (approximately 54 mg l^{-1} of NAs and 569 mg l^{-1} of Na); b) diluted OSPW (approximately 40 mg l^{-1} NAs and 400 mg l^{-1} Na); and c) rainwater (control treatment). A diluted treatment was included because OSPW leaching from the tailing ponds will most likely be diluted with uncontaminated groundwater in reclaimed areas. OSPW was obtained from the Suncor Energy oil sands operation in Fort McMurray, Alberta and was shipped to Quebec City in clean oil barrels.

The experiments were carried out in plastic tubs measuring $61 \times 41 \times 42$ cm. Fen peat from an undisturbed moderate-rich fen near Fort McMurray was shipped to Quebec City to fill plastic tubs of three blocks. For the other two blocks, industrial horticultural peat from Québec was used. To increase the pH in these two blocks from *circa* 4.3 to circumneutral, 5 g of lime per 100 L of peat were added. The implementation of irrigation treatments was achieved by a system designed to discharge groundwater within a 10 cm layer of sand at the base of the tubs which could then move upward into 30 cm of overlying peat. Peat was saturated and tubs were periodically watered with rainwater until OSPW addition began.

After a period of 70 days for plant establishment (see below), tubs were completely drained for 24 h and OSPW was introduced at the base of each tub until a water table of −15 cm was achieved. OSPW was pulled upward by evapotranspiration and the water level in the supply reservoir was reset every two days to −15 cm by filling it to the prescribed level with OSPW. A supplementary above-ground watering was done every two weeks to simulate some rains. For the first 180 days, watering was adjusted to normal precipitations in Fort McMurray region during growing seasons (Table 1). Watering was considerably reduced after that, as well as during the second growing season, and around 1.5 L of rainwater was added atop of each tub (equal to around 10 mm of rain per month). The watering amounts were reduced to simulate periods of drought as rainfall in Fort McMurray is extremely variable. Mosses were misted with a spray-bottle atomizer approximately three times per week to ensure a just enough moist carpet (too dry = no growth, too wet = fungi contamination) and protect against the potential bias of moss desiccation vs. moss contamination. Between growing seasons, tubs were moved outside during winter (December to February). See Table 1 for a summary of the growing conditions during the entire greenhouse experiment.

2.2. Plant establishment

All tested species are common in fens of the oil sands region (Chee and Vitt, 1989): *Calamagrostis stricta* (Timm) Koeler, *Carex atherodes*, *Carex utriculata* Boott, *Trichophorum cespitosum* (L.) Hartm. and *Triglochin maritima* as vascular plant species, and *Aulacomnium palustre* (Hedw.) Schwägr., *Campylium stellatum* (Hedw.) C.E.O. Jensen, *Scorpidium scorpioides* (Hedw.) Limpr. and *Tomentypnum nitens* (Hedw.) Loeske as moss species. Common species were chosen as these are the most likely species to be used in fen creation in post-disturbed areas following oil sands exploitation and, in some cases, are believed to be tolerant to saline conditions (as *C. stellatum*).

Vascular plant material was collected in natural moderate-rich fens located approximately 50 km northwest of Fort McMurray, Alberta in October, 2008. Plants were stored at 4 °C for approximately three months until their transplantation into plastic tubs. Each tub was separated in two to accommodate the testing of two

Table 1
Summary of growing conditions in greenhouses throughout the different phase of each growing seasons of the experiment.

Growing season	Duration (days)	Simulated precipitation (mm/month)	Photoperiod (hours)	Day/night temperature (°C)	Day/night humidity (%)
1st – Establishment phase	70	40–70[a]	16	19/10	50/60
1st – With OSPW	110	40–70[a]	16	19/10	50/60
1st – With OSPW	90	10	16	19/10	50/60
Winter period	90	–	0[b]	−8[c]	–
2nd – Establishment phase	21	10	16	20/16	60/72
2nd – With OSPW	115	10	16	20/16	60/72

[a] Adjusted to normal precipitation in Fort McMurray region during summer months (Environment Canada, 2011).
[b] Under snow.
[c] Mean temperature for the wintering period (for Québec City, between November 1st 2009 and January 26th 2010).

species per tub (half of a tub was considered an experimental unit). According to species characteristics, between four and ten individuals of each species were transplanted within a tub half. Mosses were collected in a rich fen near Bic-St-Fabien, Québec, during fall of 2009. We took the first 5–10 cm of the moss carpet and stored them in plastic bags at 4 °C until the start of the experiment. For mosses, a tub half was separated in four (each part was considered as an experimental unit). Moss fragment for a given species were thus reintroduced on a quarter of an experimental unit (tub half) and covered around 25% of the available area at the reintroduction moment. Seventy days were given to vascular plants and mosses to be established before OSPW was introduced. As some vascular plants did not survive the transplantation (dead before OSPW addition), new individuals were transplanted at the end of the first growing season when OSPW addition was stopped for the winter period.

