TABLE OF CONTENTS

ACKNOWLEDGEMENTS .... **i**

PREFACE .... **iv**

LIST OF FIGURES .... **iv**

LIST OF TABLES .... **iv**

RÉSUMÉ .... **x**

ABSTRACT .... **xii**

CHAPTER I GENERAL INTRODUCTION **1**

1.1 Background 1

1.1.1 Autecology of white pine 3

1.1.2 Restoration and management of white pine 8

1.1.3 Traditional ecological knowledge 10

1.2 Rationale of the dissertation 11

1.3 Study area 13

1.4 Objectives of the study and structure of the dissertation 15

CHAPTER II Cultural importance of white pine (*Pinus strobus* L.) to the Kitcisakik Algonquin community of western Quebec, Canada **16**

2.1 Abstract 17

2.1 Résumé 18

2.2 Introduction 19

2.3 Methods 21

2.3.1 Study area 21

2.3.2 Data collection and analysis 24

2.4 Results 25

2.4.1 Perception of white pine 26

2.4.1.1 Cultural and spiritual importance 28
2.4.1.2 Medicinal value 28
2.4.2 Food and habitat for wildlife 29
2.4.3 Other services provided by white pine 30
2.4.4 Threats to white pine 30
2.4.5 Management and restoration... 31
2.5 Discussion... 32
2.5.1 White pine as a cultural keystone species 33
2.5.2 Comparing traditional knowledge and ecological studies....................... 35
2.5.3 Importance of cultural values and traditional ecological knowledge recognition 36
2.6 Acknowledgments 39
2.7 References.. 40
CHAPTER III White pine (*Pinus strobus* L.) regeneration dynamics at the species' northern limit of continuous distribution 46
3.1 Abstract.. 47
3.1 Résumé 48
3.2 Introduction... 49
3.3 Methods 50
3.3.1 Study area 50
3.3.2 Site selection and data collection 52
3.3.2.1 Detailed regeneration study.. 53
3.3.2.2 Regeneration according to distance from a remnant stand 53
3.3.2.3 Blister rust and weevil damage according to canopy cover................. 54
3.3.3 Data analysis 54
3.3.3.1 Detailed regeneration study.. 54
3.3.3.2 Regeneration according to distance from a remnant stand 57
3.3.3.3 Blister rust and weevil damage according to light availability, dryness, and white pine density 57

3.4 Results 58
3.4.1 Tree species composition of white pine stands 58
3.4.2 Detailed regeneration study 58
3.3.3 Substrate–seedling associations in white pine stands 62
3.3.4 Regeneration according to distance from a remnant stand 63
3.3.5 Blister rust and weevil damage according to canopy cover 65
3.5 Discussion 66
3.6 Conclusion 71
3.7 Acknowledgements 71
3.8 References 71
CHAPTER IV Culturally-adapted white pine (*Pinus strobus* L.) restoration and management at the species' northern limit of continuous distribution 77
4.1 Abstract 78
4.1 Résumé 79
4.2 Introduction 80
4.3 Methods 82
4.3.1 Study area 82
4.3.2 The Kitcisakik community 83
4.3.3 Developing restoration and management scenarios 84
4.4 Current state of knowledge 85
4.4.1 Cultural importance of white pine to the Kitcisakik Algonquin 85
4.4.2 Ecology of white pine at its northern limit of continuous distribution 85
4.4.3 Restoration and management options for white pine 87
4.4.3.1 Site selection 87
4.4.3.2 Site preparation 89
4.4.3.3 Shelterwood system for white pine restoration and management 89
4.4.3.4 Underplanting white pine 91
4.4.3.5 Mixed plantation 91

4.4.3.6 Pure white pine plantation 92
4.5 Scenarios for white pine restoration and management 94
4.5.1 Scenario I: Scattered individuals of all ages 95
4.5.2 Scenario II: Supercanopy pines 95
4.5.3 Scenario III: Mature pure stands of natural origin 99
4.5.4 Scenario IV: Timber production 99
4.5.5 Scenario V: Mixed stands 99
4.6 Conclusion 101
4.7 Acknowledgements 102
4.8 References 102
CHAPTER V GENERAL CONCLUSION 110
5.1 White pine as a cultural keystone species 110
5.2 Regeneration dynamics of white pine 111
5.3 Culturally-adapted white pine restoration and management 112
5.4 Future perspectives 112
5.5 References (for General Introduction and General Conclusion) 113

LIST OF FIGURES

Figure 1.1 Distribution of eastern white pine in eastern North America. 4

Figure 1.2 Location of the study area in the Abitibi-Témiscamingue region of western Quebec. 14

Figure 2.1 Location of Kitcisakik's ancestral territory in western Quebec 22

Figure 3.1 Location of the study area (Kitcisakik's ancestral territory) in the balsam fir – yellow birch bioclimatic domain in western Quebec 51

Figure 3.2 White pine combined size distribution 60

Figure 3.3 Effect of balsam fir basal area (m^2/plot) on white pine regeneration (seedlings + saplings) abundance (log regeneration/subplot). 62

Figure 3.4 Percent area of forest floor covered by each substrate type (grey bars) and percent seedlings found on each substrate type (black bars) 63

Figure 3.5 Effect of distance from the remnant stand on white pine regeneration abundance (log regeneration/subplot)... 65

Figure 4.1 Location of Kitcisakik's ancestral territory in western Quebec. 84

Figure 4.2 White pine restoration and management framework for the Kitcisakik Algonquin territory 100

LIST OF TABLES

Table 2.1 White pine rating for the six elements used to identify cultural keystone species. 26

Table 2.2 Key features of cultural importance and traditional ecological knowledge relating to white pine in the Kitcisakik Algonquin community 27

Table 2.3 Correspondence of traditional ecological knowledge with scientific studies concerning white pine 37

Table 3.1 Candidate linear mixed-effects models used to explain white pine regeneration abundance.. 55

Table 3.2 Frequency of occurrence and basal area of tree species in the quadrats.... 59

Table 3.3 Ranking of linear mixed models predicting the abundance of white pine regeneration based on AICc. 61

Table 3.4 Ranking of linear mixed models predicting the effects of remnant stands and refuge trees on the abundance of white pine regeneration in logged stands, based on AIC_c 64

Table 3.5 Ranking of logistic regressions with random effects predicting the effect of canopy cover on blister rust damage in roadside transects, based on AIC_c 66

Table 4.1 Uniform shelterwood system for white pine regeneration........................ 90

Table 4.2 Ecological types and suggested scenarios for white pine restoration and management.. 96

RÉSUMÉ

Le pin blanc (*Pinus strobus* L.) était autrefois une composante importante des forêts du nord-est de l'Amérique du Nord. La diminution marquée de l'abondance de l'espèce au cours des derniers siècles est attribuable à des changements des régimes de perturbations. Le déclin du pin blanc est source d'inquiétude pour les écologistes, les aménagistes forestiers et les peuples autochtones. La communauté algonquine de Kitcisakik est fortement concernée par le déclin du pin blanc et demande qu'une stratégie de restauration et d'aménagement durable de l'espèce soit développée pour son territoire ancestral. Dans ce contexte, cette thèse vise à développer des scénarios de restauration et d'aménagement du pin blanc à la limite nordique de répartition continue de l'espèce – correspondant au territoire ancestral de la communauté de Kitcisakik, dans l'ouest du Québec.

Comme première étape en vue de l'atteinte de cet objectif, des entrevues ont été réalisées avec des informateurs clés afin de documenter l'importance culturelle, spirituelle et écologique du pin blanc pour la communauté de Kitcisakik, ainsi que les savoirs traditionnels en lien avec cette espèce (Chapitre II). Le pin blanc était perçu comme une composante importante de la vie traditionnelle, fournissant de nombreux biens et services aux membres de la communauté. L'espèce figure dans les légendes, est utilisée comme plante médicinale, fournit un habitat à des espèces fauniques d'intérêt, et est une partie importante des paysages culturels. Le pin blanc est une espèce culturelle clé pour la communauté de Kitcisakik. Les gens de la communauté ont identifié la surexploitation des forêts de pin blanc comme raison principale du déclin de l'espèce sur leur territoire ancestral. Ils ont suggéré que des plantations mixtes pourraient être utilisées dans une stratégie de restauration culturellement adaptée.

La deuxième étape du projet visait à quantifier la régénération naturelle de pin blanc dans des peuplements matures. Les facteurs influençant l'abondance de régénération ont été identifiés, de même que les impacts de la rouille vésiculeuse (*Cronartium ribicola* J.C. Fisch.), du charançon (*Pissodes strobi* Peck) et de l'herbivorie (Chapitre III). L'influence de peuplements résiduels et de semenciers refuges sur la répartition spatiale de la régénération a également été étudiée. Les résultats révèlent un recrutement faible mais continu de pin blanc. Le sapin baumier (*Abies balsamea* (L.) Miller) a un impact négatif important sur la régénération en pin blanc. La régénération était plus abondante sur les substrats humides. L'impact de la rouille vésiculeuse et du charançon était beaucoup plus faible qu'escompté en fonction des cartes de risque du ministère des Ressources naturelles. La distance a un peuplement résiduel a un impact significatif sur la régénération en pin blanc dans les aires de

coupe. Il est possible de restaurer le pin blanc à la limite nordique de sa répartition continue en ciblant des peuplements mésiques à humides, mais sous un couvert forestier modéré afin de minimiser les risques d'attaque par la rouille vésiculeuse.

L'étape finale du projet s'appuyait sur une revue de littérature sur la sylviculture du pin blanc pour proposer des scénarios de restauration et d'aménagement du pin blanc qui répondent aux besoins de Kitcisakik tout en tenant compte des types écologiques (végétation potentielle et conditions abiotiques) (Chapitre IV). Le scénario I concerne l'utilisation du pin blanc comme plante médicinale et s'appuie sur la régénération naturelle dans les types écologiques où le pin blanc est une composante secondaire. Le scénario II vise à maintenir ou produire des arbres géants utilisés pour l'orientation sur le territoire et comme habitat par des espèces fauniques d'intérêt. La régénération naturelle est suggérée, de même que la plantation d'individus épars dans tous les types écologiques où le pin blanc peut pousser. Le scénario III a pour objectif de générer des peuplements purs matures naturels qui serviront d'habitat pour des espèces fauniques d'intérêt, et aussi de lieux de resourcement pour les membres de la communauté. La coupe progressive d'ensemencement est suggérée dans les types écologiques (co)dominés par le pin blanc. Le scénario IV vise à produire des peuplements purs matures à des fins de production de matière ligneuse. La plantation sous couvert est suggérée dans les types écologiques dominés par les résineux. Le scénario V vise la restauration et le maintien du pin blanc comme composante du paysage à des fins esthétiques et de préservation d'habitats fauniques en ayant recours à des plantations mixtes dans des types écologiques où le pin blanc est une composante secondaire.

ABSTRACT

Once an important component of northeastern North American forests, eastern white pine (*Pinus strobus* L.) has greatly decreased in abundance over the last few centuries owing to changes in disturbance regimes. White pine decline has raised concerns from ecologists, forest managers, and aboriginal peoples. The Kitcisakik Algonquin community is one of the stakeholders that has been deeply concerned by white pine decline, and calling for restoration and management of the species on its ancestral territory. In this context, this dissertation aimed to develop restoration and management scenarios for white pine at its northern limit of continuous distribution – corresponding to Kitcisakik's ancestral territory in western Quebec.

As a first step towards this goal, key informants were interviewed to document the cultural, spiritual and ecological importance of white pine to the Kitcisakik Algonquin community, as well as traditional ecological knowledge related to this species (Chapter II). White pine was perceived as an important component of traditional life, providing several goods and services. The species is featured in legends, used as a medicine, provides habitat for flagship wildlife species, and is a prominent part of cultural landscapes. White pine is a cultural keystone species for the Kitcisakik Algonquin community. Local people point to extensive logging as the reason behind white pine decline on the ancestral territory. They suggest that mixed plantations should be used in a culturally-adapted restoration strategy.

Next, we quantified natural white pine regeneration in mature stands, identified the most important variables influencing it, and evaluated the impact of damaging agents, namely white pine blister rust (*Cronartium ribicola* J.C. Fisch.), white pine weevil (*Pissodes strobi* Peck) and herbivory. We also quantified the influence of remnant stands and refuge trees on the spatial distribution of regeneration in logged sites (Chapter III). The results revealed continual but low recruitment of white pine. Balsam fir (*Abies balsamea* (L.) Miller) had a strong negative effect on white pine regeneration. Regeneration was more abundant than expected on moister substrates. The occurrence of blister rust and weevil was much lower than expected based on the available risk maps of the Ministry of Natural Resources. Distance from remnant stands had a significant effect on white pine regeneration in logged areas. It is possible to restore white pine at its northern limit of continuous distribution by targeting mesic to moist stands, but only under moderate shade so as to minimize the risk of blister rust occurrence.

In the final step, we propose culturally- and ecologically-adapted restoration and management scenarios based on a literature review of white pine silviculture, as well

as on the particular cultural and ecological settings of the Kitcisakik ancestral territory (Chapter IV). We present five scenarios aiming to answer different needs of the Kitcisakik community, while taking into account ecological types (potential vegetation and abiotic conditions). Scenario I addresses the need for white pine as a medicinal plant. It relies on natural regeneration of scattered white pine trees in ecological types where white pine is a minor component. Scenario II fulfills the need for scattered supercanopy white pine trees that are used as landmarks and as habitat for flagship wildlife species. It relies on conservation of current supercanopy white pines, and sporadic natural regeneration and plantation to renew the stock. Scenario III aims to provide habitat for flagship wildlife species and forest stands where people can go for resourcing. Pure mature stands are produced by shelterwood cuts in ecological types (co)dominated by white pine. Scenario IV aims to produce pure mature stands for timber production by favoring under canopy plantations in ecological types dominated by conifer species. In scenario V, mixed plantations in all ecological types where white pine is a minor component will serve for aesthetic purposes, as wildlife habitat, and to protect biodiversity.

CHAPTER I

GENERAL INTRODUCTION

1.1 Background

Eastern white pine (*Pinus strobus* L.) has historically been one of the most valuable species in North America and remains a very important species culturally, ecologically and economically (Schroeder 1992, Abrams 2001, Burgess and Wetzel 2000, Ostry et al. 2010). White pine possesses important symbolic and spiritual value, e.g. as a symbol/spirit of peace in the Iroquois tradition (Schroeder 1992). It is the provincial tree of Ontario and the state tree of Maine and Michigan (Anonymous 1993). The seeds, needles, bark and twigs are important food sources for many birds, reptiles and mammals including moose (*Alces alces* Clin.) and white-tailed deer (*Odocoileus virginianus* Zimm.). White pine trees provide valuable habitat for many wildlife species, e.g. bald eagles (*Haliaeetus leucocephalus* L.) prefer to nest on supercanopy white pines (Rogers and Lindquist 1992, Latremouille et al. 2008). The species is also used as a medicinal plant to treat different ailments by the aboriginal peoples of North America (Foster and Duke 2000, Uprety et al. 2012a).

Until the early 1900's, white pine harvesting generated important revenues in North America. In the USA, white pine harvesting in Michigan, Wisconsin, and Minnesota generated millions of dollars and employed thousands of people (Chapelle 1992). An estimated 315 billion board feet of white pine was harvested from the Great Lakes region between the mid 1800's and the 1930's, accounting for 60 to 82 % of the region's total annual timber production between 1869 and 1900 (Steen-Adams et al. 2007). Lumbermen preferred white pine, first because it floats and was thus easy to transport on rivers, and second because it grows into tall boles of clear wood, flexible, light, strong and durable (Steen-Adams et al. 2007).

White pine was thus overharvested over the last few centuries, as it was prized for large tree size and high wood quality (Daoust and Beaulieu 2004). Trunks were used as ship masts and large tracts of white pine were reserved for the Royal Navy during colonial times (Delwaide and Filion 1999). Because of extensive lumbering, few uncut white pine stands remain in eastern Canada and USA. With European settlement came a wave of severe disturbances, including extensive logging and slash fire that eliminated white pine seed sources and allowed early successional hardwoods to replace white pine forests (Weyenberg et al. 2004). However, intensive logging practices are increasingly scrutinized, as the existence of old-growth white pine forests is threatened (Hall et al. 1994). White pine blister rust (*Cronartium ribicola* J.C. Fisch.) and white pine weevil (*Pissodes strobi* Peck) are major threats to white pine forests (White et al. 2002, Major et al. 2009). In addition, several other factors could have various degrees of impact on white pine: changing forest management goals, officials' projections of forest economic value, financial and technical resources available to managers, changing political influence of forest companies, and shifts in land ownership and use (Steen-Adams et al. 2007).

Ongoing interest in white pine management and restoration in a variety of ecosystems has been prompted by the continuously rising demand for high-quality lumber, coupled with the species' recognized ecological, social and cultural values (Pitt et al. 2009). White pine was probably subject to more extensive cooperative tree improvement research during the last 30 years in eastern Canada and USA than any other tree species, with the exception of the southern pines (Kriebel 2004). It is also one of the most widely planted trees in the United States (Wendel and Smith 1990). Although natural regeneration of white pine is an important subject in conservation biology and forest management, restoration attempts through natural regeneration have largely been hampered by several factors including pests and diseases. Plantation is the only possible restoration tool where white pine seed trees are currently absent and natural regeneration is not possible (Pitt et al. 2009).

1.1.1 Autecology of white pine

Eastern white pine is the largest pine native to eastern North America. It is a member of a worldwide group of five-needled trees of the genus *Pinus* (Price et al. 1998). It grows in pure and mixed forests across southern Canada from Newfoundland to southeastern Manitoba and south through the northeastern and north central United States into parts of Georgia and South Carolina (Wendel and Smith 1990, Figure 1.1). The broad geographic range of the species demonstrates its adaptability to various ecological conditions (Sterns 1992). White pine can live for up to 450 years and reach 67 m in height and 180 cm diameter at breast height (Wendel and Smith 1990, Anonymous 1993).

White pine occurs on many soil types (Wendel and Smith 1990) but it is most competitive on moderately well-drained sandy soils of low to medium site quality (Burgess and Wetzel 2000). The root system normally consists of 3-5 large roots that spread outward from the base of the trunk. Further development of smaller lateral roots occurs from the main roots. However, the forms and distribution of white pine roots vary with soil characteristics. Climate over the range of white pine is cool and humid, with July temperature averages between 18^{o}C and 23^{o}C and a growing season extending 90-180 days. The species is mid-successional and intermediate shade tolerant (Wendel and Smith 1990). It can be a pioneer species in old fields abandoned after agriculture use and site disturbances such as recent burns and eroded areas that expose mineral soil that generally favor seedling establishment and early growth (Abrams 2001).

Figure 1.1 Distribution of eastern white pine in eastern North America (Adapted from Abrams 2001).

White pine does not have serotinous cones, nor does it reproduce vegetatively. Being a monoecious species, the female and male strobili are formed separately. Self-pollination is prevented as female strobili (cones) are borne in the upper crown and male strobili in the lower crown. Pollination occurs in early June, fertilization after 13 months and seeds and cones mature in August-September of that year (Stearn 1992). White pine begins to bear cones before it is 20 years old and seed production increases with age until 90-100 years, and dominant trees are the best seed producers (Lancaster and Leak 1978, Wendel and Smith 1990, Stearns 1992). Good seed years occur every 3-5 years and mast years occur about every 10 to 12 years. Seed predation by the white pine cone beetle (*Conophthorus coniperda* (Schwarz)) and by red squirrels (*Tamiasciurus hudsonicus* Erxl.) can occur (Wendel and Smith 1990).

White pine seedlings grow slowly in their first five years under the shadow created by taller trees. Seedlings survive and grow with as little as 20% of full sunlight. However, regeneration and growth are enhanced under increased light conditions (Wetzel and Burgess 2001).

White pines grown in open canopy are more susceptible to blister rust and weevil. Trees grown beneath the moderate shade of partial overstory provided by hardwood, mixedwood or conifer stands are safer both from the insect and rust (Burgess et al. 2005, Major et al. 2009). Blister rust is a disease caused by an exotic fungus introduced into North America from Europe in the early 1900's. It was imported from Germany, brought along with planting stocks needed to meet domestic reforestation needs (Hunt 2003, Daoust and Beaulieu 2004). Blister rust is now considered to be the most prevalent disease affecting eastern white pine in eastern Canada (Lavallée 1986). The disease can infect and kill pines at any age but mortality is higher at the seedling stage (Latremouille et al. 2008). Larger trees can be killed as branch dieback proceeds over time (White et al. 2002). Blister rust completes its life cycle in two alternative hosts: white pine and *Ribes* species. It is highly virulent in areas characterized by low daily maximum temperature or long cool periods during the day (White et al. 2002, Zambino 2010).

The white pine weevil has long been recognized as the most important insect pest of eastern white pine throughout its range in eastern North America, where white pine is the favoured host of the insect among many other species that can be attacked (Belyea and Sullivan 1956, Wendel and Smith 1992, Major et al. 2009). The first serious attack by this insect usually occurs when the saplings are about five years of age and less than 1 m in height. Severity of attacks increases rapidly during following years, but drops off by the time trees have reached a height of 6 m and is often negligible by the time they are 7-9 m in height. Severe damage may occur during the first 15 to 20 years (Belyea and Sullivan 1956). Weevil kills the terminal shoot of young trees and sometimes even the trees themselves (Belyea and Sullivan 1956, Major et al. 2009).

