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Early recruitment of boreal forest trees in hybrid poplar plantations of different densities on mine waste rock slopes

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ABSTRACT

Mine wastes create harsh recruitment conditions for forest tree seedlings, especially waste rock piles where erodible slopes are prone to drought. Plantations using fast-growing tree species can potentially accelerate the conversion of degraded mine sites into forests through facilitation of tree recruitment, while contributing to the stability of slopes. In this study, hybrid poplars were tested as a means of achieving reclamation objectives by providing shelter for forest tree seedlings on waste rock slopes (3H:1V ratio) in the Canadian southern boreal region. Density effects of young hybrid poplars were assessed on the emergence and survival of early, mid and late successional species, naturally occurring or hand-seeded, and on the understory micro-environmental parameters in plantations of different spacings (1 × 1, 2 × 2, 4 × 4 m and control without planted trees). Results were also compared in 2 × 2-m plantations with and without a hydroseeded herbaceous cover, traditionally used to control erosion in slopes. During the 2nd growing season of the plantations, seedling emergence of naturally established *Salicaceae* (*Populus* and *Salix*) species followed a quadratic pattern along the density gradient, as emergence values were higher under an intermediary density. Nonetheless, decrease in light transmission emerged as a limiting factor of seedling survival for these early-successional, shade-intolerant species by the next summer. Following a spring sowing experiment in the 3rd growing season of the plantations, emergence rates for later-successional *Picea glauca* and *Abies balsamea* seedlings increased with hybrid poplar density. During their peak emergence period, in early season, higher soil moisture content was found under denser cover. However, at the end of the third year of the plantations, only *A. balsamea* showed moderate increase in early recruitment success rates under denser tree cover. In hydroseeded plots, a competitive effect of the herbaceous cover was observed on *Salicaceae* emergence and *A. balsamea* survival. These results suggest that planting of young plantations without a hydroseeded cover may offer a more suitable solution in order to quickly provide early recruitment opportunities for later-successional seedlings in waste rock slopes. Despite this, a significant decrease in moisture content recorded during the second half of the 3rd growing season under the 1 × 1-m cover, compared to the 2 × 2-m, likely signalled an increasing competitive effect from hybrid poplars, which may compromise their nursing potential in the longer term. Therefore, further monitoring is imperative for a better understanding of longer-term facilitation and competition interactions between nurse trees and understory seedlings in waste rock slopes, where competition for limited resources, such as water, may be severe.

1. Introduction

Understanding the processes involved in ecosystem recovery provides useful insights for re-establishing successional trajectories towards productive and self-sustaining ecosystems (Del Moral and Walker, 2007; Walker and del Moral, 2009; Polster, 2011). There is growing scientific evidence that tree plantations can have a *catalytic effect* (Parrotta et al., 1997) on forest succession on severely degraded sites, where ecological barriers would otherwise impede recolonization by native species (Guariguata et al., 1995; Parrotta, 1995; Carnevale and Montagnini, 2002; Boothroyd-Roberts et al., 2013). In the boreal region, vast areas of land supporting forest ecosystems are rendered unproductive because of mining activities. Recruitment is often the stage that hinders the natural regeneration of native forest trees (Young et al., 2005). The facilitation successional theory (Connell and Slatyer, 1977), as applied in restoration practice, suggests that planting of pioneer tree species able to grow on the newly exposed mine landform will assist the colonization of other species into the restored community

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(Nichols et al., 2010), and especially of later-successional species. The stress-gradient hypothesis predicts that positive interactions among plants increase with abiotic stress exposure (Bertness and Callaway, 1994), hence hinting at the potential of facilitation in reclamation efforts because of the inhospitable nature of mining substrates.

When surface-mined, all the biotic components are removed from the forested area –including tree canopy, shrub layer, soil, rootstock and seed bank (Burger and Zipper, 2002)– and replaced by accumulations of waste material. Waste rocks form one of the two main solid mine wastes along with mill tailings, and originate from rock material surrounding the ore, extracted by explosion and dumped in piles with steep slopes and flat tops (Brooks, 1990). The main forest reclamation strategy on the flat areas consists in tree planting on a respread topsoil (Drake, 1986; Kost and Vimmerstedt, 1994; Ashby, 1997; Emerson et al., 2009; Pietrzykowski, 2010; Landhäusser et al., 2012; Sloan and Jacobs, 2013). On the other hand, fast-growing herbaceous plants seeding with agronomic species is generally used on the slopes (Torbert and Burger, 1994; Aubuchon, 2010; Fields-Johnson et al., 2012), where soil erosion proves to be a significant barrier to plant establishment (Espigares et al., 2011). A ground cover of fast-growing herbaceous species allows the rapid stabilization of the soil surface and limits soil erosion on slopes (Helm, 1995). However, species commonly used (mainly grasses and legumes) often compete with tree seedlings for water, nutrients and light resources (Rizza et al., 2007; Polster, 2010; Franklin et al., 2012). Tree seedling establishment, survival and growth are thus often found to be very low on sites revegetated with herbaceous species (Andersen et al., 1989). Traditional reclamation treatments used in waste rock slopes to minimize short-term erosion may consequently hinder long-term recovery goals (Holl, 2002).

