Well-spaced and free-growing: Effects and interactions of ecosite and renewal treatments on regenerating stands in northwestern Ontario

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WELL-SPACED AND FREE-GROWING: EFFECTS AND INTERACTIONS OF ECOSITE AND RENEWAL TREATMENTS ON REGENERATING STANDS IN NORTHWESTERN ONTARIO

by

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ABSTRACT

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Effective renewal of harvested stands in Ontario is mandated in the Crown Forest Sustainability Act (CFSA 1994). Properly prescribed silviculture leads to forested stands that are regenerated successfully, have predictable future yields, increased value, and will meet management objectives. Regeneration status in Ontario is determined by the Well-Spaced Free-Growing Regeneration (WSFG) Assessment Procedure. The objective of this study is to determine the effects and interactions of ecosite and renewal treatments on the number of WSFG trees per plot evaluated using the WSFG Regeneration Assessment Procedure on Blackwater Blocks of the Lake Nipigon Forest in northwestern Ontario. Five null hypotheses resulted from the review of current literature: that 1) ecosite, 2) regeneration method, 3) mechanical site preparation and 4) chemical herbicide application, do not have a statistically significant effect on the number of WSFG trees per plot. The fifth hypothesis was that the interaction of ecosite, regeneration method, mechanical site preparation, and herbicide application does not have statistically significant effect on the number of WSFG trees per plot. In testing these null hypotheses, an analysis of plot data included a two-way ANOVA with ecosite and herbicide treatment, and one-way ANOVAs for ecosite and regeneration methods. A plot level statistical analysis was also used to supplement these results. Results of the ANOVAs indicate that ecosite and regeneration method both have a statistically significant effect on the number of WSFG trees per plot. Independent t-test findings were that mechanical site preparation does not significantly effect on the number of WSFG trees per plot, but herbicide application does. The key finding is that ecosite specific prescriptions for renewal treatments will lead to more WSFG trees per plot and establishment of stands which achieve the desired future forest conditions.

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INTRODUCTION

The International Union of Forest Research Organizations (IUFRO 2005) defines silviculture as "the art and science of controlling the establishment, growth, composition, health, and quality of forests". In Ontario, silviculture contributes to the primary goal of every forest management plan: a healthy, sustainable forest ecosystem as legislated in the Crown Forest Sustainability Act (1994). Silvicultural treatments are actions taken at the stand level to achieve forest management objectives (Groot et al. 2005). When silviculture treatments are prescribed properly management objectives can be met in a sustainable, economical and ecologically appropriate manner (Nyland 2016). Management objectives can include timber production, wildlife, recreation, ecological functions, aesthetics, or any combination of these or other forest uses (BCMoF 1999a). Prescribing appropriate silvicultural treatments for each stand harvested results in meeting these management objectives (BCMoF 1999a). Proper silviculture leads to forested stands that are regenerated successfully, have predictable future yields, increased value, and will meet management objectives (BCMoF 1999a). Improper silvicultural prescriptions may cause stands to fail to meet objectives and are a waste of valuable resources invested in forest renewal.

The Well-spaced Free-growing (WSFG) Regeneration Assessment Procedure for Ontario is designed to determine the regeneration status of a young stand (White et al. 2005). This procedure is based on the regeneration principles outlined in the Crown Forest Sustainability Act (CFSA 1994). The CFSA (1994) states that every area harvested in Ontario must be regenerated to a standard, defined in the Forest Management Planning Manual (FMPM) as, "the mandatory level of observable measures of a regenerating area to provide confidence that the target stand condition can be achieved" (OMNRF 2017). The WSFG assessment provides the observable measures referred to in the FMPM (OMNRF 2017). The WSFG assessment is an "intensive ground-based survey method designed to produce consistent results while maintaining operational efficiency" (White et al. 2005). It is intended to provide reliable quantitative information to determine the effectiveness of silvicultural treatments and provide a more reliable prediction of stand development (White et al. 2005).

The CFSA (1994) states that every area harvested in Ontario must be regenerated to an acceptable standard where: 1) the standard must be achieved as soon as possible after harvest, 2) the standard must be based upon the best science available, 3) the standard is specific to definitions of target and acceptable species and silvicultural objectives as determined through the forest management planning process, 4) the standards reflect the early dynamics of even-aged management systems, and 5) every regenerated area will be eligible for an independent audit of silvicultural effectiveness (White et al. 2005).

Data collected during the WSFG assessments is invaluable in determining regeneration status, if silviculture treatments were applied effectively, and if the regenerating stand is meeting management objectives regarding the desired future forest condition (White et al. 2005). Regeneration status has only two possible outcomes: Satisfactorily Regenerated (SR) or Not Satisfactorily Regenerated (NSR) (White et al. 2005). The Ontario Ministry of Natural Resources and Forestry (OMNRF previously OMNR) defines satisfactorily regenerated stands as stands that meet stocking and height as specified in the SGR, and are considered to be healthy and essentially free from competing vegetation (OMNRF 2017). Once designated as SR, the regenerating forest stand can be re-entered into the forest inventory and used in subsequent allowable harvest calculations (Sharma et al. 2010). The SR designation is based on the achievement of the desired future forest condition (management objective) as specified in the Silvicultural Ground Rules (SGRs) (OMNR 2001). The OMNRF explains the desired future forest condition (DFFC) as the "forest structure and composition and the goods and services, which are desired from the forest to achieve a balance of social, economic and environmental needs" (OMNRF 2017). In Ontario, the Forest Management Planning Manual (OMNRF 2017) requires that ecosites be used as the basis for the description of forest units, in the development of SGRs, and in developing and reporting forest operations prescriptions. Classification of ecosites, therefore, is important to provide the basis for satisfactorily regenerating a stand and achieving forest management objectives.

ECOLOGICAL LAND CLASSIFICATION

Ecological Land Classification (ELC) is used to organize, evaluate and stratify ecosystems. The modern ELC is hierarchical, providing ecosystem classification at multiple spatial scales (Sims et al. 1996). ELC can provide a framework for classifying ecosystems for forest management planning (Klijn 1994).

In *Book II: Ecological and Management Interpretations for Northwest Ecosites* the OMNR states that in a managed forest, the DFFC can be achieved by understanding forest ecosystems and applying management practices consistent with that understanding (OMNR 1997). Natural Resources Canada (1995) also considers ecosystems essential to provide a framework for silviculture treatment prescriptions, and to understand and explain successes and failures. Silviculture treatments are used in forest management planning in Ontario to manipulate stand composition and structure to meet DFFC and associated management objectives. Many of these treatments are prescribed in the SGRs and forest operation prescriptions (OMNR 1997). The OMNR (1997) states that the most efficient and effective silvicultural treatments are often correlated to a knowledge and understanding of specific stand and site attributes. The Ontario ELC program has provided an opportunity to develop site-specific silvicultural management (OMNR 1997). Site specific management requires integrating silvicultural practices with ecological conditions to meet desired objectives (OMNR 1997).

In Ontario, the goal of the ELC program is to have a standardized way to identify, describe, name and map ecosystems at different scales (OMNR 2009a). The scales or hierarchy developed in Ontario includes ecozones, ecoregions, ecodistricts, ecosections and ecosites, representing the broad to fine spatial scale (OMNR 2009a). Ecosites (10 to 100 ha scale) were developed to identify typical recurring associations of vegetation and substrate types in Ontario (OMNR 2009a). Delineation of an ecosite polygon begins with the substrate form and depositional type because these physical features have a strong effect on the vegetation present (OMNR 2009a). Next, the ecosite polygon is further delineated by the vegetation or vegetation community present (e.g. treed, shrub, herbaceous) (OMNRF 2009). According to the OMNR (2009), a forested ecosite polygon is a community of trees possessing sufficient uniformity in composition, constitution, age, arrangement or ecological condition to be distinguishable from adjacent communities.

Ecosites are delineated, coded and then Ecosite Factsheets are produced by the OMNR for each forest ecosite. The Ecosite Factsheets are found in the three silviculture guide books published by the OMNR. Book II: Ecological and Management Interpretations for Northwest Ecosites (OMNR 1997) specifically identifies acceptable silvicultural treatment packages (required in the SGRs for a site) within the ELC framework (treatments by ecosite). The factsheets provide science-based information about the ecosite. This information includes the ecosite description, substrate description, substrate regime, vegetation description, vegetation table, ecology, and ecoregional variability. For each ecosite a species-specific silvicultural interpretation table is presented. The tables include recommendations by tree species for silviculture system, renewal treatments and tending treatments. These factsheets provide resource managers with site specific silviculture information and recommendations to manage an ecosite for an acceptable tree species and provide to achieve DFFC desired future forest conditions.

RENEWAL TREATMENTS

A silvicultural system is a planned program of silviculture treatments that extends throughout the life of a stand for the purposes of controlling stand establishment, composition, and growth (Smith et al 1997). Renewal treatments are part of the silvicultural system and involve a planned set of treatments applied at the stand level after harvest to establish a DFFC. Renewal treatments include site preparation, regeneration, tending and thinning (OMNRF 2015).

Site preparation is used as a renewal treatment to create suitable, well-distributed microsites for the establishment of desired species (OMNRF 2015). It involves the disturbance of the forest floor and upper soil horizons prior to regeneration. Site preparation treatments can include manual, mechanical, chemical, and/or prescribed burning (OMNRF 2015). Manual treatment includes the use of boot/shovel screefing or manual or motor-manual tools to set aside surface litter, suppress competing vegetation, and to prepare microsites for regeneration (OMNRF 2015). Mechanical treatment includes the use of machinery to prepare microsites and may be combined with a herbicide application in a single operation. Methods for mechanical treatments (shearing, screefing, inverting, mounding, trenching, mixing) vary in their disturbance of the forest floor, and the degree of mixing between the organic and mineral soil layers (OMNRF 2015). Chemical treatment includes the application provincially approved herbicides by licensed applicators prior to regeneration (OMNRF 2015). Herbicides can be applied from aircraft, ground machine (e.g. skidder mounted airblast), or using manual tools (e.g. backback sprayer) (OMNRF 2015). Finally, prescribed burning involves the application of fire to a specific land area to prepare for regeneration (OMNRF 2015). All site preparation treatments are used to: 1) prepare an optimal seedbed for regeneration, 2) provide easy access for planting, ground seeding, aerial seeding, or tending, 3) improve the moisture, nutrient and/or temperature conditions, and 4) discourage competing vegetation (Jeglum et al. 2003). Overall, site preparation reduces the vulnerability of newly planted seedlings. Site preparation treatment should be chosen based on ecosite, forest stand condition and the desired species to be regenerated (Jeglum et al. 2003).

Regeneration is "the establishment of a new cohort of trees either by natural or artificial means" (OMNRF 2015). Natural regeneration is the establishment of desired tree species by natural seeding, sprouting, suckering, or layering, while artificial regeneration involves either direct seeding or the planting of seedlings or cuttings (OMNRF 2015). Artificial direct seeding can be broadcast (e.g. aerial) or precision (e.g. machine mounted). Direct seeding depends on proper site selection, adequate site preparation, and good seed quality and distribution. Seeding is most successful on sites where competition from other vegetation is minimal (OMNRF 2015). Planting is suitable for a wide range of sites and is often chosen for productive and competitive sites, although on competitive sites tending may be required to ensure the DFFC is achieved.

Tending includes a variety of treatments that are used for the benefit of an already established forest (OMNRF 2015). Tending includes cleaning, which is a treatment conducted to "release a regenerating stand from competing vegetation, including undesired tree species, that allows crop trees to establish dominance of the site" (OMNRF 2015). Cleaning methods include chemical, manual, and mechanical cleaning. Chemical cleaning involves applying herbicides by aerial spraying or through on-ground treatments using vehicle mounted equipment, or backpack sprayers to control non-crop vegetation. Manual cleaning is the manual cutting of competing vegetation with motorized or non-motorized tools (e.g. motorized brush saws). Mechanical cleaning is the use of machinery with motorized cutting attachments to remove woody vegetation. Cleaning allows for efficiently channelling limited site resources into crop species rather than into non-commercial plant species (Walstad and Kuch 1987). Following harvest, numerous pioneer plant species (e.g. raspberry (*Rubus idaeus* spp.) and trembling aspen

(*Populus tremuloides* Michx.)) which are well-adapted to post-harvest conditions easily outcompete newly planted crop tree seedlings for nutrients, light, water and growing space (Wagner et al. 2001).