Role of fire in white pine ecology

White pine has thick bark and is adapted to surface fires, which play an important role in the ecology of the species (Wendel and Smith 1990, Stiell et al. 1994, Burgess et al. 2005). According to Frelich (1992), under natural conditions white pine is most abundant in forests with a fire rotation period of 150 to 300 years between catastrophic crown fires. Surface fires of moderate intensity occurring every 20-40 years maintain and regenerate white pine by preparing seedbeds and eliminating invasion by late-successional species (Heinselman 1981). Such fires also reduce cone insect populations and allow sunlight to reach the ground (OMNR 2008). When good seed crops closely follow fires, white pine regenerates abundantly (Ahlgren 1976). On mesic sites white pine cannot establish without fire due to heavy competition. Increased fire activity would give white pine a competitive advantage over fire-susceptible species (Bergeron et al. 1997). Post-fire white pine regeneration is possible even at the species' northern distribution limit (Engelmark et al. 2000).

Suppression of surface fires caused decreased white pine regeneration and development (Stiell et al. 1994, Burgess et al. 2005, OMRN 2008). As a result, many white pine stands are now undergoing succession towards late-successional species such as balsam fir (*Abies balsamea* (L.) Miller), black spruce (*Picea mariana* (Mill.) B. S. P.), and white spruce (*Picea glauca* (Moench) Voss) in the northern part of the species' range, or red maple (*Acer rubrum* L.), sugar maple (*Acer saccharum* L.), and eastern hemlock (*Tsuga canadensis* (L.) Carr.) in the southern and eastern parts of its range (Weyenberg et al. 2004).

White pine and climate change

The average temperature of northern North America is predicted to increase by 1.4°C to 5.8°C during the 21st century (IPCC 2007). Climate change will influence the structure, composition, and function of forest ecosystems, and thus how they are managed. Effects might be due to increased atmospheric carbon dioxide concentration, increased temperature and (perhaps) drought, and more frequent disturbance and extreme climatic events (Parker et al. 2000). White pine populations and individuals are less abundant and more scattered than previously at the northern limit of continuous distribution and this may be challenging for the species' maintenance in the area (Major et al. 2009). However, as white pine possesses wide genetic variation and because the species is outcrossing, tree improvement programs could help develop white pine varieties with improved growth potential or adaptation to climatic stress (Daoust and Beaulieu 2004).

White pine was widely distributed and abundant in eastern North America during the Holocene climatic optimum, ca. 3000-8000 years ago, characterized by a warmer, wetter climate less conductive to stand-replacing fires (Terasmae and Anderson 1970, Jacobson 1992, Richard 1995). White pine abundance gradually decreased during the Neoglacial period (the last 3000 years), as stand-replacing fires became more frequent in response to a cooler, dryer climate. Thus, white pine could adapt to climate warming, which could lead to increased abundance of the species at the northern part of its range (Jacobson 1992, Latremouille et al. 2008). However, climate change might cause higher frequency of stand-replacing fires, and also favour the spread of diseases and pests, such as white pine weevil, mountain pine beetle (*Dendroctonus ponderosae* Hopkins) and white pine blister rust (William et al. 2000, Colombo 2008) which might cancel the positive effect of warmer temperature.

1.1.2 Restoration and management of white pine

Restoration is an intentional attempt to bring an ecosystem back to some historical state and regain ecological integrity and resilience (Palmer et al. 2008). It can be viewed as an attempt to recover a natural range of ecosystem composition, structure, and dynamics (Palmer et al. 2008). Restoration is necessary because the relationship between social and natural systems is not always as mutualistic as it should be (Perrow and Davy 2002). Restoration ecology has received increasing attention in recent years, as the need for recovery from environmental damage caused by misuse or mismanagement of natural resources became evident. However, it requires multiple efforts as multiple disturbances have pushed ecosystems beyond their ability to naturally recover.

Although it promises enormous opportunities for social, ecological and economic benefits, white pine management and restoration is challenging (OMNR 2008), and that for many reasons: specific site requirements for regeneration, slow initial growth rate, susceptibility to damage from blister rust and weevil, heavy browsing by herbivores (e.g., snowshoe hare [*Lepus americanus* Erxl.], moose and white-tailed deer), etc. (Tester et al. 1997, Burgess et al. 2005, Steen-Adams et al. 2007, Latremouille et al. 2008).

Vegetation competition is another major problem for white pine regeneration in high quality sites. Thinning, scarification, and even herbicide treatment might be necessary in such situations (Heckman 1992, Burgess and Wetzel 2000, Boucher et al. 2007). The uniform shelterwood cut system is used in some regions to minimize vegetation competition (Pinto 1992). In this system, residual trees provide suitable microclimatic conditions to seedlings and saplings and reduce the risk of attack by the blister rust and weevil by favoring predators and parasites. Hence, the uniform shelterwood system, when combined with site preparation, can offer adequate conditions for natural white pine regeneration (Boucher et al. 2007).

Application of successful restoration and management strategies depends on a better understanding of ecosystem functioning (Tester et al. 1997). Such knowledge will help interpret environmental impacts of management decisions traditionally based on more empirical evidence and driven by economic and social concerns (Wetzel and Burgess 2001). Sound silvicultural recommendations also rely on knowledge of the morphological and physiological plasticity of the targeted species (Boucher et al. 2007), especially regarding its response to different stresses, site conditions and management options. Substrate type and litterfall also have profound effects on conifer seedling survivorship (Simard et al. 2003). Stand characteristics, such as light, water, and nutrient availability, as well as form and structure of the roots and stem affect survival and growth (Stearns 1992).

Nitrogen is a limiting factor to white pine seedling growth (Burgess and Wetzel 2000). White pine also shows a positive response to increased light and moisture (Burgess and Wetzel 2000). Soil moisture stress during the growing season decreases seedling growth (Francis 1979), and white pine regeneration positively responds to increased light levels created by crown openings (Wetzel and Burgess 2001). Natural white pine regeneration can be favored by using partial harvesting and microsite preparation where mature white pine trees are present (Burgess and Wetzel 2000, Doyon and Bouillon 2003). Restoration efforts should be focused on stands known to have previously supported white pine. Careful stand selection considering topography is important to reduce the likelihood of blister rust infection. Repeated pruning of the lower branches to minimize mortality by blister rust and corrective pruning of individuals damaged by weevil were also suggested (Latremouille et al. 2008).

1.1.3 Traditional ecological knowledge

Living in close association with nature since time immemorial, indigenous people have gained a deep understanding of the complex ways in which the different components of the environment are interconnected (Berkes 2008). Forest-dependent aboriginal people have witnessed the impacts and consequences of natural and human disturbances to forest resources over broad temporal and spatial scales (Stevenson 2005). The knowledge systems of aboriginal people are deeply rooted in social and cultural values. Traditional ecological knowledge (TEK) emerges through generations of observation, experiences, traditions, and beliefs transmitted orally and practically (Berkes et al. 2000). TEK is a recognized tool that can link cultural and biological diversity and thus make modern methods acceptable to local populations (Ramakrishnan 2009).

Traditional (ecological) knowledge, sometimes referred to as local knowledge or indigenous knowledge depending on the context, has increasingly been recognized in recent years and efforts have been made to link it with science, particularly in the area of environmental management (Cheveau et al. 2008, Uprety et al. 2012b). But TEK alone is not sufficient; it needs to be integrated with modern methods to bring about ecological conservation and sustainable development (Stevenson 2005). In this context, TEK should be taken into account in restoration and management of forest stands on aboriginal territory.

Ecological restoration could be more efficient, and restoration activities could be facilitated if indigenous people were involved. The knowledge developed over generations of interactions between indigenous people and ecosystems can make a valuable contribution to ecological restoration (Berkes 2008). TEK can be used in different stages of restoration and management activities, such as recognizing disturbance factors and identifying suitable restoration sites. Incorporation of TEK can contribute to build a strong partnership for the successful implementation of restoration projects and to increase social acceptability, economic feasibility and ecological viability (Uprety et al. 2012b). Therefore, restoration ecology and TEK are complementary (Shebitz 2005).

1.2 Rationale of the dissertation

The abundance of white pine has been significantly reduced throughout its distribution range (Whitney 1987, Buchert 1994, Schulte et al. 2005, Pinto et al. 2008). This has raised concerns from ecologists, forest managers, timber companies, as well as aboriginal peoples. The Kitcisakik Algonquin community of western Quebec is one of the stakeholders that has been deeply concerned by white pine decline, and calling for restoration and management of the species on its ancestral territory. In recent years, evolving forest management policies throughout the world have moved to incorporate social and aboriginal values by promoting active participation in decision making regarding forest management (Wyatt et al. 2011, Trosper and Parrotta 2012). The profound modifications that were recently made to Quebec's forest management policies (Gouvernement du Québec 2010) also give more room to local decisions by introducing the concept of proximity forests. Such forests might allow for the flexibility necessary to properly restore and manage white pine stands on Kitcisakik's ancestral territory.

Site characteristics and the prevalence of natural disturbances that are crucial for restoration and management can vary significantly throughout white pine's range (Abrams 2001). Therefore, any restoration and management efforts require better understanding of ecosystem functioning, and species morphological and physiological characteristics (Tester et al. 1997, Boucher et al. 2007). This emphasizes the importance of assessing local site conditions rather than relying on regional generalizations (Ostry et al. 2010). However, no research has yet been done on Kitcisakik's ancestral land concerning white pine ecology, restoration and management. The knowledge regarding white pine, both scientific and practical, largely applies to the central part of the species' range (e.g., Ahlgren 1976, Dovčiak et al. 2003, Burgess et al. 2005), with some studies also conducted at the northern distribution limit (e.g., Holla and Knowles 1988, Bergeron et al. 1997, Engelmark et al. 2000). The causes and timing of white pine decline are well documented (Delwaide and Filion 1999, Abrams 2001, Weyenberg et al. 2004, Latremouille et al. 2008, Ostry et al. 2010) and there are widespread arguments that intensive harvesting pressure in past centuries, coupled with blister rust and weevil damage, have limited white pine to small and isolated stands. However, knowledge is still fragmentary relatively to the species' ecology at its northern limit of continuous distribution – corresponding to Kitcisakik's ancestral territory. Such knowledge is nevertheless crucial to suggest alternative, viable scenarios to restore the species and sustainably manage the forest.

In addition to a better understanding of the species' ecology, it is essential to understand the indigenous uses, perceptions and knowledge relative to white pine in order to develop restoration and management alternatives that respect the needs and viewpoints of the Kitcisakik Algonquin community. Woodley (2005) argues that the development process must be based on an understanding of TEK if projects are to be sustainable, both environmentally and socially. Previous studies have determined that aboriginal communities can recognize and have comprehensive knowledge of the ecology, reproductive biology, and uses of the species present in their territories (Stevenson 2005). Because of this comprehensive knowledge, indigenous people can make valuable contributions to ecosystem management programs.

According to Stevenson (2005), the reasons behind the little impacts of TEK in resource management are that research issues are identified by non-aboriginals (e.g. government or company managers, consulting scientists, independent researchers), and that the research questions are framed by those trained in the “western” scientific knowledge tradition and resource management thinking. The present study was prompted by questions from the Kitcisakik community regarding how white pine could be restored and sustainably managed on its ancestral lands.

Important questions needed to be asked before suggesting restoration and sustainable management strategies for white pine on Kitcisakik's ancestral territory. It was necessary to document why exactly the species was important for the Kitcisakik Algonquins. Is the Kitcisakik’s territory suitable for white pine restoration and, if so, how could white pine populations be restored and managed on Kitcisakik’s ancestral grounds?

1.3 Study area

The study area is located in the La Vérendrye Wildlife Reserve in western Quebec (Figure 1.2), and is part of the ancestral territory of the Kitcisakik Algonquin community. Average annual temperature is 1.2-3.3°C, and average precipitation is 914-1014 mm/year, with 22-33% falling as snow (Val-d'Or and Mont-Laurier weather stations, Environment Canada: http://www.climate.weatheroffice.gc.ca/climate_normals). The study area corresponds to the northern limit of continuous white pine distribution. It is located in the balsam fir – yellow birch (*Betula alleghaniensis* Britton.) bioclimatic domain (Saucier et al. 1998). The species' northern limit is reached ca. 150 km to the north-west, in the Lake Duparquet and Lake Abitibi regions where scattered stands and trees are present (Bergeron et al. 1997; Engelmark et al. 2000). Bergeron et al. (1997) suggested that the disequilibrium between present and past fire regimes may explain why northern pines have discontinuous distributions inside their range limits. A fossil record of white pine from Val St-Gilles that lies some 200 km from the present study area indicates a former northward extension of the range of this species during the mid-Holocene, possibly as far north as James Bay region (Terasmae and Anderson 1970, Liu 1990).

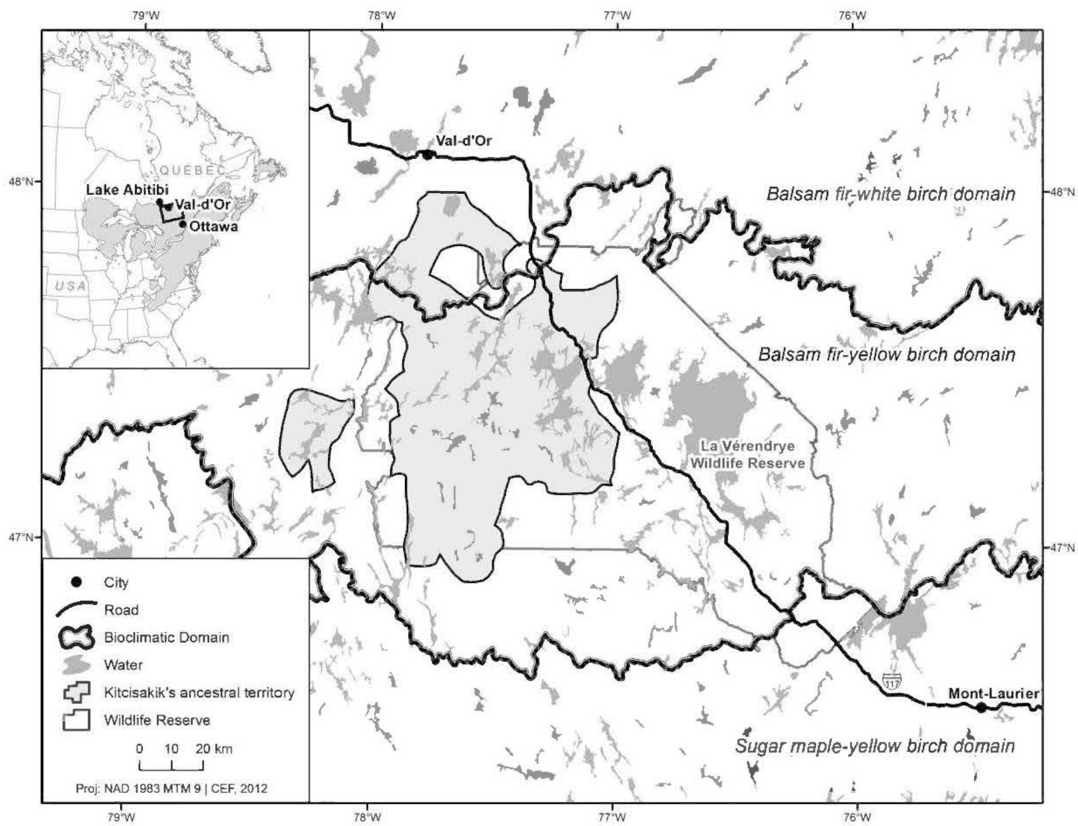

Figure 1.2 Location of the study area in the Abitibi-Témiscamingue region of western Quebec. The shaded area in the inset shows the continuous distribution of eastern white pine (*Pinus strobus* L.) in northeastern North America (after Wendel and Smith, 1990).

Mixed forests are dominant in the region, with balsam fir and black spruce accompanied by white spruce, white pine, eastern white cedar (*Thuja occidentalis* L.), yellow birch, paper birch (*Betula papyrifera* Marsh.), sugar maple, red maple, and trembling aspen (*Populus tremuloides* Michx.). Red pine (*Pinus resinosa* Ait.) and jack pine (*Pinus banksiana* Lamb.) are present on xeric sites.

The Kitcisakik Algonquin community (ca. 430 members) has maintained a lifestyle based on hunting, trapping, fishing and gathering that was strongly dependent on the forest. In the early 1900s, the arrival in the area of non-aboriginal settlers had important consequences on land use and occupation, as well as on the social organization of the community (Leroux et al. 2004). The Kitcisakik people now live on what is considered “crown land” (under governmental jurisdiction) and they are still struggling for legal recognition of their ancestral territory by the Canadian government. In the meantime, most of the territory has been allocated to forestry companies and more than 60% of productive forests have been clearcut over the last 40 years (Saint-Arnaud et al. 2009). Prior to that, selective logging for large-diameter hardwoods and pines (white and red), was practiced for several decades (Asselin 1995).

1.4 Objectives of the study and structure of the dissertation

The general objective of this dissertation was to develop restoration and management strategies for white pine at its northern limit of continuous distribution – corresponding to Kitcisakik's ancestral territory. The specific objectives were:

1. to document the cultural, spiritual and ecological importance, as well as traditional ecological knowledge of the Kitcisakik Algonquin community regarding white pine (chapter II);
2. to investigate the reproductive biology, population dynamics, community ecology and damaging agents of white pine in selected white pine stands representative of the species' northern limit of continuous distribution (chapter III);
3. to develop culturally-adapted white pine restoration and management strategies based on knowledge of the species' cultural importance and ecological dynamics (chapter IV).

CHAPTER II

Cultural importance of white pine (*Pinus strobus* L.) to the Kitcisakik Algonquin community of western Quebec, Canada

Yadav Uprety, Hugo Asselin and Yves Bergeron

Article published in
Canadian Journal of Forest Research
Vol. 43, pages 544-551

2.1 Abstract

Trees and forests have always played a significant role in the cultural and spiritual lives of societies. Understanding cultural importance of tree species is necessary to develop socially acceptable forest management and restoration strategies. White pine (*Pinus strobus* L.) used to be abundant in northeastern North America, including on the ancestral territory of the Kitcisakik Algonquin community (western Quebec, Canada). The community is calling for restoration and sustainable management of white pine on their ancestral territory. As a first step towards this goal, key informant interviews were used to document the cultural importance of white pine to the Kitcisakik community. White pine was perceived as an important component of traditional life, providing several goods and services. White pine is featured in legends, used as a medicine, provides habitat for flagship wildlife species, and is a prominent part of cultural landscapes. White pine is a cultural keystone species for the Kitcisakik Algonquin community. Local people point to extensive logging as the reason behind white pine decline on the ancestral territory. They suggest that mixed plantations should be used in a culturally-adapted restoration strategy.

Keywords: Aboriginal people, Algonquin, Cultural keystone species, Restoration, Sustainable forest management, White pine

2.1 Résumé

Les arbres et les forêts ont toujours joué un rôle important dans la culture et la spiritualité des sociétés. La compréhension de l'importance culturelle des espèces arborescentes est nécessaire pour développer des stratégies de restauration et d'aménagement socialement acceptables. Le pin blanc (*Pinus strobus* L.) était autrefois plus abondant dans les forêts du nord-est de l'Amérique du Nord, notamment sur le territoire ancestral de la communauté algonquine de Kitcisakik (Québec, Canada). La communauté revendique la restauration et l'aménagement durable du pin blanc sur son territoire ancestral. Un premier pas vers cet objectif a été franchi en réalisant des entrevues avec des informateurs clés de la communauté afin de documenter l'importance culturelle de l'espèce. Le pin blanc était perçu comme une composante importante de la vie traditionnelle, fournissant de nombreux biens et services. L'espèce figure dans des légendes, est utilisée comme plante médicinale, procure de l'habitat à des espèces fauniques d'intérêt, et est une constituante importante des paysages culturels. Le pin blanc est une espèce culturelle clé de la communauté algonquine de Kitcisakik. Les gens de la communauté ont identifié la surexploitation des forêts de pin blanc comme raison principale du déclin de l'espèce sur leur territoire ancestral. Ils ont suggéré que des plantations mixtes pourraient être utilisées dans une stratégie de restauration culturellement adaptée.

Mots clés: Algonquin, Aménagement forestier durable, Espèce culturelle clé, Peuples autochtones, Pin blanc, Restauration

2.2 Introduction

Trees and forests have considerable cultural, spiritual and ecological significance for people around the world (Dudley et al. 2005, Trigger and Mulcock 2005). They provide goods and services that benefit society in various ways. It is sometimes forests, as part of cultural landscapes, or often specific tree species that are deeply ingrained in the cultures and beliefs of societies. However, the ways in which societies benefit from trees differ widely, as patterns of resource use are shaped by the values, priorities, perceptions, and expectations of each cultural group. For example, aboriginal communities living in forested areas or close to forested areas view their surrounding landscape as a cultural entity (Berkes and Davidson-Hunt 2006, Ramakrishnan 2007). Forests are sacred for them and considered an integral part of their collective identity and culture (Young 1999). Many native trees have long held special significance to society – partly valued as economic resources, but also as sources of inspiration, symbols of place and metaphors for life (Trigger and Mulcock 2005, Turner et al. 2009). The banyan tree (*Ficus benghalensis* L.) in Nepal, the baobab (*Adansonia* spp.) in Madagascar and the monkey puzzle tree (*Araucaria araucana* (Molina) K. Koch) in Chile are examples of such culturally important tree species (Dudley et al. 2005).

Garibaldi and Turner (2004) were among the first to coin the term "cultural keystone species" while referring to the importance of western red-cedar (*Thuja plicata* Donn ex D. Don) to Northwest Coast cultures. Species that have fundamental roles in diet, production of material goods, medicine, and/or spiritual practices and beliefs can be designated as cultural keystone species (Garibaldi and Turner 2004). According to Platten and Henfrey (2009), cultural keystone species are essential to maintaining the complexity of social–ecological systems. The cultural keystone species concept provides a framework for assessing the impacts of environmental change on a particular group of people and their life ways (Garibaldi and Turner 2004). As such, it is a useful tool for ecological conservation and restoration.

