Northern white-cedar (*Thuja occidentalis*) regeneration following operational scale selection cutting in western Quebec.

Résumé

Des pratiques sylvicoles mal adaptées ainsi qu'une augmentation des populations de cerf de Virginie ont fort probablement contribué au déclin du thuya dans les forêts mixtes de l'est de l'Amérique du Nord. Cette situation a conduit les aménagistes forestiers à tester diverses approches sylvicoles afin de permettre le maintien du thuya au sein des peuplements auxquels il était présent. Des études expérimentales antérieures ont permis de déterminer que la proximité des semenciers, la qualité du microsite d'implantation, l'ouverture du couvert ainsi que le broutement par les herbivores sont des facteurs déterminants du succès de régénération du thuya. Toutefois, les recommandations issues de ces études n'ont pas été validées à l'échelle opérationnelle. L'objectif de cette étude était de valider si les coupes de jardinage réalisées par l'industrie permettent au thuya de se régénérer. Les sites étudiés font partie du réseau de suivi des effets réels du jardinage établi par le Ministère des forêts, de la faune et Parcs (MFFP) en 1995. Ce réseau est composé d'un total de 971 parcelles permanentes (traitées et témoins) établies dans des coupes opérationnelles. Au total, 70 placettes-échantillons permanentes comportant un minimum de 10% de la surface terrière marchande en thuya ont été visitées durant l'été 2014. Des données sur les arbres prélevés, le couvert arborescent ainsi que l'abondance et l'état de la régénération 15 à 20 ans après traitement ont été relevées lors de la réalisation des inventaires. Les résultats obtenus indiquent que même dans un contexte opérationnel, les coupes de jardinage peuvent favoriser la régénération de thuya. Toutefois, l'intensité de coupe, la présence de semenciers à proximité, la disponibilité de microsites propices et la présence de végétation concurrente viennent influencer l'abondance, la croissance ainsi que le recrutement des semis et gaules de thuya dans le peuplement résiduel.

Abstract

Poorly adapted silvicultural practices and an increase in white-tailed deer (*Odocoileus virginianus* Zimmerman) populations have most likely contributed to the decline of northern white-cedar (*Thuja occidentalis* L.) in the mixedwood forests of eastern North America. This situation has led forest managers to use silvicultural treatments such as selection cutting in stands with a white-cedar component to ensure its return after harvesting activities. The main objective of this study was to evaluate the effectiveness of the current strategies of selection cutting conducted at an operational scale to regenerate white-cedar. The study sites are part of the network of permanent plots established by the Forest, Wildlife, and Parks Ministry of Quebec, Canada. The network is composed of 282 stands managed under Timber Supply and Forest Management Agreements. It includes a total of 971 permanent plots distributed in paired treated and control areas. A total of 70 permanent plots with a minimum of 10% of the merchantable basal area in white-cedar were visited during the summer of 2014. A regeneration inventory was carried out 15 to 20 years after harvesting activities. The results indicate that the current strategies of selection cutting allow a good establishment of white-cedar when deer densities are low, which was the case on the study sites. However, presence of seed trees, harvesting intensity, competition and the availability of establishment microsites influence the abundance, growth, and recruitment of white-cedar seedlings and saplings in the residual stand.

Introduction

A decline of northern white-cedar (*Thuja occidentalis* L.), hereafter white-cedar, was observed during the nineteenth century (Siccama 1971; Lorimer 1977; Smith et Borczon 1981; Schaffer 1996; Heitzman et al. 1997, 1999; Cornett et al. 2000*a*, 2000*b*; Cogbill et al. 2002; Boucher et al. 2004; Etheridge et al. 2005; Larouche 2006; Dupuis et al. 2011).This decline may be due in part to poorly adapted silvicultural practices to regenerate white-cedar (Larouche 2006). Silvicultural treatments are more focused on the regeneration success of species with high commercial value and high abundance in the stand. Mixedwoods stands can be managed with different approaches depending on stand structure and composition. Partial cutting allows the establishment of shade-tolerant species such as white-cedar and provides favourable conditions for height growth. Selection cutting is known to be efficient to regenerate many shade-tolerant species. However, selection cutting conducted at an industrial scale set targets for several hectares without taking account of local differences in stand composition. Also, at an operational scale, the local variability of basal area removal can create heterogeneous light conditions and affect the growth and establishment conditions for the regeneration. The scarcity of white-cedar regeneration after harvesting may be due to a combination of factors.