Prescribing renewal treatments based on ecosite is a well-developed process (OMNR 1997). The OMNR provides recommendations on specific treatments through ecosite-based renewal treatment guidelines for each of the forest zones in the province of Ontario. The practical application of these guidelines should lead to a satisfactorily regenerated stand that meets the standards set in the SGR for the site and eventually achieves the DFFC. The WSFG Regeneration Assessment Procedure is a valuable tool that can quantify if the renewal treatments were applied effectively, and that the regenerating stand is meeting management objectives. The plot data from the WSFG assessment can be used to identify which renewal treatments were effective and which were not.

To evaluate how ecosites and the renewal treatments described above interact, WSFG plot data from the Blackwater area harvest blocks on the Lake Nipigon Sustainable Forest Licence in northwestern Ontario was analyzed. Specifically, the objective of this analysis is to determine the effects and interactions of ecosite, mechanical site preparation, regeneration method and herbicide application on the number of WSFG trees per plot evaluated using the WSFG Regeneration Assessment Procedure. The study assesses the effectiveness of renewal prescriptions in achieving management objectives.

LITERATURE REVIEW

There is limited literature on the effects of ecosite, regeneration method, mechanical site preparation (MSP), and/or herbicide, as they interact with specific WSFG (or free-to-grow in other regions) plot data. In contrast, there is research on the effects of MSP, herbicide and regeneration method on the immediate survival, growth, and composition of softwood stands. The target species (Appendix I) for establishment under the Blackwater block area silvicultural ground rules (SGRs) are jack pine (*Pinus banksiana* L.), black spruce (*Picea mariana* (Mill.) BSP) and white spruce (*Picea glauca* (Moench) Voss). The available literature was therefore screened for these species. Given the lack of information on the interaction of renewal treatments with WSFG plot data, the focus of this literature review is to summarize the study information regarding the effects of ecosite, regeneration method, MSP, or herbicide, on regenerating softwood stands. Of key importance in this literature review is the recommendation that early control over site elements such as competing vegetation can improve the survival and growth of tree seedlings and accelerate or ensure the development of a free-growing stand (BCMoF 1999b; MacDonald and Weetman 1993; and many others).

ECOSITE

OMNR (1997) recommends the development of ecosite specific silvicultural treatment packages in order to meet forest renewal and DFFC objectives as established in the SGRs. Site specific management requires integrating silvicultural practices with ecological conditions to meet desired objectives. Classifying forested areas in Ontario by ecosite allows the OMNR to make scientific based recommendations for determining the opportunities for managing either black spruce, jack pine or aspen on the ecosite (OMNR 1997). Management interpretations were developed with the goal of achieving at least 80 percent stocking of black spruce, jack pine or aspen (OMNR 1997). Each ecosite is given a silvicultural interpretations table in *Book II: Ecological and Management Interpretations for Northwest Ecosites* (OMNR 1997), which assists in designing cost-effective and biologically appropriate silvicultural treatment packages. The tables include recommendations by species for silviculture system, renewal and tending treatments.

These recommendations provide resource managers with site specific silviculture information to manage an ecosite for a suitable tree species and provide guidance to help reach the DFFC. For example, on Ecosite 20 (or B049TtM n) for the establishment of jack pine, all forms of site preparation are recommended (mechanical, chemical and prescribed burn), the recommended regeneration method is natural seeding, artificial planting or artificial seeding, and tending treatments are recommended depending on localized competition levels. This type of detailed analysis and development of silvicultural treatment packages by ecosite will improve the success of softwood plantations (OMNR 1997; Taylor et al. 2000) and likely lead to WSFG stands.

REGENERATION METHOD

When assessing a harvested site for regeneration options, a regeneration method should be chosen that is appropriate for the specific site (OMNR 1997; Chrosciewicz 1990). The first consideration is the establishment of a target tree species, for example jack pine, as silviculture treatments vary by species as well as ecosite according to *Book II: Ecological and Management Interpretations for Northwest Ecosites* (OMNR 1997). The most common regeneration treatments for jack pine are natural and artificial seeding or planting. Natural seeding of jack pine should only be done when exposed mineral soil is present, as it is the optimal seedbed for establishment of jack pine regeneration as found by Eyre and LeBarron 1944, Baker 1950, Haig 1959 and many more. As well, target ecosites should have been pure jack pine stands prior to harvesting and have low levels of competition (Eyre and LeBarron 1944). In order to facilitate natural regeneration, harvesting must adequately scatter cone bearing logging slash (tops and branches) throughout the clearcut (Eyre and LeBarron 1944). Although harvesting operations cause some disturbance of the forest floor, this can be inadequate for the natural seeding of jack pine, so either MSP or controlled burning should be used to increase mineral soil exposure (Cayford 1958; Chrosciewicz 1960).

For artificial regeneration of jack pine, the OMNR (1997) and Eyre and LeBarron (1944) suggest that exposed mineral soil provides the best seedbed or microsite for aerial (direct) seeding or artificial planting, respectively. When direct seeding jack pine, MSP is necessary to provide an adequate seedbed. In general, direct seeding is less reliable than planting because of the possibility of severe mortality due to heat, drought and overtopping by competing vegetation on site (Eyre and LeBarron

1944). When planting jack pine, seedlings that have not been overwintered should be planted on low competition sites (Eyre and LeBarron 1944). Seedlings that are two years old or are overwintered stock should be used on more competitive sites as they have a height advantage, over the competing vegetation (Eyre and LeBarron 1944). The choice of regeneration method should be site specific and should consider the level of competition present.

MECHANICAL SITE PREPARATION

There are many studies analyzing the effects of mechanical site preparation (MSP) on seedling survival and growth. Some studies have found MSP is advantageous because it creates optimal microsites resulting in improved seedling growth and survival while reducing competing vegetation. Lafleur et al. (2011) tested four different MSP methods and found all methods increased black spruce height by 15% irrespective of MSP technique relative to control stands. MSP was found to have a statistically significant ($p < 0.0001$) effect on stand growth parameters. Increased growth was presumed to be from MSP exposing better substrate (mineral soil) and improving drainage at the microsite scale (Lafleur at al. 2011). MSP is also beneficial because it can control competing vegetation (Von der Gönna 1992). In British Columbia MSP increased seedling survival rates of lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.). With MSP, survival tended to stabilize after two growing seasons, but survival rates continued to decline over time on control sites with no site preparation (BCMoF 2001). Likewise, Burgess et al. (2010) found jack pine survival increased from

51% in control plots to 84% with MSP in New Brunswick. The use of MSP has the potential to improve survival and growth rates of seedlings, likely resulting in greater numbers of WSFG trees.

In contrast, some studies have found that MSP can increase coppicing of competing vegetation and does not significantly increase seedling growth or survival. On more competitive sites MSP alone is ineffective in suppressing competing vegetation, negatively impacting the establishment and growth of crop trees (Walstad et al. 1987; Thiffault et al. 2003). MacKinnon and McMinn (1988) argue similarly that MSP alone has demonstrated little or, at best, short-term control of competing vegetation and can even promote vegetative resprouting. For example, Frey at al. (2003) found that light MSP may stimulate suckering of trembling aspen. Macdonald et. al (1998) found MSP did not significantly affect white spruce seedling survival. Sutherland and Foreman (2000) found that, other than mixed-mound site preparation, no other MSP method significantly improved the growth of black spruce over manual-boot-screefing by tree planters. Furthermore, White (2004) found that on lower productivity sites, harvesting operations may provide sufficient soil disturbance to provide adequate microsites, thereby negating the need for MSP. Due to the deliberations around the benefits of MSP, an analysis of the WSFG assessments is required in order to determine if MSP had a significant effect on the number of WSFG trees.

HERBICIDE APPLICATION

Herbicides have been found to effectively control competing vegetation and increase the composition, survival and growth of crop seedlings. Wood and Mitchell (1995) treated both bareroot and container stock plantations with glyphosate (a common herbicide), effectively reducing 97% of competing vegetation (principally trembling aspen), relative to untreated control plots. Similarly, Wood and von Althen (1993) also treated both bareroot seedling and container stock plantations with glyphosate and reduced 20% of herbaceous cover and 25% of woody vegetation cover.

In softwood plantations in Nova Scotia where no herbicides were used, 87% of plantations were outright failures, and an additional 10% did not meet free-to-grow standards 6-8 years post-harvest (Nicholson 2007). Likewise, Daggett (2003) found crop tree (softwood) composition was 74% in herbicide treated plots compared with 23% in untreated plots due to increased competing vegetation. As well, Pitt et al. (2004) found annual applications of glyphosate for five consecutive growing seasons resulted in nearly complete regeneration success of black spruce.

Herbicide application is clearly associated with increased survival, height, diameter and volume growth of softwood crop trees. The association of herbicide use with increased crop tree responses in terms of height, diameter, and volume growth is well documented (Pitt et al. 1999, 2000, 2004; Pitt and Bell 2005; Dampier et al. 2006; Bell et al. 2011). Wood and von Althen (1993) found survival of white spruce seedlings receiving post-planting herbicide application was significantly higher ($p < 0.05$). Burgess et al. (2010) found jack pine seedling survival increased from 51% in control plots to 82% with intensive herbicide applications. Pitt et. al (2004) found annual vegetation removal treatments resulted in black spruce trees exhibiting 16-55% gains in height and 112-476% increase in stem volume growth over untreated trees. The degree of stem volume gain among treatments was positively correlated with the level of vegetation control during the first few years after treatment. Wagner et al. (1999) found that if vegetation was controlled for a critical period after planting jack pine, red pine (*Pinus resinosa* Ait.), eastern white pine (*Pinus strobus* L.), and black spruce, productivity could be maximized. Stem volume production for jack pine, red pine, eastern white pine, and black spruce increased by 116%, 212%, 216% and 349%, respectively, ten years after planting if surrounding vegetation was controlled for the first one to three years after planting. As well, Wagner and Robinson (2006) found that stand volume was 117%, 208%, 224% and 343% higher for jack pine, red pine, white spruce, and black spruce, respectively after five years of consecutive herbicide use, than the control group.

The majority of the literature is in agreement that chemical herbicide treatment effectively controls competing vegetation, while increasing the composition, survival and growth of crop seedlings. There are few mentions of how herbicide treatment affects WSFG status. In Alberta since the enactment of Free-To-Grow (FTG) standards, there has been a well documented increase in herbicide use to meet the FTG standards (CCFM 2006). This suggests that herbicide increases the likelihood of a stand to reach FTG status, and further may suggest that at the plot level there will be a significant effect of herbicide on the number of WSFG trees.

The interactions between ecosite, regeneration method, MSP and herbicide application are not well studied. Robinson et al. (2001) results indicated that for plots treated with MSP and glyphosate there was an approximate reduction of 100% in herbaceous and woody vegetation cover, relative to the untreated control plots, three years post-planting. More studies are required to determine the interactions between ecosite, regeneration method, MSP and herbicide application.

Ecosite and regeneration method are important considerations when choosing renewal treatments. There are clear contradictions between scientific studies on the effects of MSP and whether it does increase seedling survival and growth. Chemical herbicide treatment studies conclude that it does increase seedling survival and growth. Further investigation is necessary to understand the effects and interactions of ecosite, regeneration method, MSP and herbicide application on regeneration, specifically at the WSFG stage.

NULL HYPOTHESES

Based on a review of the literature, five null hypotheses have been formed that are worthy of further investigation: 1) ecosite does not have a statistically significant effect on the number of WSFG trees per plot, 2) regeneration method does not have a statistically significant effect on the number of WSFG trees per plot, 3) mechanical site preparation does not have a statistically significant effect on the number of WSFG trees per plot, 4) herbicide application does not have a statistically significant effect on the number of WSFG trees per plot, and 5) the interaction of ecosite, regeneration method, mechanical site preparation, and herbicide application does not have statistically significant effect on the number of WSFG trees per plot.

MATERIALS AND METHODS

STUDY AREA

The WSFG assessments were carried out in the Blackwater area, located in the Thunder Bay District, in the Municipality of Greenstone, Ontario, Canada. The data collection was undertaken in the summer of 2018 and was analyzed in the winter of 2018-2019. The study area is in the Boreal Forest Region in Ecoregion 3W (Lake Nipigon Ecoregion), Ecodistrict 3W-4 (Figure 1) (OMNR 2009b). Common Boreal Forest Region tree species are jack pine, black spruce, white spruce, white birch (*Betula papyrifera* Marshall), trembling aspen, tamarack (*Larix laricina* (Du Roi) K. Koch) and balsam fir. All of these tree species can be found in the immediate area of the Blackwater Blocks.