Forest managers understand the economic and environmental importance of trees but they seldom grasp their cultural and symbolic significance and the traditions that surround them (Schroeder 1992, McDonough 2003). However, in recent years, evolving forest management policies have moved to incorporate social and aboriginal values (UN 2007; Trosper and Parrotta 2012). There is indeed a pervasive public support for new approaches of sustainable forest management that significantly involve public input and meaningfully manage forests for multiple values (Robinson and Hawley 1997). In this context, managing forests only for timber is no longer acceptable, especially in landscapes occupied and used by aboriginal peoples. This raises the crucial issue of how the interests and knowledge of all people can be incorporated into forest management (Cheveau et al. 2008, Trosper and Parrotta 2012).

Although aboriginal worldviews generally give equal importance to all species (Turner 2005), particular species can be more prominent in certain circumstances. For example, the Kitcisakik Algonquin community of western Quebec is concerned by the reduced abundance of eastern white pine (*Pinus strobus* L.) on its ancestral territory. White pine has indeed been overharvested over the last few centuries in northeastern North America and its abundance has severely decreased (Liu 1990; Delwaide and Filion 1999; Thompson et al. 2006; Barrette and Bélanger 2007), including in the Abitibi-Temiscamingue region (Asselin 1995), where the ancestral territory of the Kitcisakik Algonquin people is located. Extensive logging to meet timber demand eliminated white pine seed sources and allowed early successional hardwood species to replace white pine forests (Weyenberg et al. 2004). The Kitcisakik Algonquin are calling for restoration and sustainable management of white pine on their ancestral territory. However, white pine management is challenging because of specific site requirements, slow initial growth rate, susceptibility to damage from white pine blister rust (*Cronartium ribicola* J. C. Fisch.) and white pine weevil (*Pissodes strobi* Peck.), and heavy browsing (White et al. 2002, Major et al. 2009).

Before culturally adapted white pine restoration and management scenarios can be elaborated for the Kitcisakik territory, it is crucial to document why and how the species is important to the community. Furthermore, aboriginal people possess considerable traditional ecological knowledge (TEK) that can inform scientific approaches to adaptive management (Berkes 2008). Hence, this study sought to document the cultural, spiritual and ecological importance of white pine to the Kitcisakik Algonquin community, as well as TEK related to this species.

2.3 Methods

2.3.1 Study area

The study area is the ca. 5000 km^2 territory occupied by the ca. 430 members of the Kitcisakik Algonquin community. Aboriginal peoples of Canada include First Nation, Metis, and Inuit communities. The Kitcisakik community is part of the Algonquin First Nation. Its territory is located primarily within the boundaries of the Réserve Faunique La Vérendrye in western Quebec, less than 300 km north of Ottawa (Ontario) the Canadian capital (Figure 2.1). Average annual temperature in the study area is 1.2-3.3°C, and average precipitation is 914-1014 mm/year, with 22-33% falling as snow (Val-d'Or and Mont-Laurier weather stations, Environment Canada: http://www.climate.weatheroffice.gc.ca/climate_normals). The study area is located in the balsam fir (*Abies balsamea* (L.) Miller) – yellow birch (*Betula alleghaniensis* Britton.) bioclimatic domain (Saucier et al. 1998). Mixed forest types are dominant, with balsam fir and yellow birch sometimes accompanied by sugar maple (*Acer saccharum* Marsh.), red maple (*Acer rubrum* L.), trembling aspen (*Populus* *tremuloides* Michx.), paper birch (*Betula papyrifera* Marsh.), black spruce (*Picea mariana* (Mill.) BSP.), white spruce (*Picea glauca* (Moench) Voss), red pine (*Pinus resinosa* Aiton), jack pine (*Pinus banksiana* Lamb.), and white pine. Pure white pine stands are rare.

Until the 20th century, the Kitcisakik Algonquins (Algonquins refer to themselves in their own language as *Anicinapek*, in plural, and *Anicinape*, in singular, which means "true people") maintained a semi-nomadic lifestyle based on hunting, trapping, fishing and gathering that was strongly dependent on the forest (Saint-Arnaud et al. 2009). In the early 1900s, the arrival in the area of non-aboriginal settlers had

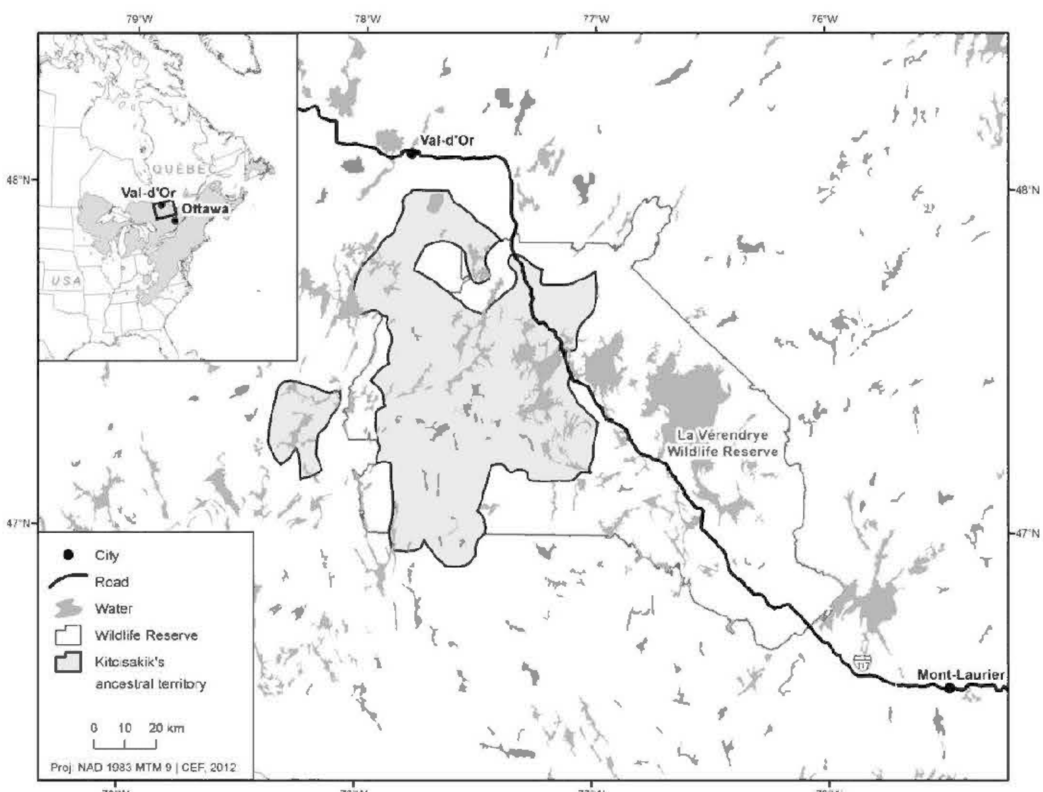

Figure 2.1 Location of Kitcisakik's ancestral territory in western Quebec. The inset shows the distribution of white pine in eastern North America (after Wendel and Smith 1990).

important consequences on land use and occupation, as well as on the social organization of the community (Leroux et al. 2004). Nevertheless, people from Kitcisakik still rely massively on subsistence activities, as the welfare rate reaches 80% in the community (Papatie 2004). Members of the Kitcisakik community now live on what is considered "crown land" (under governmental jurisdiction) and they are still struggling for legal recognition of their ancestral territory by the Canadian government. In the meantime, most of the territory has been allocated to forestry companies and more than 60% of productive forests have been clearcut over the last 40 years (Saint-Arnaud et al. 2009). Prior to that, selective logging for large-diameter hardwoods and pines (white and red), was practiced for several decades (Asselin 1995).

The intensification of industrial forestry activities on the territory has engendered feelings of unlawful misappropriation of the land and has led to frustration, tensions, and conflict (Saint-Arnaud et al. 2009). Since the late 1990s, the community has a Forest Committee (now called the *Aki* [Land] Department) that has been mandated by the community to protect its interests in the forest management planning process, to assess the state of the forest, to identify sites of cultural interest and high conservation value forests, and to develop research priorities (Papatie 2004). Following decisions from the Supreme Court of Canada, government officials and forestry companies have the obligation to consult and accommodate aboriginal people during forest management planning (Gouvernement du Québec 2008, Tikina et al. 2010, Government of Canada 2011). The *Aki* Department thus participates in consultation, but as it often occurs late in the planning process, the role of the community in decision-making remains marginal.

2.3.2 Data collection and analysis

The study stemmed from a request from the Kitcisakik *Aki* Department, thus ensuring its legitimacy and facilitating active participation from community members (Asselin and Basile 2012). The research protocol was approved by the Research Ethics Board of Université du Québec en Abitibi-Témiscamingue (UQAT). Qualitative data were collected through key informant interviews. Key informants were selected based on peer selection by applying chain referral, also called snowball sampling, in which participants suggest other local holders of knowledge (Gamborg et al. 2012). A community facilitator appointed by the *Aki* Department helped identify and contact participants. The subject and the objectives of the study were explained to the participants in order to obtain clear and informed consent.

An interview guide was prepared to facilitate semi-directive interviews. The guide included 21 questions and was validated by the *Aki* Department. It was subdivided into two parts: (1) cultural and spiritual importance of white pine, (2) traditional ecological knowledge related to white pine. Not all questions were always asked or answered, depending on the turn of the conversation and on the knowledge of the respondents. Photographs were used to make sure that respondents clearly identified white pine (and could differentiate it from red pine or jack pine). Photographs were also used to show damages due to blister rust and weevil. Native names of trees and animals were often used to facilitate communication, as most respondents were more comfortable with Algonquin than French or English names. Interviews were conducted in French, with the help of a local Algonquin-French translator for the three oldest participants.

We interviewed 15 community members (5 women and 10 men) during May-June 2012, representing 29% of the ≥45 years old population (according to the latest data available from the Canadian Department of Aboriginal Affairs and Northern

Development). Informants from older age groups ($\geq$ 45 years) were selected since they were expected to have observed long-term history of white pine on their territory (Souto and Ticktin 2012). Four respondents were aged 45-49 yrs (all men), three were 50-54 yrs (all men), four were 55-59 yrs (all women) and four were more than 65 years old (including one woman). These individuals included a healer, hunters, a former timber logger, and members of past and present Band Councils. Interviews lasted approximately 30 minutes. They were scheduled at the convenience of the participants and took place in a location chosen by them. Interviews were audio-recorded to facilitate transcription and content analysis, whenever the consent was granted by the respondents.

Content analysis was used to extract the main themes from the interview transcripts (May 2002). The framework developed by Garibaldi and Turner (2004) was used to determine if white pine is a cultural keystone species for the Kitcisakik Algonquin community. This framework consists of six different elements that must be considered when identifying a cultural keystone species (Table 2.1). This study was conducted in parallel with another study that assessed ecology and reproductive biology of white pine on the Kitcisakik Algonquin territory (Uprety et al. submitted). Data from this study and from a review of the relevant literature on white pine ecology were compared to TEK documented in the present study. The results and interpretations presented in this paper were discussed with the Kitcisakik *Aki* Department. The community facilitator who was present in all interviews ensured that everyone was properly cited.

2.4 Results

Content analysis of the interviews revealed key features of cultural importance and traditional ecological knowledge relating to white pine (Table 2.2). The following sections elaborate on these perceptions.

2.4.1 Perception of white pine

Since only knowledgeable persons were interviewed, all respondents were familiar with white pine, referred to locally as *Cigwâtik*. There was no specific pattern of

Table 2.1 White pine rating for the six elements used to identify cultural keystone species (Garibaldi and Turner 2004): 5 = "yes, very high"; 4 = "yes, high"; 3 = "yes, moderate"; 2 = "yes, low"; 1 = "yes, although low or infrequent"; and 0 = "no, not used." The higher the sum total for all questions, the more likely that the species is a cultural keystone species. The highest possible rating is 35. Ratings for each question are based on the information gathered from the interviews.

	Elements that indicate a cultural keystone species	**Rating**
1	Intensity, type and multiplicity of use • Is the species used intensively (routinely, and/or in large quantities)? • Does the species have multiple uses?	5 5
2	Naming and terminology in the language, including use as seasonal or phenological indicators, names of months or seasons, place names • Does the language incorporate names and specialized vocabulary relating to the species?	2
3	Role in narratives, ceremonies, or symbolism • Is it prominently featured in narratives and/or ceremonies, dances, songs, or as a major crest, totem, or symbol?	5
4	Persistence and memory of use in relationship to cultural change • Is the species ubiquitous in the collective cultural consciousness and frequently discussed?	5
5	Level of unique position in culture • Would it be hard to replace this species with another available native species?	5
6	Extent to which it provides opportunities for resource acquisition from beyond the territory • Is this species used as a trade item for other groups?	1
TOTAL		28

knowledge distribution between male and female respondents. White pine was perceived as a majestic tree and was considered as the "king" or "chief" (*Okima*) of the forest because of the giant trunk size and height (relative to the other common tree species in the area). Interestingly, respondents were generally referring to mature or old white pine during the interviews, sometimes associating white pine with old growth forest. Several respondents said that magnificent landscapes of old growth forest with white pine made them feel relaxed and at peace. Furthermore, they said that wind produces a pleasant, appeasing sound when blowing through pine trees. Tall white pine trees were also said to be important for providing shade.

Table 2.2 Key features of cultural importance and traditional ecological knowledge relating to white pine in the Kitcisakik Algonquin community.

	Key feature	**Percentage of respondents**
1	Important as a habitat or food source for many species of wildlife, including eagle and moose, which are important cultural species	100
2	Many intangible services are obtained from white pine, e.g. it provides shade, acts as a landmark, protects from lightning strikes, and acts as a water filter	100
3	Logging is a major factor responsible for the decline of white pine on the ancestral territory	100
4	Mixed plantations could be a good option for white pine restoration and management	80
5	White pine is an important timber species	80
6	White pine is an important traditional medicine	75
7	The cultural and spiritual roles of white pine cannot be replaced by another species of native origin	62
8	Fire used to play an important role in the life cycle of white pine	40
9	Damage due to white pine blister rust and white pine weevil is sometimes seen in open areas but is not perceived as a serious problem on the territory	27

The use of tall white pine trees for orientation was reported by several respondents. White pine trees towering above the canopy are used as landmarks and can even be used for orientation “at night, under the moonlight”. The orientation of the branches is also used as an indicator of wind direction (and thus cardinal points), as branches are often longer on the side opposite to dominant (western) winds. The clear understory of white pine forests was also said to be important, as it facilitates movements (especially during portage) and allows hunters to see animals from afar.

2.4.1.1 Cultural and spiritual importance

When asked about cultural and spiritual significance of white pine trees and forests, all respondents said that their culture and beliefs were connected to this species. Some respondents said that white pine was part of traditional stories and myths, thus highlighting its cultural and spiritual salience. White pine was considered a sacred tree and was believed to give protection to the people. An elder said "I talk to him so that he protects me because it is the largest and tallest tree in our forests". When asked if it would be possible to replace the role of this species in their culture by another native tree species available on the territory, most of the respondents that answered this question said it would not be possible.

All respondents said that bald eagles (*Haliaeetus leucocephalus* L.) nest on tops of tall white pine trees. Eagles are sacred in the Algonquin culture, help people get through grief. One woman said "they fly away with our problems". An elder said "The eagle protects us. When things go well, the eagles are there".

2.4.1.2 Medicinal value

Most of the respondents were knowledgeable about the medicinal properties of white pine. Even though they were reluctant to disclose the detailed medicinal recipes, respondents identified various ailments that were treated using white pine cones, roots, twigs with needles, and bark: heart diseases, high blood pressure, tooth problems, muscle pain, wounds and swellings. Some respondents also said that white pine can be used as a tonic, to strengthen the system.

Two respondents mentioned that white pine was used to prepare remedies after it was struck by lightning. A healer said "when lightning falls on a white pine, it makes a powder that is used to treat decayed teeth". The "yellow roots" collected from mature white pines were used to treat heart diseases. Twigs and needles of young white pine trees were boiled and given to the people with high blood pressure. Bark was also used to treat high blood pressure. Cambium was applied on wounds and swellings. Half of the respondents said that other medicinal plant species were associated with old growth white pine forests, without specifying species names.

2.4.2 Food and habitat for wildlife

Respondents were asked to list the wildlife species that they had observed eating white pine seeds, branches or bark. This question had two objectives: determine white pine dependent wildlife, and species potentially threatening to white pine by predating seeds or feeding on branches or bark. According to the respondents, squirrels (*Tamiasciurus hudsonicus* Erxl.) eat the seeds, whereas porcupines (*Erethizon dorsata* L.) eat the bark.

As previously mentioned, eagles preferred big white pine trees for nesting. Some duck species also nested in woodpecker holes on large white pine trees. The base of supercanopy white pine trees also provided denning sites for black bears (*Ursus americanus* Pal.). Moose (*Alces alces* Clin.) used white pine trees as shelter in winter and during the rut, in addition to occasionally feeding on young stems. White pine forests are a major habitat for furbearers such as marten (*Martes americana* Tur.), fisher (*Martes pennanti* Erxl.), and wolverine (*Gulo gulo* L.). According to the respondents, these species are less abundant than before because there is less white pine left. One of the respondents said that "if you set a trap beneath a white pine, it will attract animals into the trap".

2.4.3 Other services provided by white pine

Children made art craft with needles, cones and cone scales. White pine was considered as a good timber species by most of the respondents, although it was not better than other softwood species (*Pinus*, *Picea*, *Abies*, *Thuja*, *Larix*). However, some respondents mentioned that white pine attracts lightning and that they would not use it as a construction material. White pine wood was also used to make furniture. One respondent said that large white pine trees were used to construct dugout canoes in the past. Old white pines were also used as fuelwood but some respondents mentioned that it produces black smoke. According to one respondent, white pine cones were used to dye fishing nets and remove human scent. White pine was said to act as a water filter, providing potable water.

2.4.4 Threats to white pine

All of the respondents said that logging was the main reason for white pine decline on the territory. There was a consensus among the respondents that white pine was less abundant today than in their childhood because of clearcut logging, although the decline had already started back then because of selective logging. They were concerned that forestry companies might log the remaining white pines in the near future. According to the respondents, forests were “more alive” when there were more large white pines. Although some of the respondents mentioned that squirrel was a major predator of white pine seeds they did not mention it as a threat. Two of the respondents also indicated that recent windfalls (ca. 1992 and 2006) killed several white pines. Lightning strikes were also said to occasionally kill some big white pine trees, although forest fires are now very rare on the territory.

When we showed pictures of damage from blister rust and weevil, none of the respondents cited these as potential reasons for white pine decline on the territory. Nevertheless, a few respondents were familiar with these problems and they indicated that they were mostly prevalent along roadsides and in pure plantations. Some respondents also noticed that diseases appeared on residual white pine trees after logging when machinery passed too close.

2.4.5 Management and restoration

When asked if fire plays a role in white pine's life cycle, some of the respondents indicated that fire used to play an important role in white pine ecology but could not elaborate. They nevertheless said that surface forest fires are very rare on the territory since almost a century and do not anymore provide suitable seedbeds for natural white pine regeneration.

According to the respondents, there were very little, if any white pine restoration efforts on the territory. They were highly dissatisfied with the fact that forestry companies were more interested in logging than in restoration. They deplored that companies cut white pine and plant jack pine.

When asked about the appropriate measures for white pine restoration, all of the respondents said that mixed plantations would be necessary. However, opinions varied about the other species that should be planted along with white pine. The most cited species were white spruce (4 times), balsam fir (3 times) and birch (2 times). Three respondents suggested that plantation along with balsam fir might not be a good option, as there is a legend saying that white pine and balsam fir are enemies. Some of the respondents noticed that white pine was in competition with hardwoods, mostly with trembling aspen and paper birch. One of the respondents suggested pure white pine plantations, not very dense, and control of hardwood species.

Two of the women respondents were worried about the medicinal efficacy of planted white pine. They said they never tried to use planted white pines for medicinal purposes. A healer said "I dig into the earth at the foot of mature white pines and pick up the yellow roots to treat heart diseases. Would there still be yellow roots if trees are planted rather than naturally grown? I don't know". Another respondent said that "cedars [*Thuja occidentalis* L.] planted in cities do not work as medicinal plants".

Respondents were not familiar with the optimal growth conditions for white pine. They said that it would be wise to plant white pine where it used to grow. They mentioned that restoration should take place all over the territory (in every family hunting ground where it used to be present), and at higher densities near settlements.

2.5 Discussion

The social and ecological significance of forests and trees is relatively less studied for aboriginal peoples of Canada than for other cultural groups, e.g., Indigenous people of the Amazon (Berkes and Davidson-Hunt 2006). We have documented the cultural and spiritual importance and the traditional ecological knowledge of white pine in the Kitcisakik Algonquin community. Some of the respondents were reluctant to share information about medicinal uses of white pine. This reluctance could possibly be explained by the respondents wanting to keep cultural and spiritual aspects confidential or having concerns about the respect of intellectual property rights (Karjala et al. 2002), especially as legal protection is insufficient in Canada (Uprety et al. 2012a). There is evidence that traditional knowledge has been used by scientists in the past with no consideration for, or validation from, aboriginal people (Berkes 2008). Nevertheless, respondents were generally open to discuss other topics and there was very strong coherence between interviews. This, combined to the fact that several and various topics were covered, provides sufficient material to use the keystone species framework (Garibaldi and Turner 2004).

