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Specialty Forests and their Environment

Identifying and preserving old-growth attributes in mixed forest stands dominated by yellow birch (*Betula alleghaniensis*) and balsam fir (*Abies balsamea*) in the context of ecosystem management in Québec.

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Acronyms

Note : The French words or expressions are shown in italics

CPI : *Coupe Progressive Irrégulière*

CPR : *Coupe Progressive Régulière*.

CPRS : *Coupe avec Protection de la Régénération et des Sols*.

CPI-M1 : *Coupe Progressive Irrégulière en peuplement Mixte n˚1.*

Dbh : Diameter at breast height.

DRF : *Direction de la Recherche Forestière.*

EFE : *Écosystème Forestier Exceptionnel.*

MFFP : *Ministère de la Forêt, de la Faune et des Parcs.*

SSAM-II : *Système Sylvicole Adaptés à la forêt Mélangée, protocole de la phase II.*

1. Introduction

1.1 The Direction of Forest Research

This study was made at the *Direction de la Recherche Forestière* (DRF) of the *Ministère de la Forêt, de la Faune et des Parcs du Québec* (MFFP). This branch aims to develop new ways of management for the Québec forest in a context of sustainable management. For this reason, the DRF drives or take part in numerous research projects

The work presented in this report was made at the *Service de la sylviculture et du rendement des forêts* of the DRF. Most precisely in the mixed forest research team of the pole "*Sylviculture et rendement des forêts naturelles*".

1.2 The context of the ecosystem management

The government of Québec has recently taken the decision to apply the ecosystem management to the whole public forest (90% of Québec forest). It can be explained by three reasons : the appearance of environmental issues related with forest exploitation, an improvement of the ecological knowledge and an increase in public sensibility for the protection of our natural heritage (Grenon & al., 2010).

The ecosystem management can be defined as the contribution of an ecologic vision to forest management. Its goal can be resumed as the decrease of the gap between the managed forest and pre-industrial forest and the conservation of natural variability of key elements in natural forests. Its application is in general a management close to the natural dynamic (ibid.).

1.3 The yellow birch – conifer domain

Our study focuses on two ecosystems of the mixed forest named "Balsam fir – Yellow birch stand" and "Yellow birch – Balsam fir stand". The distinction is made according to the most dominating species between yellow birch and balsam fir, mostly because of the ecological conditions in the stand. The expression "Yellow birch – conifer stands" will be used in this study to represent both of them.

They are the main ecosystems of the mixed forest, an ecotone of 98 600 km², 12% of the total forest superficies of Québec. It represents the transition between the broadleaved temperate forest of the south and the boreal coniferous forest of the north. Yellow birch – conifer stands can also be found in the broadleaved temperate forest but in minor proportions.

At the most advanced and most stable stage of natural dynamic, yellow birch – conifer stands follow an irregular or complex structure, mainly dominated by yellow birch (*Betula alleghaniensis)*, balsam fir (*Abies balsamea*) and red spruce (*Picea rubens*). The dynamic is mainly created by the regular creation of small gaps. Following the site ecological characteristics, the leading species can be either yellow birch (MJ type according to the ecological classification of Québec) or balsam fir (MS type) (Ministère des Ressources Naturelles, 2013a).

Before this state, yellow birch – conifer stands following several steps. The first strictly forest state is composed of intolerant species : paper birch (*Betula papyrifera*), trembling aspen (*Populus tremuloides*) or red maple (*Acer rubrum)*. Balsam fir comes next, progressively, and create a mixture with paper birch and red maple to a step we can consider as intermediate. Red spruce and yellow birch appears after this stage, creating the stability state (ibid.).

According to this transitory aspect, knowledge is still missing on yellow birch – conifer stands. It mostly affects the old-growth stands, for which few information are available (Doyon et Varady-Szabo, 2012). Yet, this kind of forest represents the main part of preindustrial forest in the mixed forest domain (ibid. ; Barrette et Bélanger, 2007 ; Vaillancourt et al., 2009). It is therefore not a secondary stand but a main component of the natural forest.

1.4 Old-growth and naturalness

1.4.1 Old-growth stands, an important ecosystem

Conservation of old-growth stands characteristics is a main issue of the ecosystem management (Grenon et al., 2010). Forest exploitation in its main aspects tends to rejuvenate the stands. Focusing on the optimal harvest period, forestry stops the maturation and old-growth stages (Rossi et Vallauri, 2013).

It is now well-admitted that old-growth stands have a strong importance for biodiversity at the landscape scale as well as at the stand scale (Vaillancourt et al., 2009). Thus, it is primordial to balance society needs with environmental preservation. The development of process of forest management able to protect old-growth attributes is an urgency.

However, management tools allowing the realization of this objective are still rare. In order to achieve the goal previously presented, it appears necessary to develop efficient and ergonomic protocols which can meet the managers expectations.

1.4.2 The evaluation of naturalness, an inspiration

Naturalness is a complex notion for which it is still difficult to found a well-admitted definition (Winter, 2012). However, the one presented by Vallauri (2007) seems to be the most relevant : "*Naturalness is the expression in one place of Nature, its biodiversity, its organization, its complexity and its spontaneous and self-governing dynamic"*. On the other side, in Québec, naturalness is considered as the gap between managed and natural forest (Groupe d'experts sur la sylviculture intensive des plantations, 2013).

The second definition use the pre-industrial forest as a reference, without consideration for the development stage. Thus, a present forest regeneration can be compared with the pre-industrial regeneration in a naturalness study. On the contrary, the first definition emphasis the dynamic and the absence of human impact : naturalness is stronger when the development were spontaneous and autonomous on a long period. A forest free from major or anthropogenic disturbances since centuries will have an higher naturalness than a spontaneous but young forest.

Thus, a proximity exists between old-growth forest and naturalness. Many parameters used for the evaluation of this notion are also consistent for the study of ancient forest (Rossi & Vallauri, 2013). Even if it is important to remind that differences exist between these notions, methods used for naturalness estimation seems to be source of instruction for the creation of an evaluation protocol of the conservation of old-growth characteristics.

1.5 Aim of the study

Our work will mostly consist in creating a method allowing the characterization of old-growth elements in a stand and their evolution after forest harvests.
The studied sites following different sylvicultural treatments. We will also try to define those which respect the most the ecosystem management exigences with a satisfying conservation of old-growth elements.
This project concerns specifically the yellow birch – conifer domain. Another aim will be to improve the still fragmentary knowledge on the old-growth stands of this ecologic group.

2. Material and methods

2.1 CPI-M1 et SSAM-II sites

2.1.1 General characteristics

These two sites are two DRF study zones, located between the cities of Saint Raymond and Rivière-à-Pierre (annex I). They are both natural but managed mixed stands. But they differ in their potential vegetation, due to different ecological characteristics. The stand named “SSAM-II*[1]” is in a context where yellow birch - balsam fir are favoured (ecological class MJ) when the stand named “CPI-M1*” favoured balsam fir - yellow birch stands (ecological class MS). A complete presentation of these experimental designs will be done in the part 2.1.2 and 2.1.3.
The past treatments were low intensity selection cuts. The last harvest has been made 20 years ago. In SSAM-II, some plots even show no cutting clues, probably because of their low accessibility.

On each site different treatments have been made on a equal number of plots, grouped into subgroups. The experimental designs CPI-M1 and SSAM-II does not share any common treatment. A simplified presentation of the scenarios applied on the two sites site can be seen on annex II.
One of the main objective of those experimental designs is the conservation of old-growth characteristics. The hammer finish made for all the cuts took into consideration the limits that such a decision requires. Its concrete effect is a minimal preservation of dead-wood (10-15 snags per hectare in CPI-M1 protocol ; at least 10 snags with a dbh* superior to 19 cm per hectare for SSAM-II) and the conservation of a minimum rate of trees with a wildlife value like cavity trees (5 to 10 trees per hectare in CPI-M1 ; at least

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[1] All the terms followed by the symbol * are explained in the presentation of the acronyms.

6 per hectare in SSAM-II). Moreover, specific recommendations have been made in SSAM-II for the red spruce : it was unauthorized to harvest any healthy red spruce with a dbh under 35 cm.

2.1.2 The experimental design CPI-M1

The principal objective of this experimental design is to estimate the efficiency of the irregular shelterwood method (CPI*) for the conservation of mixed stands characteristics and composition while being economically interesting. The conservation of old-growth characteristics is an other aim of this protocol.

The site is divided between 20 plots of 70 x 70 m equally distributed between five treatments : irregular shelterwood system with continuous cover (CPI-CP) ; irregular shelterwood system extended (CPI-RL) ; shelterwood system (CPR*) ; clearcut (CPRS*) and control plots were no treatments have been made. Some of these forestry processes occur in several steps spread over twenty years (CPI-RL and CPR). At the moment this study has been realized, we only have observed the effects of the establishment cuts for two of these treatments and not those of the final cut.

2.1.3 The experimental design SSAM-II

This protocol studies the effect of selection cuts made on small tree groups on the dynamic and conservation of old-growth attributes in yellow birch – conifer stands. Another aim is the study of red spruce regeneration, a declining species for which the conservation in managed forest is complex (Dumais & Prévost, 2007).

The site is divided between 20 plots of 80 x 80 m where 4 treatments (5 plots per treatment) are equally applied. Three of them consist in a selection cut by groups. The size of these gaps varies and their distribution is not homogeneous. They differ by the harvest intensity, defined by the residual basal area (strong : 13 m²/ha ; medium : 16 m²/ha ; low : 19 m²/ha). The last scenario is used as reference.

2.1.4 Collected data

Our study is mainly based on data already collected on our experimental designs, before the harvest and one year after. On each plot a complete inventory of living and dead trees with a dbh superior to 9 cm has been realized. A wide variety of parameters has been collected such as species, vitality (dead, declining, alive…), vertical situation of the crown, degradation step for the snags…

An evaluation of coarse woody debris has also been realized for each situation except for CPI-M1 before harvest. This protocol used two perpendicular and linear 40m long transects . Each debris crossed by the transect with a diameter on this section superior to 9 cm has been noted. Then, the volume was converted with the Von Wagner method (Von Wagner, 1968) : $V = \pi^2 * \Sigma d^2 / 8L$. d being the diameter of each debris and L the length of the transect.

All additional data required by our methodology has been recorded during summer 2014. For these reasons, they will only affects the context after harvest.