Figure 1. Map of forest regions of Ontario with Blackwater study area (red).

The study area is located approximately 23 km east of Beardmore, Ontario and is directly adjacent to Highway 11 (Figure 2). The Blackwater area is within the Lake Nipigon Sustainable Forest Licence. The study area covers from 49.65° N to 49.66° N, and 87.79° W to 87.62° W, which is approximately 13 km wide east to west.

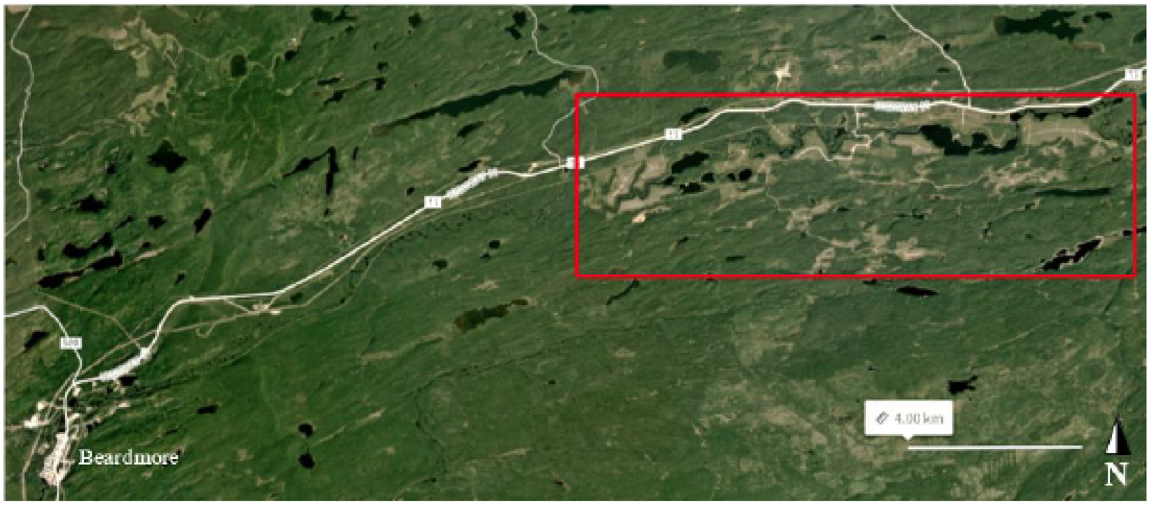

Figure 2. Planet Labs imagery from August of 2018 of the study area (in red).

Figure 3. Planet Labs imagery showing the study area in detail.

RENEWAL HISTORY OF THE STUDY AREA

Blackwater Blocks numbered "Black 1 to 8" were harvested between 2010 and 2013. Black 5 was harvested in 2010 followed by Black 1, 2, 3 and 7 in 2011, Black 6 and remainder of 7 in 2012 and Black 4 from 2012-13 (Table 1). Black 1, 2 and 8 were aerial seeded with jack pine by helicopter in 2013. Black 3 and 4 were left for natural regeneration. Black 6, 7 and part of 5 were planted with jack pine, black spruce, and white spruce in 2013. Most of Black 5 was planted in 2012. Figure 4 illustrates the regeneration treatments for the Blackwater Blocks (also shown in Table 1).

The Blackwater Blocks had a number of different renewal treatments: 1) only MSP, 2) only chemical herbicide applications, 3) neither, or 4) both (Table 1). Figure 5 illustrates areas where MSP and chemical herbicide applications took place. Black 1 had MSP and was partially treated with herbicide. Black 2 had MSP and herbicide. Black 3 and 4 had neither. Black 5 and 6 had no MSP and partial coverage with herbicide. Black 7 and 8 had MSP and partial coverage with herbicide (Table 1).

Table 1. Summary of harvesting and regeneration in Blackwater Blocks 1 to 8.

Block No.	Year Harvested	Regeneration Type	Year Regenerated	MSP	Herbicide
Black 1	2011	Seed	2013	Y	P
Black 2	2011	Seed	2013	Y	Y
Black 3	2011	Natural	N/A	N	N
Black 4	2012-13	Natural	N/A	N	N
Black 5	2010	Plant	2012-13	N	P
Black 6	2012	Plant	2013	N	P
Black 7	2011	Plant	2013	Y	P
Black 8	2012	Seed	2013	Y	P

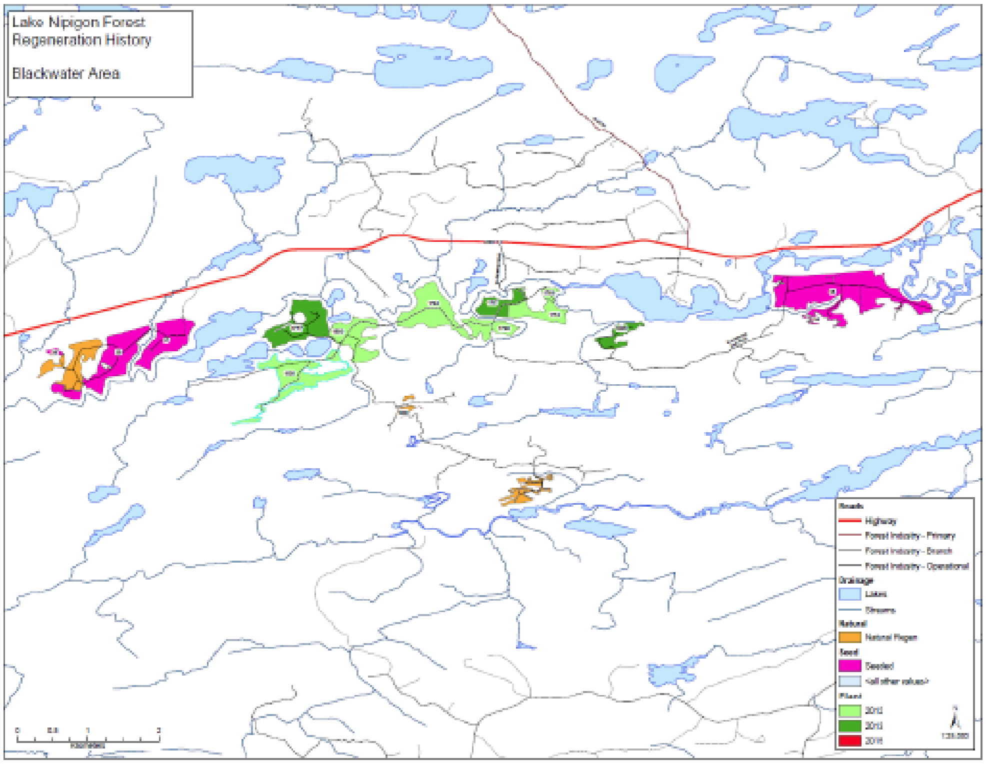

Figure 4. Regeneration history map of Blackwater area.

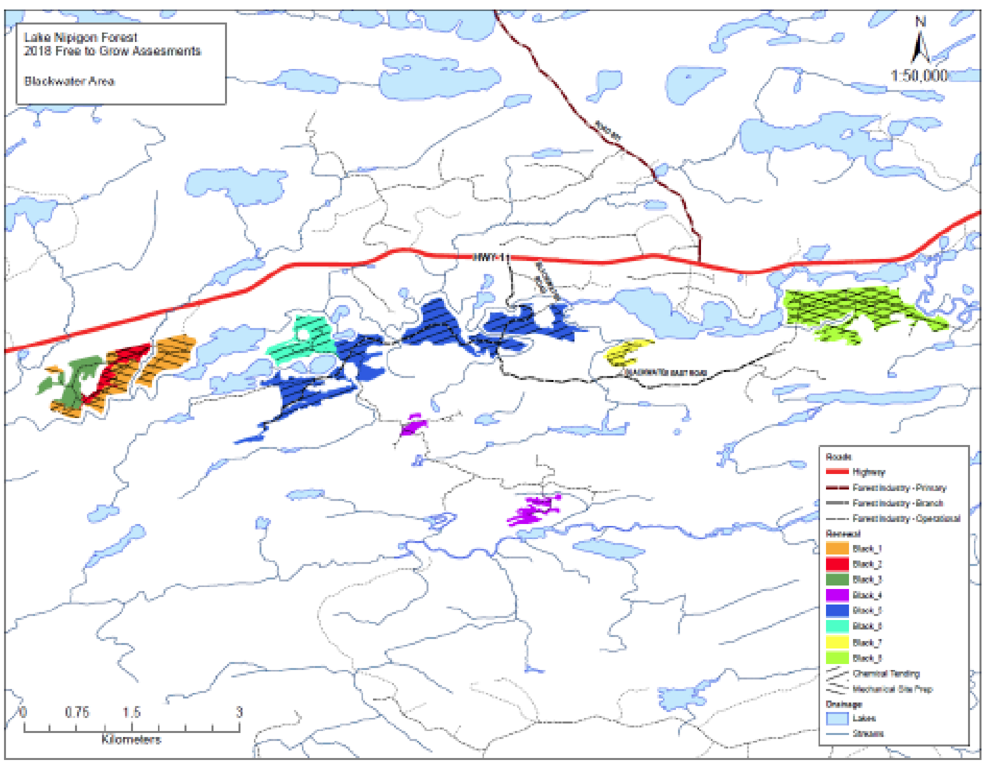

Figure 5. Location and distribution of Blackwater Blocks overlain with hatching to show locations for MSP and herbicide application.

The Blackwater area has seven ecosites that will be referred to in this study. The ecosites are the primary ecosites taken from the Forest Resource Inventory data for the Lake Nipigon Forest SFL. The codes will be used throughout the results and discussion. The names of the ecosites can be found in Table 2. The codes used in the rest of this report are the current *Ecosites of Ontario* (OMNR 2009a) codes. The new silvicultural guide for these boreal codes has not yet been released by the OMNRF therefore, for the purposes of this study *A Guide to translate northwestern Ontario ecosites into Ecosites of Ontario* (OMNR 2012) was used to translate the new codes to the previous Terrestrial and Wetland Ecosites of Northwestern Ontario (Racey et al. 1996) codes to get the silviculture interpretations for each ecosite.

Table 2. Previous and current names of ecosites in the Blackwater Blocks.

Block Number	Current Ecosite of Ontario Code (OMNR 2012)	Ecosite Name (OMNR 1997)	Previous Code (OMNR 1997)
Black 8	B035TtD k	Pine–Spruce Mixedwood: Sandy Soil	ES14
Black 1 & 5	B049TtD n	Spruce–Pine / Feathermoss: Fresh, Sandy–Coarse Loamy Soil	ES20
Black 5, 6 &7	B050TtD n	Spruce–Pine / Feathermoss: Fresh, Sandy–Coarse Loamy Soil or Fir–Spruce Mixedwood: Fresh, Coarse Loamy Soil	ES20 or ES21
Black 2, 4	B055TtD n	Hardwood–Fir–Spruce Mixedwood: Fresh, Sandy–Coarse Loamy Soil	ES19
Black 1, 3 & 4	B065TtD n	Spruce–Pine / Ledum / Feathermoss: Moist, Sandy–Coarse Loamy Soil	ES22
Black 5	B128TtD n	Intermediate Swamp: Black Spruce (Tamarack): Organic Soil	ES36

EXPERIMENTAL DESIGN

The WSFG Regeneration Assessment Procedure for Ontario outlines 10 steps to complete the WSFG procedure. These steps are split into office tasks and field tasks. The office tasks are steps 1 through 4. Step 1 was to stratify areas to be assessed and group them into homogeneous units (strata). Permanent (primary and branch) roads, non-productive forest conditions (e.g wetlands), uncut areas and permanent water area were excluded from the sampling area. The final strata were delineated on a map.

Step 2 was to determine the sample size for each stratum. A minimum of 31 plots were required to satisfy the statistical assumptions associated with the later calculations. If the stratum area was equal to or less than 10 ha, the minimum number of plots required was 31. If the stratum was greater than 10 ha, the minimum sample size was determined by dividing the stratum area (ha) by two and adding the resulting number to 31. The maximum sample size was determined by adding 31 to the total area (ha) of the stratum. For example, if the stratum was 20 ha the minimum number of plots was 41 and the maximum was 51.