During the first growing season, an initial vegetation assessment was carried out during the days just before the addition of OSPW as a benchmark against which to assess subsequent changes. The other assessments were 70, 140 and 200 days after the start of irrigation with OSPW. A second above-ground initial vegetation assessment was carried out 21 days after the start of the second growing season; thus, after a simulated winter period of three months and just before adding OSPW. The others were done 35, 80 and 115 days after calibration assessment in the second growing season.

During these assessments, a plant health index was noted by species (vascular plants and mosses). The plant health index ranged from 7 to 1: 7 = 100% healthy (100% green), 6 = 1–10% dead (1–10% with yellow or brown leaves), 5 = 10–20% dead, 4 = 20–40% dead, 3 = 40–70% dead, 2 = 70–99% dead and 1 = 100% dead (100% with yellow or brown leaves). For the vascular plant species, number of leaves per plant (reconsidered later as number of leaves per experimental unit) as well as length of their longest shoot (from the base to the end of green part) was measured for each individual plant during the first growing season. For *Trichophorum cespitosum*, during the second growing season, plants were often too dense to measure each plant individually. In those cases, measurements were done for 10% of individuals (with a minimum of ten individuals) systematically chosen across the experimental unit. Numbers of living and dead individuals were noted in both growing seasons. At the end of both growing seasons, the above-ground biomass of all vascular plants was collected. Below-ground biomass of vascular plants was also estimated for non-diluted OSPW and rainwater treatments after the second growing season. Biomass for all plants was dried at 40 °C for 3 days and weighted to the nearest 0.00 g. For mosses, percentage cover of each species was also visually estimated. Finally, after each vegetation assessment, 1–2 g of plant tissues of the above-ground parts of each species (vascular plants and mosses) was sampled for sodium (Na) and potassium (K) analyses (by spectrophotometry, with an ICP Optima 4300 DV from Perkin–Elmer Inc.), two important elements in cell salt control (Cooper, 1982).

2.3. Statistical analyses

Above-ground biomass, plant health index, number of leaves per unit and length of the longest shoot were analyzed using the procedure Mixed available in SAS software (version 9.1; SAS Institute Inc., Cary, NC, USA) to enable a repeated measure analysis. In the case that the interaction among days since OPSW addition and OSPW concentration was significant; data was then analyzed separately for each time step using the GLM procedure of SAS software. Other variables (cover, below-ground biomass, and number of living or dead plants) were analyzed in ANOVAs using the GLM procedure of SAS software. Protected LSDs (Least Significant Differences) were run if a treatment effect was significant. All analyses were done separately for each species as growth form and plant development differ between species. Significant probability levels were set to $\alpha = 0.05$. All data were tested for homogeneity and normality and no transformation was needed. All values in results section will be expressed as mean ± SE.

3. Results

3.1. Vascular plant species

There was generally no difference among treatments for plant health index, maximum length and number of leaves per unit for most species. After both growing seasons, there was a slight decline for plant health index towards the end of the season (plant health index = 4 or more, that means 60–80% alive or more; $P < 0.01$ for effect of days since OSPW addition). An exception concerned the health index of *Carex utriculata* that stayed stable in the second growing season ($P = 0.73$ for effect of days since OSPW addition). Species reached their maximum length somewhere during the mid-season and then decreased until season end ($P = 0.02$ or less for effect of days since OSPW addition). Number of leaves per unit increased over the course of both growing seasons (all $P < 0.01$ or less for effect of days since OSPW addition).

Two species showed differences between treatments, both during the second growing season. *Trichophorum cespitosum* was always in better health in presence of rainwater than in presence of non-diluted OSPW (at the end; index of 5.0 ± 0.5 vs. 3.3 ± 0.7; Fig. 1A). Plant health index of *Triglochin maritima* changed less rapidly through time and length of the longest shoot increased more quickly in presence of OSPW than in presence of rainwater (at the end: mean index of 4.7 ± 0.2 and mean length of 47 ± 3 cm for non- and diluted OSPW, and index of 3.5 ± 0.2 and length of 30 ± 5 cm for rainwater; Fig. 1B and C).