As an alternative reclamation strategy, fast-growing tree plantations could benefit the regeneration of native species that can hardly grow in open environments or in competition with a herbaceous ground cover (Carnevale and Montagnini, 2002). This nursing effect is first mediated by a *tree cover effect*. A number of mechanisms have been proposed to account for the better recruitment of native tree species under a plantation canopy, especially changes in understory microclimatic conditions (Lugo, 1997; Otsamo, 2000), reduction in competitive herbaceous species (Powers et al., 1997; Otsamo, 2000) and improvement of soil fertility through readily decomposable litter (Filcheva et al., 2000). Secondly, fast-growing trees develop an extensive root system which rapidly colonizes the available soil volume (Wilkinson, 1999; Douglas et al., 2010). Tree roots thus provide soil reinforcement that improves the stability of slopes (Abe and Ziemer, 1991), where soil erosion could adversely affect tree colonization by reducing the availability of seeds, nutrients, and water in soil (Espigares et al., 2011).

While most trees can arguably exert a facilitating role, fast-growing broadleaf species are generally regarded as better catalysts (Parrotta et al., 1997). Hybrid poplar plantations were recently observed to accelerate the colonization of native species and the restoration of forest attributes on abandoned farmlands (Boothroyd-Roberts et al., 2013). Hybrid poplar cultivars have some of the most vigorous growth among trees available for reclamation (Guy and Bateman, 1989; Casselman et al., 2006) and generally show good survival rates on mine sites (Czapowskyj, 1978; Clark Ashby, 1995; McGill et al., 2004). Some clones allocate a large proportion of their resources to roots (Larchevêque et al., 2011), which could foster the development of an extensive root system as well as a fast canopy closure to stabilize the soil and improve the understory micro-environment.

Tree spacing or density is regarded as an important factor of plantation design, potentially mediating facilitation performances in the restored community through its structuring effect on the understory micro-environment (Geldenhuys, 1997; Paquette et al., 2008; Trindade and Coelho, 2012). Denser tree covers generally offer less extreme temperatures and moisture deficiencies, but provide a more limiting light environment (Man and Lieffers, 1999). If soil moisture is known to be the main limiting factor for the germination of boreal tree species (Greene et al., 1999), light quickly becomes limiting for the survival of shade-intolerant pioneer tree species (Karrenberg et al., 2002). Shading also hinders the development of light-demanding, weedy herbaceous species (De Keersmaeker et al., 2004). Dense weed layers not only compete for resources, but create a barrier to tree seedling establishment through leaf litter accumulation (Coates et al., 1994). The increased tree cover effect may thus maintain availability of favourable recruitment microsites and create opportunities for later-successional tree species (Boothroyd-Roberts et al., 2013), more vulnerable to desiccation than to constraints in light (Lieffers and Stadt, 1994; Landhäusser and Lieffers, 2001).

The restoration objective associated to this project was defined within a conceptual framework of community ecology (Naeem, 2006) and aimed at reestablishing native boreal tree species to restore the structure of a forest community. The facilitating role of plantations in mining conditions was examined by few studies in relation to soil redevelopment process (Dutta and Agrawal, 2002; Singh et al., 2004; Singh and Singh, 2006; Singh and Zeng, 2008) but remains largely unexplored regarding tree recruitment (Densmore, 2005; Frouz et al., 2015), especially on waste rock slopes. This study aimed to test the facilitation hypothesis using young hybrid poplar plantations and to understand how nurse tree spacing influences the limiting factors for the recruitment of boreal tree species in a waste rock slope (3H:1V ratio). Three hybrid poplar spacings were compared to two control treatments: bare soil without planting or seeding, and soil with planted trees and a traditional hydroseeded cover treatment. Field experiments were carried out to evaluate the effects of these plantation designs on the understory micro-environmental parameters, and on the emergence and early survival of early, mid and late successional tree species. First, we monitored soil humidity and temperature conditions, available light at ground level, leaf litter accumulation and herbaceous biomass in the plantation understories. Second, we surveyed the naturally established pioneer seedlings in each plantation designs. Third, we surveyed later-successional *Picea glauca* and *Abies balsamea* seedlings following a seed-sowing experiment. We first hypothesized that planting of hybrid poplars as nurse trees would quickly exert a structuring effect on the understory micro-environmental parameters. Secondly, it was postulated that the nurse tree cover would benefit forest tree seedling performances compared to bare soil. More specifically, we predicted better seedling emergence under denser tree cover in the young plantations because of higher soil moisture content. However, seedling mortality rates are expected to increase during canopy closure for shade-intolerant pioneer species. Thirdly, we hypothesized that the presence of a hydroseeded cover would adversely affect the emergence and survival of forest tree seedlings.

2. Materials and methods

2.1. Mine site and waste rocks

The field experiments were conducted at the Canadian Malartic mine site, located in Northwestern Quebec, Canada (48°13′N, 78°12′W). Climate is cold-temperate continental with an average annual temperature of 1.5 °C and a mean annual total precipitation of 929 mm (Government of Canada, 2015). Average length of growing season ranges between 120 and 130 days with a mean frost-free period of 97 days (Agriculture and Agri-Food Canada, 2014). The region belongs to the balsam fir-white birch bioclimatic domain in the southern portion of the boreal zone (MERN, 2003). Forest stands surrounding the mine site includes balsam fir (*Abies balsamea* (Linnaeus) Miller), black spruce (*Picea mariana* (Miller) BSP), trembling aspen (*Populus tremuloides* Michaux), white birch (*Betula papyrifera* Marshall), balsam poplar (*Populus balsamifera* Linnaeus), jack pine (*Pinus banksiana* Lambert), white spruce (*Picea glauca* (Moench) Voss) and tamarack (*Larix laricina* (Du Roi) K. Koch).

The site is an active open-pit gold mine since 2011, where 55,000