Step 3 was to map the sampling grid and survey lines. Using a grid-based sampling design allowed all parts of the stratum to have an equal opportunity to be sampled (White et al. 2005). The size of the stratum and the minimum number of plots determined the grid size and pattern. Potential plot locations were systematically identified along each grid line on a map to ensure the minimum number of plots was met and there was adequate coverage.

Step 4 was the final office procedure, which is to complete the project information header sheet and assemble field equipment. DDFC and regeneration standards information was taken from the silvicultural ground rules; this included the target forest unit, crop tree species and their associated minimum heights. This information was then entered onto the WSFG Regeneration Assessment Header Sheet used in the field. Equipment needed for field surveys included: a 2.26 m long measuring stick with 10 cm divisions and special markings to clearly indicate 0.3 m, 1.2 m, and 1.8 m, flagging tape or a metal pin (to mark the centre of each plot), metric tape measure, compass, GPS (Samsung tablets with Avenza Maps) with plot locations delineated, and tally sheets.

The field tasks as outlined in White et al. (2005) include steps 5-10. Step 5 was establishing the plots at the pre-determined sampling points. This included locating the plot centres using a tablet, marking the plot centres with flagging tape and determining the plot boundaries using the 2.26 m measuring stick.

Step 6 was to tally all trees by species and height class. Within each plot, the total number of stems (including both crop and non-crop tree species) were tallied by height class using the measuring stick (Table 3). For the smallest height class (1) a maximum of 16 trees per species per plot were tallied. Final tree counts were recorded on the tally sheet. As well as trees, competing vegetation species (Appendix II), their average heights and percent cover were recorded.

Table 3. Height classes by species from White et al. (2005).

	Height Classes		
Species	1	2	3
Sb, Sw, Bf, Ce	0.3 to 0.79	0.8 to 2.0	>2.0
Pj, Pr, Pw, L	0.3 to 0.9	1.0 to 2.0	>2.0
Hardwoods	0.3 to 1.9	2.0 to 2.9	>3.0

Step 7 was to apply the well-spaced criteria to crop trees. A crop tree is defined in the WSFG procedure (2005) as a, "healthy, vigorous tree of either a target or acceptable species that meets a minimum height standard as defined in the appropriate silvicultural ground rule". Only crop trees can be considered for well-spaced and free-growing status. A prominent crop tree within the plot was selected as the starting tree. It was then determined if the crop tree met the well-spaced criteria. If the tree under consideration had no other crop trees closer than 1.8 m, either inside or outside of the plot, it was counted as a well-spaced tree. If there was a crop tree or trees less than 1.2 m away from the tree being considered, the most vigorous tree was chosen and evaluated for the WSFG criteria. If there was another crop tree equal to or further than 1.2 m and less than 1.8 m away from the tree being considered, the tree was only tallied as well-spaced if two quadrants within a 1.8 m radius around the crop tree were free of other crop trees more than one-half the height of the selected tree. For an example see Figure 6. Systematically moving from the starting tree, each crop tree was evaluated for well-spaced criteria. The total number of well-spaced trees was recorded by species on the tally sheet to a maximum of four well-spaced crop trees per plot.

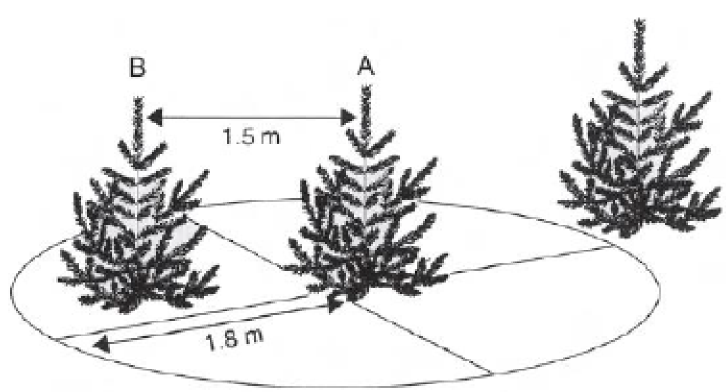

Figure 6. Tree A is well-spaced because more than two quadrants are free of crop trees (White et al. 2005).

Once the well-spaced crop trees were chosen, Step 8 is applying the free-growing criteria to the well-spaced trees. The free-growing assessment is carried out within a 1.2 m radius "cylinder" around each well-spaced tree (Figure 7). To be considered competition, brush and tree competitor stems must have been rooted within the cylinder or have a main stem growing vertically within the cylinder. A well-spaced tree is considered free-growing if it is not underneath a closed canopy or overtopped, is at least 1.5 times taller than each brush stem (list of species provided in Appendix II) within a 1.2 m radius (or the well-spaced crop tree is at least 2.5 m tall) and is at least twice as tall as each tree competitor (list of species provided in Appendix II) within a 1.2 m radius. If the well-spaced tree is not taller than the brush, the brush must be confined to two quadrants of the 1.2 m cylinder and the tree competitors must be confined to one quadrant of the 1.2 m cylinder for the well-spaced tree to be considered free-growing. Figure 8 shows a flow chart to determine if a well-spaced tree is also free-growing (White et al. 2005). All plots of the Blackwater study area were evaluated following steps 5-8.

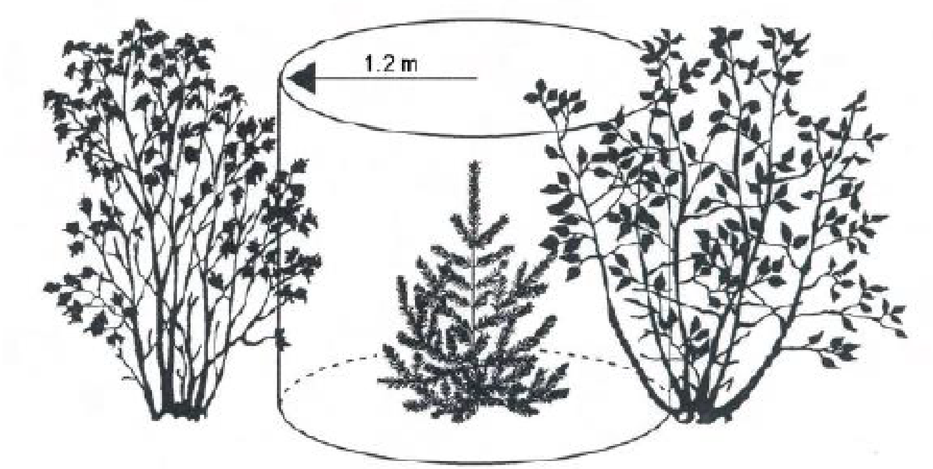

Figure 7. To determine if a well-spaced tree is free-growing, a 1.2 m radius is assessed for competition (White et al. 2005).

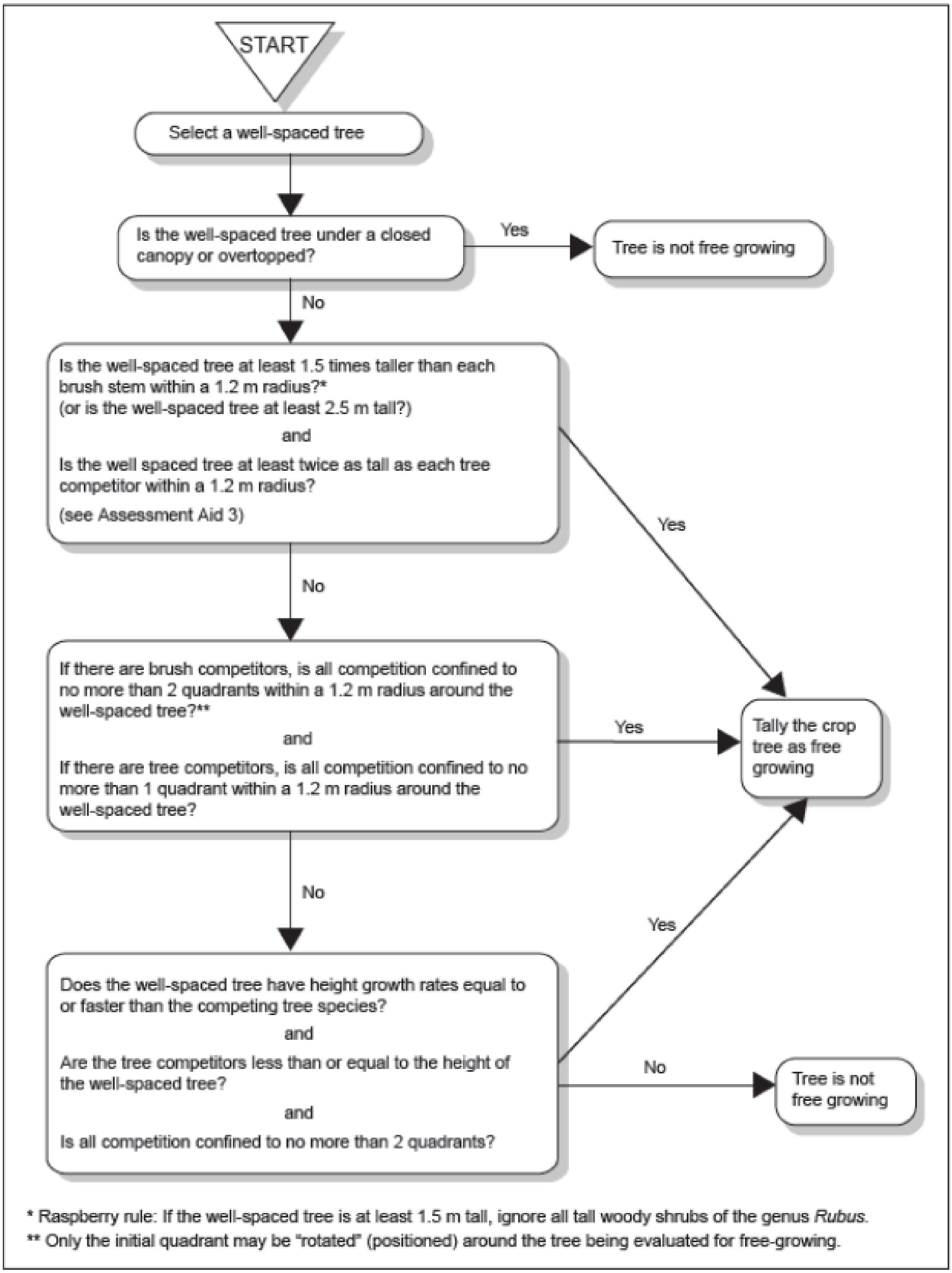

Figure 8. Flow chart for determining if a tree is WSFG (White et al. 2005).

Following the field data collection, there were 2 final office tasks. Step 9 was to determine the regeneration status of the stratum. Regeneration status has only two possible outcomes: Satisfactorily Regenerated (SR) or Not Satisfactorily Regenerated (NSR) (White et al. 2005). Step 9 includes a set of calculations to determine if the stratum is SR or NSR (see Appendix III for full calculations). First, the mean number of WSFG stems/ha (MEAN) for each stratum was calculated. Since none of the Blackwater Blocks were under 10 ha a lower confidence limit (LCL) about the mean number of WSFG trees/ha at the 90% probability level was calculated. The standard deviation value (STD) used in the calculations was the standard deviation for the sample rather than the population. The regeneration standard was compared with MEAN and LCL to determine the free-growing status of the stratum. If the regeneration standard was less than LCL, then the stratum was considered SR. If the regeneration standard was greater than MEAN, the stratum was considered NSR. The WSFG Regeneration Assessment Procedure for Ontario states that if the regeneration standard falls between MEAN and LCL, the regeneration status of the area is uncertain and additional plots must be established to improve the statistical precision for MEAN and LCL.

The final office step was Step 10, completing post-survey assessment and evaluation. For each stratum, results were analyzed to determine the need for follow-up treatments and to determine the status of regeneration in the survey stratum.

PLOT LEVEL STATISTICAL ANALYSIS

Only the target species as listed in each SGR (Appendix I) were used for the following calculations. Within blocks with was more than one SGR the target species were added together for the number of WSFG target species trees per plot. There was a total of 472 plots, each plot had a variable for ecosite (6 treatments), regeneration type (3 treatments), MSP (2 treatments - yes or no), herbicide (2 treatments - yes or no) (Table 4).

Table 4. Independent variables for the plot analysis.