2.2 EFE data

The EFE* labels forests with exceptional characteristics. The reason can be their rarity, their ancientness or the presence of rare or threatened plant species. Their status is validated after a field inventory realized by the *Direction de l'Aménagement et de l'Environnement Forestier* (DAEF) agents of the MFFP, previously *Ministère des Ressources Naturelles* (MRN).

These inventories follow a strict methodology, close to what is used in our experimental designs (diameter, species, snags…). Thus, a comparison can be easily done. To allow the validation of the stand as an EFE, the inventory has to be made where the exceptional aspect is the stronger. For this reason, they do not represent the whole stand in its complete complexity.

Data from 15 of these inventories have been transmitted by the DAEF. They all concern yellow birch – conifer stand of the ecological class MJ (MS class is very rare as an EFE in our ecological context) distributed on the whole domain of the western mixed forest. Each inventory has been made on a 400 m² area.

2.3 Old-growth clues selection

2.3.1 Literature review on naturalness evaluation

In order to realize a methodology for the evaluation of old-growth characteristics, we studied 6 different protocols of naturalness evaluation : Schnitzler & Borlea, 1998 ; Bus de Warnaffe & Devillez, 2002 ; Haye, 2006 ; Winter & al., 2010 ; St Hilaire, 2011 ; Rossi & Vallauri, 2013.

These studies show a wide variety of clues (annex III). A selection had to be done to retain only the most relevant for our study. This choice has been made following three main axes directions :

- Simplicity : we try to obtain an ergonomic methodology, which requires a small amount of data and is easily reusable. Moreover, we are also constrained by our study limits.
- Old-growth characteristics : As point 1.4.2. shows, the concept of naturalness goes further than old-growth aspects. If some clues can be pertinent for the evaluation of the first, they may not apply to the former.
- Québec context : the main part of naturalness literature comes from Europe,in a context where forests are mostly recent, fragmented and where exploitation has been strong and regular. But the context is different in Québec and some parameters hold no relevance here.

2.3.2 Final parameters selection

Because of the conditions previously shown, we will mainly use dendrometric parameters. The advantages of these elements are the simplicity of their measurement and their common use for forest inventories. The utilization of our methodology for other study will be not constrained by a requirement in very specific skills.

Our protocol can be divided into 4 main parts (table 1). The first focuses on the diversity in tree species (diversity) and their proportion in basal area at the stand-level (succession). It allows us to locate stands in their theoretical dynamic. An old-growth forest should be dominated by species of the final succession stage (Rossi & Vallauri, 2013). However, mature stands of intermediate stages can also be interesting for biodiversity (Vaillancourt & al., 2009). These data also permit their identification.

Group	Criterion	Description
Dynamic	Diversity	Specific richness in tree species (nb.)
	Succession	Parameter obtained with a comparison of the basal area of different groups of tree species according to the yellow birch - conifer stand dynamic : - Young (Yo.) : paper birch, trembling aspen and red maple - Intermediate (Int.) : balsam fir, red maple and paper birch - Stable (St.) : balsam fir, red spruce and yellow birch - Companion (Comp.) : other species (sugar maple, american beech...) The group with the highest basal area is considered as the dominant succession stage.
Microhabitats	Woodpecker lodge	Number of trees, alive or dead, containing at least one woodpecker lodge (nb./ha)
	Natural cavity	Number of trees, alive or dead, containing at least one natural cavity (nb./ha)
	Other microhabitats	Number of living trees only with other microhabitats than the one previously defined (nb./ha)
Structure	Density	Number of living stems with a dbh ≥ 9 cm (nb./ha)
	Basal area	Calculated basal area of the stand (m²/ha)
	Mean diameter	Mean diameter at breast height of the living trees (cm)
	Maximum diameter	Highest diameter at breast height in the stand (cm)
	Stems dbh ≥ 30 cm	Number of living stems with a dbh ≥ 30 cm (nb./ha)
	Stems dbh ≥ 40 cm	Number of living stems with a dbh ≥ 40 cm (nb./ha)
	Stems dbh ≥ 50 cm	Number of living stems with a dbh ≥ 50 cm (nb./ha)
	Stems dbh ≥ 60 cm	Number of living stems with a dbh ≥ 60 cm (nb./ha)
Dead wood	Snags	Number of snags with a dbh ≥ 9 cm (nb./ha)
	Snags dbh ≥ 30 cm	Number of snags with a dbh ≥ 30 cm (nb./ha)
	Snags dbh ≥ 50 cm	Number of snags with a dbh ≥ 50 cm (nb./ha)
	Volume of coarse woody debris	Volume in coarse woody debris with a diameter ≥ 9 cm at the transect intersection (m³/ha)
	Debris ø ≥ 30 cm	Part of the coarse woody debris volume with a diamter ≥ 30 cm (%)
	Débris ø ≥ 50 cm	Part of the coarse woody debris volume with a diamter ≥ 50 cm (%)

Table 1 Presentation of the parameters studied in the old-growth evaluation.

The second part concerns the elements allowing the development of fauna, flora and fungus on trees : the microhabitats. We consider an important part of forest vertebrates and invertebrates to be depending on these microhabitats (Blanc & Martin, 2012). Forest exploitation has often been the cause of their decrease. It could have been a direct action – some microhabitats are considered as a defect that motivates the harvest of the tree – or an indirect one – with the stand rejuvenation or the suppression of the senescence stage (Rossi & Vallauri, 2013). Their abundance in natural forest, and especially old-growth forests is acknowledged (Winter, 2008 ; Rossi & Vallauri, 2013).

We defined three microhabitat classes : cavity originally excavated by woodpeckers (Woodpecker lodges), cavity created by other means (Natural cavities) and the last class which regroups other kind of microhabitats in living trees only (Other microhabitats). A same tree can be contained in these tree class. A more detailed presentation is shown in annexe IV.

The third focus on the structure created by the living trees in the stand. It contains some general elements (basal area, density, mean and maximum diameter) but also more specific ones. Especially the stand largest diameters class density. With these parameters, we can study these declining elements in managed forest but also the structural complexity of the whole stand. An old-growth forest should contain a significant part of large diameter elements (Rossi & Vallauri, 2013) but should also follow a complex structure (Vaillancourt & al., 2009).

The last part relates to the part of dead wood in the stand, focusing both on snags and on coarse woody debris. This element is very important for biodiversity (Vaillancourt, 2008 ; Angers, 2009) and is threatened by forest exploitation (Rossi & Vallauri, 2013). Same pattern applies for both classes. First, an indicator of global composition (density for snags, volume for coarse woody debris). Then the part of two large diameter class.

2.4 Statistical analysis

Each test has been conducted with the R software, version 3.03. All results, were considered significant when p-value ≤ 0.05 and considered illustrating a trend when p-value ≤ 0.1.

Qualitative variables have been tested with a Khi² test. For quantitative variables, the test was different according to the hypothesis we were working on. The choice made for each assumption will be presented in the following points.

Some of these tests required variances equality and data normality. For each of them, a Bartlett and a Shapiro-Wilks tests have been realized to lead us to the test choice.

2.4.1 Comparison of CPI-M1 and SSAM-II before the harvest

We tried to establish if some significant differences existed at the initial state between the experimental designs CPI-M1 and SSAM-II and on which parameters. The objective was to estimate the relevance of a comparison between these two stands.

In order to do so, we used for each quantitative variable a non-paired Student test to verify if the data respected normality and equality of the variance, or, if not, a Wilcoxon test.

2.4.2 Effect of the different treatments

The experimental designs CPI-M1 and SSAM-II are respectively divided between five and four forest treatments. For each parameter, a first test has been conducted on each site before the harvest. The aim was to discover existence of some pre-existing differences due to the natural variability of forest stands. In this case, these results should have been taken into consideration during the interpretation. Then, a second test has been made to observe the effects of the different treatments on each experimental site.

The parameter with a variances equality and a data normality has been studied with an analysis of variance test (Anova). For the other variables, and according to the low number of data (20 for each site), we choose to realize the non-parametric Kruskall-Wallis test but also an Anova. If the two tests showed same results (significant or not), we considered it valid. In case of results divergence, we considered them as invalid.

For each parameter giving a significant result, we then realized a multiple comparison analysis. Its aim was to define the treatments where differences occurred.

3. Results

3.1 Initial state

3.1.1 Comparison of CPI-M1 and SSAM-II

The stands studied in the experimental designs CPI-M1 and SSAM-II are very different. Every parameter, except the diversity, show significant differences or tendency between the two sites (table 2).

CPI-M1 experimental design presents a stand with an high basal area and high density (30.49 m²/ha and 1115.6 stems/ha) but with a lack of mature elements. However, 73% of the stems recorded (dbh ≥ 9 cm) have a dbh under 30 cm and these of 50 cm or more are quite inexistent. Same pattern applies for the snags. The density in CPI-M1 is superior compared to SSAM-II (256 snags/ha in the first and 107.2 in the second) but again, they are mainly composed of snags with a dbh under 30 cm.

SSAM-II plots show significantly higher diameter stems for living trees as well as for snags. Only the living stems with a diameter superior or equal to 60 cm show a tendency (p-value = 0.05513). The reason is probably the natural low density of these elements which limits the test efficiency. The results of the mean and maximum diameters confirm this image of SSAM-II : a richer in mature elements experimental design.

Even if the specific richness is the same, the repartition of the different species is different. The stable state (dominated by the yellow birch – red spruce – balsam fir group) is, on average, the most commonly found on the two sites. Nevertheless, the strong proportion of red maple in CPI-M1 causes a domination of the intermediate group characterized by red maple, white birch and balsam fir in 6 plots. This group is absent of SSAM-II. This explains the significant difference at the Khi² test (p-value = 0.02068).

As a summary of these observations, it appears the stands studied on experimental designs CPI-M1 and SSAM-II are strongly different. The old-growth characteristics are significantly more present in the second one. Due to the absence of coarse woody debris data for CPI-M1 before the harvest, we cannot display results on this aspect.