A significant effect of irrigation treatment ($P = 0.01$) was found only for the above-ground biomass of *Carex atherodes*: 3.7 times more biomass for the first growing season and 1.8 more for the second growing season under non-diluted OSPW treatment than under rainwater (Fig. 2A). Below-ground biomass was not significantly different under non-diluted OSPW and rainwater for all species (all $P > 0.23$; Fig. 2B). Only few individual vascular plants died throughout experiment, but that was not linked to irrigation treatment (all $P > 0.16$). Number of living plants was more variable in the second growing season (between 5 ± 0.3 for *T. maritima* and 78 ± 15 for *T. cespitosum*) but no difference was found among treatments (all $P > 0.26$).

3.2. Moss species

Treatments did not affect plant health index of mosses even if health decreased over the course of the first growing season ($P < 0.01$ for effect of days since OSPW addition). Moss covers were also not affected by treatment (all $P > 0.18$). At the end of the first growing season, *Campylium stellatum* showed the best health (index of 5.9 ± 0.3 vs. a mean of 2.7 ± 0.2 for other species) and the best cover (68 ± 3% vs. a mean of 26 ± 3% for other species). During the second growing season, moss health index changed less rapidly through time for all species in presence of rainwater than in

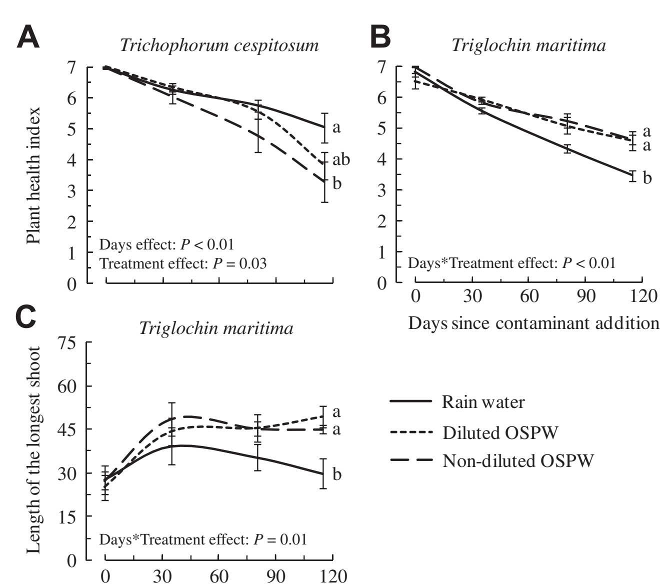

Fig. 1. Effect of treatments with OSPW over the course of the second growing season (means ± SE) for A) health index of *Trichosphorum cespitosum*, B) health index of *Triglochin maritima* and C) length of the longest shoot (cm) for *T. maritima*. For health index, a value of 7 indicates 100% alive and a value of 1 indicates 100% dead. Letters indicates significant differences between treatments at the growing season end (protected LSDs).