Ecosite Type	Regen Method	MSP	Herbicide
B049TtDn	Natural	Y	Y
B065TtDn	Seed	N	N
B055TtDn	Plant		
B128TtDn			
B050TtDn			
B035TtDk			

A linear model two-way independent ANOVA was used to examine the effects of ecosite and chemical herbicide application. Both ecosites had MSP and were aerial seeded. The ecosite variables were B049TtDn with and without herbicide and B035TtDk with and without herbicide. There was an uneven number of replicates for the interaction between ecosite and herbicide (yes or no), B035TtDk had only seven replicates (plots) that had herbicide applied. Therefore, to choose seven plots for ANOVA analysis a random number generator was used in EXCEL to assign a number to each plot for B049TtDn with herbicide and without and to B035TtDk without herbicide. The plots were then ordered smallest to largest, and the first seven replicates were chosen to make the number of replicates equal (N = 7) (total of 28 plots). IBM SPSS Statistics Ver. 24.0 was then used to complete the two-way ANOVA.

A one-way ANOVA was completed to compare ecosite and regeneration effects. The first ANOVA used five of the six ecosites as Ecosite B128TtDn had only eight plots. The next lowest number of plots was 60 for Ecosite B065TtDn so 60 replicates (N = 60) were randomly chosen for the other 4 ecosites as described above (total of 300 plots). IBM SPSS was then used to run the one-way ANOVA. This process was repeated for comparing the three regeneration methods with 97 plots for each method (N = 97) (total of 291 plots).

An independent t-test was used to compare the effects of MSP as well as herbicide application. For plots with MSP, N = 218 (total of 436 plots). For herbicide application, N = 171 (total of 342). For MSP and herbicide application in the Independent-Samples T-test options screen in SPSS bootstrapping was applied with a Bias corrected accelerated (BCa) confidence interval. Then the t-test was run.

Other statistics to illustrate the effects and interaction of ecosite, MSP, regeneration method and herbicide application were calculated using Microsoft EXCEL, the average number of WSFG trees per plot, and the standard deviation. These three statistics were calculated using all 472 plots. The calculations were done separately for each ecosite (6 ecosites), regeneration type (3 types), MSP (yes or no), herbicide (yes or no) and for MSP with herbicide (yy,nn,yn,ny) (independent of all other variables). The dependent variable was the number of WSFG trees of the target species (as indicated in the SGR for each block) (Appendix I).

RESULTS

The results for each Blackwater Block are split into two rows of calculations, one for the number of WSFG target species from the SGR and one for all the tree species present (Table 5).

Table 5. Regeneration status by block.

Block	Species Included	# of WSFG trees	#WSFG/ plot	#WSFG/ ha	SGR Min. Density of target species	SR or NSR	LCL #WSFG/plot	LCL #WSFG/ha	SGR Min. Density of target species	SR or NSR
BLACK-1	Target: Pj	102	1.73	1080.51	1500	NSR	1.40	877.84	1500	NSR
	Sb, Sw Po, Bf, Bw, Ce, La	129	2.19	1366.53	1500	NSR	1.86	1163.86	1500	NSR
BLACK-2	Target: Pj, Sb, Sw	33	0.80	503.05	1250	NSR	0.62	387.97	1250	NSR
	Po, Bf, Bw, Ce, La	77	1.88	1173.78	1250	NSR	1.69	1058.70	1250	NSR
BLACK-3	Target: Sb, Sw	29	0.63	394.02	1500	NSR	0.44	277.52	1500	NSR
	Pj, Po, Bf, Bw, Ce, La	56	1.22	760.87	1500	NSR	1.03	644.37	1500	NSR
BLACK-4	Target: Pj, Sb	12	0.24	147.06	1000	NSR	0.14	86.50	1000	NSR
	Sw, Po, Bf, Bw, Ce, La	68	1.33	833.33	1000	NSR	1.24	772.78	1000	NSR
BLACK-5	Target: Pj, Sb, Sw	235	2.20	1372.66	1250	SR	1.96	1223.31	1250	NSR
	Po, Bf, Bw, Ce, La	257	2.40	1501.17	1250	SR	2.16	1351.82	1250	SR
BLACK-6	Target: Pj	55	1.10	687.50	1500	NSR	0.79	491.84	1500	NSR
	Sb, Sw Po,Bf,Bw,Ce,La	94	1.88	1175.00	1500	NSR	1.57	979.34	1500	NSR
BLACK-7	Target: Pj	29	0.73	453.13	1500	NSR	0.41	257.03	1500	NSR
	Sb, Sw Po,Bf,Bw,Ce,La	53	1.33	828.13	1500	NSR	1.01	632.03	1500	NSR
BLACK-8	Target: Pj	75	0.93	578.70	1500	NSR	0.69	429.95	1500	NSR
	Sb, Sw, Po, Bf, Bw, Ce, La	88	1.09	679.01	1500	NSR	0.85	530.26	1500	NSR

Ecosite had a statistically significant effect ($p < 0.05$) on the number of WSFG trees per plot (Table 6). The effect of herbicide on the number of WSFG trees per plot was not significant, although the interaction of ecosite and herbicide was significant at 90% confidence ($p < 0.09$).

Table 6. Results of ANOVA for ecosite B049TtDn versus B050TtDn herbicide and no herbicide.

Tests of Between-Subjects Effects

Dependent Variable: Number of WSFG trees per plot

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	12.286[a]	3	4.095	2.774	0.063
Intercept	46.286	1	46.286	31.355	0.000
Ecosite	7.000	1	7.000	4.742	0.039
Herbicide	0.143	1	0.143	0.097	0.758
Ecosite * Herbicide	5.143	1	5.143	3.484	0.074
Error	35.429	24	1.476		
Total	94.000	28			
Corrected Total	47.714	27			

a. R Squared = .257 (Adjusted R Squared = .165)

In the one-way ANOVA between ecosites there was a significant difference ($p < 0.05$) in the effect of ecosite on the number of WSFG trees per plot (Table 7). There was also a difference in the mean number of WSFG trees per plot (Figure 9).

Table 7. Results of ANOVA for ecosites.

ANOVA

Number of WSFG trees per plot

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	78.8	4	19.7	16.1	0.0
Within Groups	361.5	295	1.2		
Total	440.3	299			

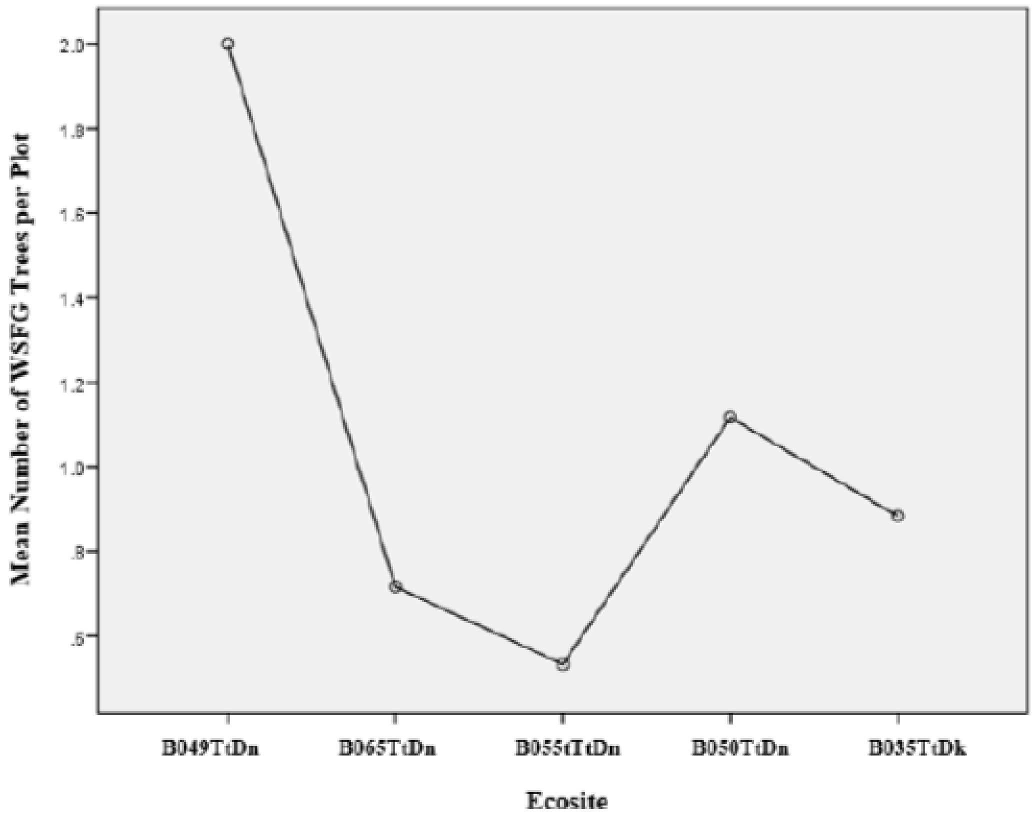

Figure 9. ANOVA results for the mean number of WSFG trees per plot by ecosite.

In the one-way ANOVA between regeneration methods there was a significant difference ($p < 0.05$) in the effect of regeneration method on the number of WSFG trees per plot (Table 8). There was also a difference in the mean number of WSFG trees per plot (Figure 10).

Table 8. Results of ANOVA for regeneration methods.

ANOVA

Number of WSFG trees per plot

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	70.85	2	35.426	27.54	0.00
Within Groups	370.47	288	1.286		
Total	441.33	290			

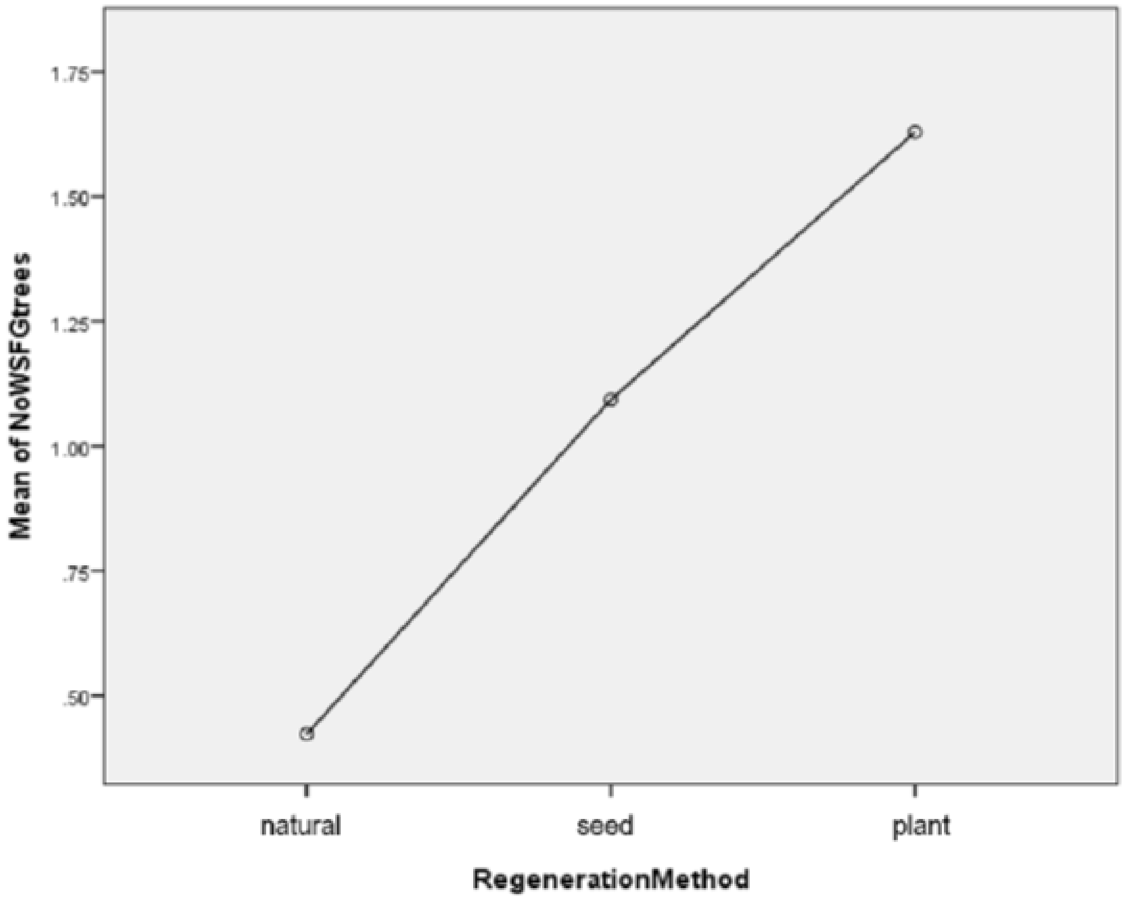

Figure 10. ANOVA results for the mean number of WSFG trees per plot by regeneration method.

