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Site factors contribute to aspen decline and stand vulnerability following a forest tent caterpillar outbreak in the Canadian Clay Belt

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ABSTRACT

Following the recent forest tent caterpillar (*Malacosoma disstria* Hbn.; FTC) outbreaks in the Canadian Clay Belt, several trembling aspen (*Populus tremuloides* Michx.) stands that have expressed variable mortality levels did not regenerate and were invaded by speckled alder (*Alnus rugosa* (DuRoi.) Sprengel.). The present study has been initiated to identify the causes of aspen dieback and of suckering inhibition, and to test silvicultural treatments to reinitiate stands having high stocking levels. A total of 84 plots were established in 2009 along a gradient of tree mortality based on the residual aspen live basal area (ALBA) in stands that had a high crown closure prior the last FTC outbreak. Treatments included winter and early summer harvest prior to the 2010 growing season, with or without alder removal in the winter of 2011. Results indicate that alder removal is not needed to regenerate the stands, that apical dominance of the residual trees played an important role in the inhibition of suckering but that ALBA was the main factor leading to higher sucker densities, suggesting that the root system was affected in the most degraded stands. A clear threshold of 11 $m^2\ ha^{-1}$ ALBA has been evidenced above which stands can be regenerated. Below this threshold, suckering is too low to regenerate to productive stands. Moreover, this study is the first to show a strong and positive association between aspen mortality, humus layer thickness and water table height. Aspen was more vulnerable to FTC defoliation on sites combining a high water table and a thick humus layer. Because the basal area increment of residual trees has been lower since the 1950s on those sites, aspen dieback following the last FTC outbreak appears to be a symptom of a slower, long-term process of aspen decline. From a management viewpoint, it is suggested to convert these degraded sites to conifer stands.

1. Introduction

Climate-induced forest decline is becoming prevalent worldwide (Allen et al., 2010). Trembling aspen (*Populus tremuloides* Michx.), the most widely distributed tree species in North America (Perala, 1990), recently exhibited evidence of widespread decline and of tree-and stand-level dieback (Frey et al., 2004; Michaelian et al., 2011; Anderegg et al., 2012; Worrall et al., 2013). The common view is that several predisposing and inciting factors initiated the decline and hastened the spread of dieback over millions of hectares (Wang et al., 2012). Drought, linked to climate change (Rehfeldt et al., 2009; Worrall et al., 2013), defoliation by insects (Cooke et al., 2009; Man and Rice, 2010; Moulinier et al., 2011), or both, acted in concert to cause widespread die-offs (Candau et al., 2002; Hogg et al., 2002).

Independent assessments have confirmed a strong link between aspen mortality and drought in western Canadian forests (Hogg et al., 2008; Steinkamp and Hickler, 2013). Aspen dieback in normally wetter areas of the eastern Canadian boreal biome such as the Clay Belt has also been extensive in the recent years. The Clay Belt of northeastern Ontario and northwestern Quebec, or the Northern Clay Section of the Boreal Forest Region of Canada (Rowe, 1972), is a 125,000 km^2 area of flat lowlands with surficial deposits resistant to drainage on which the development of organic soil is facilitated by the cold and wet climate (Lefort et al., 2002; Lavoie et al., 2005). Historically, the Clay Belt did not experience moisture limitation (Parker et al., 2012) and the increase in mean annual temperature over the last century has not led to increased summer drought severity (Girardin et al., 2004). Aspen dieback in

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Ontario's Clay Belt has been precisely mapped (Candau et al., 2002; Worrall et al., 2013) but not in Quebec. Candau et al. (2002) noted a significant drought event in 1998 for northeastern Ontario. However, in 1998 the concerned area was in the midst of a second wave of a Forest Tent Caterpillar (*Malacosoma disstria* Hbn.; FTC) outbreak, the initial wave having started in 1989 (Cooke et al., 2009). The highest levels of aspen dieback, which extended over 500,000 ha, were observed precisely where the two waves of FTC defoliation occurred with little respite between them. Hence, it is a challenge to tease apart the respective effects of climate and of defoliation on aspen dieback. Quebec's Clay Belt did not experience such a double wave of FTC attack, but defoliation reached 1.45 million ha over the period 1999–2002 with about 40% of the area experiencing more than one year of moderate to severe defoliation (Charbonneau et al., 2012). Aspen dieback was observable throughout the area following this FTC outbreak (Chouinard and Lorenzetti, 2006).

Investigations in both Ontario's and Quebec's Clay Belt indicated that aspen stands that were vulnerable following FTC defoliation have the potential to recover through gap-phase replacement dynamics, even in the presence of a shrub layer, or to accelerate the transition to coniferous dominance (Man and Rice, 2010; Moulinier et al., 2011, 2013). Although those regenerated stands expressed resilience following FTC defoliation, there is an impact on annual allowable cut. There are extensive areas in Quebec's Clay Belt, however, where forest succession halted due to a lack of aspen suckering and, presumably, to the establishment of an aggressive shrub layer (Chabot, 2009). This observation is in sharp contrast with the ability of aspen to rapidly regenerate from suckers following disturbances such as fires (Brown and Debyle, 1987; Wang, 2003) and partial- or clear-cuts (Brais et al., 2004; Gradowski et al., 2010). Aspen mortality in Quebec's Clay Belt has been shown to be a function of the number of years of moderate to severe FTC defoliation (Moulinier et al., 2011, 2013), with considerable variability when defoliation reaches three years in duration. This variability can be observed over a very small spatial scale, with aspen mortality spanning 0–100%.