	Site	SSAM-II	CPI-M1		
	Variable	Mean	Mean		
		Stand.-dev.	*Stand.-dev.*	p.value	
Dynamic	Diversity	6	6	1	n.s.
	(nb. species)	*0,9*	*1,1*		
	Succession	Stable	Stable	0.02068	*
	Stable (nb. plots)	19	14		
	Intermediate (nb. plots)	0	6		
	Compaign (nb. plots)	1	0		
Structure	Maximum age	180	113	3.462e-06	***
	(years)	*46,3*	*38,7*		
	Basal area	25,25	30,49	2.847e-05	***
	(m²/ha)	*3,5*	*3,5*		
	Mean diameter	21	18	0.001231	**
	(cm)	*3,5*	*1,3*		
	Maximum diameter	56	48	0.007511	**
	(cm)	*8,1*	*10,5*		
	Density	536,6	1115,6	9.823e-09	***
	(nb./ha)	*172,7*	*287,0*		
	Stems dbh ≥ 30 cm	118,1	68	2.218e-06	**
	(nb./ha)	*26,8*	*29,9*		
	Stems dbh ≥ 40 cm	40,6	13,4	4.236e-06	***
	(nb./ha)	*15,9*	*12,1*		
	Stems dbh ≥ 50cm	6,9	1,6	0.0005829	***
	(nb./ha)	*5,7*	*4,0*		
	Stems dbh ≥ 60 cm	2,2	0,4	0.07755	.
	(nb./ha)	*3,7*	*1,2*		
Deadwood	Snags	107,2	256	2.015e-10	***
	(nb./ha)	*53,4*	*54,9*		
	Snags dbh ≥ 30 cm	29,7	17,4	0.01405	*
	(nb./ha)	*12,1*	*16,5*		
	Snags dbh ≥ 50 cm	5,0	1,4	0.007188	**
	(nb./ha)	*3,3*	*4,8*		

Table 2 Mean values obtained in the experimental designs SSAM-II and CPI-M1 before the harvest and results of the statistical analysis ("." : p-value ≤ 0.1 ; " * " : p-value ≤ 0.05 ; " ** " : p-value ≤ 0.01 ; " *** " : p-value ≤ 0.001).

3.1.2 Initial variability between the treatments

For all parameters, there is no difference between plots grouped by their future treatment in CPI-M1 (Annex V). The comparison between treatments after the harvest will not be influenced by a pre-existing variability. The experimental design SSAM-II has different results for two of its parameters: snags with a dbh ≥ 30 cm (p-value = 0.021) and coarse woody debris with a diameter ≥ 30 cm (p-value = 0.0634).

For the snags, this difference occurred between the control and the STR13 and STR19 treatments. The control plots contain twice more snags with a dbh ≥ 30 cm compared to these two treatments. However, there is no significant difference with the snags with a dbh ≥ 50 cm. This disparity seems to occur only for snags with a dbh between 30 and 49 cm. For the coarse woody debris, we see a significant difference between the control and the STR16 treatment. The values are strongly inferior for the second. The absence of any coarse woody debris with a diameter ≥ 30 cm explain this result.

These differences always occurred over the control treatment. Thus, it will be easy to consider them in the post-harvest analysis.

3.1.3 Comparison of our results with the values of other old-growth forests

	Reference	Desponts & al., 2002	Desponts & al., 2004	McCarthy & Weetman, 2006	Roberge & Desrochers, 2004	Aakala & al., 2007	Vaillancourt, 2008	CPI-M1
	Situation	Laurentides	Gaspésie	Terre-Neuve	Gaspésie	Côte nord	Saguenay	Portneuf
	Stand main species	Balsam fir -white birch	Balsam fir -white birch	Balsam fir -white birch	Balsam fir -white birch	Balsam fir -white birch	Balsam fir -white birch	Balsam fir - yellow birch
Microhabitats	Woodpecker lodges (nb./ha)				5,1			6
Structure	Average age (years)	84,8	87,2	98,4	87		90+	87
	Maximum age (years)			264				110
	Basal area (m^2/ha)			31,68				30,49
	Mean diameter (cm)	14	24,8				26,4	18
	Maximum diameter (cm)	40		48				48
	Density (nb./ha)	1950	643	1015				1115,6
	Stems dbh ≥ 20 cm (nb./ha)	77,2				242,6	299	309,6
	Stems dbh ≥ 30 cm (nb./ha)						75	68
Deadwood	Snags (nb./ha)	182	203			187		256
	Snags dbh ≥ 20 cm (nb./ha)	14	37		51	123	199,5	73,4
	Snags dbh ≥ 30 cm (nb./ha)				25		41,8	17,4

Table 3 Bibliographical synthesis of the characteristics of old-growth stands dominated by balsam fir, compared with the results of CPI-M1 before harvest.

The lack of information about old-growth forests in the yellow birch – coniferous domain strongly appears here. Except for the data from the EFE, all information come from other ecosystems but that we can consider as close enough for a comparison. For the stand characterized by the ecological type MS (CPI-M1), we referred to data coming from the balsam fir – paper birch domain (Desponts & al., 2002 ; Desponts & al., 2004 ; Roberge & Desrochers, 2004 ; McCarthy & Weetman, 2006 ; Aakala & al., 2007 ; Vaillancourt & al., 2008). This ecosystem is the one following the yellow birch - conifer ecosystem toward the north. For the stand characterized by the ecological type MJ (SSAM-II), we will use the work of Shwarz & al. (2001). This forest is located in the New Hampshire (USA) and is dominated by American beech (*Fagus grandiflolia)* but, due to an altitudinal gradient, is close to the yellow birch – balsam fir ecosystem (HBef and Bowl stands). We will also use the work of Fortin & al. (2003) on the pre-industrial yellow birch – balsam fir forest despite some methodological differences which limits the comparison.

The comparison between data collected in different old-growth balsam fir – paper birch forests is difficult because of their strong variability (table 3). The mean diameter in some stands (Vaillancourt & al, 2008) is half of the others (Desponts & al, 2002). The density in some stands (Desponts & al, 2004) can be three times superior to another one (Desponts & al, 2002). And the ratio of snags with a dhp ≥ 20 cm between to stands can be up to fourteen (Desponts & al., 2002 ; Vaillancourt & al., 2008). These important differences between stands all considered as old-growth forest is a piece of information: old-growth forests dominated by balsam fir can take a wide variety of shapes. We also underline the lack of information about living stems or snags with a dhp superior to 30 cm. It is a strong limit for the study and the comparison of the most mature elements of the forest.

	Source	Schwarz et al., 2001 Hbef stand	Schwarz et al., 2001 Bowl stand	EFE analysis	SSAM-II
Structure	Average age (years)				
	Maximum age (years)			265	180
	Basal area (m²/ha)			31,75	25,25
	Mean diameter (cm)			30,6	21
	Maximum diameter (cm)	>80	>80	70	56
	Density (nb./ha)	598,3	670,2	277	536,6
	Stems dbh ≥ 20 cm (nb./ha)	278,3	273,2	195,8	258,75
	Stems dbh ≥ 30 cm (nb./ha)	120,4	111,8	120,8	118,1
	Stems dbh ≥ 40 cm (nb./ha)	47,2	44,5	85,4	40,6
	Stems dbh ≥ 50cm (nb./ha)	16,6	15,5	50	6,9
	Stems dbh ≥ 60 cm (nb./ha)	6,9	4,8	29,1	2,2
Deadwood	Snags (nb./ha)			169,6	107,2
	Snags dbh ≥ 20 cm (nb./ha)				
	Snags dbh ≥ 30 cm (nb./ha)			105,3	32,8
	Snags dbh ≥ 50 cm (nb./ha)			51,8	6,3

Table 4 Comparison of the results of SSAM-II before harvest with data from the EFE and with the work of Schwarz & al. (2001).

The experimental design CPI-M1 seems to be close to some of these old-growth forests. There is a strong similarity between its basal area,density and maximum diameter and these observed by McCarthy & Weetman (2006). The proportion of stems with a dhp superior to 20 cm and 30 cm is also close to the values of Vaillancourt & al. (2008) even if the mean diameter is lower. Snag density is superior in CPI-M1 to the other stands and the wide range of results for snags with a dhp ≥ 20 cm does not allowany comparison. We can only note that our results are situated between the lowest and the highest result.

Yet, the density of snags with a dbh ≥ 30 cm in CPI-M1 is lower than in the stands described by Roberge & Desrochers (2004) and Vaillancourt et al. (2008). If we use the data collected in control plots after the harvest, density in trees containing a woodpecker lodge is close to the results of Roberge & Desrochers (2004). But they only represent a 4 plots result. Even if there were no significant differences between the control plots and the others, we cannot ensure that these results represent the whole experimental design before harvest.

HBef and Bowl stands presented by Schwarz & al. (2001) shows very similar results with SSAM-II (table 4) for the stems with a dbh from 10 cm to 50 cm. For the higher diameters, the density is lower in SSAM-II. We could then consider that this site has a lack in strong diameter trees. We can also see a close repartition of yellow birch and red spruce between these stands. The main difference occurs for balsam fir, quite absent in the New Hampshire study, and for European beech, almost inexistent in SSAM-II. There is also see a strong difference in composition in the work of Fortin & al. (2003), especially for red spruce. This specie seems to be a very important part of the pre-industrial stands.

The data from the EFE are not very useful for a stand-level reflexion. According to their small measurement area, the transcription of the values in a one hectare density gives very strong results that do not correspond to the true variability of yellow birch – balsam fir stands. These forests are a patchwork of different and small units (Doyon & Lafleur, 2004) but the EFE data only depicts the oldest patch. However, we can extract some information about the potential maximum values in diameter or age of the old-growth elements.

3.2 Results after harvest

3.2.1 Results in CPI-M1

We can observe many significant differences between treatments after the harvest (table 5). Differences apply on the following parameters : density in stems with a dbh ≥ 20 cm containing natural (p-value = 0.0154), density in stems with a dbh ≥ 20 cm containing other microhabitats (p-value = 0.0208), basal area (p-value = 2.43e-08), density in living stems (p-value = 9.63e-06), living stems with a dbh ≥ 30 cm (p-value = 0.0195) and ≥ 40 cm (p-value = 0.0883), mean diameter (p-value = 0.0004), maximum diameter (p-value = 0.000121) and snags density (p-value = 0.000435).

For all the results concerning structure or dead wood, they always follow the same pattern : they either oppose control or CPRS with all of the remaining treatments.

The divergences with control are about density, basal area and cavity trees. Such results are logic for the first two parameters. They are indeed the most impacted by the harvest and even a soft treatment will have a strong impact on them. As for the last, this result is more surprising (we were expecting a gradual decrease correlated with the intensity of the harvest). This result can be explained by a difference in natural cavity repartition between plots before the harvest.