2.5.1 White pine as a cultural keystone species

White pine is culturally, spiritually and ecologically very important to the Kitcisakik Algonquin people. They expressed strong feelings of attachment and spiritual connection to white pine trees and forests. The oldest white pine trees can live up to 450 years and grow as tall as 70 m (Anonymous 1993). The tops of the largest trees float in the air, far above their smaller neighbors (Schroeder 1992). This characteristic makes white pine a unique species of northeastern North American forest landscapes and justifies why it is used as a landmark by people from Kitcisakik. People from the Scandinavian boreal forest also use tall trees as landmarks (Östlund et al. 2002). The reason why respondents were mostly referring to mature or old white pine might be because supercanopy trees are more conspicuous. This also suggests that scattered white pines were remnants of former more extensive pine stands (Stearns 1992). Furthermore, forest inventory data from the Quebec Ministry of Natural Resources show that younger age classes (regeneration, 30 years, and 50 years) are underrepresented in the study area.

White pine provides many ecosystem services to the people of Kitcisakik. It is also important for wildlife, providing food and shelter, notably to flagship species such as bald eagle and moose. Some of the medicinal uses of white pine documented in our study are unique and different, and some are comparable to the uses by other aboriginal groups of the Canadian boreal forest (Uprety et al. 2012a). While the use of white pine bark (cambium) to treat wounds and swellings was already documented, the uses of white pine against heart diseases, tooth problems and to strengthen the system are new from the present study. Other reported uses of white pine by North American aboriginal people include use of pitch on boils by the Delawares and use of a needle infusion on cuts, bruises, sores, and scabs by the Iroquois (Arnason et al. 1981).

For the Kitcisakik Algonquin, white pine is the “king” of trees, offering protection. People often go in white pine forests for resourcing. White pine also possesses important symbolic and spiritual value to other aboriginal cultures, e.g., the Menominee (Wood and Dewhurst 1998) and Iroquois (Schroeder 1992) people of northeastern USA. In other cultures, other tree species are regarded as living beings equivalent in status to humans (Turner et al. 2009). Cedar (*Thuja*) is known as the “tree of life” by the northwest coastal peoples of British Columbia (Stryd and Feddema 1998). In other areas, birch (*Betula*) is the “tree of health, wisdom, and safety”, cedars are the “trees of paradise”, and ash (*Fraxinus*) is the “tree of rebirth” and is planted as protection against evil creatures (Coder 1996).

The more widely or intensively a plant is used, the greater its cultural significance (Turner 1988). However, cultural significance varies in quality, intensity, and exclusivity, and this must be considered in any effort to evaluate or measure the importance of a plant (Turner 1988). Although criticisms have been raised about the framework developed by Garibaldi and Turner (2004) (see Platten and Henfrey 2009), it provides a good way of assessing both the tangible and intangible values of a species (Kanowski and Williams 2009). Platten and Henfrey (2009) emphasized that a cultural keystone should be understood as a “complex” involving several material and non-material system elements, rather than a “single biological species”. Following Bohensky and Maru (2011), we used the framework developed by Garibaldi and Turner (2004) as a tool to provide social context to link indigenous and scientific knowledge for management and restoration. Therefore, using this framework, white pine can be designated as a cultural keystone species for the Kitcisakik Algonquin community (Table 2.1). It has high spiritual and medicinal value and is featured in many narratives. The high cultural significance of the species is also reflected by the fact that, according to most of the respondents, this species cannot be replaced by another native tree species available on the territory. This could explain why the community is calling for restoration of the species on its territory.

Even if information was lacking about the existence of specialized vocabulary relating to white pine or opportunities to trade white pine products with other indigenous groups (criteria 2 and 6 of Garibaldi and Turner (2004); Table 2.1), the total ranking for white pine (28/35) was comparable to that of species identified as cultural keystone in Garibaldi and Turner (2004).

2.5.2 Comparing traditional knowledge and ecological studies

All of the ecological information gathered from the interviews corresponds to scientific findings (Table 2.3), illustrating that traditional knowledge and science could be used in complementarity (Moller et al. 2004, Rist et al. 2010, Uprety et al. 2012b). The role of fire in white pine ecology was recognized by the respondents. However, this knowledge was uncertain as there have been no large forest fires on the territory since the 1920s (Lesieur et al. 2004, Grenier et al. 2005) and respondents have thus never witnessed the impact of fire on white pine. Relatively frequent, low intensity surface fires coupled with infrequent, high intensity stand replacing fires favor the establishment of white pine (Frelich 1992). Increased fire activity gives a competitive advantage to white pine over other fire susceptible species (Bergeron et al. 1997). Such fire regimes maintain and regenerate white pine by preparing seedbeds and eliminating competition. Logging has now replaced fire as the major agent of disturbance on Kitcisakik's territory (Lesieur et al. 2004).

The tops of tall white pine trees was referred to as a preferred nesting habitat for eagles, and the base of those supercanopy trees was used as denning sites for bears. Studies have shown that white pine is indeed a preferred tree for eagles and bears (Rogers and Lindquist 1992, MNR 2008). The irregular crowns of supercanopy white pines enable birds with large wingspans to land and nest (Rogers and Lindquist 1992). Particular assemblages of bird species were also found to be associated with supercanopy pine trees (Kirk et al. 2012). In Ontario, white pine snags were preferred by woodpeckers for feeding and nesting, and the larger, more decayed snags were preferred (Quinby 1989). These woodpecker holes are also used by secondary users such as wood duck (DeGraaf and Shigo 1985). About 80% of the forest-dwelling wildlife found in central Ontario used forest associations containing red pine or white pine (Naylor 1994).

2.5.3 Importance of cultural values and traditional ecological knowledge recognition

In recent years a step has been taken to include social and cultural values in forest management (IUFRO 2007). Equally important is to incorporate traditional forest-related knowledge that can assist in interpreting and responding to feedbacks from the environment and guide resource management (Berkes et al. 2000, Turner et al. 2000, Trosper and Parrotta 2012). Recognizing these two important aspects can better promote cultural diversity, meet peoples' aspirations and encourage their participation in forest management.

Turner et al. (2008) explored a range of "invisible losses" in aboriginal contexts, that are not widely recognized or accounted for in decisions about resource planning and decision making: cultural/lifestyle losses, loss of identity, health losses, loss of self-determination and influence, emotional and psychological losses, loss of order in the world, knowledge losses, and indirect economic losses and lost opportunities. White pine is an inseparable cultural entity of the Kitcisakik aboriginal people and most of these "invisible losses" are likely to happen in the near future if the white pine decline continues.

Table 2.3 Correspondence of traditional ecological knowledge with scientific studies concerning white pine.

Characteristic	Traditional ecological knowledge	Scientific ecological knowledge
Damage due to blister rust or weevil	Sometimes seen on the territory, but mostly in open areas such as plantations or roadsides. Not perceived as a major threat on the territory.	Prevalent on the territory, mostly in open areas such as plantations and along roadsides (Uprety et al. submitted).
Role of fire	Fire used to play an important role in white pine ecology.	Fire is an important agent for white pine distribution, ecology and reproductive biology (Frelich 1992).
Potential areas for restoration	Restoration plantations should be established in areas where white pine used to be present.	Restoration efforts should focus on sites where the target species was present (Uprety et al. 2012b).
Best restoration strategy	Mixed plantations (with various companion species).	Mixed plantations with Norway spruce (Coulombe et al. 2004).
Understory vegetation	Absence of understory vegetation (makes it easier to walk when chasing game).	Understory plants are usually sparse in white pine forests (Wendel and Smith 1990).
Aesthetic value	White pine trees are landmarks, they are part of magnificent landscapes, and white pine stands are good places for resourcing.	Many tourists and outdoor enthusiasts prefer forests containing white pine, particularly those with large, old trees (MNR 2008).
Nesting habitat for eagles	Eagles prefer tall white pine trees for nesting.	Some older supercanopy trees are favoured by bald eagles for nesting (Rogers and Lindquist 1992).
Importance for other wildlife species	Porcupine, squirrel, moose, bear, fisher, and woodpecker are associated to white pine.	Inner bark is a favorite winter food of porcupines (Rogers and Lindquist 1992). Squirrel, moose, and fisher are dependent on white pine for food and shelter (Quinby 1989; Naylor 1994).
Impact of logging	Extensive logging is a major factor responsible for white pine decline on the territory.	Logging is reported as one of the major factors responsible for white pine decline throughout its distribution range (Carleton et al. 1996; Weyenberg et al. 2004).

Impact of windfall	Major windfall events contributed to reduce white pine abundance on the territory.	Severe windstorms gradually reduce the pine component and advance succession towards hardwoods (Frelich 1992).
Competition from other species	Hardwood species such as trembling aspen and paper birch, and conifer species such as balsam fir outgrow white pine and increase understory shade above critical level.	Competition from fast growing species, especially in productive sites, is a major problem (Wendel and Smith 1990; Ostry et al. 2010). A significant negative effect of balsam fir basal area was found on white pine regeneration abundance (Uprety et al. submitted).
Lightning strikes	White pine receives lightning strikes and saves houses and people.	Tall trees attract lightning strikes (Ruffner and Abrams 1998).

The intrinsic ecological worth and cultural and spiritual significance (Trigger and Mulcock 2005) of white pine as perceived by the Kitcisakik Algonquin community should be respected in forest management. As Brynaert (1985) suggested, the forestry industry must recognize that exercising its rights to utilize timber resources embodies a responsibility not to degrade or infringe upon the legitimate interests of other resource users. Considerable effort will be required to reach a high level of participation of local communities and efficient incorporation of TEK (Cheveau et al. 2008, Saint-Arnaud et al. 2009). This study, by documenting the cultural importance of white pine to the Kitcisakik Algonquin people, will hopefully help design culturally adapted restoration and management strategies.

2.6 Acknowledgments

We are grateful to the members of the Kitcisakik community for their participation in the study and for sharing their valuable knowledge. We thank Monique Pâquet, Charlie Papatie and Martine Carrier for help conducting the interviews. Thanks to Mélanie Desrochers (Centre for Forest Research, Université du Québec à Montréal) for helping with Figure 2.1 design. We also thank two anonymous reviewers for their constructive comments on an earlier version of the manuscript. The study was supported by the Social Science and Humanities Research Council of Canada (SSHRC). Scholarships provided to YU by the Aboriginal Peoples Research and Knowledge Network (DIALOG), Centre for Forest Research (CEF), Centre de recherche sur la gouvernance des ressources naturelles et du territoire (CRGRNT), Chaire Desjardins en développement des petites collectivités, and and Association quebecoise de gestion de la vegetation (AQGV) were highly appreciated.

2.7 References

Anonymous. 1993. Flora of North America vol. 2. Oxford University Press, New York.

Arnason, T., Hebda, R.J., Johns, T. 1981. Use of plants for food and medicine by Native Peoples of eastern Canada. Can. J. Bot. **59**(11) : 2189-2325.

Asselin, H., and Basile, S. 2012. Éthique de la recherche avec les Peuples autochtones : Qu'en pensent les principaux intéressés? Éthique publique, **14**(1): 333-345.

Asselin, M. 1995. L'Abitibi-Témiscamingue : trois sous-régions, une région. *In* Histoire de l'Abitibi-Témiscamingue. *Edited by* O. Vincent. Institut québécois de recherche sur la culture. pp. 21-65.

Barrette, M., and Bélanger, L. 2007. Reconstitution historique du paysage préindustriel de la région écologique des hautes collines du Bas-Saint-Maurice. Can. J. For. Res. 37: 1147-1160.

Bergeron, Y., Leduc, A., and Li, T. 1997. Explaining the distribution of *Pinus* spp. in a Canadian boreal insular landscape. J. Veg. Sci. **8**: 37-44.

Berkes, F. 2008. Sacred ecology. Taylor and Francis, Philadelphia.

Berkes, F., and Davidson-Hunt, I.J. 2006. Biodiversity, traditional management systems, and cultural landscapes: Examples from the boreal forest of Canada. Inter. Soc. Sc. J. **58**(187): 35-47.

Berkes, F., Colding, J., and Folke, C. 2000. Rediscovery of traditional ecological knowledge as adaptive management. Ecol. Appl. **10**(5): 1251-1262.

Bohensky, E.L., and Maru, Y. 2011. Indigenous knowledge, science, and resilience: What have we learned from a decade of international literature on "integration"? Ecol. Soc. **16**(4): 6.

Brynaert, K.A. 1985. Recreational and cultural use of the forest. For. Chron. **61**(2): 166-167.

Carleton, T.J., Maycock, P.F., Arnup, R., and Gordon, A.M. 1996. *In situ* regeneration of *Pinus strobus* and *P. resinosa* in the Great Lakes forest communities of Canada. J. Veg. Sci. 7: 431-444.

Chappelle, D.E. 1992. Economic values of natural resources really do matter. In: Stine, R.A. and Baughman, M.J. (Eds.), Proceedings of the White Pine Symposium: History, Ecology, Policy and Management, September 16-18, 1992, Duluth, MN. Department of Forestry Resources, University of Minnesota, St. Paul. pp. 98-107.

Cheveau, M., Imbeau, L., Drapeau, P., and Bélanger, L. 2008. Current status and future directions of traditional ecological knowledge in forest management: A review. For. Chron. **84**(2): 231-243.

Coder, K.D. 1996. Cultural aspects of trees: Traditions and myths. Cooperative Extension Service, University of Georgia, Georgia.

Coulombe, C., Bélanger, G., Lavallée, R., and Laflamme, G. 2004. A simple effective tool for controlling white pine weevil and blister rust on Norway spruce and Eastern white pine. Natural Resources Canada, Quebec.

DeGraaf, R.M., and Shigo, A.L. 1985. Managing cavity trees for wildlife in the northeast. USDA Forest Service.

Delwaide, A., and Filion, L. 1999. Dendrosérie du pin blanc (*Pinus strobus* L.) et de la pruche de l'est (*Tsuga canadensis* L. [Carr.]) dans la région de Québec. Géographie physique et Quaternaire, **53**: 265-275.

Dudley, N., Higgins-Zogib, L., and Mansourian, S. 2005. Beyond belief: Linking faiths and protected areas to support biodiversity conservation. WWF International, Switzerland.

Frelich, L.E. 1992. The relationship of natural disturbances in white pine stand development. *In* Proceedings of the white pine symposium: History, ecology, policy and management. *Edited by* R.A. Stine and M.J. Baughman. Department of Forestry Resources, University of Minnesota, St. Paul. pp. 27-37.

Gamborg, C., Parsons, R., Puri, R.K., and Sandøe, P. 2012. Ethics and research methodologies for the study of traditional forest-related knowledge. *In* Traditional forest-related knowledge: Sustaining communities, ecosystems and biocultural diversity. *Edited by* J.A. Parrotta and R.L. Trosper. World Forest XII, IUFRO, The Christensen Fund and Springer. pp. 535-562.

Garibaldi, A., and Turner, N. 2004. Cultural keystone species: Implications for ecological conservation and restoration. Ecol. Soc. **9**(3): 1.

Gouvernement du Québec, 2008. Guide intérimaire en matière de consultation des communautés autochtones. Groupe interministériel de soutien sur la consultation des Autochtones.

Government of Canada, 2011. Aboriginal consultation and accommodation. Updated guidelines for federal officials to fulfill the duty to consult. Department of Aboriginal Affairs and Northern Development.

Grenier, D.J., Bergeron, Y., Kneeshaw, D., and Gauthier, S. 2005. Fire frequency for the transitional mixedwood forest of Timiskaming, Quebec, Canada. Can. J. For. Res. **35**: 656-666.

International Union of Forest Research Organizations (IUFRO). 2007. The role of culture in sustaining today's forests. IUFRO, Fact Sheet. Available from www.iufro.org [accessed 26 June 2012].

Kanowski, P.J., and Williams, K.J.H. 2009. The reality of imagination: Integrating the material and cultural values of old forests. For. Ecol. Manage. **258**: 341-346.

Karjala, M.K., Sherry, E.E., and Dewhurst, S.M. 2002. Criteria and indicators for sustainable forest planning: A framework for recording aboriginal resource and social values. For. Pol. Econ. **6**: 95-110.

Kirk, D.A., Welsh, D.A., Baker, J.A., Thompson, I.D., and Csizy, M. 2012. Avian assemblages differ between old-growth and mature white pine forests of Ontario, Canada: A role for supercanopy trees? Av. Conser. Ecol. 7(1): 4.

Leroux, J., Chamberland, R., Brazeau, E., and Dubé, C. 2004. Au pays des peaux de chagrin : Occupation et exploitation territoriale à Kitcisakik (Grand-Lac-Victoria) au XX^{e} siècle. Presses de l'Université Laval, Québec.

Lesieur, D., Lefort, P., Bergeron, Y., and Lauzon, È. 2004. Reconstitution de l'historique des perturbations naturelles et de la composition de la forêt pré-industrielle au sud de Val-d'Or. Rapport de la Chaire industrielle en aménagement forestier durable soumis à Domtar.

Liu, K.-B. 1990. Holocene paleoecology of the boreal forest and Great Lakes-St. Lawrence forests in northern Ontario. Ecol. Monogr. 60: 179-212.

Major, J. E., Mosseler, A., Barsi, D.C., Clouthier, A., and Campbell. M. 2009. Impact of three silvicultural treatments on weevil incidence, growth, phenology, and branch level dynamics of *Pinus strobus* from large and small populations. Can. J. For. Res. **39**: 12-25.

May, T. 2002. Qualitative research in action. Thousand Oaks, California.

McDonough, M.H. 2003. Understanding the meaning and value of forests and trees. *In* Understanding community-forest relations. *Edited by* L.E. Kruger, Gen. Tech. Rep. PNW-GTR-566. USDA, Forest Service, Pacific Northwest Research Station, Portland. pp. 145-162.

Ministry of Natural Resources (MNR). 2008. State of the resource reporting. Regional report: White pine in the lake Abitibi and lake Temagami ecoregions of Ontario. Ministry of Natural Resources, Ontario.

Moller, H., Berkes, F., Lyver, B.O., and Kislalioglu, M. 2004. Combining science and traditional ecological knowledge: monitoring populations for co-management. Ecol. Soc. **9**(3): 2.

Naylor, B.J. 1994. Managing wildlife habitat in red pine and white pine forests of central Ontario. For. Chron. 70(4): 411-419.

Östlund, L., Zackrisson, O., and Hornberg, G. 2002. Trees on the border between nature and culture. Environ. Hist. 7: 48-68.

Ostry, M.E., Laflamme, G., and Katovich, S.A. 2010. Silvicultural approaches for management of eastern white pine to minimize impacts of damaging agents. Forest Pathol. **40**: 332-340.

Papatie, J. 2004. Vécu et réflexion de la communauté Anicinapek de Kitcisakik avec le régime forestier des Québécois. Brief submitted to the Commission for the study of public forest management in Québec.

Platten, S. and Henfrey, T. 2009. The cultural keystone concept: Insights from ecological anthropology. Hum. Ecol. **37**: 491-500.

Quinby, P.A. 1989. Old growth forest survey in Temagami's Wakimika Triangle. Tall Pines Project Research Report No. 2. Temagami Wilderness Society, Toronto.

Ramakrishnan, P.S. 2007. Traditional forest knowledge and sustainable forestry: A north-east India perspective. For. Ecol. Manage. **249**: 91-99.

Rist, L., Shaankar, R.U., Milner-Gulland, E.J., and Ghazoul. J. 2010. The use of traditional ecological knowledge in forest management: An example from India. Ecol. Soc. **15**(1): 3.

Robinson, D.W., and Hawley, W.L. 1997. Social indicators and management implications derived from the Canadian Forest Survey '96. McGregor Model Forest Association, British Colombia.

Rogers, L.L., and Lindquist, E.L. 1992. Supercanopy white pine and wildlife. *In* Proceedings of the white pine symposium: History, ecology, policy and management. *Edited by* R.A. Stine and M.J. Baughman. Department of Forestry Resources, University of Minnesota, St. Paul. pp. 39-43.

Ruffner, C.M., and Abrams, M.D. 1998. Lightning strikes and resultant fires from archival (1912-1917) and current (1960-1997) information in Pennsylvania. J. Tor. Bot. Soc. **125**(3): 249-252.

Saint-Arnaud, M., Asselin, H., Dubé, C., Croteau, Y., and Papatie, C. 2009. Developing criteria and indicators for aboriginal forestry: mutual learning through collaborative research. *In* Changing the culture of forestry in Canada: Building effective institutions for aboriginal engagement in sustainable forest management. *Edited by* M.G. Stevenson and D.C. Natcher. Canadian Circumpolar Institute Press, Edmonton. pp. 85-105.

Saucier, J.-P., Bergeron, J.-P., Grondin, P., and Robitaille, A. 1998. Les régions écologiques du Québec méridional (troisième version). L'Aubelle, **124**: S1-S12.

Schroeder, H.W. 1992. The tree of peace: Symbolic and spiritual values of the white pine. *In* Proceedings of the white pine symposium: History, ecology, policy and management. *Edited by* R.A. Stine and M.J. Baughman. Department of Forestry Resources, University of Minnesota, St. Paul. pp. 73-83.

Souto, T., and Ticktin, T. 2012. Understanding interrelationships among predictors (age, gender, and origin) of local ecological knowledge. Eco. Bot. **66**(2): 149-164.

Stearns, F. 1992. Ecological characteristics of white pine. *In* Proceedings of the white pine symposium: History, ecology, policy and management. *Edited by* R.A. Stine and M.J. Baughman. Department of Forestry Resources, University of Minnesota, St. Paul. pp. 10-18.

Stryd, A.H., and Feddema, V. 1998. Sacred cedar: The cultural and archaeological significance of culturally modified trees. A report of the Pacific Salmon Forest Project. David Suzuki Foundation, Vancouver.

