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Managing conservation values and tree performance: Lessons learned from 10 year experiments in regenerating eastern white pine (*Pinus strobus* L.)

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ABSTRACT

Multiple-use land management is an important aspect of sustainable forest management and requires strategies that both promote sustainable fiber production and conserve biodiversity. Studies formally integrating these two aspects of forest management are needed to develop silviculture prescriptions capable of maintaining the delivery of multiple ecosystem goods and services. Techniques used to suppress vegetation that competes with young pine seedlings have become standard practice in the regeneration of eastern white pine (*Pinus strobus* L.), but they can cause changes in plant community composition. We compared white pine performance to understory development under five vegetation suppression treatments within three experimental white pine plantations. White pine performance was assessed in terms of basal stem diameter and the percentage of trees reaching an age 10 height target. Understory development was characterized in terms of understory plant functional composition using a complementary set of functional and taxonomic diversity metrics. Plantations included one clearcut site and two sites managed under a uniform shelterwood system. Our results show that after 10 years, plots treated with a single, second-season application of herbicide that temporarily suppressed both woody and herbaceous vegetation favoured rapid white pine growth, increased pine canopy cover, and allowed the understory community to recover towards a mature functional and taxonomic composition. Repetitive suppression of either only herbaceous or woody vegetation caused major shifts in community composition that were still evident after 10 years. These shifts were due to the prevalence of competitive species that formed dominant layers in these treatments. Impacts of treatments on tree performance and understory development observed in this study have important implications for forest management. Some treatments might create problems in the long-term by delaying understory maturation, while others appear capable of balancing multiple management objectives.

1. Introduction

Eastern white pine (*Pinus strobus* L.) has been historically one of the most economically, socially, and culturally important tree species in Eastern North America (Uprety et al., 2014). However, in the centuries since European settlement, harvesting, fire and pest damage have caused its steady decline (Beaulieu et al., 1996). Early efforts to improve white pine regeneration using then standard silvicultural techniques produced inconsistent results that generated poor growth and low survival due to plant competition, white pine blister rust infection (*Cronartium ribicola* J.C. Fisch.), and white pine weevil attack (*Pissodes strobi* Peck) (Hosie, 1953; Stiell, 1985). Although a move to a uniform shelterwood system in the 1970s helped mitigate losses from white pine blister rust and weevil (De Groot et al., 2005; Hannah, 1988; Ostry et al., 2010), achieving successful white pine regeneration still remains a significant challenge, largely due to the effects of competing vegetation. Consequently there is a need for research that focuses on methods to mitigate competition (Carleton et al., 1996; Pitt et al., 2009).

Vegetation management has long been used to raise performance of desired tree species and its direct positive effects on tree growth are well documented (Pitt et al., 2016, 2015, Wagner et al., 2006). These practices usually involve the suppression of herbaceous and woody competitive species through herbicide application and/or manual removal (Wagner et al., 2006; Wiensczyk et al., 2011), providing crop

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trees with greater access to limited resources. Developing vegetation management strategies for white pine is particularly challenging because successful regeneration often relies on both managing understory environmental conditions to help mitigate weevil and blister rust damage while maintaining light levels that do not overly suppress regenerating seedlings (Hodge et al., 1989; Pitt et al., 2016; Stiell, 1985).

It can be difficult to predict the long-term outcomes that vegetation suppression will have on complex and dynamic understory communities. Vegetation suppression can be detrimental to interior forest species of the understory by altering community composition and contributing to a loss of species and plant diversity (Gauthier et al., 2015; Miller et al., 1995; Noble and Dirzo, 1997). Disturbances associated with vegetation suppression can also provide colonization opportunities by freeing up space and increasing resource availability for previously non-dominant opportunistic species (Balandier et al., 2006; Davis et al., 2000). This may lead to the formation of a dense competitive layer (or "recalcitrant layer") that has the potential to limit forest regeneration by preventing the colonization of more desirable, late successional species (Mallik, 2003; Meier et al., 1995; Royo and Carson, 2006; Young and Peffer, 2010). The persistence of competitive species could also lead to increased silvicultural efforts, and therefore costs, to ensure success of the current crop and to initiate subsequent rotations. For example, early dominance of bracken fern (*Pteridium aquilinum* (L.) Kuhn) can pose significant challenges to regenerating tree seedlings; and once it dominates a site it is very difficult to eradicate (Griffiths and Filan, 2007; Milligan et al., 2016). Since multiple-use land management is a fundamental aspect of sustainable forest management (Wang and Wilson, 2007), it requires management strategies that both promote sustainable fiber production and the conservation of biodiversity (Eriksson and Hammer, 2006; Spence, 2001; Work et al., 2003). It is of central importance for land managers seeking to ensure the sustainability and ecological integrity of commercial forests to have access to research that address the potential trade-off that exists between these two interrelated objectives so they can make informed decisions (Urli et al., 2017).