Those occurring in opposition with the CPRS impact more parameters : basal area, density, density in living stems with a dbh ≥ 30 cm, mean diameter, maximum diameter, density in living stems containing other microhabitats and density in snags. Such results are due to the extreme impact of CPRS.

	Treatment Variables	CPI_25 Mean *Stand.-dev.*		CPI_40 Mean *Stand.-dev.*		CPR_50 Mean *Stand.-dev.*		CPRS Mean *Stand.-dev.*		Témoin Mean *Stand.-dev.*		p-value	
Dynamic	Diversity	6		5		6,5		3,2		6		0.3812	n.s.
	(nb. species)	*1,4*		*0*		*1,3*		*3,9*		*1,4*			
	Succession	St.		St.		St.		Int.		St.		0.1796	n.s.
	Stable (nb. plots)	4		4		4		2		3			
	Intermediate (nb. plots)	0		0		0		2		1			
Microhabitats	Woodpecker lodges	1		1		0		1		6		0.0555	.
	(nb.stems/ha)	*2,0*		*2,0*		*0,0*		*2,0*		*5,2*			
	Natural cavities	2	a	2	a	2	a	2	a	10	b	0.0154	*
	(nb.stems/ha)	*2,3*		*2,3*		*2,3*		*4,0*		*5,2*			
	Other microhabitats	8	ab	10	ab	11	ab	3	a	30	b	0.0208	*
	(nb. living stems/ha)	*10,8*		*9,5*		*6,8*		*6,0*		*18,2*			
Structure	Basal area	18,3	a	16,1	a	16,4	a	1,17	b	31,8	c	2.43e-08	***
	(m²/ha)	*2,8*		*3,5*		*3,6*		*1,7*		*3,7*			
	Mean diameter	17	a	17,4	a	16,5	a	11	b	16,7	a	0,0004	***
	(cm)	*2,7*		*1,9*		*1,6*		*1,1*		*0,7*			
	Maximum diameter	44,5	a	53,8	a	41,4	a	14,2	b	44,3	a	0.02471	*
	(cm)	*3*		*16,8*		*5,9*		*4,4*		*3,8*			
	Density	744	a	567	a	681	a	99	b	1266	c	9.63e-06	***
	(nb./ha)	*241,8*		*90,8*		*24,7*		*134,1*		*219*			
	Stems dbh ≥ 30 cm	40	ab	39	ab	37	ab	0	a	58	b	0.0195	*
	(nb./ha)	*24,2*		*16,8*		*16,1*		*0*		*32,7*			
	Stems dbh ≥ 40 cm	11	a	10	a	6	a	0	a	11	a	0.0883	.
	(nb./ha)	*8,2*		*8,3*		*12*		*0*		*11,5*			
	Stems dbh ≥ 50cm	0		2		1		0		0		0.544	n.s
	(nb./ha)	*0*		*4*		*2*		*0*		*0*			
	Stems dbh ≥ 60 cm	0		1		0		0		0		0.438	n.s
	(nb./ha)	*0*		2		*0*		*0*		0			
Deadwood	Snags	199	a	170	a	170	a	58	b	250	a	0.000435	***
	(nb./ha)	*47,8*		*43,9*		*30,4*		*32,7*		*62,9*			
	Snags dbh ≥ 30 cm	12		13		10		11		11		0.991	n.s
	(nb./ha)	*8,6*		*13,6*		*6,9*		*6*		*6,8*			
	Snags dbh ≥ 50 cm	3		0		0		1		1		0.306	n.s
	(nb./ha)	*3,8*		*0*		*0*		*2*		*2*			
	Coarse woody debris	74,0		82,1		87,0		124,1		80,8		0.247	n.s
	(m³/ha)	*11,4*		*33,7*		*33,2*		*39,2*		*35,9*			
	Debris ø > 30 cm	0,1		0,1		0,1		0,2		0,2		0.535	n.s
	(%)	*0,1*		*0,1*		*0,1*		*0,1*		*0,1*			
	Debris ø > 50 cm	0,0		0,0		0,0		0,0		0,0		0.438	n.s
	(%)	*0,0*		*0,0*		*0,1*		*0,0*		*0,0*			

Table 5 Values obtained for each treatment after harvest in CPI-M1 and results of the statistical analysis. ("." : p-value ≤ 0.1 ; " * " : p-value ≤ 0.05 ; " ** " : p-value ≤ 0.01 ; " *** " : p-value ≤ 0.001). Letters represent significant differences between the treatments. For the parameter “Succession”, “St.” means “Stable” and “Int.” means “Intermediate”.

CPRS and control are two extremes and the situation of the other treatments compared to them is an interesting result. If the difference is only due to the CPRS, other treatments then offer a good conservation of the related parameters. When results are situated between the two limits, it then means a significant impact but softer than those of a clearcut. And if no differences between any treatments are witnessed, CPRS and control included, then these elements were too rare to be significantly impacted by the harvest. This last point mainly relates to large diameter trees. It is consistent with the point 3.1.1, where the lack of mature elements was raised.

3.2.2 Results in SSAM-II

	Treatment Variables	STR13 Mean *Stand.-dev.*		STR16 Mean *Stand.-dev.*		STR19 Mean *Stand.-dev.*		TEM Mean *Stand.-dev.*		p.value	
Dynamic	Diversity	5,6		6,6		6,4		7		0.473	n.s.
	(nb. species)	*2,1*		*0,5*		*1,7*		*0,7*			
	Succession	St.		St.		St.		St.		1	n.s.
	Stable (nb. plots)	5		5		5		5			
	Intermediate (nb. plots)	0		0		0		0			
Microhabitats	Woodpecker lodges	2,4		6,4		0,8		5,6		0.137	n.s.
	(nb.stems/ha)	*2,2*		*6,1*		*1,8*		*4,6*			
	Natural cavities	0,0	a	0,0	a	4,8	ab	8,8	b	0.0165	*
	(nb.stems/ha)	*0,0*		*0,0*		*1,8*		*8,7*			
	Other microhabitats	20,0		34,4		41,6		42,4		0.433	n.s.
	(nb. living stems/ha)	*15,0*		*12,8*		*38,9*		*18,0*			
Structure	Basal area	15,2	a	17,7	a	20,5	ab	26,0	b	0.00227	**
	(m²/ha)	*3,9*		*2,0*		*3,0*		*5,3*			
	Mean diameter	21		19,7		20,8		20		0.909	n.s.
	(cm)	*3,8*		*2,5*		*3,3*		*4,4*			
	Maximum diameter	54,8		54,3		52,6		61,4		0.477	n.s.
	(cm)	*11,4*		*11,7*		*6,1*		*6,0*			
	Density	323	a	388	ab	389	ab	575	b	0.0299	*
	(nb./ha)	*126*		*35*		*85*		*193*			
	Stems dbh ≥ 30 cm	62,5	a	77,5	ab	112,5	b	116,3	b	0.0116	*
	(nb./ha)	*37,5*		*24,0*		*4,4*		*27,1*			
	Stems dbh ≥ 40 cm	28,8		32,5		43,8		42,5		0.39	n.s.
	(nb./ha)	*19,6*		*19,0*		*12,5*		*11,2*			
	Stems dbh ≥ 50cm	6,3		6,3		7,5		7,5		0.976	n.s.
	(nb./ha)	*6,3*		*6,3*		*8,1*		*2,8*			
	Stems dbh ≥ 60 cm	2,5		2,5		1,3		2,5		0.944	n.s.
	(nb./ha)	*3,4*		*5,6*		*2,8*		*3,4*			
Deadwood	Snags	132,5		121,3		92,5		140,0		0.81	n.s.
	(nb./ha)	*100,9*		*101,2*		*54,9*		*58,9*			
	Snags dbh ≥ 30 cm	16,3	a	18,8	a	21,3	a	45,0	b	0.00496	**
	(nb./ha)	*5,6*		*12,5*		*10,5*		*16,2*			
	Snags dbh ≥ 50 cm	5,0		0,0		5,0		5,0		0.202	n.s.
	(nb./ha)	*5,2*		*0,0*		*5,2*		*3,4*			
	Coarse woody debris	38,2		21,7		57,8		27,8		0.418	n.s.
	(m³/ha)	*34,5*		*14,7*		*57,8*		*15,7*			
	Debris ø ≥ 30 cm	0,0		0,0		0,1		0,0		0.169	n.s
	(%)	*0,0*		*0,0*		*0,2*		*0,0*			
	Debris ø ≥ 50 cm	0,1		0,0		0,0		0,0		0.523	n.s
	(%)	*0,2*		*0,0*		*0,1*		*0,0*			

Table 6 Values obtained for each treatment after the harvest in SSAM-II and results of the statistical analysis. ("." : p-value ≤ 0.1 ; " * " : p-value ≤ 0.05 ; " ** " : p-value ≤ 0.01 ; " *** " : p-value ≤ 0.001). Letters represent significant differences between the treatments. For the parameter “Succession”, “St.” mean “Stable”.

The different treatments have significant impacts on parameters in the experimental design SSAM-II (table 6) such as : basal area (p-value = 0.00227), density of living stems (p-value = 0.0299), density in living stems with a dbh ≥ 30 cm (p-value = 0.0116),

density in snags with a dbh ≥ 30 cm (p-value = 0.00496), density in living stems with a dbh ≥ 20 cm containing at least one natural cavity (p-value = 0.0165).
Contrary to CPI-M1, only one of these differences relates to the control versus the remaining treatments : density in snags with a dbh ≥ 30 cm. It is important to remind that a significant difference between the plots designed for each treatment before harvest has already been showed in point 3.1.2. It concerned the STR13 and STR19 treatments. This difference is only new for STR16 treatment. If we take a look at the multiple comparison analysis, we can see the gap growing for STR13 : Pr(>|t|) = 0.0352 before the harvest and Pr(>|t|) = 0.00469 after. On the opposite, the results are balanced for STR19 : Pr(>|t|) = 0.0270 before the harvest and Pr(>|t|) = 0.01806 after. So the impact appears different between the treatments. It is strongest for STR13 and STR16 than for STR19, even if in the last case the initial low density in this element can explain this result.

There is few significant differences regarding the microhabitats whereas means are very different between treatments. The high variability between plots of the same group explains this result. Natural cavities are the only parameter impacted by the harvest (p-value = 0.0165). It is stronger for STR13 and STR16 treatments where they are absolutely absent. The extreme of this result is surprising and a pre-existing lack before harvest can have an important influence on this result. Some data collected before the harvest shows that habitats that can be considered as natural cavities was already rare in STR13 and STR16. But this methodology was different of the one used in our study and therefore limits the comparison.