Thompson, I.D., Simard, J.H., and Titman, R.D. 2006. Historical changes in white pine (*Pinus strobus* L.) density in Algonquin Park, Ontario, during the 19th century. Nat. Area. J. 26(1): 61-71.

Tikina, A.V., Innes, J.L., Trosper, R.L., and Larson, B.C. 2010. aboriginal peoples and forest certification: a review of the Canadian situation. Ecol. Soc. **15**(3): 33.

Trigger, D., and Mulcock, J. 2005. Forests as spiritually significant places: Nature, culture and 'belonging' in Australia. Aust. J. Anthropol. **16**(3): 306-320.

Trosper, R.L., and Parrotta, J.A. (eds). 2012. Traditional forest-related knowledge: Sustaining communities, ecosystems and biocultural diversity. World Forest XII, IUFRO, The Christensen Fund and Springer.

Turner, N.J. 1988. "The importance of a rose": Evaluating the cultural significance of plants in Thompson and Lillooet Interior Salish. Am. Anthropol. **90**: 272-290.

Turner, N.J. 2005. The earth's blanket: Traditional teachings for sustainable living. Douglas and McIntyre, Vancouver.

Turner, N.J., Ignace, M.B., and Ignace, R. 2000. Traditional ecological knowledge and wisdom of aboriginal people in British Columbia. Ecol. Appl. **10**(5): 1275-1287.

Turner, N.J., Gregory, R., Brooks, C., Failing, L., and Satterfield, T. 2008. From invisibility to transparency: Identifying the implications. Ecol. Soc. **13**(2):7.

Turner, N.J., Ari, Y., Berkes, F., Davidson-Hunt, I., Ertug, Z.F., and Miller, A.. 2009. Cultural management of living trees: An international perspectives. J. Ethnobiol. **29**(2): 237-270.

United Nations (UN). 2007. United Nations declaration on the rights of indigenous peoples. Available from http://www.un.org/esa/socdev/unpfii/en/declaration.html [accessed 14 July 2012].

Uprety, Y., Asselin, H., Dhakal, A., and Julien, N. 2012a. Traditional use of medicinal plants by aboriginal people of boreal Canada: Review and perspectives. J. Ethnobiol. Ethnomed. **8**: 7.

Uprety, Y., Asselin, H., Bergeron, Y., Doyon, F., and Boucher, J.-F. 2012b. Contribution of traditional knowledge to ecological restoration: Practices and applications. Ecoscience, **19**(3): 225-237.

Wendel, G.W., and Smith, H.C. 1990. *Pinus strobus* L., Eastern white pine. *In* Silvics of North America, Vol. 1, Conifers. *Edited by* R.M. Burns and B.H. Honkala. USDA, Washington, DC. pp. 467-488.

Weyenberg, S.A., Frelich, L.E., and Reich, P.B. 2004. Logging versus fire: How does disturbance type influence the abundance of *Pinus strobus* regeneration? Silva Fenn. **38**(2): 179-194.

White, M.A., Brown, T.N., and Host, G.E. 2002. Landscape analysis of risk factors for white pine blister rust in the Mixed Forest Province of Minnesota, USA. Can. J. For. Res. **32**: 1639-1650.

Wood, D.B., and Dewhurst, S.M. 1998. A decision support system for the Menominee legacy forest. Journal of Forestry **95**: 28-32.

Young, E. 1999. Reconciliation or exclusion? Integrating indigenous and non-indigenous land management concepts for Australia's Native Title era. Asia Pac. Viewpoint **40**(2): 159-171.

CHAPTER III

White pine (*Pinus strobus* L.) regeneration dynamics at the species' northern limit of continuous distribution

Yadav Uprety, Hugo Asselin, Yves Bergeron and Marc J. Mazerolle

Manuscript submitted to
New Forests

3.1 Abstract

The abundance of eastern white pine (*Pinus strobus* L.) has been significantly reduced across its distribution range over the past few centuries. While the species' regeneration dynamics is well documented in the centre of its range, data are missing at the northern limit of continuous distribution. To fill this gap, we quantified natural white pine regeneration in mature stands, identified the most important variables influencing it, and evaluated the impact of damaging agents, namely white pine blister rust (*Cronartium ribicola* J.C. Fisch.), white pine weevil (*Pissodes strobi* Peck) and herbivory. We also quantified the influence of remnant stands and refuge trees on the spatial distribution of regeneration in logged sites. The results reveal continuous but low recruitment. The basal area of balsam fir (*Abies balsamea* (L.) Miller) had a strong negative effect on white pine regeneration. Regeneration was more abundant than expected on moister substrates, including moss, decaying wood and organic matter. The occurrence of blister rust and weevil was much lower than expected based on the available risk maps. Distance from remnant stands had a significant effect on white pine regeneration in logged areas. The northern limit of continuous distribution holds potential for white pine restoration, which would likely be more successful in mesic to moist stands, but only under moderate shade so as to minimize the risk of blister rust occurrence.

Keywords: White pine; Regeneration; Blister rust; Weevil; Remnant stands; Moss; Balsam fir

3.1 Résumé

L'abondance du pin blanc (*Pinus strobus* L.) a diminué considérablement au cours des derniers siècles. Alors que la dynamique de la régénération de l'espèce est bien documentée dans la portion sud de son aire de répartition, les données manquent à la limite nordique de répartition continue. Afin de combler cette lacune, nous avons quantifié la régénération naturelle de pin blanc dans des peuplements matures. Les facteurs influençant l'abondance de régénération ont été identifiés, de même que les impacts de la rouille vésiculeuse (*Cronartium ribicola* J.C. Fisch.), du charançon (*Pissodes strobi* Peck) et de l'herbivorie. L'influence de peuplements résiduels et de semenciers refuges sur la répartition spatiale de la régénération a également été étudiée. Les résultats révèlent un recrutement faible mais continu de pin blanc. Le sapin baumier (*Abies balsamea* (L.) Miller) a un impact négatif important sur la régénération en pin blanc. La régénération était plus abondante sur les substrats humides, incluant la mousse, le bois en décomposition et la matière organique. L'impact de la rouille vésiculeuse et du charançon était beaucoup plus faible qu'escompté en fonction des cartes de risque. La distance a un peuplement résiduel a un impact significatif sur la régénération en pin blanc dans les aires de coupe. La limite nordique de répartition continue offre un potentiel pour la restauration du pin blanc, dont les chances de succès seront plus grandes dans les peuplements mésiques à humides, mais sous un couvert forestier modéré afin de minimiser les risques d'attaque par la rouille vésiculeuse.

Mots clés: Charançon, Mousses, Peuplements résiduels, Pin blanc; Régénération; Rouille vésiculeuse; Sapin baumier

3.2 Introduction

Eastern white pine (*Pinus strobus* L.) has historically been one of the most important species in North America for its ecological, economic, social, and cultural values (Wendel and Smith 1992; Steen-Adams et al. 2007). The species' abundance decreased across its distribution range over the last few centuries due to extensive logging and fire management practices that eliminated seed sources and seed beds (Carleton et al. 1996; Weyenberg et al. 2004). White pine restoration and management are deemed problematic because of specific site requirements, slow initial growth rate, susceptibility to damage from white pine blister rust (*Cronartium ribicola* J.C. Fisch.) and white pine weevil (*Pissodes strobi* Peck), and heavy browsing by herbivores (Katovich and Morse 1992; Burgess et al. 2005; Steen-Adams et al. 2007; Latremouille et al. 2008). Nevertheless, there is a sustained interest for white pine restoration and management (Carleton et al. 1996; Pitt et al. 2009).

The interaction between site characteristics, light availability, and interspecies competition are considered important in determining the success or failure of natural white pine regeneration (Ahlgren 1976; Hibbs 1982; Stearns 1992). Surface fires play an important role by clearing competing vegetation, opening canopy, and preparing seed beds for seedling establishment (Heinselman 1981; Bergeron et al. 1997). White pine blister rust and white pine weevil seldom kill seedlings or saplings. However, they can affect growth, thus reducing wood quality and postponing the onset of seed production (Belyea and Sullivan 1956; Wendel and Smith 1992; White et al. 2002; Major et al. 2009).

Site characteristics and the prevalence of natural disturbances can vary significantly throughout the species' range (Abrams 2001). The knowledge regarding white pine, both scientific and practical, largely relates to the central part of the species' range (e.g., Ahlgren 1976; Dovčiak et al. 2001, 2003; Burgess et al. 2005), with some studies also conducted at the northern distribution limit (e.g., Holla and Knowles 1988; Bergeron et al. 1997; Engelmark et al. 2000). There is considerable potential for white pine restoration and management in between these two areas, near the limit of continuous distribution, but a better understanding of the species' regeneration dynamics is needed, especially with regards to potential damage by blister rust and weevil. The present study aims to (1) quantify white pine regeneration at the species' northern limit of continuous distribution; (2) evaluate the impact of blister rust, weevil, and herbivory; and (3) determine which habitat characteristics are most important to explain white pine regeneration patterns. We tested the following hypotheses: (1) canopy cover (inversely related to light availability) is the most important variable explaining white pine regeneration; (2) competition from other species reduces white pine establishment potential; (3) remnant white pine stands or trees in logged areas influence the spatial pattern of white pine regeneration; (4) damaging agents such as blister rust and weevil affect white pine regeneration; and (5) suitable germination sites are available to ensure long-term white pine presence. We wanted to determine if these hypotheses, based on previous studies conducted in the central part of the species' range, were also valid at the northern limit of continuous distribution, where climate is cooler and site characteristics are different.

3.3 Methods

3.3.1 Study area

The study area is located in the La Vérendrye Wildlife Reserve in western Quebec (Figure 3.1), and is part of the ancestral territory of the Kitcisakik Algonquin community. Average annual temperature is 1.2-3.3°C, and average precipitation is 914-1014 mm/year, with 22-33% falling as snow (Val-d'Or and Mont-Laurier weather stations, Environment Canada:

http://www.climate.weatheroffice.gc.ca/climate_normals). The altitude ranges from 316-415 m with an average of 368 m. Surface covers are mostly glacial and fluvioglacial deposits.

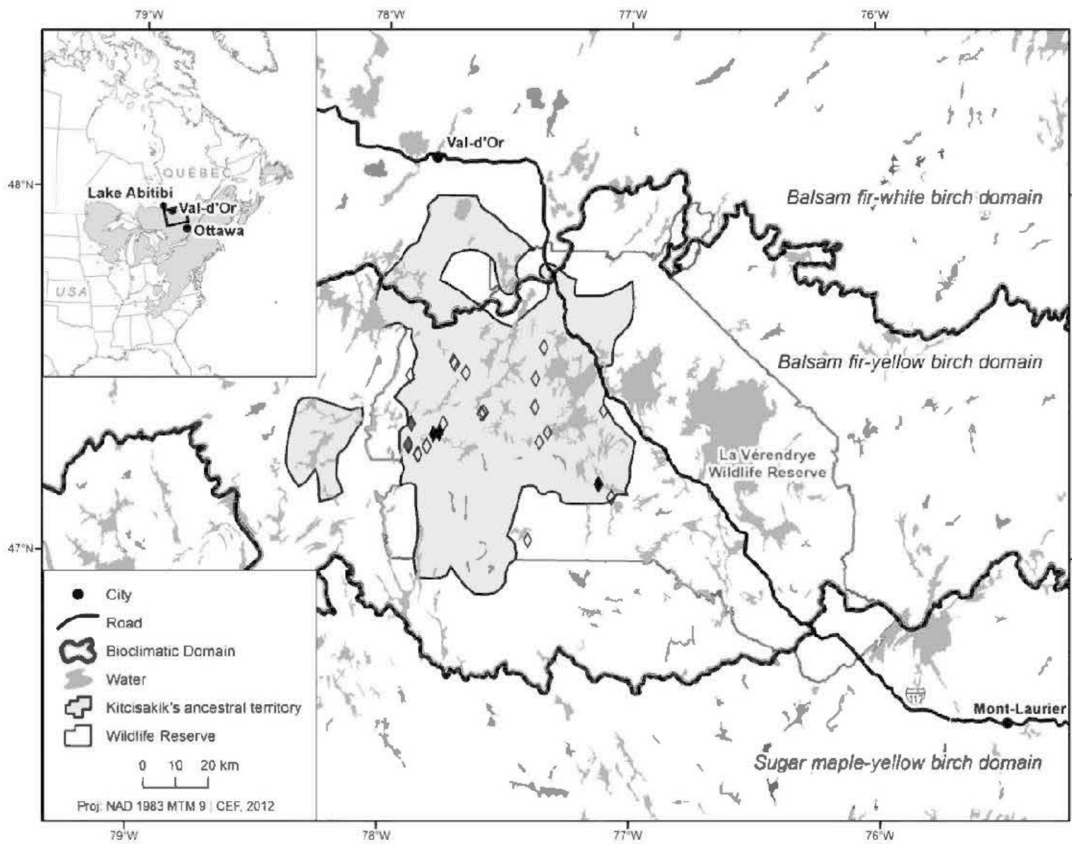

Figure 3.1 Location of the study area (Kitcisakik's ancestral territory) in the balsam fir – yellow birch bioclimatic domain in western Quebec. The 22 sampled stands are indicated by diamonds. Black diamonds are stands where transects extending into logged areas were sampled, and grey diamonds are sites where roadside transects were sampled (two transects at the northernmost stand). The shaded area in the inset shows the continuous distribution of eastern white pine (*Pinus strobus* L.) in northeastern North America (after Wendel and Smith 1990).

The study area corresponds to the northern limit of continuous white pine distribution. The species' northern limit is reached ca. 150 km to the north-west, in the Lake Duparquet and Lake Abitibi regions where scattered stands and trees are present (Bergeron et al. 1997; Engelmark et al. 2000). The study area is located in the balsam fir (*Abies balsamea* (L.) Miller) – yellow birch (*Betula alleghaniensis* Britton.) bioclimatic domain (Saucier et al., 1998). Mixed forests are dominant in the region, with balsam fir and black spruce (*Picea mariana* (Mill.) BSP.) accompanied by white spruce (*Picea glauca* (Moench) Voss), white pine, eastern white cedar (*Thuja occidentalis* L.), yellow birch, paper birch (*Betula papyrifera* Marsh.), sugar maple (*Acer saccharum* L.), red maple (*Acer rubrum* L.), and trembling aspen (*Populus tremuloides* Michx.). Red pine (*Pinus resinosa* Ait.) and jack pine (*Pinus banksiana* Lamb.) are present on xeric sites. Since the 1970s, more than 60% of the productive forest land within the study area has been harvested by timber companies (Saint-Arnaud et al. 2009). Logging replaced fire as the main disturbance in the study area. Fire cycles of the pre-industrial and industrial periods were estimated at 257 and 2083 years, respectively (Bergeron et al. 2006).

3.3.2 Site selection and data collection

Stands that were dominated or co-dominated by white pine were located on ecoforestry maps of the Québec Ministry of Natural Resources. From those, 22 stands were accessible (i.e., less than 30 min walk from a forest road) and were selected for sampling. At each stand, we established a 20 m × 20 m quadrat ensuring that at least three white pine seed trees were included. The precise location of the quadrats was determined randomly. Good seed production can be expected when white pine trees are at least 20 to 30 years old (Ahlgren 1976; Wendel and Smith 1992), corresponding to a diameter at breast height (DBH) of 10-15 cm (Holla and Knowles 1988). We used this criterion to identify white pine seed trees. Old cut stumps were present at one site, but the other 21 sites showed no indication of logging.

Within each quadrat, every tree having a DBH $\geq$ 10 cm was measured and identified to species level. Basal area was calculated for each species. For white pine, we recorded any indication of disease, namely the presence or absence of blister rust, weevil, *Ribes* spp. (an alternative host of blister rust (Zambino 2010)), herbivory, and seed predation by red squirrel (*Tamiasciurus hudsonicus* Erxl.). We also measured slope, aspect, and elevation at each plot. The type of surface deposit was obtained from ecoforestry maps.

3.3.2.1 Detailed regeneration study

To study regeneration, five 4 m × 4 m subplots were positioned in a 4 m × 20 m strip at the centre of each 400 m^2 quadrat following a north-south axis. White pine seedlings (stems < 1.37 m tall) were counted and assigned to one of three height classes (0-50 cm, 51-100 cm and 101- 137 cm), and substrate type was recorded. Seedlings were likely < 10 years old, and thus substrate type probably still reflected that on which germination occurred (Weyenberg et al. 2004). Saplings were also counted and assigned to one of two DBH classes (0.1-5.0 cm and 5.1-10 cm). On all subplots, percent cover was visually estimated to the nearest 5% for substrate types, herbs, and shrubs. Ten different substrate types were identified: conifer litter; hardwood litter; mixed conifer and hardwood litter; fern litter; undecomposed dead logs; decaying wood; moss; bare rock; organic matter (decomposed litter); and mineral soil. Canopy cover was estimated in each subplot and assigned to one of three classes (0-32 %, 33-65 % and 66-100 %). Evidence of blister rust or weevil damage was also recorded, if any. The depth of the organic soil layer was measured in the four corners of each subplot and averaged.

3.3.2.2 Regeneration according to distance from a remnant stand

We sampled three recently logged stands that were located close to white pine remnant stands in order to evaluate the importance of distance from seed trees in explaining regeneration patterns. At each site, we sampled a 4 m × 96 m long transect divided into 24 subplots (4 m × 4 m), extending from the edge of the remnant stand into the cutover. White pine basal area in the remnant stands was 10.87, 14.06, and 23.75 m^2/ha, corresponding to 3-7 white pine seed trees per stand. We counted seedlings in each subplot. Scattered refuge white pine seed trees were located along the transects. For each subplot, we measured the DBH of the nearest refuge tree, as well as its distance to the centre of the subplot.

3.3.2.3 Blister rust and weevil damage according to canopy cover

To determine the effect of canopy cover on blister rust and weevil occurrence, we counted white pine seedlings and saplings in three 4 m × 80 m transects, each starting from a roadside and extending into a forest. These transects were divided into 20 subplots (4 m × 4 m) where we visually estimated canopy cover and assigned it to one of three classes (0-32 %, 33-65 % and 66-100 %). We recorded presence/absence of blister rust and weevil damage on individual seedlings and saplings in each subplot.

3.3.3 Data analysis

3.3.3.1 Detailed regeneration study

We analyzed the data using linear mixed-effects models to account for the multiple measurements in each quadrat (i.e., 5 subplots each). Thus, we treated quadrat as a random effect. We excluded a number of variables from the analysis because of low or no variability. Specifically, all stands had glacial or fluvioglacial deposits. Elevation was also excluded from the analysis as it showed little variation. No evidence of disturbance by weevil or blister rust was noted, so these variables were not included in the analysis. Herbivory (probably by snowshoe hare [*Lepus americanus* Erxl.], moose [*Alces alces* Clin.], or white-tailed deer [*Odocoileus virginianus* Zimm.]) and seed predation by squirrels were noted (in 13 % and 45 % of the stands, respectively), but were not included in the analysis as mast years were expected to counteract the effects of seed predation (Smith 1970; Gurnell 1983; Parker et al. in press) and herbivory was not present in enough quadrats.

We used an information-theoretic approach based on Akaike's information criterion to determine the importance of different variables on white pine regeneration. We formulated fourteen candidate models (Table 3.1), each corresponding to a single variable or to combinations of variables and based on the published literature to test

Table 3.1 Candidate linear mixed-effects models used to explain white pine regeneration abundance. Each model reflects biological hypotheses from the literature and is translated into explanatory variables to be entered in the model.

Model	Tested hypothesis	Explanatory variable(s)
mod1	Seed trees (Wendel and Smith 1990; Fredericksen and Agramont 2013)	Basal area of white pine
mod2	Microsite conditions (Ahlgren 1976; Hibbs 1982; Stearns 1992)	Slope, aspect, depth of organic matter, moss cover
mod3	Seed trees and microsite conditions (Dovčiak et al. 2003)	mod1 + mod2
mod4	Canopy cover (Major et al. 2009)	Canopy cover
mod5	Seed trees and canopy cover	mod1 + mod4
mod6	Understory cover (Abrams 2001)	Herb cover and shrub cover
mod7	Competition from overstory and understory (Smidt and Puettmann 1998, Abrams 2001, Dovčiak et al. 2003, Major et al. 2009)	mod4 + mod6
mod8	Seed trees and competition (Dovčiak et al. 2003)	mod1 + mod6
mod9	Microsite conditions and canopy cover	mod2 + mod4
mod10	Seed trees, microsite conditions and canopy cover	mod1 + mod2 + mod4
mod11	Balsam fir (Smidt and Puettmann 1998, Uprety et al. 2013)	Basal area of balsam fir
mod12	Hardwood species (Pitt et al. 2009; 2011)	Percentage of total basal area represented by hardwood species
mod13	Null model	-
mod14	Global model	All variables

our hypotheses. Some of our models were based on aboriginal knowledge, as we included balsam fir basal area. Indeed, an Algonquin legend mentions that white pine and balsam fir are enemies (Uprety et al. 2013). We used Pearson correlations to verify collinearity among numeric explanatory variables and we avoided entering variables with $| r | > 0.7$ in the same models.

Parameters were estimated by maximum likelihood in R with the nlme package (Pinheiro et al. 2011, R Development Core Team 2012). To meet assumptions of homoscedasticity and normality of the residuals and to linearize the relationship, we log-transformed the response variable (white pine regeneration). We used Akaike's information criterion corrected for small sample sizes (AIC_c) to quantify the support in favor of each model (Burnham and Anderson 2004; Mazerolle 2006). We also computed Akaike weights for each model, which quantify the probability that any given model is the most parsimonious in the model set. When more than a single model had support (i.e., Akaike weights of top model < 0.90), we based our inferences on the entire model set by computing model-averaged estimates of the variables using the AICcmodavg package (Burnham and Anderson 2002; Mazerolle 2006; 2012). Multi-model inference (model averaging) produces parameter and error estimates for each explanatory variable that are not conditional on any single model but instead derived from weighted averages from all models (Symonds and Moussalli 2011). In other words, models with strong support contribute more to estimates than poor models.