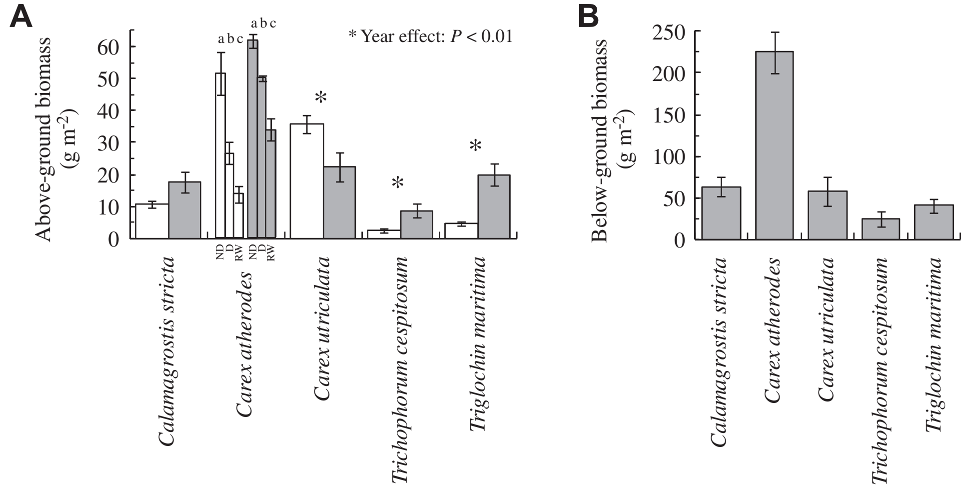

Fig. 2. A) Above-ground biomass (g m^{-2}; means ± SE) at the end of both growing seasons and B) below-ground biomass (g m^{-2}; means ± SE) for vascular plants at the end of the second growing season. Except for above-ground biomass of *Carex atherodes*, all irrigation treatments were averaged as there was no significant difference among them ($P = 0.17$ or more). White bars = first growing season and gray bars = second growing season. ND = non-diluted OSPW, D = diluted OSPW and RW = rainwater. Letters indicate significant difference between treatments (protected LSDs).

presence of non- or diluted OSPW (interaction days*treatment, $P = 0.02$ or less; situation at the end of second growing season on Fig. 3). Except for *Campylium stellatum*, no significant difference for the regeneration abilities (% cover) of moss species was found between treatments (all $P > 0.33$). *C. stellatum* had a significant higher regeneration ($P = 0.04$) under rainwater (cover of 56 ± 3%) than under non- or diluted OSPW (24 ± 3%), but its regeneration under OSPW was still higher than regeneration of other three species (between 9 ± 1% and 15 ± 1%).

3.3. Potassium and sodium concentrations in plant tissues

No clear patterns were seen for potassium concentrations in vascular plants, but for mosses, potassium concentration was higher under rainwater treatment and decreased with increasing OPSW concentration (Table 2). For all species, sodium concentrations generally increased with increasing OSPW concentrations in irrigation treatments and were up to 23 times higher at the end of the experiment under non-diluted OSPW than under rainwater (Table 2).

4. Discussion

4.1. Vascular plant growth in OSPW groundwater

Vascular plants were not impacted by OSPW after two growing season of irrigation up to approximately 54 mg l^{-1} of NAs and 569 mg l^{-1} of Na. No sign of stress was detected over the course of the two growing seasons even if simulated rainwater inputs decreased radically to favor a higher upwards flux of OSPW. Differences observed between species for number of individuals, biomass and longest shoot length were only a reflection of the plants' structure. Plant health index and the length of the longest shoot decrease from the middle to the end of growing seasons were

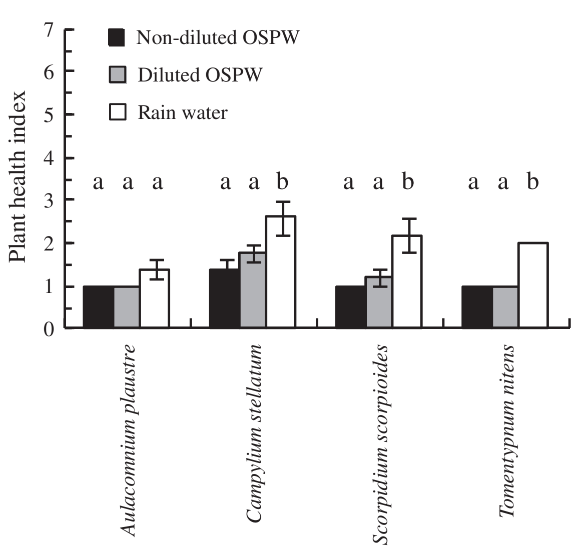

Fig. 3. Moss health index (means ± SE) at the end of the second growing season. A value of 7 indicates 100% alive and a value of 1 indicates 100% dead. Letters indicate significant difference between treatments at the end of the second growing seasons (protected LSDs).

Table 2
Potassium (K) and sodium (Na) concentration (ppm) in plant tissues before OSPW additions (in the first growing season) and at the experiment end (end of second growing season). "Mosses" represents values for a combined sample of four moss species.