For the remaining parameters, we observe that the strongest differences occurred between the STR13 treatment and the control. For the two other treatments, behaviour is more complex even if STR19 is mostly close to the control. Because of the graduation in intensity of the different treatments, with STR19 being the lowest and STR13 the highest, these results are logic. The absence of significant difference for the most mature elements of the stand can prove, on the other side, a satisfying conservation of them in each treatment. Their low occurrence (especially stems with a dbh ≥ 50 cm) can also have an impact on this result still being better than in CPI-M1. Our statistical tests was not efficient for rare events.

Even in the absence of significant differences, we see a strong and unexpected variability of coarse woody debris after the harvest. The debris with a diameter superior to 30 cm disappear in three treatments and the mean volume in the control is divided by two. We should not see such important variations in a stand in free evolution and on a short period. A change in transect line between the two inventories can explain this result. So we can consider the methodology used for the estimation of coarse woody debris as non-satisfying.

4. Discussion

4.1 An overview of old-growth yellow birch – conifer stands

4.1.1 Stands dominated by balsam fir

The study of the literature on old-growth forest dominated by balsam fir and the results of the CPI-M1 experimental design show the variety of forms that this ecosystem can take. The strong dynamic of the main species of the stand can explain this observation. The regeneration of balsam fir can persist under the canopy cover for decades and up to one century. When the canopy opens, its development is strong and the competition important. But for trees that have reached the dominant stage, the decline comes quickly (McCarthy & Weetman, 2006). Balsam fir is mostly a short longevity specie, around 100 years (Hébert & Huot, 2009). There are older specimens in the boreal forest (up to 260 years-old) but their longevity is due to exceptional environmental conditions or a long waiting period under the overstory (McCarthy & Weetman, 2006). Natural disturbances have also a significant impact on the dynamic of balsam fir, especially spruce budworm epidemics which strongly affect the balsam fir (Ministère des Ressources Naturelles, 2013a). For these reasons, stands dominated by balsam fir tend to follow a complex structure due to the regular occurrence of mortality by small groups or by individual (ibid.).

In the studied balsam fir – yellow birch stands, the stand structure is complex but balsam fir rarely grows over 40 cm of dbh and even less above 50 cm (Burns & Honkala, 1990). Only red spruce and yellow birch are found in these highest diameter class in our experimental design. The lack of reference for such elements in the stands described in the literature appears as a consequence of balsam fir characteristics, mainly unable to reach this class because of its high sensibility to disturbances (spruce budworm, windfall). Red spruce and yellow birch (species absent in balsam fir – paper birch stands) do not provide a high number of large stems in CPI-M1 stands, especially compared with SSAM-II. Three factors can explain this statement : the ecological conditions in CPI-M1 are not optimal for yellow birch and red spruce (Ministère des Ressources Naturelles, 2013a) ; some natural disturbances rejuvenated the stands decades ago ; species with highest diameter were harvested first by forest exploitation. The important proportion of typical species of the intermediate development stage seems to support the hypothesis of past disturbances, but combination of these three factors can also be expected.

As a conclusion, it seems difficult to give a single representation of old-growth stands dominated by balsam fir in the yellow birch – conifer domain. The dynamic of balsam fir is the main factor explaining this difficulty. If we can agree with the natural complex structure of these stands (Doyon & Lafleur, 2004), yet their apparent rarity in very mature elements differs to our vision of old-growth stands.

4.1.2 Stands dominated by yellow birch

The stands of the experimental design SSAM-II are very different from those of CPI-M1. Even if we found expected complex structure in each site (Fortin & al., 2003 ; Doyon & Lafleur, 2004), SSAM-II is richer in old-growth and large-diameter elements. This experimental design is closer to the usual representation of old-growth forests than CPI-M1 (Bauhus & al., 2008).

The proximity of our results in SSAM-II with those of the old-growth forests in New Hampshire (Schwarz & al, 2001) bring the hypothesis of a stems larger than 30cm at the dbh deficit. High diameter trees are not a specificity of southern stand, as proved by the results from the EFE. A past exploitation can be the explanation of this difference. We also have to keep in mind that the study of Schwarz & al. is not in the same ecological context, even if they are close. Thus, American beech is an important specie in New Hampshire stands and is almost absent in SSAM-II whereas it is the contrary for balsam fir. Differences in climatic conditions, warmer in the american state, can also explain these differences.

The results from the EFE gave us interesting information about the composition or the most ancient and mature patches that composed yellow birch – balsam fir stands (Doyon & Lafleur, 2004). Even if the sampling area (400 m²) was twice the mean patch area in these forests (Hébert & Huot, 2009), it does not enable a general vision of the stand in its whole complexity. Further studies are required to improve the knowledge on this ecosystem.

However, the study of Fortin & al. (2003) shows a different composition of the natural stands. In pre-industrial forests, the species have a distribution strongly different from that observed in SSAM-II. Especially for red spruce, which represents half of the basal area in pre-industrial forest but only 21% in SSAM-II. Even if the decrease of red spruce in Québec is known (Dumais & Prévost, 2007), we observe in the New Hampshire old-growth forest of Schwarz & al. (2001) a distribution of this species close to SSAM-II (figure 5.2.). Thus, red spruce can potentially be a more important specie in yellow birch – conifer stands but its proportion in SSAM-II stays in the natural variability of old-growth forests.

4.1.3 Old-growth forest in the yellow birch-conifer domain

Old-growth forests can appear under different aspects in the yellow birch – conifer domain, according to the dominant species in the stand. If yellow birch is the main specie, we stay close of old-growth characteristics usually expected in temperate broadleaved forests. The structure is complex and high diameter living or dead trees are common. If balsam fir is the dominant specie then we are not in this representation of old-growth forest anymore. Its composition is strongly variable on many parameters (density, snags…) and mature elements lack. The complex structure is the only certainty about these stands. This natural behaviour is a potential explanation for the prevalence of stands of the MJ ecological class in the yellow birch – conifer domain in the studied EFE : the MS stands are not consistent with the usual representation of old-growth forest and are therefore rarely selected.

Yet, the lack of knowledge about old-growth stands in the yellow birch conifer domain (Doyon & Varady-Szabo, 2013) have made our work more difficult. The experimental designs SSAM-II and CPI-M1 are insufficient to provide an accurate picture of old-growth forests. Furthermore, the ecological differences between these sites and those studied in the literature also limit the comparison. More important studies must be made in the yellow birch – conifer domain to provide more precise clues for the ecosystem management.

4.2 Impact of the harvest on old-growth elements

4.2.1 Experimental design CPI-M1

Among the different management processes applied in CPI-M1, one result is obvious : the strong impact of the CPRS. As a clearcut, its intensity compared to the other treatments was predictable. Such harvests can even change, or at least severely slow down, the natural dynamic of the stand (Arcahmbault & al., 1997, Tremblay, 2009). Thus, a decrease of these practices seems necessary. The other treatments are not much different from one another, control excepted. The low density of trees with natural cavities seems to be the only common effect between the four harvest methods. Again, the lack of previous data limits the interpretation for this parameter.

Two points may explain these results. First, the initial density in mature and large elements was low in the majority of plots. Then, these densities were close to the minimal conservation standard for old-growth elements used during the hammer finish (Déry & Leblanc, 2005). The harvest of these elements was then strongly limited for each treatment, except for the CPRS. For the stems with a dbh ≥ 50 cm, the comparison with clearcut does not show any result because of their initial low density.
It is also necessary to take into account the next harvests. For two treatments, CPI-RL and CPR, it was only an opening of the canopy for the development of the regeneration. In the next decades, the remaining will also be harvested. We can therefore expect an impact close to the CPRS for the old-growth elements. However, for the CPI-CP treatment, the exact same harvest will be repeated around 20 years. The aim of this scenario is to always keep at least 40% of the canopy. This treatment is expected to enable a great conservation of old-growth elements (Raymond & al., 2009 ; Doyon & Varady-Szabo, 2011).

Moreover, the repetition of harvest aiming to keep a complex structure can also lead to an standardisation and a loss in natural elements of these stands (Angers & al., 2005). The strong decrease of living trees with other microhabitats than cavities and with a dbh ≥ 20 cm seems to be a clue of this threat. These stems are those with the highest probability to develop some cavities or lodges in the future. Their regular harvest has a high probability to lead to a decrease in the number of the microhabitats in the stand, and so to impact the biodiversity. So long-term survey are necessary to corroborate this hypothesis.

4.2.2 Experimental design SSAM-II

Most of the differences we can observe between treatments are predictable : the impact will be much stronger as the harvest will be intense. Yet, all the treatments tend to preserve the complex structure and the old-growth elements. Stems with a dbh ≥ 40 cm do not show important variations. The snags with a dbh ≥ 30 cm are the only parameter where treatments seems to have a strong impact. But in fact, they only enlarge a pre-existing gap between control and the other treatments. However, if we are only looking at the intensity of the harvest, we can notice that its effect on this element is stronger in STR16 whereas we expected this result for the treatment STR13. Maybe the standard for the conservation of dead wood has limited the impact for this last scenario.
However, it seems difficult to give an interpretation for the microhabitats. We consider that the lack of any natural cavities in the treatments STR13 and STR16 cannot be explained only by the harvest. An initial lack in these elements is very likely. The same logic is true for woodpecker lodges in STR19. Their low density does not seem consistent with the low impact of this scenario. Nevertheless, the results for living trees with microhabitat follow the intensity of the harvest : their density decrease when this parameter increase.

In general, these treatments confirm the confidence in selection cuts for the conservation of old-growth characteristics (Colloque sur les vieilles forêts boréales, 2009 ; Doyon & Varady-Szabo, 2011). However, with the intensity of the harvest increases the minimal period between two cuts for a good regeneration of the stand. A selection cut remains very different from the natural mortality of a stand (Doyon & Lafleur, 2004) and does not have the same impact than individual mortality or regeneration by small gaps (Doyon & Bouffard, 2009).
A low-intense and frequent treatment seems to be the best way to maintain a dynamic close to the natural one while keeping some plasticity in the management. A soft harvest allows a more precise choice among the stems so a better conservation of old-growth elements. Again, a long-term survey is necessary to be sure that the repetition of the harvest does not lead to a standardisation or a modification of the stand (Angers & al., 2005).