We determined the suitability of the different substrate types as seedbeds for white pine by comparing their availability (%) with the proportion of the total seedlings they had (%) using chi-square (χ^2) analysis following Simard et al. (1998) and Parent et al. (2003). Some substrates such as undecomposed dead logs and bare rock are not germination substrates and were thus excluded from the analysis. Mineral soil was not included in the analysis since it covered too little area. Some substrates representing similar growth conditions were combined in order to meet the assumptions of the chi-square test. Hence, moss, decaying wood, and organic matter were combined as they all have good moisture retention capacity. Mixed hardwood and conifer litter, hardwood litter, and fern litter were also combined, but conifer litter was treated as a separate class.

3.3.3.2 Regeneration according to distance from a remnant stand

We analyzed the abundance of white pine regeneration in cutover stands according to distance from remnant stands using linear mixed-effects model and multimodel inference, as described in the previous section. This time, we considered the transect as a random effect. We tested four different hypotheses: (1) effect of distance from remnant stand (regeneration should decrease with distance: Asselin et al. 2001; Weyenberg et al. 2004); (2) effect of distance from refuge trees and their DBH (regeneration clumps are expected near refuge trees: Asselin et al. 2001); (3) combined effect of distance from remnant stand, distance from refuge trees and their DBH; and (4) a null model (intercept only) to evaluate the effects of unmeasured variables. The response variable (abundance of white pine seedlings) was log-transformed to meet the assumption of normality. We used a variance function to homogenize variances (Pinheiro and Bates 2000).

3.3.3.3 Blister rust and weevil damage according to light availability, dryness, and white pine density

Data on weevil damage were too scarce to analyze and we do not discuss them further. We analysed the effect of canopy cover on blister rust damage using logistic regressions with random effects (i.e., transect and subplot within transect as random effects) and multimodel inference, because our response variable was binary (presence or absence of blister rust damage). We tested six hypotheses: (1) canopy cover (as an inverse proxy of light availability, shaded sites being less prone to blister rust infection: White et al. 2002); (2) combined effect of canopy cover and distance from the road margin (as a more complete inverse proxy of light availability, as light not only arrives from above, but also from stand edge: Greene et al. 2002); (3) distance from the road margin (as an inverse proxy of dryness, roadsides being drier than interior forest and dry sites being less prone to blister rust infection: Katovich and Mielke 1993); (4) white pine seedling and sapling density (sites with higher white pine density are more prone to blister rust infection: Field et al. 2012); (5) combined effect of canopy cover, distance from the road margin, and density of white pine seedlings and saplings; and (6) a null model (intercept only). Parameters were estimated by maximum likelihood with lme4 package in R (Bates et al. 2012).

3.4 Results

3.4.1 Tree species composition of white pine stands

Apart from white pine, 11 tree species were recorded in the quadrats (Table 3.2). Jack pine and eastern larch (*Larix laricina* (Du Roi) K. Koch) were also present in the area but not recorded in the quadrats. Balsam fir, black spruce, paper birch, red maple, and red pine were the most frequent companion species.

3.4.2 Detailed regeneration study

Only 59 seedlings and 48 saplings were counted in the subplots. Canopy cover varied between subplots, 30 had low cover (0-32%), 23 medium (33-65%), and 57 high (66-100%). A combined histogram (N = 22 sites) showing the abundance of all white pine individuals according to 19 DBH classes follows a negative exponential (Figure 3.2).

Table 3.2 Frequency of occurrence and basal area of tree species in the quadrats.

Species	Percentage of the sites	Mean basal area (m^2/ha)	Mean relative basal area (%)	Maximum relative basal area (%)
Pinus strobus L.	100	25.78±13.40	57.71	91.73
Abies balsamea (L.) Miller	90	4.89±4.59	10.91	26.08
Picea mariana (Mill.) BSP.)	82	4.55±5.01	12.74	50.63
Betula papyrifera Marsh.	54	2.98±4.00	8.26	40.10
Acer rubrum L.	50	1.30±2.28	3.25	25.28
Pinus resinosa Ait.	50	1.06±2.72	2.32	17.07
Thuja occidentalis L.	18	1.00±3.30	2.24	35.75
Acer saccharum L.	9	0.06±0.20	0.13	2.08
Picea glauca (Moench) Voss	9	0.15±0.38	0.42	5.18
Populus tremuloides Michx.	9	1.05±4.50	1.90	38.38
Betula alleghaniensis Britton.	4	0.01±0.08	0.04	1.00
Prunus pensylvanica L.f.	4	0.02±0.08	0.07	1.60

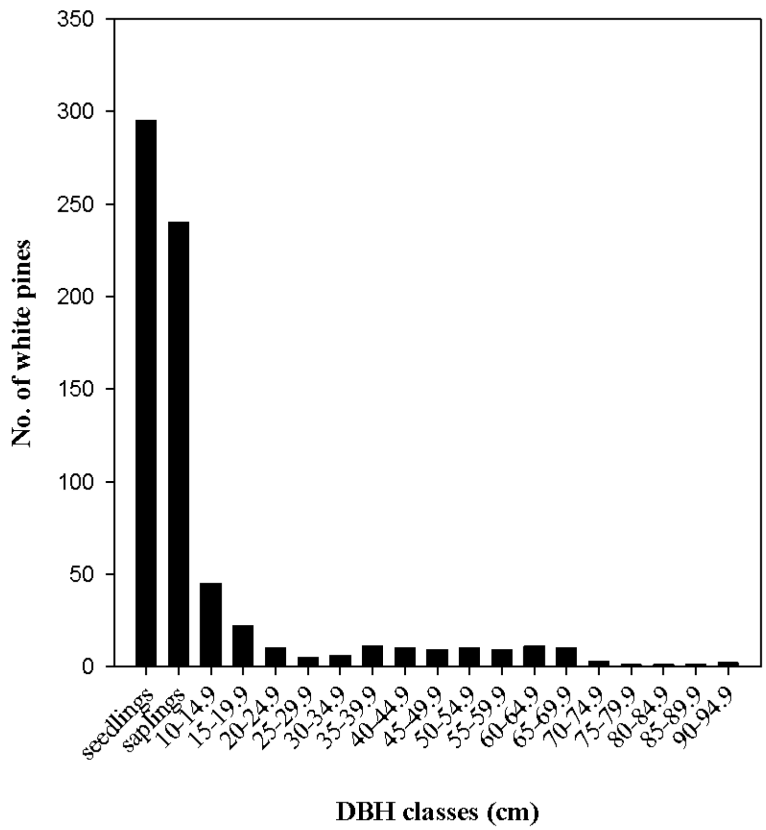

Figure 3.2 White pine combined size distribution (total no. of stems in 22 quadrats, each of 400 m2).

Six models had $\Delta AIC_c < 4$, meaning that they were all reasonably good at explaining white pine regeneration abundance (Table 3). The top-ranked model consisted of the basal area of balsam fir as a single predictor, and this model had 4 times more support than the second-ranked model which included only microsite condition (evidence ratio = 0.40/0.10 = 4). The abundance of white pine regeneration decreased with balsam fir basal area (model-averaged estimate: -1.12, 95% CI = -1.99, -0.25; Figure 3.3). The abundance of white pine regeneration increased weakly with moss cover (model-averaged estimate: 0.0092, 95% CI: 0.0030, 0.0153) and herb cover (model-averaged estimate: 0.0074, 95% CI: 0.0002, 0.0146). White pine regeneration did not vary with any other of the variables we considered.

Table 3.3 Ranking of linear mixed models predicting the abundance of white pine regeneration based on AICc. Note that ΔAICc gives the difference in AICc of each model compared to the top-ranked model, and Akaike weights (wi) indicate the probability that any given model is the best among the candidate model set.

Model ID[a]	**Tested hypothesis**	**Log-likelihood**	**K**[a]	**AIC$_c$**	**ΔAIC$_c$**	**w$_i$**
mod11	Balsam fir	−93.40	4	195.17	0.00	0.40
mod2	Microsite conditions	−91.41	7	197.93	2.76	0.10
mod4	Canopy cover	−93.92	5	198.42	3.25	0.08
mod6	Understory cover	−93.95	5	198.49	3.31	0.08
mod13	Null model	−96.19	3	198.61	3.44	0.07
mod3	Seed trees and microsite conditions	−90.84	8	199.10	3.93	0.06
mod12	Hardwood species	−95.45	4	199.27	4.10	0.05
mod9	Microsite conditions and canopy cover	−90.08	9	199.95	4.78	0.04
mod7	Competition from overstory and understory	−92.50	7	200.11	4.94	0.03
mod8	Seed trees and competition	−93.88	6	200.58	5.41	0.03
mod5	Seed trees and canopy cover	−93.92	6	200.65	5.47	0.03
mod1	Seed trees	−96.19	4	200.76	5.59	0.02
mod10	Seed trees, microsite conditions and canopy cover	−89.64	10	201.51	6.34	0.02
mod14	Global model	−86.98	14	206.38	11.21	0.00

[a] Parameter count includes intercept, residual variance, and variance of random effect.

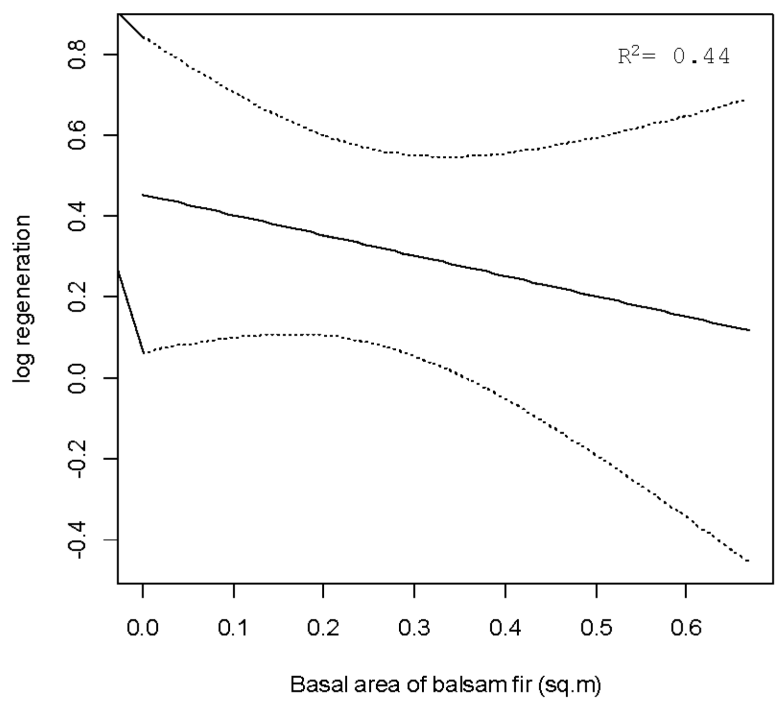

Figure 3.3 Effect of balsam fir basal area (m^2/plot) on white pine regeneration (seedlings + saplings) abundance (log regeneration/subplot). Results are based on model-averaged predictions. Dotted lines indicate 95% confidence limits.

3.3.3 Substrate–seedling associations in white pine stands

The observed frequency distribution of seedlings per substrate type differed significantly from the expected distribution according to the area covered by the substrate types (Figure 3.4; $\chi^2 = 113.78$; $P < 0.001$). Seedling density was higher than expected on moss, decaying wood, and organic matter, and lower than expected (in fact, 0) on conifer litter.

3.3.4 Regeneration according to distance from a remnant stand

Two models had support in explaining the distribution of white pine along the transects (Table 3.4). Both models included distance to the remnant stand as a predictor, suggesting a strong effect of the variable. Indeed, white pine abundance decreased with distance to the remnant stand (model-averaged estimate: -0.0063, 95% CI = -0.0099, -0.0028; Figure 3.5). The abundance of white pine was not influenced by any other variables we considered.

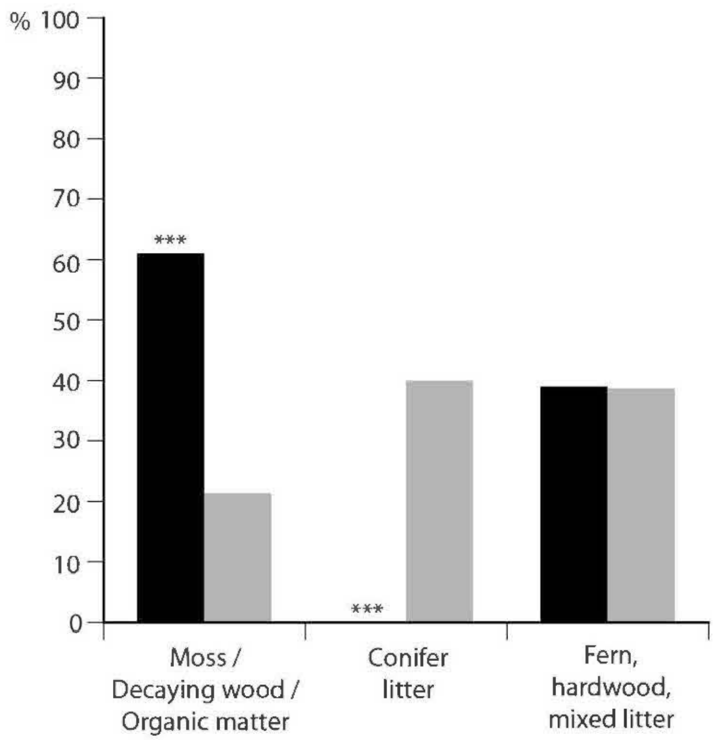

Figure 3.4 Percent area of forest floor covered by each substrate type (grey bars) and percent seedlings found on each substrate type (black bars). Asterisks indicate that observed seedling numbers are significantly ($p < 0.001$) lower or higher than expected according to the area covered by the substrate type.

Table 3.4 Ranking of linear mixed models predicting the effects of remnant stands and refuge trees on the abundance of white pine regeneration in logged stands, based on AIC_c. Note that ΔAICc gives the difference in AICc of each model compared to the top-ranked model, and Akaike weights (wi) indicate the probability that any given model is the best among the candidate model set.

Model	**Model**	**Log-likelihood**	**K^a**	**AIC_c**	**ΔAIC_c**	**w_i**
Distance from the remnant stand	mod3	−52.53	6	118.35	0.00	0.80
Distance from the remnant stand+ distance to the nearest refuge tree + DBH of the nearest refuge tree	mod1	−51.57	8	121.42	3.07	0.17
Distance to the nearest refuge tree + DBH of the nearest refuge tree	mod2	−54.88	7	125.51	7.16	0.02
Null model	mod4	−59.72	5	130.35	12.00	0.00

[a] Parameter count includes intercept, residual variance, and two variance function parameters to homogenize variances.

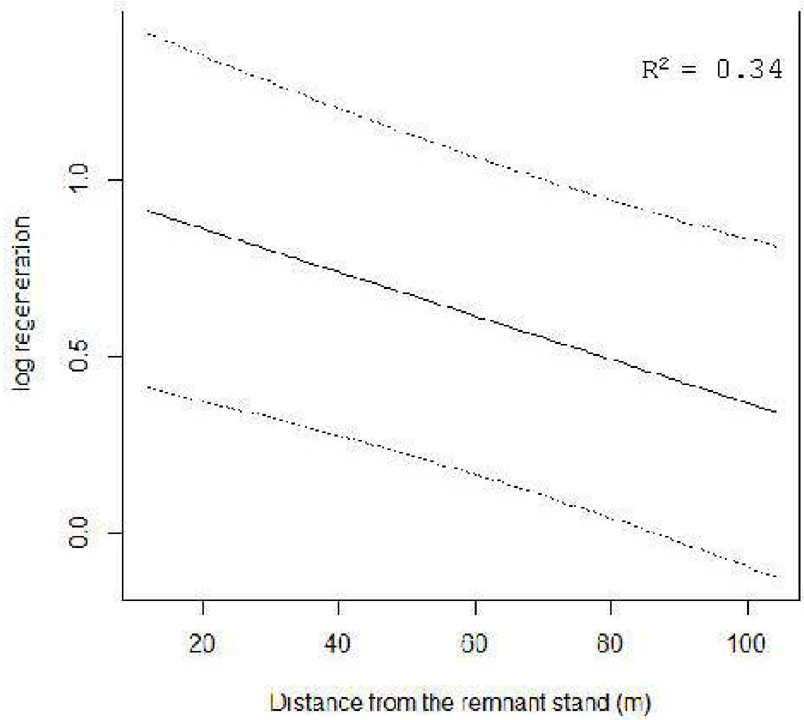

Figure 3.5 Effect of distance from the remnant stand on white pine regeneration abundance (log regeneration/subplot). Results are based on model-averaged predictions. Dotted lines indicate 95% confidence limits.

3.3.5 Blister rust and weevil damage according to canopy cover

Only 3.6% of the seedlings and saplings found in the roadside transects showed damage from weevil, which prevented us from using the data in our models. Blister rust damage was common enough (28%) to be analyzed. Although the top-ranked model consisted of the distance from the road margin, the model was followed closely by the null model, which suggests weak evidence for an effect of distance from the road margin (Table 3.5). In fact, none of the explanatory variables we considered could explain the occurrence of blister rust damage.

Table 3.5 Ranking of logistic regressions with random effects predicting the effect of canopy cover on blister rust damage in roadside transects, based on AIC_c.

Model	**Model**	**Log-likelihood**	**K[a]**	**AIC_c**	**ΔAIC_c**	**w_i**
Distance from the road margin	mod3	-104.89	4	218.03	0.00	0.42
Null model	mod6	-106.62	3	219.39	1.36	0.21
Canopy cover	mod1	-104.88	5	220.13	2.10	0.15
Canopy cover and distance from the road margin	mod2	-104.15	6	220.81	2.78	0.10
White pine seedling and sapling density	mod4	-106.61	4	221.47	3.44	0.08
Canopy cover, white pine seedling and sapling density, and distance from the road margin	mod5	-104.10	7	222.90	4.87	0.04

[a] Parameter count includes intercept, and two random effects (variance between transects, variance between plots nested in transect).

3.5 Discussion

White pine is a versatile species, and in our study area it was found with eleven accompanying tree species confirming previous studies at the species' northern distribution limit (Quinby 1991; Latremouille et al. 2008). The widespread occurrence of supercanopy white pine trees suggests that these scattered individuals were remnants of former more extensive stands (Stearns 1992). White pine size-class distribution shows a typical negative exponential trend explained by constant mortality and recruitment by fire at the landscape scale (Bergeron et al. 2002). A similar pattern was found at the white pine northern distribution limit (Holla and Knowles 1988). Such a size class distribution indicates continuous recruitment, but at very low levels compared to other temperate or boreal species in comparable areas (Bergeron et al. 2002), or to white pine itself in the centre part of its range (Dovčiak et al. 2001). Thus, while very few seedlings germinate and establish, those that do can make it to the canopy with a success equivalent to that of other species. Indeed, white pine seedlings have high mortality (Holla and Knowles 1988; Carleton et al. 1996), but seedlings that survive through this period have a high probability of long-term survival (Holla and Knowles 1988). One explanation for low white pine regeneration is the lack of fire. The stand-replacing fire cycle in the study area is considerably longer than in the pre-industrial era (Grenier et al. 2005; Bergeron et al. 2006), and surface fires are actively suppressed since the 1970s. Fire, especially surface fire, creates good regeneration conditions for white pine by removing competing vegetation, both on the ground and in the canopy (Heinselman 1981). Engelmark et al. (2001) have indeed shown continuous recruitment for white pine in frequently burned sites. However, low but continual white pine recruitment is possible even without recent fire disturbance, provided that small scale gaps suitable for regeneration are available (Holla and Knowles 1988; Quinby 1991).

Recruitment is the result of several processes including seed dispersal, availability of suitable seedbeds, germination, seedling establishment, and subsequent survival (Houle 1995; Cornett et al. 1997). The abundance of seed trees did not have a significant effect on white pine regeneration abundance in our detailed regeneration study in forest plots. It could be because we sampled stands that were dominated or co-dominated by white pine, and thus that seed availability was always higher than a minimum threshold. Tree canopy cover had no effect on white pine regeneration abundance and thus we rejected our hypothesis that tree canopy cover was the most important variable explaining regeneration in white pine stands. Regeneration can occur in the understory, and survival and slow growth can be maintained as long as light levels are at least 20% of full sunlight (Wendel and Smith 1990). However, passage to the sapling stage requires increased light conditions (Fredericksen and Agramont 2013).

Interspecies competition is often stated as a possible mechanism limiting white pine regeneration (Ahlgren 1976; Carleton et al. 1996; Pitt et al. 2009; Parker et al. 2012).