The independent samples t-test showed that Levene's test for equality of variances was significant (Table 9), so the numbers for further analysis were taken from the equal variances not assumed row (Table 10). On average, MSP plots had more trees per plot (M = 1.26, SE = 0.09), than plots that did not have MSP (M = 1.10, SE = 0.08) (Table 9). This difference, 0.16, BCa 95% CI [-0.08, 0.41] (Table 11), was not significant $t(424.8) = 1.32$, $p = 0.19$ (Table 10).

Table 9. Group statistics for MSP.

MSP			Statistic	Bootstrap[a] Bias	Std. Error	BCa 95% CI Lower	Upper
Number of WSFG trees per plot	0- N	N	218				
		Mean	1.26	0.00	0.09	1.08	1.43
		STD	1.36	-0.01	0.05	1.26	1.43
		SE	0.09				
	1- Y	N	218.00				
		Mean	1.10	0.00	0.08	0.95	1.24
		STD	1.17	-0.01	0.05	1.08	1.24
		SE	0.08				

a. Unless otherwise noted, bootstrap results are based on 1000 bootstrap samples

Table 10. Independent samples t-test results for MSP.

		Levene's Test for Equality of Variances F	Sig.	t-test for Equality of Means t	df	Sig. (2-tailed)	Mean Differen	Std. Error	95% Confidence Lower	Upper
Number of WSFG trees per plot	Equal variances assumed	9.46	0.00	1.32	434.00	0.19	0.16	0.12	-0.08	0.40
	Equal variances not assumed			1.32	424.78	0.19	0.16	0.12	-0.08	0.40

Table 11. Bootstrap for independent samples t-test for MSP.

		Bootstrap[a]					
						BCa 95% Confidence Interval	
		Mean Difference	Bias	Std. Error	Sig. (2-tailed)	Lower	Upper
Number of WSFG trees per plot	Equal variances assumed	0.16	0.00	0.12	0.19	-0.08	0.41
	Equal variances not assumed	0.16	0.00	0.12	0.19	-0.08	0.41

The results of the independent samples t-test showed that Levene's test for equality of variances was significant, so the numbers for further analysis were taken from the equal variances not assumed row (Table 13). On average, herbicide plots had more trees per plot (M = 1.40, SE = 0.09), than plots that did not have herbicide (M = 0.87, SE = 0.10) (Table 12). This difference, -0.53, BCa 95% CI [-0.79, -0.28] (Table 14), was significant $t(331.56) = -3.95$, $p = 0.00$ (Table 13).

Table 12. Group statistics for herbicide.

				Bootstrap[a]			
						BCa 95% CI	
Herbicide			Statistic	Bias	Std. Error	Lower	Upper
Number of WSFG trees per plot	0 - N	N	171				
		Mean	0.87	0.00	0.09	0.71	1.05
		STD	1.14	-0.01	0.07	1.02	1.26
		SE	0.09				
	1 - Y	N	171				
		Mean	1.40	0.00	0.10	1.22	1.61
		STD	1.34	0.00	0.05	1.24	1.43
		SE	0.10				

Table 13. Independent samples t-test results for herbicide.

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Differenc	Std. Error	95% Confidence Lower	Upper
Number of WSFG trees per plot	Equal variances assumed	13.97	0.00	-3.95	340.00	0.00	-0.53	0.13	-0.80	-0.27
	Equal variances not assumed			-3.95	331.56	0.00	-0.53	0.13	-0.80	-0.27

Table 14. Bootstrap for independent samples t-test for herbicide.

		Bootstrap[a]					
						BCa 95% Confidence Interval	
		Mean Difference	Bias	Std. Error	Sig. (2-tailed)	Lower	Upper
Number of WSFG trees per plot	Equal variances assumed	-0.53	0.00	0.14	0.00	-0.79	-0.28
	Equal variances not assumed	-0.53	0.00	0.14	0.00	-0.79	-0.28

The average number of WSFG trees per plot and standard deviation were affected by independent variables at the plot level. Plots in ecosite B049TtDn had the highest average with 2.09 WSFG trees per plot and a standard deviation (STD) of 1.33 WSFG trees per plot, while plots in ecosite B049TtMn had the lowest average with 0.00 WSFG trees per plot and 0.00 for STD (Table 15; Figure 11).

Table 15. Average and standard deviation of WSFG trees per plot by ecosite.

Ecosite	Average number of WSFG trees per plot	Standard Deviation
B049TtDn	2.09	1.33
B128TtDn	1.50	1.60
B050TtDn	1.34	1.30
B035TtDk	0.93	1.09
B065TtDn	0.72	0.92
B055TtDn	0.49	0.79

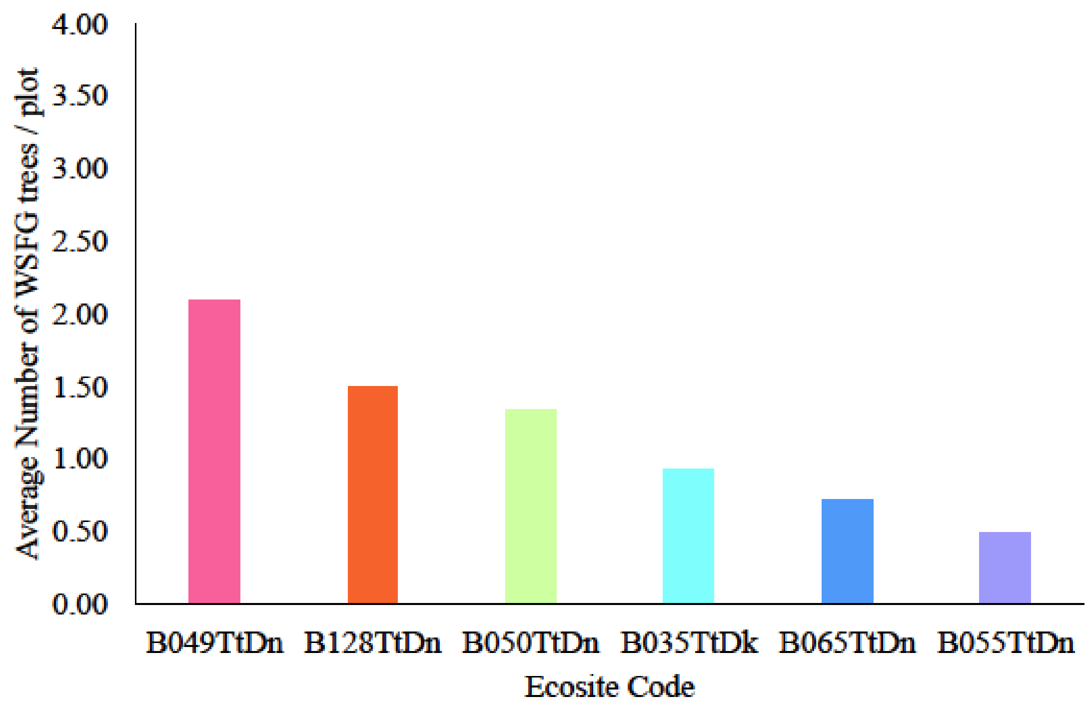

Figure 11. The average number of WSFG trees per plot by ecosite.

For plot level analysis for regeneration method results show that plots that were planted had the highest average with 1.62 WSFG trees per plot and a STD of 1.40 WSFG trees per plot, while plots that were naturally regenerated had the lowest average with 0.42 WSFG trees per plot and a SD of 0.67 WSFG trees per plot (Table 16; Figure 12).

Table 16. Average and standard deviation of WSFG trees per plot by regeneration method.

Regeneration Method	Average Number WSFG trees / plot	Standard Deviation
Plant	1.62	1.40
Seed	1.16	1.19
Natural	0.42	0.67

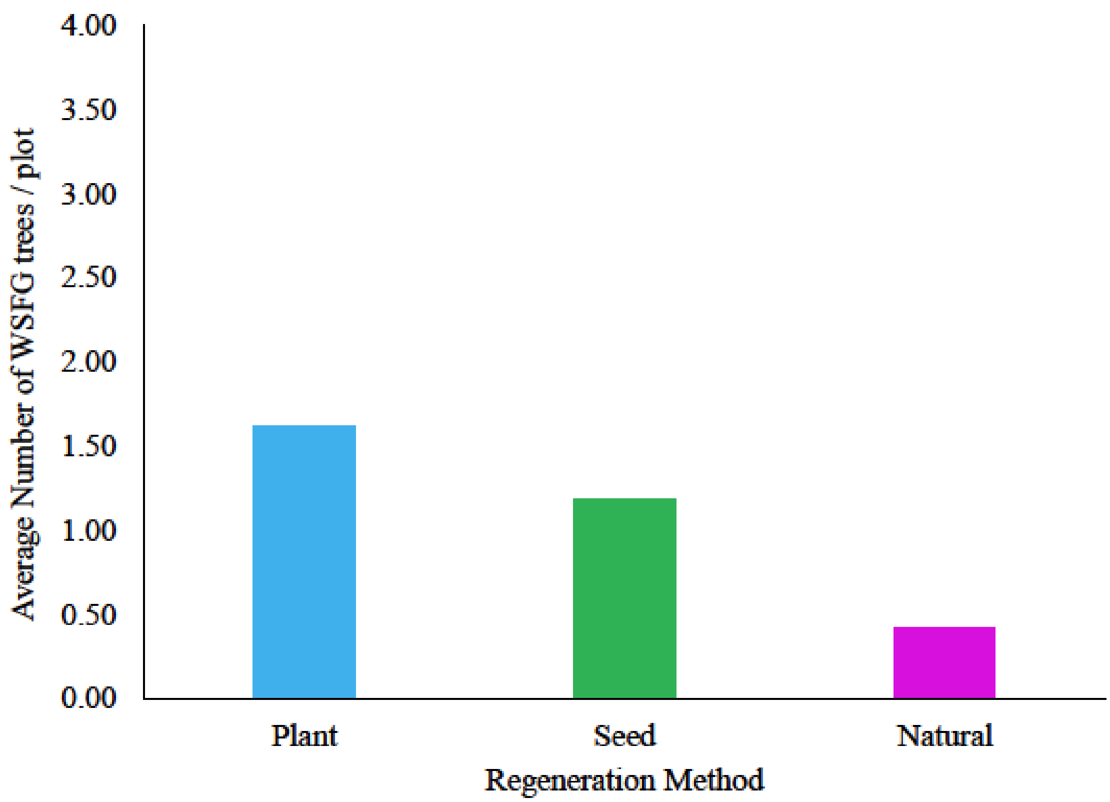

Figure 12. The average number of WSFG trees per plot by regeneration method.

Results from MSP plot data show that plots without MSP had the highest average with 1.30 WSFG trees per plot and a STD of 1.37 WSFG trees per plot, while plots with MSP had an average of 1.08 WSFG trees per plot and a STD of 1.17 WSFG trees per plot (Table 17; Figure 13).

Table 17. Average and standard deviation of WSFG trees per plot by MSP.