4.2.3 Comparison of these results with old-growth standards

The interpretation of the standard submitted by Déry & Leblanc (2005) is relatively free. They do not show any precise diameter categories, preferring the use of the word “large”. Thus, they advise maintaining (per hectare) 10 to 15 “large” snags, 5 to 10 “large” living stems, with microhabitats or not, and at least 5 m³ of “large” coarse woody debris. The use of this word instead of a specified threshold seems to be an important limit.

If we consider as “large” a dbh of 40 cm for living trees (Ministère des Ressources Naturelles, 2013b) and 30 cm for a snag (Vaillancourt et al., 2008), we note the compliance with this standard in CPI-M1 as shown in point 3.2.1. However the decrease of these thresholds have a strong impact: a living tree with a dbh of 32 cm can be considered as large (Fortin & al., 2003) and a snag can be considered large at 20 cm (Roberge et Desrochers, 2004). It would allow an intensification of the harvest without a decrease of old-growth characteristics. Referring ourselves to point 3.2.1 results we can observe this situation to be non-sensical. Last, this standard is not adapted for SSAM-II. Even with the largest diameter categories, every threshold is substantially exceeded.

The one from the Ontario Tree Marking Guide (OMNR, 2004) is strongly different. It advises to keep at least 12 cavity trees per hectare, half with a dbh ≥ 40 cm, the others ≥ 20 cm. Among these stems, 6 should contain woodpecker lodge with at least one with a dbh ≥ 40 cm. Every 4 hectares one supercanopy tree with a dbh ≥ 60 cm should be maintained. The standard also advises not to harvest until the basal area exceeds 28 m^2/ha and to keep at least a residual basal area of 20 m^2/ha (including 3 m^2/ha of trees with a dbh between 50 and 60 cm and 2 m^2/ha of trees above 60 cm).

About microhabitats, the results in the control plots of SSAM-II are above the thresholds. CPI-M1 controls plots are also close to them, except a lack in cavity trees with a dbh ≥ 40 cm, certainly because of their low density in these stands. The advices for the harvest are close to our previous conclusions but the basal area thresholds for trees with a dbh above 50 cm seems to be inadequate with our stand, especially for CPI-M1 and to a lower extent for SSAM-II. Its values are half of those recommended by the OMNR. A difference of productivity between our stands and those used for the definition of these threshold can explain this result. Moreover, the advice of one supercanopy tree can be relevant in balsam fir –yellow birch stands but not in stands where yellow birch is the main specie.

As a conclusion, the Déry & Leblanc's standard can be an interesting tools for stands dominated by balsam fir but its lack in clear thresholds is an important limit. The standard developed by the OMNR is very interesting and its advice for microhabitats could be used in mixed forest but the thresholds related with the basal area of the stand do not appear adapted to this ecosystem. It underlines again the necessity to improve our knowledge about old-growth stands in the yellow birch conifer domain for a development of relevant thresholds.

4.3 Critic of our methodology

Our methodology is mostly based on data usually collected during forest inventories. For this reason, its use and repetition seems very simple even if some differences between CPI-M1 and SSAM-II results show the limits of some parameters. For example the high diameter trees in CPI-M1 are too rare to have a significant impact on statistical analysis but still are important for a right vision of the stand. The transformation of such data into a presence/absence figure can be a solution.

Applying this methodology in other stands of the yellow birch – conifer domain is necessary to improve our knowledge on this ecosystem. It will lead to the development of relevant old-growth threshold but will however show the limits of our method and then will permit its amelioration (for example a new protocol for coarse woody debris evaluation with the Von Wagner method). The high variability of its results is probably due to the use of different transects in the two collect sessions. Thus, even if it is a time-efficient method, it seems better to choose a more precise protocol.

The absence of some parameters usually linked with the notion of old-growth forests can also be seen as an error. As an example an analysis of the vertical structure (Bauhus, 2009) or the availability in dead wood depending of the rotting classes (Winter, 2010). But this lack can be explained by different reasons. No data about the vertical structure has been collected in our experimental designs and they require a complex methodology (Haye, 2006). This is the opposite of our objective to offer a simple methodology. Moreover, we consider that the presentation of the different diameter classes allows the evaluation of the stand horizontal complexity but also, indirectly, its vertical complexity. The use of rotting class was an interesting parameter but a clear presentation of its results was complex. Furthermore, we consider that a better knowledge about deadwood in the yellow birch – conifer domain is necessary to use as a relevant parameter.

Improving the ecological knowledge on the old-growth mixed forest of yellow birch and balsam fir is another important aim. A large part of forest biodiversity depends on old-growth characteristics (Colloques sur les vieilles forêts boréales, 2009). That is why we have to certify the efficiency of these elements protection in managed forests. Moreover, some methodologies for naturalness evaluation use wildlife indicator and are therefore very important to understand in the connexion between old-growth forests and biodiversity (St-Hilaire, 2011). Yet, methodologies using dendrometric parameters appear more efficient due to their capacity to be used by most forest workers and not only by specialists.

Conclusion

This study highlights the complexity of defining old-growth yellow birch and balsam fir forests. Their characteristics can be very different according to the dominant species of the stand. Our work showed the lack of knowledge about these ecosystems yet they represent an important part of pre-industrial mixed forests. This can be interpreted as a limit for a correct application of the ecosystem management in mixed forest.

Our methodology seems relevant to enhance this knowledge while focusing on data commonly collected by forest workers. Moreover, a largest utilization is necessary to identify its limits and so being able to improve it.

This study also underlines the efficiency of continuous-cover treatments such as selection cuts or irregular shelterwood systems to maintain old-growth attributes. However, long-term analysis are necessary to ensure the real effect of such treatments on stands. Moreover, the current standards for conservation of old-growth elements are not satisfying in a mixed forest context.

Further studies are necessary to improve our knowledge about old-growth mixed forests and about the best ways to maintain these elements in managed stands. It will provide essential information for the application of the ecosystem management in this ecosystem.

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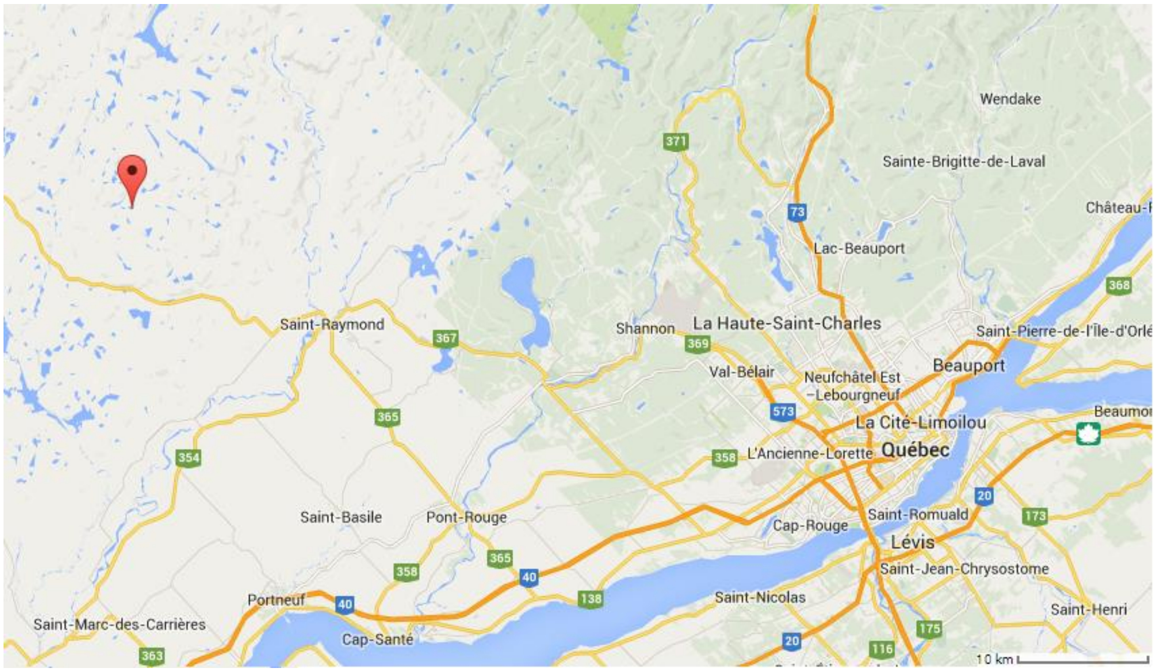
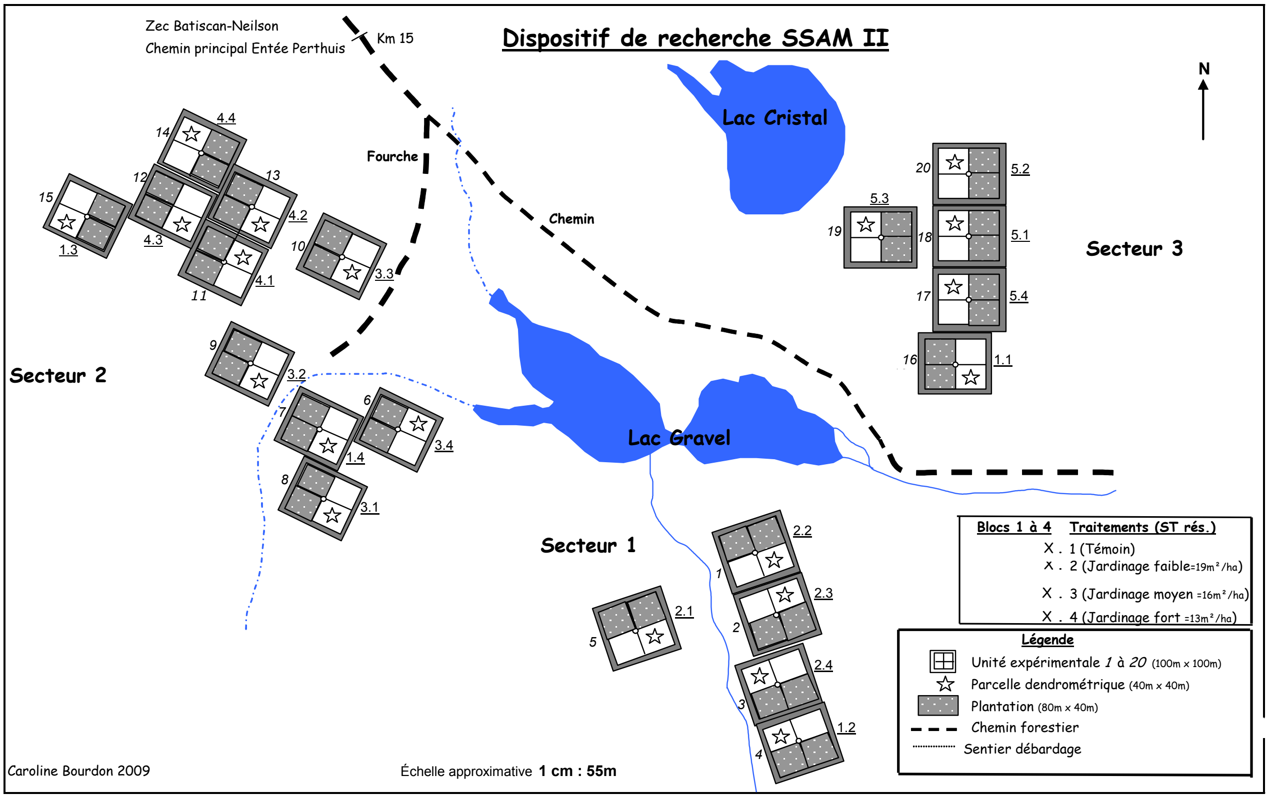
Annexes