The decline of white-cedar is also closely related to the increase in white-tailed deer (*Odocoileus virginianus* Zimmerman) populations (Heitzman et al. 1997; Cornett et al. 2000a, 2000b). The density of large herbivores is an important driver of the structure and composition of the forest ecosystem, particularly for species with a strategy based on a seedling bank like white-cedar (Tremblay et al. 2007). The increased browsing associated with a large deer population hinders the development of white-cedar regeneration and limits recruitment of seedlings into higher height classes (Cornett et al. 2000*a*; Larouche et al. 2010).

In mixedwood stands, natural regeneration is generally abundant after disturbances or harvesting activities. White-cedar can regenerate using both vegetative and sexual reproduction. Sexual reproduction of white-cedar depends on several factors including seed production, dispersal and availability of establishment microsites (Johnston 1990). The presence of seed trees in the stand is very important since the seed dispersal distance is short (<60 m) (Rooney et al. 2002). Many studies indicate that the microtopography of the establishment microsite and the rooting substrates have a significant impact on the presence of seedlings (Hébert 2007; Palik et al. 2014). Disturbed substrates and woody debris mounds (decayed wood) would be favorable for germination of white-cedar seeds (Heitzman et al. 1997; Rooney et al. 2002; Hébert 2007). Water retention of dead wood would prevent seedlings from dying and promote their long-term survival (Cornett et al. 1997). However, harvesting activities at an operational scale may not always result in the presence of favourable establishment microsites.

Previous experimental studies have determined that proximity of seed trees, quality of the implantation microsite, canopy opening as well as browsing are decisive factors in the success of white-cedar regeneration. However, the recommendations from these studies have not been validated at operational scale. The objective of this study was to determine if selection cutting conducted at an operational scale is efficient to create conditions to insure the regeneration of white-cedar in mixedwood stands. The influence of harvesting intensity, establishment microsite, environmental factors, and browsing were examined.

The first hypothesis suggests that white-cedar seedlings abundance will be higher in treated plots (Larouche et al, 2011, Boulefroy et al., 2012) than in the control if the number and the distribution of white-cedar seed trees in the residual stand is sufficient (Cornett et al 1997, Rooney et al., 2002). The second hypothesis states that white-cedar seedlings are found more frequently on woody debris compared to the general distribution of available microsites in the plot. The last hypothesis, based on previous studies, suggests that plots located in sites with high presence of white-tailed deer would have lower abundance of white-cedar seedlings taller than 30 cm (Cornett et al 2000b, Forester et al. 2008, Larouche et al. 2010).

Materials and methods

Study sites

This study used 23 sites from a larger network established by the Ministère des Forêts, de la Faune et des Parcs, Quebec, Canada (MFFP) in order to monitor operational effects of selection cutting. The network is composed of 282 stands managed under Timber Supply and Forest Management Agreements. It includes a total of 971 permanent plots distributed in paired treated and control areas. Both areas presented similar characteristics, did not had recent interventions and were located close one to each other. The harvesting activities took place between 1995 and 1999 and were conducted according to operational guidelines. For the study, only groups of permanent plots (treated and control) located in mixedwood stands with a minimum of 10% of the merchantable basal area in white-cedar before harvesting activities were selected. Difficult access to certain areas 20 years after the first data collection allowed a total of 70 permanent plots to be retained for the study. Permanent plots were 400 m^2 in area (circular plot of 11.28 m radius) and were measured by MFFP before harvesting and 0, 5 and 10 years after harvesting. Data from these inventories were provided according to a collaboration agreement between MFFP and Laval University. Additional regeneration and browsing inventories were conducted for this study during summer 2014.

The sites were located in three different regions of western Quebec. Nine sites were located approximately 100 km South East of the town of Ville-Marie in the Témiscamingue Region (47°20’N, 79°26’W), four sites were located 65 km north of the town of Mont-Laurier in the Hautes-Laurentides Region (46°33’N, 75°30’W) and the remaining sites were located 70 km North of the town of Ottawa in the Outaouais Region (45°90’N, 75°62’W). Most of the sites are within the sugar maple-yellow birch bioclimatic domain but the four northernmost lie within the Balsam fir-yellow birch bioclimatic domain (figure 3). Mean annual temperature ranges from 2.5 to 5.0 °C and mean annual precipitation reaches 1000 mm for the sugar maple-yellow birch bioclimatic domain (Saucier et al. 2009). For the Balsam fir-yellow birch bioclimatic domain, the mean annual temperature range is lower (1.5 to 2.5 °C) and the precipitation is slightly higher (1100 mm). Undifferentiated till was the main surface deposit, all sites are mesic and elevation ranged from 260 to 485 meters.