Species	Treatment	Experiment start		Experiment end	
		K	Na	K	Na
Calamagrostis stricta	In rainwater	6784	1436	5641	405
	In diluted OSPW	–	–	8701	393
	In non-diluted OSPW	–	–	12 457	2148
Carex atherodes	In rainwater	17 550	220	9957	198
	In diluted OSPW	–	–	19 583	848
	In non-diluted OSPW	–	–	14 884	4612
Carex utriculata	In rainwater	18 875	660	14 622	272
	In diluted OSPW	–	–	18 968	353
	In non-diluted OSPW	–	–	19 126	871
Trichophorum cespitosum	In rainwater	9314	314	15 327	771
	In diluted OSPW	–	–	10 915	3564
	In non-diluted OSPW	–	–	10 937	3400
Triglochin maritima	In rainwater	45 210	1475	36 986	1434
	In diluted OSPW	–	–	37 143	17 461
	In non-diluted OSPW	–	–	32 115	24 658
Mosses	In rainwater	4862	1250	2340	2327
	In diluted OSPW	–	–	1186	13 954
	In non-diluted OSPW			954	15 377

unrelated to OSPW treatments. As both variables were linked to yellow parts of plant, results were rather related to natural plant senescence occurring at the end of growing seasons.

Our results were consistent with those of Trites and Bayley (2008), which showed that whole transplants of *Triglochin maritima*, *Schoenoplectus maritimus*, *Carex aquatilis*, and *Carex atherodes* (in decreasing order of survival rates) were able to survive in wetlands influenced by tailings materials. In our case, growth of *T. maritima* was stimulated by OSPW. Similarly, Foote and Hornung (2007) determined that *Typha latifolia* grown in reclaimed wetlands containing tailings materials had greater above-ground biomass than those wetlands containing fresh water and peat soil. Authors attribute the growth to higher nutrient levels in the OSPW with the presence of ammonia in particular. It seems also that OSPW increased photosynthetic rates in *T. latifolia* and *Trifolium hybridum* when compared to fresh water treatments (Bendell-Young et al., 2000; Crowe et al., 2001). Similar conclusions likely apply for other fen species, but have yet to be tested.

In salt marshes, sedges and grasses maintain high potassium (K) concentrations associated with high concentration of low molecular weight carbohydrates in their tissue to block the entry of sodium (Na) and thus, keep Na concentrations in tissue in check (Albert and Popp, 1977; Cooper, 1982; Gorham et al., 1980). Carbohydrates were not estimated in vascular plant leaves coming from our experiments, but K concentrations were high under OSPW treatments and Na concentrations increased with increasing OSPW percentage in irrigation treatments. However, even if K concentrations were often as high as those found in tissue of salt marsh species (for example: up to 7955 mg L^{-1} for *Spartina anglica* C.E. Hubbard or 66 300 mg L^{-1} for *Juncus gerardii* Loisel.; Cooper, 1982; Gorham et al., 1980), they were not really different between OPSW concentrations. As a result, Na concentrations were slightly higher under non-diluted OSPW treatment compared to rainwater treatment. However, the critical threshold of Na concentrations affecting vascular plant growth was probably not reached. One reason could be that salt contaminations in our experiment are rather insignificant (still considered as non-saline landscapes as salt concentration was lower than 1340 mg L^{-1}; Purdy et al., 2005). Contrary to salt marsh species that grow in environment influenced by sea (around 35 000 mg L^{-1}) or brackish water (between 1000 and 10 000 mg L^{-1}), vascular plants probably did not required any acclimation to live under an influence of OSPW at the concentrations tested in our experiment (maximum of 569 mg l^{-1} of Na). In addition, vascular plant growth did not decrease when affected by OSPW even in cases when NAs concentrations went up to 70 mg L^{-1} (Crowe et al., 2002; our study). The only negative impact is that plants contaminated by OSPW must maintain water potential slightly lower than those without contamination to acquire water from OSPW (Close, 2007). Both increasing salinity and NAs inhibit water uptake and might reduce plant growth in certain conditions (Armstrong et al., 2008; Kamaluddin and Zwiazek, 2002; Munns and Termaat, 1986). Consequently, they would probably be more prone to water stress during drought period.