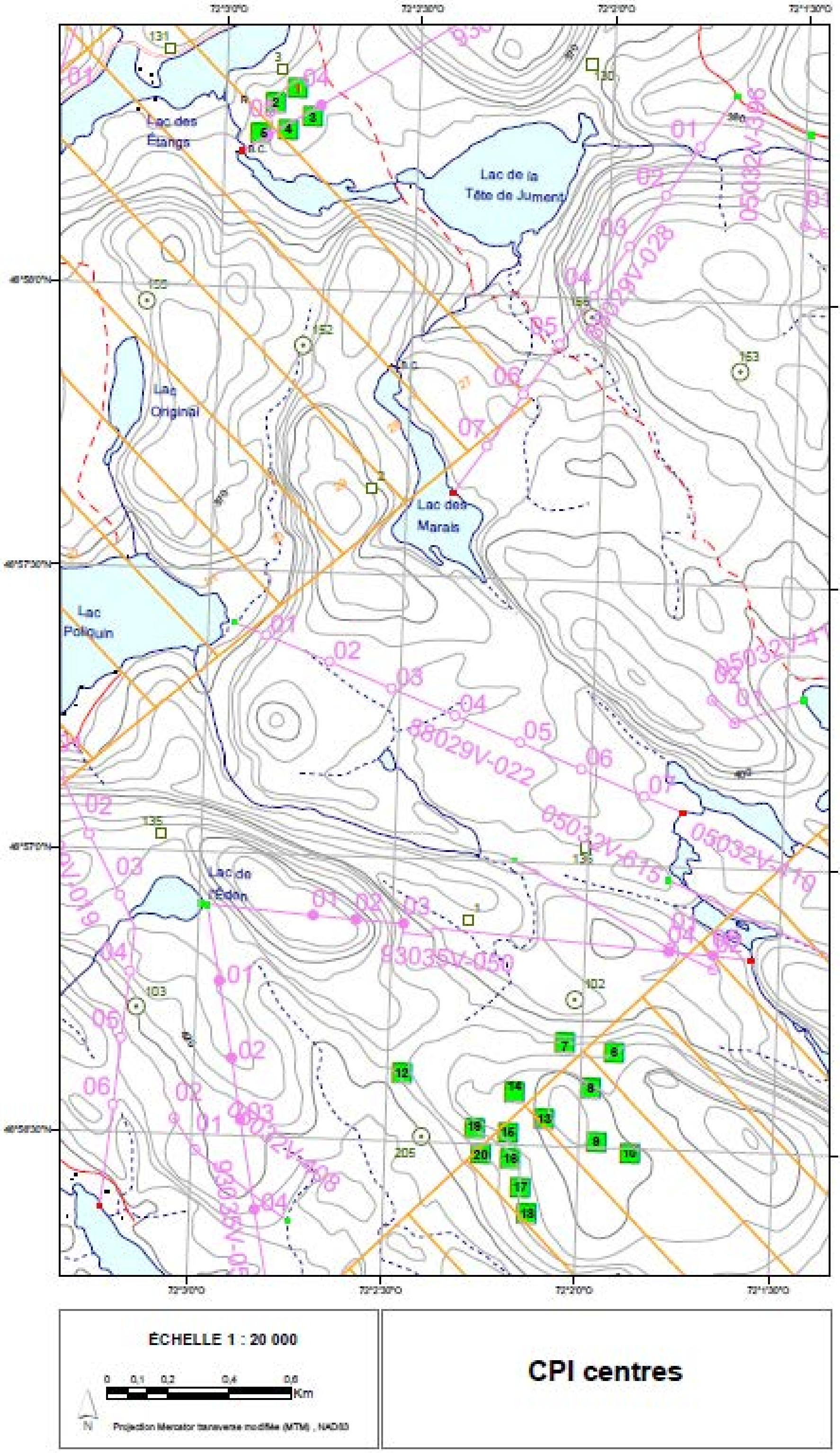
Annex I : Cartography of the experimental designs CPI-M1 et SSAM-II



Localisation of the two experimental designs (source : Google.ca)



Experimental design SSAM-II (source : C. Bourdon)



Experimental design CPI-M1 (Source : J. Noël)

Annex II : Presentation of the different treatments in CPI-M1 et SSAM-II

(source : Ministère des Ressources Naturelles, 2013b)

Regular shelterwood method (CPR) :

The CPR is a regeneration process consisting in an harvest in several steps. It starts with a partial opening of the canopy. Then, other partial harvest can be made until the final harvest, where all the remaining stand is cut. The duration of this process does not exceed $^1/_5$ of stand revolution.

Irregular shelterwood method (CPI) :

The CPI follows the same steps than the CPR but in a period exceeding the fifth of the revolution. The final harvest is also optional. But three different CPI types exist and two were applied in our study :

- Continuous cover (CPI-CP) : its aim is to maintain a continuous cover in the stand. Thus, a harvest shall keep at least 40% of the commercial stems.
- Extended (CPI-RL) : This process is very close to the CPR. The main difference is the longer period between the opening of the canopy and the final harvest (more than $^1/_5$ of the revolution)

Clearcut (CPRS) :

In a clearcut, all the commercial stems of the stand are harvested. But forest machines can only use predefined skid trails to limits the damages on soil and regeneration.

Selection cut (CJPG) :

A selection cut regroup three different aims in one cut : harvest, amelioration and regeneration. For this reason, a selection harvest just applies to a part of the stand. In our context, it was made by gap creations. Their repartition and their size where heterogeneous (maximum diameter : 25m).

Annex III : Naturalness clues raised in the literature review

Category	Criterion	Reference
Fauna and flora	Number of indigenous species	Rossi & Vallauri, 2013
	Group of species	St Hilaire, 2011
	Diversity in compaign species	St Hilaire, 2011
	Stand type (broadleaved, coniferous, mixed)	St Hilaire, 2011
	Comparison with potential vegetation	Schnitzler & Borlea, 1998 ; Winter & al., 2010
	Number of species (indigenous or not)	Haye, 2006
	Number of epiphytic species	Bus de Warnaffe & Devillez, 2002
	Number of cavernicolous species	Bus de Warnaffe & Devillez, 2002
	Number of xylobiont species	Bus de Warnaffe & Devillez, 2002
	Patrimonial species or habitats	Rossi & Vallauri, 2013
Indigénat	Indigénat	Schnitzler & Borlea, 1998 ; Haye, 2006 ; Rossi & Vallauri, 2013
Ecosystems related	Wetland	Rossi & Vallauri, 2013
	Rockland	Rossi & Vallauri, 2013
	% of open forest habitats	Rossi & Vallauri, 2013
Microhabitats	All type of microhabitats	Haye, 2006 ; Winter & al., 2010
	Woodpecker lodges	Rossi & Vallauri, 2013
	Tree with polypores	Rossi & Vallauri, 2013
	Other microhabitats	Rossi & Vallauri, 2013
	Forked trees	Winter & al., 2010
Structure	Basal area	Haye, 2006 ; Rossi & Vallauri, 2013
	Vertical heterogeneity	Bus de Warnaffe & Devillez, 2002 ; Haye, 2006 ; St Hilaire, 2011 ; Rossi & Vallauri, 2013
	Type of structure	Schnitzler & Borlea, 1998 ; Rossi & Vallauri, 2013
	Age of the stand	Rossi & Vallauri, 2013
	Density in very large trees	Rossi & Vallauri, 2013
	Diameter repartion	Haye, 2006
	Small woods variation coefficient	Haye, 2006
	Standing volune	Haye, 2006
	Maximum diameter	Haye, 2006 ; Winter & al., 2010
	Ecological unit area	Bus de Warnaffe & Devillez, 2002
	Horizontal heterogeneity	Bus de Warnaffe & Devillez, 2002
Deadwood	For each species, description of the less healthy stem	Winter & al., 2010
	Total deadwood volume	Schnitzler & Borlea, 1998 ; Haye, 2006 ; Winter & al., 2010 ; St Hilaire, 2011 ; Rossi & Vallauri, 2013
	Deadwood volume of the pioneer and competition species	Bus de Warnaffe & Devillez, 2002
	Deadwood volume of the mature and senescence species	Bus de Warnaffe & Devillez, 2002
	Decomposition class of standing deadwood	Haye, 2006 ; Winter & al., 2010 ; St Hilaire, 2011
	Decomposition class of coarse woody debris	St Hilaire, 2011
	% in soil contact and luminous conditions	Winter & al., 2010
	Number of stumps	Winter & al., 2010 ; Rossi & Vallauri, 2013
	Volume per species	Haye, 2006
	Volume per diameter class	Haye, 2006
	Living trees/Deadwood ratio	Haye, 2006
	Snag density	Haye, 2006