Mechanical Site Preparation	Average Number WSFG trees / plot	Standard Deviation
No	1.30	1.37
Yes	1.08	1.17

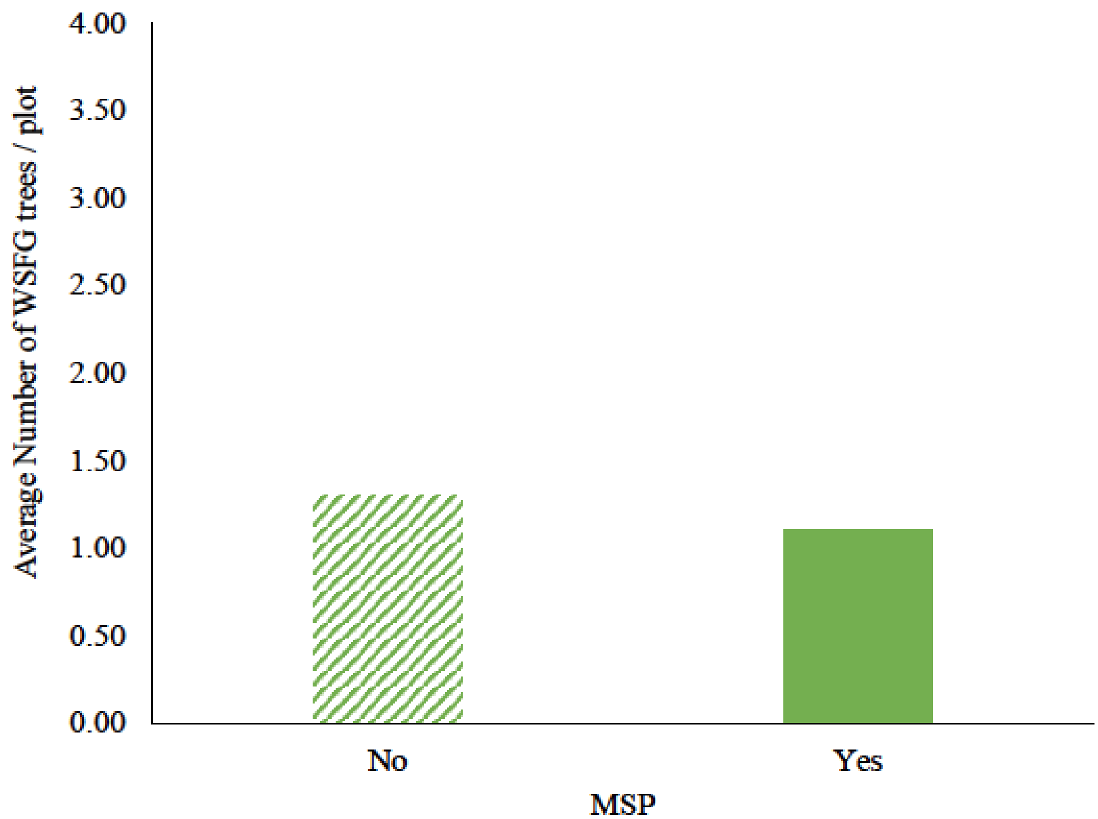

Figure 13. The average number of WSFG trees per plot with and without MSP.

For chemical herbicide application, plots with herbicide application had the higher average with 1.40 WSFG trees per plot and a STD of 1.32 WSFG trees per plot, while plots without herbicide had an average of 0.86 WSFG trees per plot and a SD of 1.14 WSFG trees per plot (Table 18; Figure 14).

Table 18. Average and standard deviation of WSFG trees per plot by herbicide application.

Chemical Tending	Average Number WSFG trees / plot	Standard Deviation
Yes	1.40	1.32
No	0.86	1.14

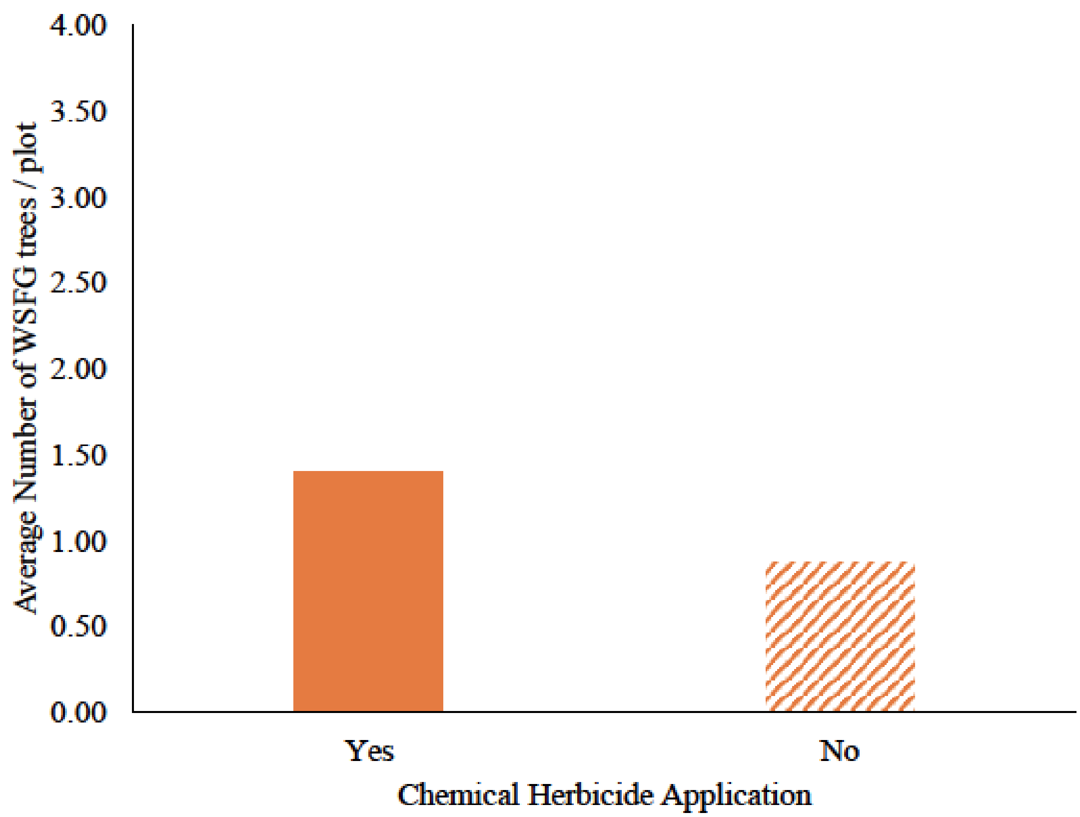

Figure 14. The average number of WSFG trees per plot with and without herbicide application.

The interaction of MSP and chemical herbicide application results show that plots with only herbicide application had the highest average with 1.94 WSFG trees per plot and a STD of 1.39 WSFG trees per plot, while plots with neither MSP or herbicide application had the lowest average of 0.51 WSFG trees per plot and a STD of 0.66 WSFG trees per plot (Table 17; Figure 15).

Table 19. Average and standard deviation of WSFG trees per plot with herbicide application and MSP.

Site Prep and Tending	Average Number WSFG trees / plot	Standard Deviation
Herbicide only	1.94	1.39
MSP only	1.49	1.48
MSP and Herbicide	0.93	1.05
Neither	0.51	0.66

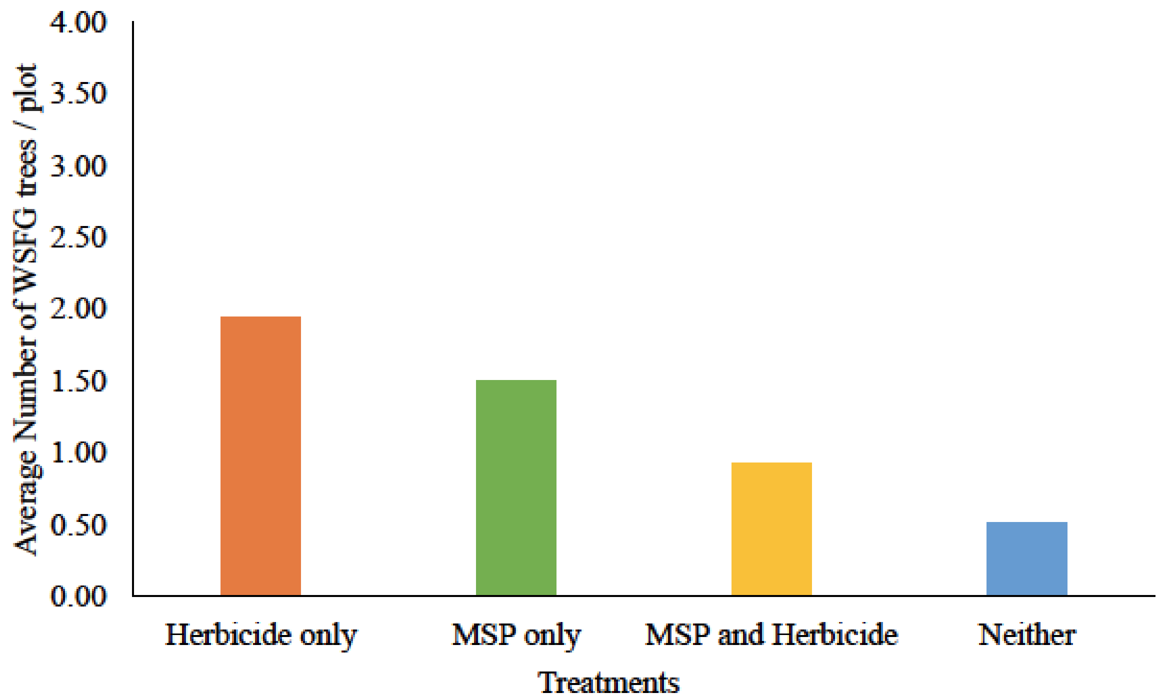

Figure 15. The average number of WSFG trees per plot with only herbicide application, only MSP, both and neither.

DISCUSSION

Blackwater Blocks 1, 2, 3, 4, 6, 7, 8 all are not satisfactorily regenerated. Only Black 5 was satisfactorily regenerated to the SGR requirements for minimum density. These results indicate that there is a lack of effective renewal treatments in the Blackwater area.

The results of the two-way ANOVA indicate that ecosite did have a significant effect on the number of WSFG trees per plot at the 95% confidence level ($p < 0.05$) (Table 6). As well, the one-way ANOVA for ecosites also found it to have a significant effect on the number of WSFG trees per plot ($p < 0.05$) (Table 7). This would indicate that the OMNRF is correct in suggesting that ecosystems, and their classification as ecosites, should be the basis for silviculture treatments. The number of WSFG trees per plot in this study varied by ecosite. Likely, this difference is due to the level of competition on each ecosite. B049TtDn (ES20 Spruce–Pine / Feathermoss: Fresh, Sandy–Coarse Loamy Soil) had the highest average number of WSFG trees per plot at 2.09, which is 1.6 more trees than the ecosite that had the lowest average number of WSFG trees per plot (Table 15). The target species on B049TtDn were jack pine, black spruce and white spruce. The OMNR (1997) states that this is a low competition site and recommends for the establishment of jack pine: MSP, followed by either seeding or planting. They also state that cleaning (herbicide) is not usually required. The Blackwater Blocks with this ecosite were Black 1 and 5. Black 1 had MSP, then was aerial seeded and was partially sprayed with herbicide. Black 5 had MSP, was planted and was partially sprayed with herbicide. Black 5 was the only block to pass as satisfactorily regenerated. Likely, this is because the OMNR (1997) guideline recommendations were followed for the establishment of jack pine, and as such the renewal treatments were effective because they were tailored to the ecosite.

In contrast, ecosite B035TtDk (Pine–Spruce Mixedwood: Sandy Soil) had an average of 0.93 WSFG trees per plot (Table 15). The target species on B035TtDk was jack pine. The OMNR (1997) states that there is higher competition on this site and recommends for the establishment of jack pine: chemical site preparation, artificial planting and seeding as the regeneration method and chemical herbicide (cleaning treatments). Black 8 was on ecosite B035TtDk and it had MSP, was seeded and then was sprayed with herbicide. The OMNR (1997) guidelines were partially followed for this site as chemical site preparation was recommended. The use of artificial seeding on this site was not an adequate regeneration method. This could possibly be due to the fact that this ecosite is prone to seasonal drought (OMNR 1997) and this could have influenced the success of the seed germination and seedling survival. A recommendation that comes from these results is that ecosite B035TtDk should be planted, as Table 16 shows that planting can significantly increase the number of WSFG trees per plot. Planting jack pine on competitive sites is advantageous according to the literature (Eyre and LeBarron 1944). In conclusion, the ANOVA proved that there was a statistically significant difference in the number of WSFG trees per plot between ecosites B049TtDn and B035TtDk. Therefore, in this case the first null hypothesis that ecosite does not have a statistically significant effect on the on the number of WSFG trees per plot is rejected.

The second null hypothesis is that regeneration method does not have a statistically significant effect on the number of WSFG trees per plot. The one-way

ANOVA was statistically significant ($p < 0.05$) in the effect of regeneration method on the number of WSFG trees per plot (Table 8). The average was higher for planting (1.62 WSFG trees per plot) as compared to seeding (1.16 WSFG trees per plot) and natural regeneration (0.42 WSFG trees per plot) (Table 16). This coincides with the literature reviewed that planting is generally more successful than seeding or natural regeneration (Eyre and LeBarron 1944). Therefore, the second null hypothesis is rejected as regeneration method has a demonstrated effect on the number of WSFG trees per plot.