Herb cover in our study area was low (mean = 16.82%) and had a very weak *positive* effect on white pine regeneration abundance. It is possible that low herb cover provides moist conditions favouring white pine establishment. Although shrub cover was higher than herb cover (38.69%), it did not affect white pine regeneration abundance. This is contrary to Weyenberg et al. (2004) who reported a negative effect of shrub cover on seedling and sapling densities. We also did not find an effect of hardwood species abundance on white pine regeneration abundance. Potential effects of shrubs or hardwoods could have been masked by the very strong negative effect of balsam fir basal area, by far the most important factor explaining white pine regeneration abundance. A negative effect of coniferous species (including balsam fir) on white pine regeneration was previously reported, along with the effects of other limiting variables (Ahlgren 1976; Carleton et al. 1996; Smidt and Puettmann 1998). Our study is the first to show a disproportionate negative effect of balsam fir (but not other coniferous species) on white pine regeneration, whereas other variables have considerably less impact. Interestingly, a negative effect of balsam fir on white pine was reported by people of the Kitcisakik Algonquin community, who claimed that, according to a legend, balsam fir and white pine are enemies (Uprety et al. 2013). Our study area was located in a balsam fir-dominated bioclimatic domain, contrary to previous studies conducted more to the south. Balsam fir is an aggressive species, with abundant regeneration leading to dense, compact stands letting little light penetrate to ground level. Furthermore, balsam fir foliar leachates have strong inhibitory properties on nitrification and oxidation of ammonium (Thibault et al. 1982) that could potentially impair white pine regeneration and establishment. This could explain that white pine regeneration was absent on conifer litter in our study, contrary to findings of Weyenberg et al. (2004), where balsam fir was not dominant and where other coniferous species were more abundant.

Regeneration was more abundant than expected on humid substrates, including moss, decaying wood and organic matter, even though the moss variable only had a weak effect according to our analysis. Moss keeps the ground compact, moist, and relatively free from competition (Ahlgren 1976), and was found to be a favorable germination substrate for white pine (Weyenberg et al. 2004) and other conifer species (Simard et al. 1998, Parent et al. 2003). None of the other microsite conditions tested had an effect on white pine regeneration abundance.

Distance from a remnant stand played a significant role in explaining white pine regeneration abundance in logged areas, as observed in previous studies on white pine (Weyenberg et al. 2004) and other conifer species (Greene and Johnson 1996; Asselin et al. 2001). Contrary to our hypothesis, refuge seed trees in cutovers did not play a role. It was probably because the net effect of a single tree was too small to detect. An alternative explanation would be that refuge trees were present all along transects, so their effect was more difficult to isolate.

Contrary to our hypothesis, damaging agents such as blister rust and weevil were not major problems affecting white pine in our study area. We found no evidence of damage by blister rust and weevil in closed forests, contrary to previous findings from areas more to the south (Van Arsdel 1972; White et al. 2002). We also did not record any occurrence of *Ribes* spp., the alternative host of blister rust (Zambino 2010). We did record some blister rust damage in open areas along roadsides, but the percentage of affected trees was lower than what was reported in other studies conducted in open areas (Latremouille et al. 2008; CFS 2012). Moreover, we found no effect of canopy cover and distance from the road (into the forest) on the occurrence of blister rust damage. This could be due to blister rust incidence being already low near roadsides (28%), much lower than expected as the northern part of white pine's distribution is supposed to be more prone to this pathogen (Van Arsdel 1972; Katovich and Mielke 1993). Cool, humid climatic conditions favorable for the spread of blister rust usually prevail at the northern limit of continuous distribution of white pine (Lavallée 1986). However, Katovich and Mielke (1993) and Fahey and

Lorimer (2013) showed that even in high hazard zones, the incidence of rust was very low in some parts of the Lake States. Our roadside transects were south-east facing and thus drier than the general conditions in the study area, which could explain the low occurrence of blister rust (White et al. 2002; CFS 2012). Hence, maybe the positive effect on blister rust of accrued light at roadsides was cancelled-out by the negative effect of dryness. In contrast, we observed 100% blister rust infection in a plantation site (visited but not sampled), comparable to high infection rates recorded in other plantations (Latremouille et al. 2008; CFS 2012). The plantation we visited (one of only a few in the study area) was on a cool lower slope, exposed to the north, surrounded by matured forest. Such conditions are highly favorable for blister rust (Katovich and Mielke 1993).

We reported very low incidence of weevil infestation (3.6%) in full light conditions. White pines grown in open conditions are deemed particularly susceptible to repeated attacks (Katovich and Morse 1992). Major et al. (2009) have reported 42% of weevil infestation in full light conditions in the centre of white pine's distribution. In another study, damage due to weevil in open canopies affected almost 100% of the trees (Stiell and Berry 1985).

Low incidences of blister rust and weevil in our study area do not correspond with the hazard maps developed for Quebec (Vlasiu et al. 2001 for weevil and Lavallée 1986 for blister rust), maybe because sampling effort was lower at the northern limit of continuous distribution. Our results call for revision of these maps. Browsing by herbivores was not important inside white pine stands, even in roadside plots, where white pine regeneration was more abundant. It could mean that herbivore populations were low, or that there was enough availability of preferred food sources (Pastor 1992; Saunders and Puettmann 1999). The snowshoe hare population in the study area was in a cycle trough at the time of sampling (Paul and Trudeau 2010).

3.6 Conclusion

Natural white pine regeneration does occur at the species' northern limit of continuous distribution, but in low amounts. Recruitment is more abundant on moister substrates, but is strongly influenced by competition and inhibitory effects of balsam fir. Low occurrence of blister rust and weevil damage is contrary to expectations based on risk maps. The northern limit of continuous distribution holds potential for white pine restoration, for example by preserving remnant white pine stands that can contribute natural regeneration in logged areas. Antagonistic interaction between light availability and site dryness with regards to blister rust hazard suggests that white pine restoration on mesic to moist sites is more likely to be successful under moderate shade than in the open.

3.7 Acknowledgements

We thank Sophie Delisle for help preparing field work, and Carine Côté-Germain and Ahmed El Guellab for help in the field. Thanks also to Mélanie Desrochers (Centre for Forest Research, Université du Québec à Montréal) for helping with Figure 3.1 design.

3.8 References

Abrams MD (2001) Eastern white pine versatility in the presettlement forest. BioScience 51: 967-979

Ahlgren CE (1976) Regeneration of red and white pine following wildfire and logging in northeastern Minnesota. J Forest 74: 135-140

Asselin H, Fortin M-J, Bergeron Y (2001) Spatial distribution of late-successional coniferous species regeneration following disturbance in southwestern Quebec boreal forest. For Ecol Manage 140: 29-37

Bates D, Maechler M, Bolker B (2012) lme4: Linear mixed-effects models using S4 classes. R package version 0.999999-0. http://CRAN.R-project.org/package=lme4 Accessed 25 September 2012

Belyea RM, Sullivan CR (1956) The white pine weevil: a review of current knowledge. For Chron 32: 58-67

Bergeron Y, Leduc A, Li T (1997) Explaining the distribution of *Pinus* spp. in a Canadian boreal insular landscape. J Veg Sci 8: 37-44

Bergeron Y, Cyr D, Drever CD, Flannigan M, Gauthier S, Kneeshaw D, Lauzon É, Leduc A, Le Goff H, Lesieur D, Logan K (2006) Past, current, and future fire frequencies in Quebec's commercial forests: implications for the cumulative effects of harvesting and fire on age-class structure and natural disturbance-based management. Can J For Res 36: 2737-2744

Bergeron Y, Leduc A, Harvey BD, Gauthier S (2002) Natural fire regime: a guide for sustainable management of the Canadian boreal forest. Silva Fenn 36: 81-95

Burgess D, Robinson C, Wetzel S (2005) Eastern white pine response to release 30 years after partial harvesting in pine mixed wood forest. For Ecol Manage 209: 117-129

Burnham KP, Anderson DR (2002) Model selection and multimodel inference: A practical information–theoretic approach, second ed. Springer, New York

Burnham KP, Anderson DR (2004) Multimodel inference. Understanding AIC and BIC in model selection. Sociol Method Res 33: 261-304

Canadian Forest Service (CFS) (2012) White pine blister rust: knowledge, control and innovation. Canadian Forest Service, Quebec

Carleton TJ, Maycock PF, Arnup R, Gordon AM (1996) *In situ* regeneration of *Pinus strobus* and *P. resinosa* in the Great Lakes forest communities of Canada. J Veg Sci 7: 431-444

Cornett MW, Reich PB, Puettmann KJ (1997) Canopy feedbacks and microtopography regulate conifer seedling distribution in two Minnesota conifer-deciduous forests. Ecoscience 4: 353-364

Dovčiak M, Frelich LE, Reich PB (2001) Discordance in spatial patterns of white pine (*Pinus strobus*) size-classes in a patchy near-boreal forest. J Ecol 89: 280-291

Dovčiak M, Reich PB, Frelich LE (2003) Seed rain, safe sites, competing vegetation, and soil resources spatially structure white pine regeneration and recruitment. Can J For Res 33: 1892-1904

Engelmark O, Bergeron Y, Flannigan MD (2000) Age structure of eastern white pine, *Pinus strobus* L., at its Northern distribution limit in Quebec. Can Field Nat 114: 601-604

Fahey RT, Lorimer CG (2013) Restoring a midtolerant pine species as a component of late-successional forests: Results of gap-based planting trials. For Ecol Manage 292: 139-149

Field SG, Schoettle AW, Klutsch JG, Tavener SJ, Antolin MF (2012) Demographic projection of high-elevation white pines infected with white pine blister rust: a nonlinear disease model. Ecol Appl 22: 166-183

Fredericksen TS, Agramont ARE (2013) Regeneration patterns of Eastern white pine (*Pinus strobus* L.) in hardwood-dominated forests in Virginia, USA. New Forest 44: 51-61

Greene DF, Johnson EA (1996) Wind dispersal of seeds from a forest into a clearing. Ecology 77: 595-609

Greene DF, Messier C, Asselin H, Fortin M-J (2002) The effect of light availability and basal area on cone production in *Abies balsamea* and *Picea glauca*. Can J For Res 80: 370–377

Grenier DJ, Bergeron Y, Kneeshaw D, Gauthier S (2005) Fire frequency for the transitional mixedwood forest of Timiskaming, Quebec, Canada. Can J For Res 35: 656-666

Gurnell J (1983) Squirrel numbers and the abundance of tree seeds. Mammal Rev 13: 133-148

Heinselman ML (1981) Fire intensity and frequency as factors in the distribution and structure of northern ecosystems. In: Proceedings of the Conference Fire Regimes and Ecosystem Properties, US Forest Service Technical Report WO-26, pp. 7-57

Hibbs DH (1982) White pine in the transition hardwood forest. Can J Bot 60: 2046-2053

Holla TA, Knowles P (1988) Age structure analysis of a virgin white pine, *Pinus strobus*, population. Can Field Nat 102: 221-226

Houle G (1995) Seed dispersal and seed recruitment: The missing link(s). Ecoscience 2: 238-244

Katovich SA, Morse FS (1992) White pine weevil response to oak overstory girdling. Results from a 16 year-old study. North J Appl For 9: 51-54

Katovich SA, Mielke M (1993) How to manage eastern white pine to minimize damage from blister rust and white pine weevil. USDA, NAFR-01-93

Latremouille C, Parker WC, McPherson S, Pinto F, Fox B, McKinnon L (2008) Ecology and management of white pine in the Lake Abitibi (3E) and Lake Temagami (4E) ecoregions of Ontario. Ontario Ministry of Natural Resources, Ontario

Lavallée A (1986) Zones de vulnérabilité du pin blanc à la rouille vésiculeuse au Québec. For Chron 62: 24-28

Major JE, Mosseler A, Barsi DC, Clouthier A, Campbell M (2009) Impact of three silvicultural treatments on weevil incidence, growth, phenology, and branch level dynamics of *Pinus strobus* from large and small populations. Can J For Res 39: 12-25

Mazerolle MJ (2006) Improving data analysis in herpetology: using Akaike's information criterion (AIC) to assess the strength of biological hypotheses. Amphibia Reptilia 27: 169-180

Mazerolle MJ (2012) AICcmodavg: model selection and multimodel inference based on (Q)AIC(c). R package version 1.13. http://CRAN.Rproject.org/package=AICcmodavg. Accessed 25 September 2012

Parent S, Simard M-J, Morin H, Messier C (2003) Establishment and dynamics of the balsam fir seedling bank in old forests of northeastern Quebec. Can J For Res 33: 597-603

Parker WC, Pitt DG, Morneault AE (2012) Influence of herbaceous and woody vegetation control on seedling microclimate, leaf gas exchange, water status, and nutrient relations of *Pinus strobus* L. seedlings planted in a shelterwood. For Ecol Manage 271: 104-114

Parker WC, Noland TL, Morneault AE (in press) Comparative mast seed production in unmanaged and shelterwood white pine (*Pinus strobus* L.) stands in central Ontario. New Forest DOI 10.1007/s11056-013-9366-8

Pastor J (1992) Browsing damage to white pine. In: Stine RA, Baughman MJ (Eds) Proceedings of the White Pine Symposium: History, Ecology, Policy and Management. University of Minnesota, St. Paul, pp. 137-144

Paul V, Trudeau C (2010) Bilan d'exploitation du lynx du Canada (*Felis lynx*) en Abitibi-Témiscamingue. Ministère des ressources naturelles, Rouyn-Noranda, Quebec

Pinheiro JC, Bates DM (2000) Mixed-effects models in S and S-PLUS. Springer, New York

Pinheiro J, Bates D, DebRoy S, Sarkar D (2011) nlme: linear and nonlinear mixed effects models. R package version 3.1-104. http://CRAN.R-project.org/package=nlme. Accessed 27 September 2012

Pitt DG, Morneault A, Parker WC, Stinson A, Lanteigne L (2009) The effects of herbaceous and woody competition on planted white pine in a clearcut site. For Ecol Manage 257: 1281-1291

Pitt DG, Morneault A, Parker WC, Lanteigne L, Hoepting MK, Stinson A (2011) Influence of herbaceous and woody competition on white pine regeneration in a uniform shelterwood. For Chron 87: 653-668

Quinby PA (1991) Self-replacement in old-growth white pine forests of Temagami, Ontario. For Ecol Manage 41: 95-109

Saint-Arnaud M, Asselin H, Dubé C, Croteau Y, Papatie C (2009) Developing criteria and indicators for aboriginal forestry: mutual learning through collaborative research. In: Stevenson MG, Natcher DC (Eds) Changing the Culture of Forestry in Canada: Building Effective Institutions for Aboriginal Engagement in Sustainable Forest Management. Canadian Circumpolar Institute Press, pp. 85-105

Saucier J-P, Bergeron J-P, Grondin P, Robitaille A (1998) Les régions écologiques du Québec méridional (troisième version). L'Aubelle 124 : S1-S12

Saunders MR, Puettmann KJ (1999) Use of vegetational characteristics and browsing patterns to predict deer damage in eastern white pine (*Pinus strobus*) plantations. North J Appl For 16: 96-102

Simard M-J, Bergeron Y, Sirois L (1998) Conifer recruitment in the southeastern Canadian boreal forest: the importance of substrates. J Veg Sci 9: 575-582

Smidt MF, Puettmann KJ (1998) Overstory and understory competition affect underplanted eastern white pine. For Ecol Manage 105: 137-150

Smith CC (1970) The coevolution of pine squirrels (*Tamiasciurus*) and conifers. Ecol Monogr 40: 349-371

Stearns F (1992) Ecological characteristics of white pine. In: Stine RA, Baughman MJ (Eds) Proceedings of the White Pine Symposium: History, Ecology, Policy and Management. University of Minnesota, St. Paul, pp.10-18.

Steen-Adams MM, Langston N, Mladenoff DJ (2007) White pine in the Northern Forests: An ecological and management history of white pine on the Bad River Reservation of Wisconsin. Environ Hist 12: 614-648

Stiell WM, Berry AB (1985) Limiting white pine weevil attacks by side shade. For Chron 61: 5-9

Symonds MRE, Moussalli A (2011) A brief guide to model selection, multimodel inference and model averaging in behavioural ecology using Akaike's information criterion. Behav Ecol Sociobiol 65: 13-21

Thibault R, Fortin A, Smirnoff WA (1982) *In vitro* allelopathic inhibition of nitrification by balsam poplar and balsam fir. Am J Bot 69: 676-679

Uprety Y, Asselin H, Bergeron, Y (2013) Cultural importance of white pine (*Pinus strobus* L.) to the Kitcisakik Algonquin community of western Quebec, Canada. Can J For Res 43: 544-551

Van Arsdel EP (1972) Environment in relation to white pine blister rust infection. USDA Forestry Service Technical Report 1221

Vlasiu PD, Nolet P, Doyon F (2001) Le pin blanc: Revue de littérature. Institut québécois d'aménagement de la forêt feuillue. Quebec.

Wendel GW, Smith HC (1990) Eastern white pine. In: Burns RM, Honkala BH (Technical Coordinators), Silvics of North America, Vol. 1, Conifers. USDA, Agricultural Handbook, Vol. 654, Washington, DC, pp. 476-488

Weyenberg SA, Frelich LE, Reich PB (2004) Logging versus fire: how does disturbance type influence the abundance of *Pinus strobus* regeneration? Silva Fenn 38: 179-194

White MA, Brown TN, Host GE (2002) Landscape analysis of risk factors for white pine blister rust in the Mixed Forest Province of Minnesota, U.S.A. Can J For Res 32: 1639-1650

Zambino PJ (2010) Biology and pathology of *Ribes* and their implications for management of white pine blister rust. Forest Pathol 40: 264-291

CHAPTER IV

Culturally-adapted white pine (*Pinus strobus* L.) restoration and management at the species' northern limit of continuous distribution

Yadav Uprety, Hugo Asselin and Yves Bergeron

Manuscript submitted to
Forest Ecology and Management

4.1 Abstract

Markedly reduced abundance of white pine (*Pinus strobus* L.) across the species' range result from overharvesting and suppression of surface fires. The Kitcisakik Algonquin community of western Quebec has been calling for restoration and sustainable management of white pine on its ancestral territory. Here, we propose culturally- and ecologically-adapted restoration and management scenarios based on a literature review of white pine silviculture, as well as on the particular cultural and ecological settings of the Kitcisakik ancestral territory. We present five scenarios aiming to answer different needs of the Kitcisakik community, while taking into account ecological types (potential vegetation and abiotic conditions). Scenario I addresses the need for white pine as a medicinal plant. It relies on natural regeneration of scattered white pine trees in ecological types where white pine is a minor component. Scenario II fulfills the need for scattered supercanopy white pine trees that are used as landmarks and as habitat for flagship wildlife species. It relies on conservation of current supercanopy white pines, and sporadic natural regeneration and plantation to renew the stock. Scenario III aims to provide habitat for flagship wildlife species and forest stands where people can go for resourcing. Pure mature stands are produced by shelterwood cuts in ecological types (co)dominated by white pine. Scenario IV aims to produce pure mature stands for timber production by favoring under canopy plantations in ecological types dominated by conifer species. In scenario V, mixed plantations in all ecological types where white pine is a minor component will serve for aesthetic purposes, as wildlife habitat, and to protect biodiversity.

Keywords: Aboriginal people; Ecological restoration; Ecological types; Plantation forestry; Shelterwood system.

4.1 Résumé

Une diminution marquée d'abondance du pin blanc (*Pinus strobus* L.) dans son aire de répartition résulte de la surexploitation et à la suppression des feux de surface. La communauté algonquine de Kitcisakik (ouest du Québec) revendique la restauration et l'aménagement durable du pin blanc sur son territoire ancestral. Nous proposons des scénarios de restauration et d'aménagement culturellement et écologiquement adaptées en nous basant sur une revue de la littérature sur la sylviculture du pin blanc, de même que sur les contextes culturel et écologique particuliers du territoire ancestral de Kitcisakik. Nous présentons cinq scénarios visant à répondre aux différents besoins de la communauté de Kitcisakik tout en tenant compte des types écologiques (végétation potentielle et conditions abiotiques). Le scénario I concerne l'utilisation du pin blanc comme plante médicinale et s'appuie sur la régénération naturelle dans les types écologiques où le pin blanc est une composante secondaire. Le scénario II vise à maintenir ou produire des arbres géants utilisés pour l'orientation sur le territoire et comme habitat par des espèces fauniques d'intérêt. La régénération naturelle est suggérée, de même que la plantation d'individus épars dans tous les types écologiques où le pin blanc peut pousser. Le scénario III a pour objectif de générer des peuplements purs matures naturels qui serviront d'habitat pour des espèces fauniques d'intérêt, et aussi de lieux de resourcement pour les membres de la communauté. La coupe progressive d'ensemencement est suggérée dans les types écologiques (co)dominés par le pin blanc. Le scénario IV vise à produire des peuplements purs matures à des fins de production de matière ligneuse. La plantation sous couvert est suggérée dans les types écologiques dominés par les résineux. Le scénario V vise la restauration et le maintien du pin blanc comme composante du paysage à des fins esthétiques et de préservation d'habitats fauniques en ayant recours à des plantations mixtes dans des types écologiques où le pin blanc est une composante secondaire.

Keywords: Coupes progressives d'ensemencement; Peuples autochtones; Plantation; Restauration écologique; Types écologiques.

4.2 Introduction

Eastern white pine (*Pinus strobus* L.) is a highly valuable species for several reasons: cultural, spiritual, aesthetic, ecological and economic (Rogers and Lindquist, 1992; Schroeder, 1992; Ostry et al., 2010; Uprety et al., 2013). Once an important component of northeastern North American forests, white pine has greatly decreased in abundance over the last few centuries owing to overharvesting and suppression of surface fires (Abrams, 2001; Ostry et al., 2010; Steen-Adams et al., 2011). White pine decline has raised concerns from ecologists, forest managers, and aboriginal peoples; though the reasons for concern differ between groups. Ongoing interest for white pine restoration and management in a variety of ecosystems is guided by the rising demand for high-quality lumber coupled with the species' recognized ecological and cultural values (Pitt et al., 2009). However, white pine restoration and management are challenging for many reasons: specific site requirements for regeneration, slow initial growth rate, susceptibility to damage from white pine blister rust (*Cronartium ribicola* J.C. Fisch.) and white pine weevil (*Pissodes strobi* Peck), heavy browsing by herbivores, and suppression of surface fires (Tester et al., 1997; Burgess et al., 2005; Steen-Adams et al., 2007; Latremouille et al., 2008). These constraints must be considered to design effective restoration and management strategies. Equally important in forest restoration and management is an understanding of historical and current ecosystem processes driving forest structure and composition of the target site (Pinto et al., 2008; Boucher et al., 2011). Forest restoration and management prescriptions should therefore use the template of preindustrial forest conditions (Barrette and Bélanger, 2008), as well as the context under which the targeted site will grow (Pinto et al., 2008). Therefore, natural disturbance regimes, succession trajectories, and preindustrial forest structure and composition are important in formulating successful restoration and management strategies.