4.2. Moss growth under groundwater discharge of OSPW

Moss health was better in the presence of rainwater, but the health index rapidly declined during the second growing season. The decline in moss health irrigated with OSPW was interpreted to a toxicity effect coupled with water stress (with a rain simulation of around 10 mm per month). In fact, in another greenhouse experiment with the same watering design, moss health was not affected during the first growing season when rain simulation was more similar to the amount of precipitation that historically falls each summer in the oil sands region (40–70 mm per month in Fort McMurray; Environment Canada, 2011; Rezanezhad et al., in press). Two characteristics of mosses, namely a moss membrane with a single cell thickness and a high cationic exchange capacity (Clymo, 1963; Rippy and Nelson, 2007), promote the contaminant absorption and may make the mosses more sensitive to contaminants present in OSPW. In addition, partial loss of intracellular potassium coupled with net influx of sodium (as found in moss tissue concentrations, see Table 2) can be considered as possible causes of photosynthesis disturbance and protein synthesis decline (Bates and Brown, 1975). The same process could be a realistic explanation for the observed diminution of moss health.

4.3. Implications for fen creation in contact with OSPW

All vascular plant species tested can probably grow in contact with OSPW at the level currently being produced by oil sand activity in northwestern Canada. Graminoid species should thus be used in the early stages of reclamation or fen creation. However, some plants regenerated better and began reproducing more quickly than others. As a result, they produced much more biomass and might be better peat-accumulating species. In our case, *Carex* species (*C. atherodes* and *C. utriculata*) as well as *Triglochin maritima* produced more biomass than *Calamagrostris stricta* and *Trichophorum cespitosum*, making the former more useful for restoring a vegetative cover quickly following oil sands exploitation and, potentially, creating a peat-accumulating system.

Conditions simulated in this greenhouse experiment were most likely more stressful for plants than field conditions for fen creation in landscapes influenced by OSPW. From known current practices in northwestern Canada, peat thickness in fen creation will be much thicker than in our experimental units (Daly et al., in press). To create stable fen conditions, Price et al. (2010) proposed that a peat layer of around two meters covering an area of about one hectare is needed. Peat could be taken in a new lease being opened for oil sands extraction. Additionally, it appears that peat has a high buffering capacity. By adsorbing most of the contaminants, peat highly retards the transport of Na and NAs (Rezanezhad and Price, submitted for publication). This suggests that several years may pass before any effect of OSPW on plants becomes detectable, potentially allowing a healthy cover of graminoid vegetation to establish and consequently build up of a thick litter layer further isolating the surface plants from below-ground water flows influenced by OSPW. Moreover, oil sands region receives more precipitation annually than the simulated rainwater inputs in the greenhouse. So, potential for OSPW losses by downward leaching, horizontal transport and surface runoff would be greater in the created fens. More research on the impacts of OSPW on fen vegetation is thus critical for future reclamation projects in the oil sands as influence of OSPW on plant growth in field conditions is still poorly understood. Long-term field experiments need to be carried out.

Ground-water discharge of OSPW in the greenhouse proved to be detrimental for *Campylium stellatum* in situations of water stress (decrease of health index and cover). During wetter years, when precipitation is sufficient to keep the moss carpet moist, mosses will not have to acquire water by capillarity from the lower part of the peat column where concentration of OSPW is high. Water control should thus be a crucial step in fen creation. Also, the peat from Alberta contained spores for mosses such as *Bryum pseudotriquetrum* (Hedw.) G. Gaertn., B. Mey. & Scherb. and *Pohlia nutans* (Hedw.) Lindb. that spontaneously regenerated in our experiment (a cover of up to 80%). These pioneer species created competition for the introduced species, leading to their low regeneration after active introduction. The biological outcome in competition revealed that it might be interesting to work with

B. pseudotriquetrum. Among tested moss species *C. stellatum* and *B. pseudotriquetrum* (also common in saline fens; Trites and Bayley, 2009) could be the best choices for fen creation in contact with OSPW. Other species did not regenerate well. However, salinity thresholds or the best hydrology to have in created fens still have to be understood for mosses.

5. Conclusions

Plant species' responses to irrigation treatments with OSPW were linked to the water absorption method: by roots (vascular plants) or directly through cell membranes (mosses). After two growing seasons, vascular plants were not impacted by OSPW (up to and 569 mg l^{-1} of Na and 54 mg l^{-1} of NAs), but moss health was considerably affected under dry water regime (with rain simulation of 10 mm per month). As a starting point, *Carex* species (*C. atherodes* and *C. utriculata*) and *Triglochin maritima* as well as *Campylium stellatum* and *Bryum pseudotriquetrum* should be tested in field conditions. Our greenhouse experiments demonstrated that these species would be capable of rapid restoration of a vegetation cover and would be useful in the creation of a new peat-accumulating system.

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