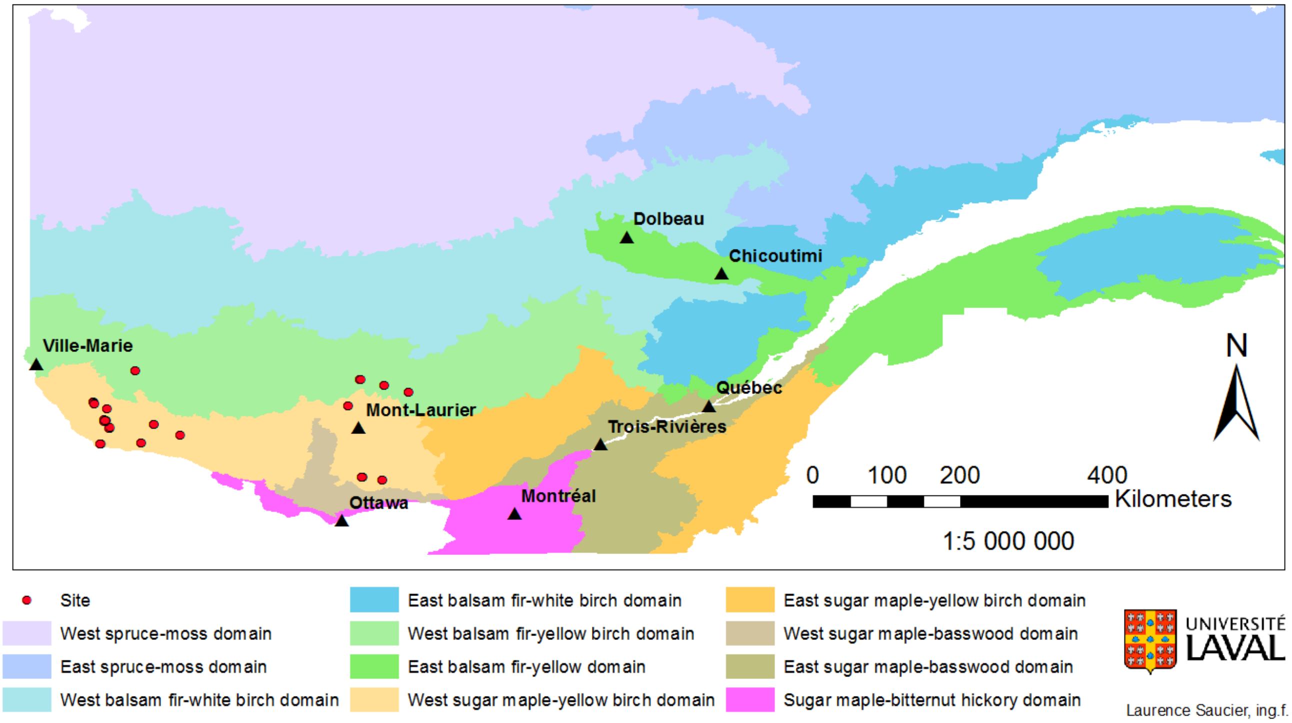

Figure 3: Location of the study sites within bioclimatic subdomains.

Forest description and harvest treatments

The majority of the plots were located in mixedwood stands dominated by deciduous species. The most representative stand types were dominated by yellow birch (*Betula alleghaniensis* Britt.) with a minor component of white-cedar or sugar maple (*Acer saccharum* Marsh.). Mixedwood stands dominated by sugar maple or evergreen species such as hemlock (*Tsuga canadensis* (L.) Carrière) or white-cedar were also found on a few plots. Table 1 presents the main forest stands and the distribution of the plots. Table 2 shows the characteristics before, after, and 10 years after harvesting for the main types of mixedwood stands. Before the treatment, mean diameter at breast height (DBH measured at 1.3 m) was 21.1 cm, mean basal area was 24.3 m^2/ha and mean basal area in white-cedar was 4.6 m^2/ha. After treatment, mean DBH increased by 1.0 cm while mean basal area decreased by 1.5 m^2/ha. The white-cedar basal area has not decreased much, suggesting that very few stems were targeted during the selection cutting. Ten years after treatment, mean DBH increased to 23.0 cm, mean basal area increased to 25.6 m^2/ha and mean basal area in white-cedar increased slightly from 4.2 m^2/ha to 4.4 m^2/ha.