This study was undertaken to specifically investigate the very low resilience observed in many aspen stands following the last FTC outbreak in Quebec's Clay Belt. Because apical dominance is considered an important factor inhibiting aspen sucker initiation (Farmer, 1962; Schier, 1975; Schier et al., 1985; Frey et al., 2003), a first objective was to determine the magnitude of this effect by cutting the trees still alive after the last FTC outbreak over a large range of aspen residual basal area. A second objective was to evaluate the benefits, or lack thereof, of speckled alder (*Alnus rugosa* (DuRoi.) Sprengel.) removal on aspen suckers generated after cutting. Our final objective was to investigate site factors that may explain the variation in stand vulnerability to FTC defoliation in the first place.

2. Material and methods

2.1. Study site

Located 95 km north of Amos, Quebec, Canada (Fig. 1), the study area is at the transition between the balsam fir-white birch and the black spruce-feather moss bioclimatic domains (Saucier et al., 1998). Mean annual temperature is −0.7 °C and mean annual precipitation is 905.5 mm, including 313.8 cm of snow (Environment Canada, 2012). The area belongs to the Canadian Clay Belt which is a vast physiographic region formed of glacio-lacustrine deposits originating from the proglacial Ojibway Lake (Vincent and Hardy, 1977). Mature aspen stands that originated from fires in the 1910s and 1920s contemporaneously dominate the area (Bergeron et al., 2004). These aspen stands extend over 10,000 ha (Chabot, 2009). Following a FTC outbreak of large amplitude in the early 2000s (Charbonneau et al., 2012), the stands started to exhibit different stages of decline and to be invaded by speckled alder (Chouinard and Lorenzetti, 2006). In 2009, georeferenced forest inventory maps produced in the late 1990s were used to delimit a large contiguous area which was homogenous for aspen dominance and for high crown closure. Poorly drained areas were avoided. Using this information, it was possible to delineate an operational-scale study site 300 ha in size. The study site lies close to the eastern edge of the Harricana interlobar moraine (Allard, 1974; Fig. 1; *inset*). An analysis of pre-disturbance aerial photos (1995) further confirmed that there were no large gaps or groups of snags at the selected site prior to the last FTC outbreak.

2.2. Experimental design and silvicultural treatments

A post-disturbance LANDSAT satellite image (2005) of the study site was calibrated to define three classes of aspen decline: 0–33, >33–66 and >66–100%. The resulting map served two purposes. First, it helped in delineating areas to apply different silvicultural treatments. Second, it served in 2009 to distribute evenly to each class of decline a total of 84 circular plots 20 m in radius (1256.6 m^2). The true residual aspen live basal area (ALBA) in each plot was then measured on the ground with the aid of a prism (factor of 2 $m^2\ ha^{-1}$). One measurement was taken at 10 m from the center in each of the cardinal directions and the four measurements were averaged to obtain the ALBA for the plot. The 84 plots covered a range of 0–36.5 $m^2\ ha^{-1}$. ALBA was thus considered as a planned covariable in this study.

Sections of the study site were harvested during the winter (February and March of 2010) to circumvent the buildup of apical dominance through hormonal control during leaf flush (Schier et al., 1985; Weber, 1990). The remaining of the study site was harvested starting at the onset of the northern summer (June to mid-July 2010) when aspen trees were developing their leaves and apical dominance is thus the greatest. Since the stands have been determined to have no signs of dieback prior to the last FTC outbreak, it was expected that the residual basal area would have little to no effect on the density of aspen suckers. Winter- and summer-cut areas each encompassed 27 plots covering the ALBA range. No heavy machinery was allowed within the experimental plots. Trees too deep into the plots to be reached with a harvester head were cut using a chain saw, felled towards the edges of the plots and removed using a cable. The passage of the machinery at the edges of the 20 m-radius plots respects the prescription of keeping skid trails at a minimum distance of 20 m of each other so as to minimise soil compaction on the cutover area. This prescription is referred to as harvest with protection of soils (HPS). Hence, hereafter, the winter- and early summer-cut treatments will be referred to as HPS W and HPS S, respectively.

Alder was cleared in the winter of 2011 (January to March) in sections of both the winter and summer cutovers to test the hypothesis that alder impeded aspen sucker initiation and growth (Mundell et al., 2007). A bulldozer equipped with a sharp blade was run over the frozen ground without disturbing the forest floor (*protocol modified from* Ministère des ressources naturelles du Québec (MRNQ), 2010). The treatment encompassed 18 plots covering the ALBA range in both the winter and summer cutovers, leaving 9 winter-cut and 9 summer-cut plots untouched. Plots in which the alder removal treatment (AR) was performed will be referred to as HPS W+AR and HPS S+AR.

Of the 30 remaining plots, also covering the ALBA range, 18 were uncut and left as controls and 12 were used to cut down individual trees for dendrochronological analysis (*see* Section 2.3.3). It is to be noted that one HPS S+AR plot and one plot for dendrochronological