This paper aims to compare understory development to gains in crop tree performance under contrasting vegetation suppression treatments. To explore this topic we took advantage of three experimental sites initiated in 2000 to evaluate the effects of timing and duration of vegetation suppression treatments on planted white pine survival and growth. Our objective was to address the following questions: (1) How do vegetation suppression treatments alter the trajectory of understory development over time? (2) How do understory communities respond to these treatments after 10 years? (3) What are the responses of competitive species and interior forest species? (4) What are the effects of these treatments on planted white pine performance? We used a trait-based approach in addition to traditional taxonomic information to provide a comprehensive assessment of understory community development. This approach is particularly useful because it provides greater comparability among geographically distant sites (Garnier et al., 2016). Another aspect of our study is that it included vegetation suppression treatments designed to isolate the response from removal of specific understory components (i.e. suppression of either herbaceous-only or woody-only vegetation). Only a few studies have looked at the response of understory vegetation and crop tree performance to suppression of specific competitive components (e.g. Little et al., 2018; Miller et al., 2003) and, to our knowledge, none have been conducted in Eastern North America.

Our intent is to identify vegetation suppression approaches and intensities (i.e., duration of suppression in years) that provide adequate resources for successful white pine regeneration in terms of stem diameter and height, with minimal effects on understory plant community composition. These results can provide an empirical basis on which to develop vegetation suppression prescriptions designed to optimize investment both in the short- and long-term.

2. Methods

The study was conducted in three planted white pine sites – two in Ontario, Canada (henceforth: Clearcut-ON and Shelterwood-ON) and one in New Brunswick, Canada (henceforth: Shelterwood-NB). All three sites are part of the White Pine Competition Study (Pitt et al., 2016, 2011, 2009). The sites were harvested using either one of two conventional silviculture systems: clearcut or uniform shelterwood. Both create conditions for even-aged regeneration, but the clearcut system generally involves the harvest of all overstory trees from an area at one time. The uniform shelterwood system consists of harvesting overstory trees in two or more successive cuts, depending on the management objective, with the primary intent of managing the understory environment – in the case of white pine, to mitigate damage from white pine weevil and white pine blister rust (Hodge et al., 1989; Stiell, 1985). Site histories and characteristics of these sites are summarized in Table 1; for more details on white pine response and ecophysiology effects of treatments from previous investigations within these sites, see Pitt et al. (2016, 2011, 2009) and Parker et al. (2012, 2010, 2009).

2.1. Study sites

2.1.1. Climate and soil conditions

Clearcut-ON (World Geodetic System; WGS 84: 46°42′44.3″ N; 79°22′14.4″ W) and Shelterwood-ON (WGS 84: 46°43′50.7″ N; 79°22′46.1″ W) are located 2.2 km apart in the Great-Lakes-St. Lawrence forest region (Rowe, 1972), northeast of the city of North Bay. Shelterwood-NB (WGS 84: 46°24′30″ N; 66°04′26″ W) is located in the Acadian forest region (Rowe, 1972) of central New Brunswick, near the city of Doaktown. The Ontario sites had mean annual, January, and July temperatures of 4.4 °C, −12.2 °C, and 18.8 °C, respectively, with 1574 annual growing degree days and 475 mm of precipitation from May to September. The New Brunswick site had a similar climate with mean annual, January, and July temperatures of 5.0 °C, −10.5 °C, and 18.9 °C, respectively, with 1559 annual growing degree days and 480 mm precipitation during May to September.

Both Ontario sites represent Ecosite G033 (Ontario Ministry of Natural Resources, 2009) and are typical of white and red pine-dominated (*Pinus resinosa* Aiton) mixedwood forests. Shelterwood-NB is located within the transitional zone between the Castaway and Bantalor ecodistricts of the Eastern Lowlands Ecoregion and is classified as an Ecosite 5 (Zelazny et al., 2007). Both Ontario sites have approximately 10 cm of fine loamy sands that overlay deep, medium- to coarse-textured sands, with a rooting depth of about 60 cm and no signs of mottling or gleying. By contrast, Shelterwood-NB has less than 10 cm of fine loamy sand soil underlain by formations of grey lithic and feldspar sandstone (Colpitts et al., 1995; Loucks, 1962).

2.1.2. Site history

Prior to harvesting, sites were mature stands likely of fire origin (approximately 86 years old for the Clearcut site and 100 years old for the Shelterwood sites). Clearcut-ON was full-tree harvested in spring 2000 with subsequent manual felling of all remaining residual trees to emulate a true clearcut harvest condition. No advanced regeneration remained following harvest. Shelterwood-ON was partially harvested in 1999 following a prescription for the regeneration cut phase of the uniform shelterwood system. This harvest left an overstory of high quality *Pinus strobus* L. and *Pinus resinosa* Aiton, along with many subordinate stems of *Picea glauca* (Moench) Voss, *Abies balsamea* (L.) Mill., *Acer rubrum L.*, and *Populus tremuloides* Michx. that had been marked for harvest but left standing due to poor market conditions. To achieve the intended silvicultural prescription, these remaining marked subordinate stems were manually felled in 2000 and removed with a grapple skidder. The result was an overstory of relatively evenly spaced dominant and co-dominant trees (basal area 18 m^2/ha, 71% white pine). In 1998, Shelterwood-NB was partially harvested for the