Horizontal stand structure was mostly heterogeneous and the vertical structure was irregular with multiple layers. The understory was composed of a mix of competing species such as striped maple (*Acer pennsylvanicum* L.), mountain maple (*Acer spicatum* Lamb.), squashberry viburnum (*Viburnum edule* (Michx) Raf.) and saplings of species forming the canopy. There was no major disturbance reported, only a few stems were affected by minor windfall.

Table 1 : Number of plots by stand type

Description	Stand code	Secondary species	plots
Mixedwood stands dominated by yellow birch	**BjSb**	balsam fir	7
	BjTo	white-cedar	15
	BjEr	sugar maple	20
	BjPu	hemlock	2
Mixedwood stands dominated by sugar maple	**ErBj**	yellow birch	7
	ErSb	balsam fir	4
	ErTo	white-cedar	2
Mixedwood stands dominated by hemlock	**PuBj**	yellow birch	4
	PuTo	white-cedar	4
Mixedwood stands dominated by white-cedar	**ToBj**	yellow birch	3
	ToEr	sugar maple	2

Table 2: Characteristics before, after and 10 years after harvesting

Stand code	Characteristics	before	after	10 years after
Mean (all stands)	DBH (cm)	21.1 ± 0.5	22.2 ± 0.4	23.0 ± 0.4
	Basal area (m^2/ha)	24.3 ± 0.6	22.8 ± 0.5	25.6 ± 0.4
	white-cedar basal area (m^2/ha)	4.6 ± 0.1	4.2 ± 0.2	4.4 ± 0.2

The plots are located in the northern part of the distribution of white-tailed deer (*Odocoileus virgianus* Zimmerman) populations (Hébert et al. 2013). In the Témiscamingue region, densities of white-tailed deer are difficult to evaluate because there is no hunting record. In the Outaouais and the Hautes-Laurentides regions, the population densities of white-tailed deer in 2011 were estimated at about 0 to 2 deer/10 km^2 (Hébert et al. 2013). However, moose (*Alces alces* Gray) are also present in the study area and the populations in 2008 were estimated as 2.8 ± 0.3 moose/10 km^2 for the Témiscamingue region and slightly lower (2.4 ± 0.3

moose/10 km^2) for the Outaouais and Hautes-Laurentides regions (Lefort and Massé 2015). Hare (*Lepus americanus* Erxleben) was not abundant in the study sites, only occasional and random browsing was observed on regeneration in a few sites.

Plots implementation

Regeneration and browsing inventory

In each 400 m^2 permanent plot, a regeneration survey was carried out between June and August 2014, 15 to 19 years after harvesting activities depending on the sites. The seedlings (DBH < 1.1 cm) were numbered in 10 circular 4 m^2 subplots and all the saplings, including non-commercial tree species, were counted by species in 2 cm DBH classes (DBH between 1.1 and 9.0 cm) in one circular 100 m^2 plot (figure 4). The distance between each center of 4 m^2 subplots was 5 meters. As the requirements of the seedlings are not the same according to their stage of development, it became interesting to distinguish the seedling height classes. We distinguished three demographic categories for the regeneration based on seedling height. We classified all the regeneration between 15 to 30 cm tall as "small seedlings", those from 31 to 100 cm as "medium seedlings" and those higher than 101 cm but smaller than 1.1 cm DBH as "large seedlings". Seedlings between 0 and 15 cm were not inventoried because they were not considered as established. The establishment phase extends from seed germination until juvenile mass mortality is no longer to be feared and seedlings are able to react to canopy opening (Larouche 2009). No distinction between sexual and asexual reproduction was made because of the difficulties in differentiating both types on established seedlings without destroying them. Percent cover of the understory layer was estimated in each subplot to evaluate understory competition. Percent cover includes all concurrent species taller than seedlings (> 15 cm) such as herbaceous, shrubs and abundant species of the understory like striped maple, mountain maple, squashberry viburnum and saplings of species forming the canopy. Browsing was assessed on each seedling in subplot by herbivore type (deer or moose, and hare) and by percentage of the foliage consumed. For each white-cedar seedling, characterization of the establishment microsite was carried out according to microtopography and litter type at the rooting site (table 3). Characterization according to the same categories was also made for the center of each 4 m^2 subplot to estimate microsite and litter availability.