PLOT LEVEL RESULTS AND T-TESTS

The plot level statistical analysis and independent t-tests were used to determine the outcomes of the other three null hypotheses. The third null hypothesis is that mechanical site preparation does not have a statistically significant effect on the number of WSFG trees per plot. The independent t-test findings were that the difference between plots with MSP and those without was not significant $t = 1.32$, $p = 0.19$ (Table 10). The plot level analysis findings were that plots without MSP had an average of 0.22 more WSFG trees per plot than plots with MSP (Table 18). Furthermore, when compared to herbicide application, the average for MSP plots was 0.55 less WSFG trees per plot (Table 19). In contrast, MSP plots did have on average 0.98 more WSFG trees per plot than plots with neither MSP or herbicide application (Table 19). The findings are that MSP does not have a statistically significant effect on the number of WSFG trees per plot. This finding is similar to results found in the scientific literature and the third null hypothesis is accepted.

The fourth null hypothesis was that herbicide application does not have a statistically significant effect on the number of WSFG trees per plot. The independent t-test findings were that the difference between plots with herbicide and those without was significant $t = -3.95$, $p = 0.00$ (Table 13). The plot level analysis findings were that plots with herbicide application had an average of 0.54 more WSFG trees per plot (Table 18). Furthermore, herbicide plots had on average 1.43 more WSFG trees per plot than plots with neither MSP or herbicide application (Table 19). This is in agreement with the scientific literature on herbicide application which demonstrates that herbicide can reduce competing vegetation and increase crop tree survival and growth. In addition, the findings indicate that herbicide application does not only improve the survival and growth of seedlings, but also has a lasting effect, significantly increasing the number of WSFG trees per plot. Therefore, the fourth null hypothesis is rejected because herbicide clearly does effect the number of WSFG trees per plot.

The fifth and final null hypothesis, that the interaction of ecosite, regeneration method, mechanical site preparation, and herbicide application does not have statistically significant effect on the number of WSFG trees per plot, is inconclusive. The ANOVA resulted in a significance of 0.074 for the interaction of ecosite and herbicide on the number of the WSFG trees per plot. This is statistically significant at the 90% confidence level and may suggest that there is an increase in the number of WSFG trees per plot when each ecosite is treated with herbicide. The plot level statistical analysis had similar results; Black 4 is in Ecosite B055TtDn, it was not sprayed and had the lowest average number of WSFG trees per plot at 0.49 (Table 15).

When comparing the interaction of MSP and herbicide application there does seems to be contradictory results. When comparing herbicide plots to MSP, herbicide plots had the highest average of 1.94 WSFG trees per plot followed by plots with only MSP with an average of 1.49 WSFG trees per plot followed by plots with both MSP and herbicide with an average of 0.93 WSFG trees per plot (Table 19). These results seem to suggest that the interaction of both MSP and herbicide lead to a lower number of WSFG trees per plot. This relationship does not take into account ecosite or regeneration method. The interaction between ecosite, regeneration method, MSP and herbicide are beyond the scope of this study due to data constraints and as such, the null hypothesis that the interaction of ecosite, regeneration method, MSP, and herbicide application does not have statistically significant effect on the number of WSFG trees per plot can neither be accepted or rejected.

DEFICIENCIES

There are a number of deficiencies in this study. The data was collected not as an experiment but as part of field work, therefore the number of replicates of each independent variable and the interactions of the variables were not controlled. This resulted in very uneven numbers of replicates and large sections of data being left out of the ANOVAs. For example, there were only 21 total replicates in the one-way ANOVA in this study, two ecosites with seven plots with herbicide treatment and seven without. As well, the one-way ANOVA only used two of six ecosites due to insufficient replicates.

The dependent variable of number of WSFG trees was only for the target species as stated in the SGR for each block. This means that there were non-target tree species that were WSFG, as well as non-target trees that were well-spaced, but this study only used the data for the target species. Also, many target trees are excluded from being tallied as a WSFG tree because of limitations listed in the WSFG Regeneration Assessment Procedure (White et al. 2005). The procedure ignores trees that do not meet the exacting criteria of a WSFG tree, when in reality the tree will likely survive and grow in the stand.

PRACTICAL APPLICATIONS

The results of this study should remind forest mangers how important it is to tailor renewal treatments to achieve the desired future forest condition as designated in the SGR and legally in the CFSA (1994). The significant effect of ecosite on the number of WSFG trees per plot should reaffirm that the OMNR (1997) silvicultural guidelines that use ecosites as the basis for renewal treatments are well-researched and can be applied with confidence. This study also suggests that although seeding may be cheaper, it should be applied only on ecosites with low competition and an adequate seedbed, otherwise planting is a more effective alternative to increase the number of WSFG trees per plot. As well, MSP on some ecosites may not be worth the cost, as the findings demonstrated that it did not improve the number of WSFG trees per plot. The findings also suggest that the use of herbicide does significantly increase the number of WSFG trees per plot; however, it is not practical to treat every block with herbicide, therefore forest managers should use professional judgement to decide, based on the level of competition and ecosite, when herbicide should be applied. The finding of the significant effect of ecosite on the number of WSFG trees per plot should reaffirm that the OMNR (1997) guidelines for silviculture treatments based on ecosite are accurate and helpful to forest resource managers.

CONCLUSION

Based on the findings the five null hypothesises were either accepted or rejected. The first null hypothesis was that ecosite does not have a statistically significant effect on the on the number of WSFG trees per plot; this hypothesis was rejected because both the one- and two-way ANOVAs showed that ecosite had a significant effect on the number of WSFG trees per plot ($p < 0.05$). This indicates that the OMNRF is correct in suggesting that ecosystems, and their sub-classification as ecosites, should be the basis for silviculture treatments. The second null hypothesis was that regeneration method does not have a statistically significant effect on the number of WSFG trees per plot. This hypothesis was also rejected as the one-way ANOVA showed that regeneration method had a statistically significant effect ($p < 0.05$) on the number of WSFG trees per plot. The third null hypothesis was that MSP does not have a statistically significant effect on the on the number of WSFG trees per plot. This hypothesis was accepted as the independent t-test findings showed that the difference between plots with MSP and those without was not significant ($p > 0.05$). The fourth null hypothesis was that herbicide application does not have a statistically significant effect on the number of WSFG trees per plot. This hypothesis was rejected as the independent t-test findings indicated that the difference between plots with herbicide and those without was significant ($p < 0.05$). The fifth null hypothesis was that the interaction of ecosite, regeneration method, mechanical site preparation, and herbicide application does not have statistically significant effect on the number of WSFG trees per plot. The analysis of this hypothesis was beyond the scope of the data set and is therefore inconclusive. Overall, the analysis completed in this study demonstrates that ecosite specific prescriptions for renewal treatments will lead to greater regeneration success, more WSFG trees per plot, and the establishment of stands which will achieve the desired future forest conditions.

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APPENDICES

APPENDIX I

SGRS FOR BLACKWATER BLOCKS

Block_ID	SGR Code	Target Species	Other Acceptable	Min Density (includes only target species)	Target Density (includes only target species)
Black_1	PJC-BASC1-PJC	Pj	*Bf<10%, Sb, Po+Bw<10%	1500	2500
Black_2	POHR-INTN1-CNM	Sb, Sw, Pj	Bf<10%, (Po+Bw<30%)	1250	1400-2000
Black_3	SPC-INTN1-SPC	Sb/Sw	*Pj, (Po+Bw<10%)	1500	1600-2000
Black_4	PJC-INTN1-PJC	Pj	*Sb, (Bf+Po+Bw < 10%)	1500	1600-2000
	SPL-BASC1-SPL	Sb	Ce, La	1000	2500
Black_5	CNM-INTN1-CNM	Sb/Sw/Pj	*Bf<10%, (Po+Bw<30%)	1250	1400-2000
	PJC-INTN1-PJC	Pj	*Sb, (Bf+Po+Bw < 10%)	1500	1600-2000
	SPC-INTN1-PJC	Pj	*Sb, (Bf+Po+Bw < 10%)	1500	1600-2100
Black_6	POM-INTN1-PJC	Pj	*Sb, (Bf+Po+Bw < 10%)	1500	1600-2100
Black_7	SPC-INTN1-PJC	Pj	*Sb, (Bf+Po+Bw < 10%)	1500	1600-2100
Black_8	PJC-BASC1-PJC	Pj	*Bf<10%, Sb, Po+Bw<10%	1500	2500

* Other Acceptable Tree Species must not hinder the achievement of the future forest condition

APPENDIX II

BRUSH AND TREE COMPETITORS

Brush (According to White et al. 2005):

Alders (*Alnus* spp.)

Beaked hazel (*Corylus cornuta*)

Cherries (*Prunus* spp.)

Dogwoods (*Cornus* spp.)

Elderberries (*Sambucus* spp.)

Mountain ash (*Sorbus* spp.)

Mountain maple (*Acer* spicatum)

Raspberry/Thimbleberry (*Rubus* spp.)

Serviceberry (*Amelanchier* spp.)

Striped maple (*Acer pensylvanicum*)

Squashberry/Highbush cranberry (*Viburnum* spp.)

Willows (*Salix* spp.)

Tree (According to White et al. 2005):

Poplar (*Populus* spp.)

Birch (*Betula* spp.)

Red maple (*Acer rubrum*)

Sugar maple (*Acer saccharum*)

Ash (*Fraxinus* spp.)

Larch (*Larix laricina*)

Eastern white cedar (*Thuja occidentalis*)

Balsam fir (*Abies balsamea*)

APPENDIX III

CALCULATIONS FOR DETERMINATION OF REGENERATION STATUS

Block	Species Included		#WSFG/plot	10,000/16(m2 / plot) = 625 625 #WSFG / ha	Minimum Density of Target Species (Well-distributed stems/ha)	SR or NSR	STD	CI t= 1.96	LCL.CL * expansion factor Mean - CI trees/plot	625 trees/ha	Minimum Density of Target Species (Well-distributed stems/ha)	SR or NSR
BLACK-1	ha	54.5					1.271					
Target	#plots	59					0.165	0.324				
Species: Pj	Pj	102	1.73	1081	1500	NSR			1.40	878	1500	NSR
	Sb, Sw Po, Bf, Bw, Ce, La	129	2.19	1367	1500	NSR			1.86	1164	1500	NSR
BLACK-2	ha	16.5					0.602					
Target	#plots	41					0.094	0.184				
Species: Pj.	Pj, Sb, Sw	33	0.80	503	1250	NSR			0.62	388	1250	NSR
Sb &Sw	Po, Bf, Bw, Ce, La	77	1.88	1174	1250	NSR			1.69	1059	1250	NSR
BLACK-3	ha	24.7					0.645					
Target	#plots	46					0.095	0.186				
Species: Sb	Sb, Sw	29	0.63	394	1500	NSR			0.44	278	1500	NSR
& Sw	Pj, Po, Bf, Bw, Ce, La	56	1.22	761	1500	NSR			1.03	644	1500	NSR
BLACK-4	ha	17.0					0.35					
Target	#plots	51					0.049	0.097				
Species: Pj	Pj, Sb	12	0.24	147	1000	NSR			0.14	87	1000	NSR
& Sb	Sw, Po, Bf, Bw, Ce, La	68	1.33	833	1000	NSR			1.24	773	1000	NSR
BLACK-5	ha	138.7					1.26					
Target	#plots	107					0.122	0.239				
Species: Pj.	Pj, Sb, Sw	235	2.20	1373	1250	SR			1.96	1223	1250	NSR
Sb & Sw	Po, Bf, Bw, Ce, La	257	2.40	1501	1250	SR			2.16	1352	1250	SR
BLACK-6	ha	33.8					1.129					
Target	#plots	50					0.160	0.313				
Species: Pj	Pj	55	1.10	688	1500	NSR			0.79	492	1500	NSR
	Sb, Sw Po,Bf,Bw,Ce,La	94	1.88	1175	1500	NSR			1.57	979	1500	NSR
BLACK-7	ha	12.1					1.012					
Target	#plots	40					0.160	0.314				
Species: Pj	Pj	29	0.73	453	1500	NSR			0.41	257	1500	NSR
	Sb, Sw Po,Bf,Bw,Ce,La	53	1.33	828	1500	NSR			1.01	632	1500	NSR
BLACK-8	ha	92.5					1.093					
Target	#plots	81					0.121	0.238				
Species: Pj	Pj	75	0.93	579	1500	NSR			0.69	430	1500	NSR
	Sb, Sw Po,Bf,Bw,Ce,La	88	1.09	679	1500	NSR			0.85	530	1500	NSR