Catégorie	Critère	Publication liée
Dynamique	Stade de succession végétale	Rossi & Vallauri, 2013
	Nombre de stades du cycle sylvigénétique	Rossi & Vallauri, 2013
	Densité de stades de régénération jeunes	St Hilaire, 2011
	Fermeture du couvert d'arbres matures	St Hilaire, 2011
	Présence d'îlots de conservation	St Hilaire, 2011
	Degré de perturbation de l'humus du sol	St Hilaire, 2011
Fonctionnalité	Conservation des régimes de perturbation naturels	Schnitzler & Borlea, 1998
Cohérence spatiale	Degré de cohérence des différents habitats de l'écosystème	Schnitzler & Borlea, 1998 ; Winter & al., 2010 ; Rossi & Vallauri, 2013
Continuité temporelle	Continuité de l'état boisé depuis 1750	Rossi & Vallauri, 2013
Impact anthropique	Type de gestion	Bus de Warnaffe & Devillez, 2002
	Rapport : exportation bois/production ligneuse du groupement naturel potentiel	Bus de Warnaffe & Devillez, 2002
	Interventions diverses	Bus de Warnaffe & Devillez, 2002
	Pression touristique	Bus de Warnaffe & Devillez, 2002
	Intensité de la gestion et pollution (relevés licheniques)	Winter & al., 2010
	Empreinte ancienne	Rossi & Vallauri, 2013
	Empreinte contemporaine	Rossi & Vallauri, 2013
	Empreinte potentielle	Rossi & Vallauri, 2013

Annex IV : Microhabitats categories

Type	Description
Functional woodpecker lodge	Entry regular shape, circular to oval. Deep cavity. No wound nearby
Degraded woodpecker lodge	Entry regular shape of the entry, circular to oval. Deep cavity. Wound close to the cavity limiting protection from the elements
Woodpecker alimentation cavity	Circular to rectangular shape, 20 cm deep max. Size strongly variable
Secondary cavity	Ancient woodpecker lodge rebuilt by a new user. Rectangular shape of the opening
Stump cavity	Cavity at the soil level, opening at least 10 cm large
Decayed wood	All opening toward decayed wood
Broken top	Diameter at the break superior to 20 cm
Broken carpenter branch	Diameter at the break superior to 20 cm
Saproxylic fungus	Fruit with a diameter higher than 5 cm or group longer than 10 cm
Dead wood in the canopy	When dead branches represent at least 20 % of the top or when there is a dead branch with a diameter superior to 20 cm andat least 1 m long
Peeling bark	Surface without bark with a low alteration, superior to 600 cm² (one A4 sheet)
Crack	At least 1 m long, 1 cm large and 10 cm deep

(source : Winter & Möller, 2008 ; Rossi & Vallauri ; 2013)

In this report, microhabitats are grouped in the following way

Woodpecker lodge : Functional woodpecker lodge ; degraded woodpecker lodge ; secondary cavity

Natural cavity : Stump cavity ; Decayed wood

Other microhabitats : All microhabitats remaining

Annex V : Results of the different studied parameters in the experimental designs CPI-M1 and SSAM-II before the harvest, grouped by treatments.

	Treatment	CPI_25	CPI_40	CPR_50	CPRS	Témoin		
	Variables	Mean	Mean	Mean	Mean	Mean		
		Stand.-dev.	*Stand.-dev.*	*Stand.-dev.*	*Stand.-dev.*	*Stand.dev*	p.value	
Dynamic	Diversity	6	6	7	6,8	6	0.612	n.s.
	(nb. species)	*1,4*	0,8	*1,2*	1,0	*1,4*		
	Succession	St.	St.	St.	St.	St.	0.9169	n.s.
	Stable (nb. plots)	3	3	3	2	3		
	Intermediate (nb. plots)	1	1	1	2	1		
Structure	Basal area	31,42	29,59	30,41	29,19	31,83	0.83	n.s.
	(m²/ha)	*4,85*	*2,12*	*4,13*	3,54	*3,62*		
	Mean diameter	17,3	18,1	17,0	19,0	16,7	0.313	n.s.
	(cm)	*1,7*	*1,6*	*0,9*	2,8	*0,7*		
	Maximum diameter	44,7	54,4	44,5	51,6	44,3	0.537	n.s.
	(cm)	*2,8*	16,1	*6,8*	15,9	*3,8*		
	Density	1210	1007	1184	905	1272	0.356	n.s.
	(nb./ha)	*380*	247	*288*	243	*220*		
	Stems dbh ≥ 30 cm	63,0	73,0	58,0	87,0	59,0	0.664	n.s.
	(nb./ha)	*30,4*	*34,6*	*19,2*	34,5	*34,6*		
	Stems dbh ≥ 40 cm	11,0	13,0	7,0	25,0	11,0	0.29	n.s.
	(nb./ha)	*6,0*	8,9	*11,5*	17,4	*11,5*		
	Stems dbh ≥ 50cm	0,0	2,0	2,0	4,0	0,0	0.632	n.s.
	(nb./ha)	*0,0*	*4,0*	*2,3*	8,0	*0,0*		
	Stems dbh ≥ 60 cm	0,0	1,0	0,0	1,0	0,0	0.573	n.s.
	(nb./ha)	*0,0*	2,0	*0,0*	2,0	*0,0*		
Deadwood	Snags	279,0	216,0	280,0	263,0	242,0	0.479	n.s.
	(nb./ha)	*41,4*	62,4	*44,9*	69,8	*59,9*		
	Snags dbh ≥ 30 cm	17	20	12	27	11	0.352	n.s.
	(nb./ha)	*10*	20	*9*	12	*7*		
	Snags dbh ≥ 50 cm	3,0	0,0	0,0	3,0	1,0	0.52	n.s.
	(nb./ha)	*6,0*	*0,0*	*0,0*	3,8	*2,0*		

Results in CPI-M1 at the initial state

	Treatment	STR13		STR16		STR19		TEM			
	Variables	Mean		Mean		Mean		Mean			
		Stand.-dev.		*Stand.-dev.*		*Stand.-dev.*		*Stand.-dev.*		p.value	
Dynamic	Diversity	6,2		6,4		6,0		6,8		0.549	n.s.
	(nb. species)	*0,4*		*0,9*		*1,2*		*0,8*			
	Succession	St.		St.		St.		St.		0.3679	n.s.
	Stable (nb. plots)	4		5		5		5			
	Intermediate (nb. plots)	1		0		0		0			
Structure	Basal area	25,78		25,20		24,83		25,21		0.983	n.s.
	(m^2/ha)	*3,07*		*3,50*		*2,70*		*5,23*			
	Mean diameter	21,6		20,6		20,6		20,2		0.925	n.s.
	(cm)	*4,3*		*3,1*		*3,0*		*4,4*			
	Maximum diameter	56,4		54,7		53,0		61,1		0.471	n.s.
	(cm)	*9,3*		*10,9*		*5,3*		*6,0*			
	Density	540		559		483		565		0.89	n.s.
	(nb./ha)	*266*		*143*		*75*		*199*			
	Stems dbh ≥ 30 cm	118,8		108,8		133,8		111,3		0.482	n.s.
	(nb./ha)	*41,7*		*25,2*		*13,7*		*19,5*			
	Stems dbh ≥ 40 cm	43,8		38,8		41,3		38,8		0.96	n.s.
	(nb./ha)	*21,2*		*20,4*		*16,3*		*6,8*			
	Stems dbh ≥ 50cm	8,8		5,0		6,3		7,5		0.782	n.s.
	(nb./ha)	7,1		5,2		7,7		2,8			
	Stems dbh ≥ 60 cm	2,5		2,5		1,3		2,5		0.8944	n.s.
	(nb./ha)	*3,4*		*5,6*		*2,8*		*3,4*			
Deadwood	Snags	91,3		137,5		73,8		126,3		0.202	n.s.
	(nb./ha)	*51,5*		*65,6*		*42,0*		*38,6*			
	Snags dbh ≥ 30 cm	21,3	a	28,8	a	22,5	a	46,3	a	0.045	*
	(nb./ha)	*7,1*		*18,5*		*11,4*		*16,3*			
	Snags dbh ≥ 50 cm	7,5		2,5		5,0		5,0		0.468	n.s.
	(nb./ha)	*5,2*		*3,4*		*5,2*		*5,2*			
	Coarse woody debris	40,67		35,38		41,58		54,97		0.58	n.s.
	(m^3/ha)	*29,31*		*19,18*		*18,14*		*22,44*			
	Debris ø ≥ 30 cm	0,16	ab	0,07	a	0,29	b	0,31	b	0.0158	*
	(%)	*0,17*		*0,10*		*0,09*		*0,07*			
	Debris ø ≥ 50 cm	0,00		0,00		0,00		0,00		n.a.	n.s
	(%)	*0,00*		*0,00*		*0,00*		*0,00*			

Results in SSAM-II at the initial state

Summary

The conservation of old-growth elements in managed forest is an important aim of the ecosystem management in Québec. This work focus on their representation in yellow birch (*Betula alleghaniensis*) and balsam fir (*Abies balsamea*) stands of the mixed forest domain. We studied two experimental sites, one dominated by yellow birch and the other by balsam fir, where was estimated the effect of different forest treatments on old-growth characteristics. Our method shows the possibility to represent them with a small number of parameters, mainly dendrometric. Continuous cover treatments seems to be the most interesting systems for the conservation of these elements. However, our study raised the lack of information concerning old-growth stands in mixed forest. Yet, these data are essential for a relevant application of the ecosystem management. For this reason, further researches on this subject are necessary.

La conservation d'éléments propres aux forêts anciennes dans les peuplement aménagés est un enjeux important de l'aménagement écosystémique au Québec. Cette s'étude s'est principalement intéressée à leur expression dans les peuplements de bouleau jaune (*Betula alleghaniensis*) et de sapin baumier (*Abies balsamea*) dans le domaine de la forêt mixte. Pour cela, nous avons travaillé sur deux sites d'expérimentation, l'un dominé par le bouleau jaune et le second par le sapin baumier, visant à estimer l'effet de différents traitements forestiers sur les caractéristiques de vieilles forêts. Notre méthode montre qu'il est possible de les représenter en se basant sur un nombre réduits de paramètres, essentiellement dendrométriques. Les itinéraires de gestion sylvicole à couvert continu apparaissent alors comme les systèmes les plus adaptés à leur conservation. Notre étude a cependant mis en évidence le manque d'informations disponible sur les vieux peuplements du domaine de la forêt mixte. Ces données sont pourtant essentielles pour la réalisation concrète de l'aménagement écosystémique. De nouvelles recherches sur ces écosystèmes sont donc nécessaires.