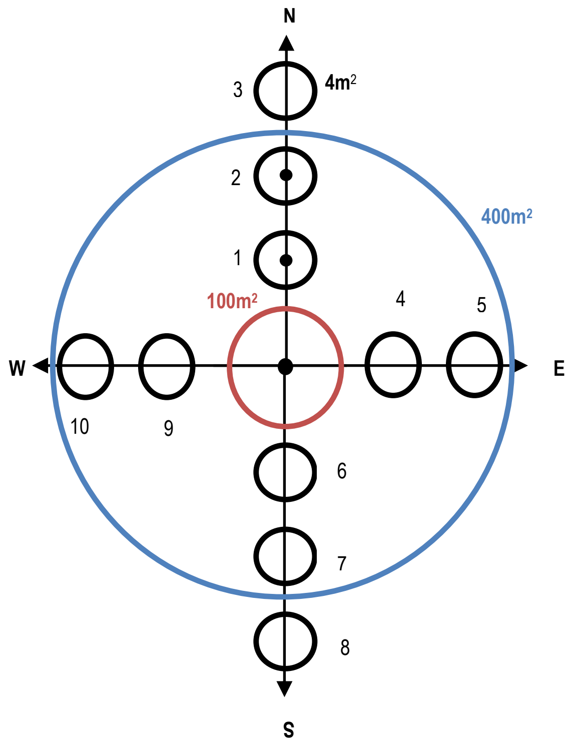

Figure 4: Illustration of the subplots distribution in one 400 m² study plot.

Table 3: Characterization of the establishment microsites according to microtopography and litter type

	Code	Description
Microtopography type		
Mound	MT	
Depression	DP	
Level ground	TU	
Litter type		
Hardwood	LF	Litter mostly composed of hardwood leaves
Softwood	LR	Litter mostly composed of softwood needles
Mixed	LM	Litter composed of softwood needles and hardwood leaves
Decaying wood	BM	All coarse woody debris, boles, stumps, or branches

Data analysis

Abundance of seedlings and sapling density

To characterize regeneration dynamics following partial harvesting, the first step was to model seedling abundance and sapling density for the main species of interest (i.e. white-cedar, sugar maple and yellow birch) after treatments. Seedling and sapling analyses were conducted separately because we assumed that the establishment of seedlings was the result of the canopy treatments and that the saplings were probably established before the interventions. All analyses were conducted using SAS (version 9.1, SAS Institute Inc., Cary, NC, USA). Mixed linear models were developed to examine the effects of canopy treatments on each species abundance using the GLIMMIX procedure. This procedure was selected because of the presence of hierarchical random effects. To reflect this hierarchical structure of variance, subplots nested within plots, which were themselves nested within sites, were considered as random effects. For the abundance of seedlings, the CLASS statement integrated canopy treatments, height class, browsing, and ecological region as classification variables. Canopy treatments were divided into four categories according to harvested basal area: three intensities of selection cutting and control (table 4). The Ecological Region was included into the model to reflect composition and vegetation dynamics of the sites. In the MODEL statement, basal area after harvesting, percent cover of the understory, and year of harvesting were also used as explanatory variables. Only the basal area of the modeled species was integrated in each model to test the importance of seed trees in the stand. Percent cover was used as an indicator of understory competition. Only the presence or absence of browsing in the subplot was integrated into the model because of the small number of observations. For sapling density, essentially the same parameters were used in the model except the percentage of cover that was replaced by the density of non-commercial tree species and the height class by DBH class. In addition, there were not enough observations of browsing on white-cedar saplings to integrate this variable into the model. Abundance of seedlings and sapling density data followed a negative binomial distribution due to the high presence of zeroes in the data set. The distribution followed by the data set was specified in the DIST statement.

Table 4: Number of plots by canopy treatments

Canopy treatments	Code	Plots	Description
Low intensity selection cutting	**TR15**	20	10 to 20% of the harvested basal area
Medium intensity selection cutting	**TR30**	23	21 to 40% of the harvested basal area
High intensity selection cutting	**TR50**	12	41 to 60% of the harvested basal area
No treatment (control)	**TE**	15	No recent harvesting activity

Establishment microsite

For each height class, the distribution of available microsites (litter and microtopography type) was compared with the distribution of microsites used by white-cedar seedlings using χ^2 test. This comparison provides information on establishment microsites preferred by white-cedar and their availability in the stand. The abundance of seedlings should be more important in areas with more favorable microsites available.