Aboriginal peoples have growing influence on contemporary forest management decisions all over the world (Trosper and Parrotta, 2012). They also are among the key stakeholders in Canadian forest management (Stevenson and Webb, 2003; CCFM, 2008). Hence, they are increasingly being invited to participate in sustainable forest management processes as a means of including their knowledge, values, and concerns (Wyatt et al., 2011), specifically after new forest policies were adopted in 1992 (CCFM, 1992). Moreover, the sustainable forest management criteria and indicators, and the forest certification process mandate governments and timber companies to include aboriginal needs in forest management strategies (Saint-Arnaud et al., 2009; Tikina et al., 2010).

Aboriginal forestry is a new form of forestry that uses knowledge and techniques drawn from both traditional and conventional forestry and is based on aboriginal values, rights, and institutions (Wyatt, 2008; Saint-Arnaud, 2009). Studies have shown that aboriginal involvement has led to positive changes in forest management. For example, the Labrador Innu have influenced the contents of forestry plans by developing an innovative approach to implement ecosystem management and demonstrated the utility of involving aboriginal people in the forest management planning processes (Wyatt et al., 2011). Forest management by the Menominee tribe has also exemplified how indigenous people can restore and manage forests by combining traditional knowledge and conventional forestry approaches (Davis, 2000; Trosper, 2007).

Aboriginal people's knowledge should be integrated into restoration and management strategies in order to fulfill their cultural and spiritual needs for different tree species and forest types (Trosper and Parrotta, 2012; Uprety et al., 2012). The Kitcisakik Algonquin community of western Quebec is concerned by the reduced abundance of white pine on its ancestral territory, mostly due to overharvesting and suppression of surface fires. White pine is a cultural keystone species for the Kitcisakik people

(Uprety et al., 2013). In this paper, we took into account both the cultural setting (Uprety et al., 2013) and ecological constraints (Uprety et al., submitted) inherent to the territory to develop culturally- and ecologically-adapted restoration and management scenarios for white pine. This integrated approach is an addition to a growing body of literature on the inclusion of sociocultural factors in forest management and planning (e.g., Steen-Adams et al., 2011; Jiao et al., 2012; Mason et al., 2012). It will thus be of interest to researchers and foresters working in a variety of ecological and cultural contexts.

4.3 Methods

4.3.1 Study area

The study area is Kitcisakik's ancestral territory (ca. 5000 km^2) located within the boundaries of the Réserve Faunique La Vérendrye in western Quebec, less than 300 km north of Ottawa (Figure 4.1). This area corresponds to the northern limit of continuous white pine distribution in the balsam fir (*Abies balsamea* (L.) Miller) – yellow birch (*Betula alleghaniensis* Britton.) bioclimatic domain (Saucier et al., 1998). The species reaches its absolute northern distribution limit ca. 150 km to the north-west, in the Lake Duparquet and Lake Abitibi regions where scattered stands and trees are present (Bergeron et al., 1997; Engelmark et al., 2000).

Average annual temperature in the study area is 1.2-3.3°C, and average precipitation is 914-1014 mm/year, with 22-33% falling as snow (Val-d'Or and Mont-Laurier weather stations, Environment Canada: http://www.climate.weatheroffice.gc.ca/climate_normals). Mixed forest types are dominant, with balsam fir and yellow birch mostly accompanied by sugar maple (*Acer saccharum* Marsh.), red maple (*Acer rubrum* L.), trembling aspen (*Populus tremuloides* Michx.), paper birch (*Betula papyrifera* Marsh.), black spruce (*Picea mariana* (Mill.) BSP.), white spruce (*Picea glauca* (Moench) Voss), red pine (*Pinus *resinosa* Ait.), jack pine (*Pinus banksiana* Lamb.), and white pine. Since the 1970s, more than 60% of productive forest lands on the Kitcisakik territory have been clearcut by timber companies (Saint-Arnaud et al., 2009) and logging has now replaced fire as the main disturbance in this landscape. Fire cycles of the industrial period were estimated at 2083 years (Bergeron et al., 2006).

The preindustrial forest dynamics was shaped by several disturbance factors including wildfire, spruce budworm outbreaks (*Choristoneura fumiferana* (Clem.)), windthrow (Boucher et al., 2011) and selective logging (Asselin, 1995). Blister rust was introduced at the beginning of the 20th century and weevil damage was also first reported in the early 20th century although the pest was first described in 1817. Crown fire was the main stand replacing disturbance controlling the landscape age structure in the preindustrial forests (fire cycle estimated at 257 years) (Bergeron et al., 2006).

4.3.2 The Kitcisakik community

The study area is the ancestral territory occupied by the ca. 430 members of the Kitcisakik Algonquin community. Until the late 20th century, the community maintained a lifestyle based on hunting, trapping, fishing and gathering that was strongly dependent on the forest. Subsistence activities are still playing a key role in the community (Saint-Arnaud et al., 2009). Young and old white pine trees and stands provide several tangible and intangible benefits to the Kitcisakik community (Uprety et al., 2013). White pine restoration and management on Kitcisakik's ancestral territory should be based on traditional knowledge, and take into account aboriginal needs.

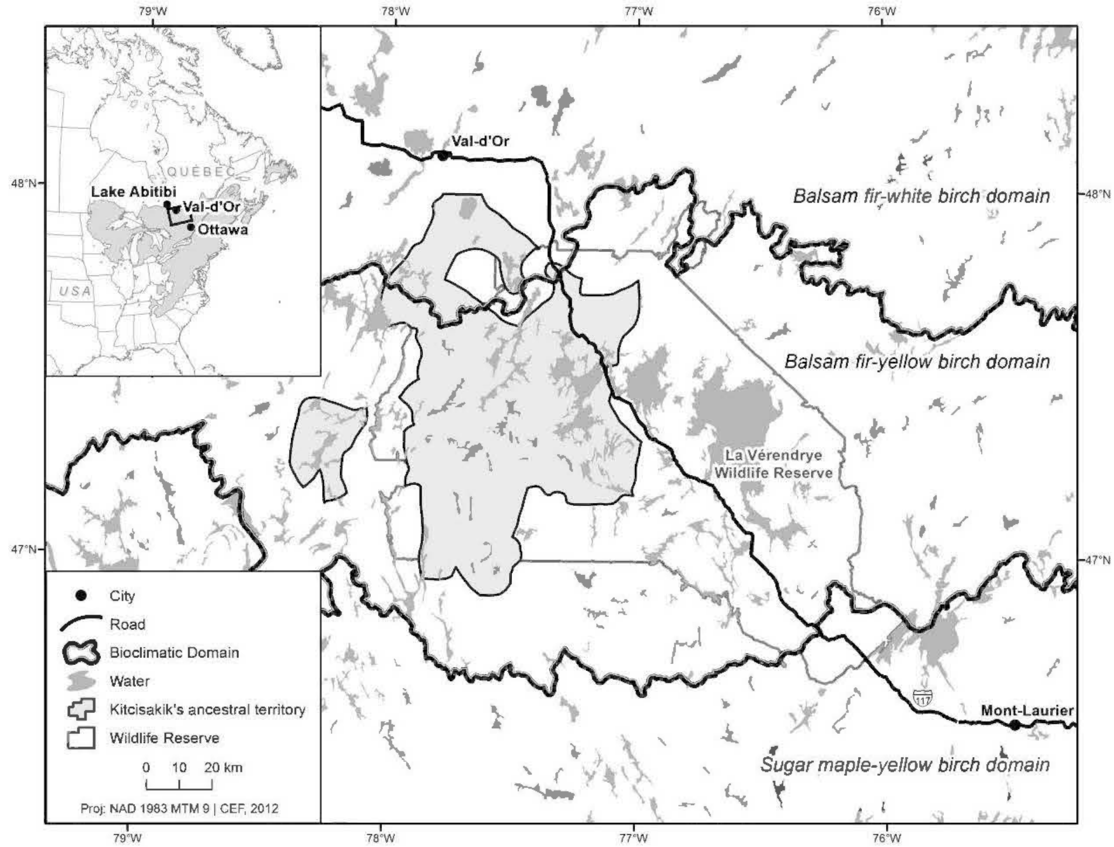

Figure 4.1 Location of Kitcisakik's ancestral territory in western Quebec. The inset shows the distribution of white pine in eastern North America (after Wendel and Smith, 1990).

4.3.3 Developing restoration and management scenarios

This study was conducted in three phases. In the first phase, we compiled information obtained from two previous studies that investigated (1) the cultural importance and traditional ecological knowledge related to white pine (Uprety et al., 2013) and (2) white pine natural regeneration dynamics (Uprety et al., submitted). In the second phase, we reviewed the literature on white pine management. In the third phase, we identified appropriate ecological types for white pine restoration and management and developed culturally- and ecologically-adapted scenarios for the Kitcisakik territory.

4.4 State of knowledge

4.4.1 Cultural importance of white pine to the Kitcisakik Algonquin

The many benefits that the Kitcisakik Algonquin get from white pine (Uprety et al., 2013) can be divided into five broad categories depending on the characteristics of trees or stands that are needed : (1) medicinal uses require scattered white pine individuals of different ages distributed equitably among family hunting grounds; (2) scattered supercanopy white pines, also distributed equitably among family hunting grounds, are used as landmarks and are key habitat elements for some flagship wildlife species; (3) mature pure white pine or white-pine dominated stands of natural origin are key habitat for other flagship wildlife species and are favored resourcing areas used by the Kitcisakik Algonquin; (4) timber production requires pure or white pine-dominated stands originating from plantations; and (5) mixed stands where white pine is a secondary or tertiary component are valued aesthetically and participate in maintaining biodiversity. Different management scenarios will be presented for each of these five cultural needs, on the appropriate ecological types.

4.4.2 Ecology of white pine at its northern limit of continuous distribution

In the study area, most white pine stands are mature (70, 90, and 120 + years) whereas young white pine stands (regeneration and age classes 30 and 50 years) are scarce (Delisle, 2011). White pine occurs as scattered individuals mixed with other tree species, mostly black spruce, balsam fir, red maple, aspen, paper birch, and red pine. Natural white pine regeneration does occur, but in low amounts compared to the central part of its range. Recruitment success is strongly influenced by competitive and inhibitory effects of mature balsam fir. Microsite conditions had a slightly positive effect on white pine regeneration, with moister substrates being more favorable (Uprety et al., submitted).

Vegetation competition, blister rust, weevil, browsing (e.g., by snowshoe hare [*Lepus americanus* Erxl.], moose [*Alces alces* Clin.], or white-tailed deer [*Odocoileus virginianus* Zimm.]), seed predation by squirrels (*Tamiasciurus hudsonicus* Erxl.), and windthrow are potential damaging agents that can limit establishment, growth and survival of white pine. However, these problems were shown to be less important in the study area than further south in the central part of white pine's range (Uprety et al., submitted). Blister rust and weevil damage only occurred in open areas (consistent with Katovich and Mielke (1993)) and were absent under moderate to deep shade. Blister rust could be problematic in hydric sites because of higher abundance of *Ribes* spp. (currant and gooseberries) that serve as alternative hosts (Katovich and Mielke, 1993; Zambino, 2010).

Damage due to the white pine cone beetle (*Conophthorus coniperda* (Schwarz)) and *Armillaria* root disease were also reported in the Lake States (Wendel and Smith, 1990; Katovich et al., 2004; Zenner et al., 2005; Hunt et al., 2010; Ostry et al., 2010), but not in the study area.

White pine regeneration competes for light and nutrients with accompanying vegetation on rich, open sites (Gillespie and Hocker, 1986; Wendel and Smith, 1990; Burgess and Wetzel, 2000; Pitt et al., 2009; Ostry et al., 2010) but the effect is minimal under closed canopy (Uprety et al., submitted). Low browsing in the study area (reported in only 13% of the stands sampled by Uprety et al. (submitted)) could mean that herbivore populations were low, or that there was enough availability of preferred alternative food sources (Pastor, 1992; Saunders and Puettmann, 1999). Seed predation was reported in 45% of the stands (Uprety et al., submitted), but was probably not an important damaging agent, as mast years were expected to counteract this effect (Smith, 1970; Gurnell, 1983; Parker et al., in press).

4.4.3 Restoration and management options for white pine

Natural regeneration or plantation can be used for restoration and management of white pine. In either case, these efforts can benefit from: (1) proper site selection and planning; (2) application of knowledge of the local environment, including climate, soils, topography, vegetation, and animal populations; and (3) timely and appropriate silviculture interventions (Ostry et al., 2010).

4.4.3.1 Site selection

Restoration efforts should be focused on stands or sites known to have previously supported white pine (Uprety et al., 2012, 2013). In the absence of precise information regarding preindustrial distribution of white pine in the study area, an alternative strategy for site selection is to target ecological types where white pine is currently found. Ecological types are a unique combination of information on potential vegetation and abiotic conditions. Current presence of white pine in stands corresponding to a particular ecological type is an indication of this ecological type's suitability as an habitat for white pine. Information about abiotic conditions (soil texture and drainage) are also important to consider (Doyon and Bouillon, 2003) and are included in the ecological types. Although nutrient-rich, mesic sites have the greatest potential for white pine regeneration, these sites present a higher risk from competing vegetation and *Ribes* (Ostry et al., 2010). Therefore, dry to mesic sites and sites having poor to medium nutrient content have been suggested for white pine restoration (Kotar, 1992; Burgess and Wetzel, 2000). Sites with fine-textured soils of high fertility can be highly productive, but only if competition is controlled (Stiell, 1978).

Open canopies permit vegetation competition, and blister rust and weevil damage. Therefore, the best silvicultural practice is to manage white pine under an existing overstory (Pinto, 1992; Katovich and Mielke, 1993; OMNR, 1998). Well-drained and well-aerated sites that are south-facing should be preferred. Such sites favour rapid evaporation of morning dew creating unsuitable conditions for blister rust. Small canopy openings are more susceptible to blister rust as they retain moisture (Van Arsdel, 1969; French, 1992; White et al., 2002). Hence, all topographic conditions and locations that favour persistent dew formation during cool, windless nights, in particular hollows or damp depressions; lower slopes, especially those with a northern exposure; small valleys or small openings surrounded by mature stands; and sites with dense vegetation where *Ribes* form large colonies should be avoided (Coulombe et al., 2004). Sites with heavily overgrown broadleaf forbs, grasses, ferns, shrubs, and woody vegetation – typically post-disturbance sites – are not suitable without site preparation. These vegetation conditions are known to limit air circulation and trap cool night air, thereby promoting high relative humidity and increased dew formation (Hodge et al., 1989).

Intermediate light conditions (33-65%) had considerably low amount of blister rust and weevil damage, while promoting sufficient regeneration in the study area (Uprety et al., submitted). Near 50% light condition is a most often suggested level for keeping balance between protection against pests and proper growth (Logan, 1966; OMNR, 1998; Messier et al., 1999; Burgess et al., 2002). There is a risk, however, for stimulation of competing vegetation (Boucher et al., 2007), suggesting that vegetation control could be needed or that lower light conditions (33-50%) should be preferred. Short term volume losses of white pine grown under shaded conditions are compensated by long term gain as white pine grows taller and larger over time than other tree species present in the study area.

Although *Ribes* spp. can threaten restoration success, their abundance within a stand is not always correlated to local rust damage because the spores can be dispersed over a very long distance (Van Arsdel et al., 1961). *Ribes* control efforts in the past mostly focused on eradication of wild and cultivated *Ribes* but this method is no longer being used as it was difficult, costly and ineffective (Zambino, 2010). However, removal from plantation sites and their close proximity could reduce the hazard (Robbins et al., 1988). New tactics emphasize biocides, biological agents, pruning, and use of silviculture to reduce *Ribes* regeneration (Hunt et al., 2010). Such methods are costly and should thus only be used in high-production plantations aimed at timber production.

4.4.3.2 Site preparation

The objective of site preparation is to create a favorable seedbed and remove competing vegetation. It can be done mechanically, as chemicals and prescribed burning (that are sometimes used, e.g. OMNR, 1998) are prohibited in Quebec. Site preparation is necessary because fire suppression policies have eliminated the chances of natural site preparation. If natural regeneration is targeted, site preparation must coincide with the occurrence of mast years to maximize stocking. Scarification provides an optimum seedbed. Clearing slash and brush is necessary to avoid competition in planting sites in addition to exposing mineral soil (Ostry et al., 2010).

4.4.3.3 Shelterwood system for white pine restoration and management

The uniform shelterwood system is an effective management tool for regenerating white pine where seed trees are present (Lancaster and Leak, 1978; Pinto, 1992; Latremouille et al., 2008). Parent trees provide seeds for regeneration, as well as overstory protection to favour establishment (Burgess et al., 2002). In this system, partial harvests (2-4 passes) are done prior to final or near-complete overstory removal depending on stand age (Pinto, 1992; Burgess and Wetzel, 2000; Burgess et al., 2002; Latremouille et al., 2008) (Table 4.1).

Stands with a white pine basal area greater than 12 m^2/ha and a low component of red pine, spruce, or hardwood species can be managed under the shelterwood system (OMNR, 1998). The selection of seed trees should be based on the following criteria: trees in the dominant or co-dominant crown class; disease-free with clear, straight boles; well-formed crowns, with fine branching; and signs of good growth as evidenced by small, tight bark-flakes and good coverage of foliage on branches (Pinto, 1992).

Table 4.1 Uniform shelterwood system for white pine regeneration (after Burgess et al., 2002).

	Implications
Preparatory cut	Also called thinning. Is used to improve the vigor of prospective seed-bearing trees. Low vigor trees are harvested while larger, healthy trees are retained.
Regeneration cut	Retains the largest, healthiest trees in the stand to be seed sources and to create conditions limiting to blister rust and weevil damage. Additional trees are kept for wildlife habitat such as live cavity, mast and supercanopy trees.
First removal cut	Applied to stands that have sufficient regeneration (at least 30 cm in height) in the understory to form a new white pine stand in the future. Some of the residual trees are harvested mimicking the eventual death of some trees after a natural disturbance such as a fire. Stands may be opened so that 50% crown closure remains after this cut. This creates conditions that reduce blister rust and weevil damage in white pine seedlings.
Final removal cut	Applied when white pine regeneration is about 3 m in height. Some parent trees (usually 10-20 per ha) are retained for ecological (e.g. veterans) and habitat (e.g., mast, supercanopy and cavity trees) value.

Assuming that a regeneration cut is properly timed to coincide with a good seed year (for white pine, good seed crops occur every 3 to 5 years (Wendel and Smith, 1990)), sites should be prepared using mechanical scarification. Exceptional recourse to plantation could be needed if the desired stocking cannot be met by natural germination alone.

4.4.3.4 Underplanting white pine

Underplanting white pine in hardwood, mixedwood, or conifer stands provides moderate shade needed to reduce blister rust and weevil damage with little growth loss. However, shading can reduce growth, vigor and survival of white pine (Messier et al., 1999). Therefore, the overstory should be removed or thinned to promote white pine growth as soon as white pines reach 5 m in height and chances of weevil attacks decrease (Latremouille et al., 2008). Underplanting in balsam fir stands should be avoided as balsam fir shows inhibitory effects on white pine regeneration (Uprety et al., submitted). In aspen stands, thinning level should be low as the species can produce vigorous root suckers after logging (Stiell, 1959). Underplanting in deciduous stands (e.g., birch, aspen, maple, but also eastern larch [*Larix laricina* (Du Roi) K. Koch]) can be problematic, as such sites are dryer in the spring, before leaf growth, and are thus more prone to weevil attacks at the time where adults are more active (Stiell and Berry, 1985).

4.4.3.5 Mixed plantation

Mixed plantation of white pine could be an option in the open or under canopy protection. According to Burgess et al. (2011), some potential was shown for using red pine as a nurse crop for establishing regeneration of white pine and red oak. Mixed plantation is also the preferred restoration option suggested by people from Kitcisakik (Uprety et al., 2013). In this system, the species to be planted and their proportion relative to white pine should be decided carefully. White pine plantation with mixedwood (conifer + hardwood) is recommended, keeping white pine proportion low (1/3). Denser stands attain crown closure more rapidly, creating less favorable conditions for blister rust and weevil but effective management of high density stands will require pre-commercial thinning when trees are 5 m in height

(Latremouille et al., 2008). White pine can compete with thin-crowned species such as paper birch, but not with aspen or maple (Engle, 1951).

In a mixed Norway spruce (*Picea abies* (L.) H. Kars.) – white pine plantation trial (1/3 white pine), weevil preferentially attacked Norway spruce over white pine (Coulombe et al., 2004). Interestingly, weevil attacks do not severely affect wood quality of Norway spruce (Coulombe et al., 2004), keeping good potential from a forestry perspective. Furthermore, in such plantations, commercially valuable spruce can be harvested during the first thinning operation (Coulombe et al., 2004).

4.4.3.6 Pure white pine plantation

Planting white pine in a clearcut, small canopy gap, or in an open field requires weighing the potential for greater tree growth against the threat of increased blister rust and weevil damage (Ostry et al., 2010). Therefore, any attempt to regenerate pure white pine stands in the open will require more intensive silviculture than in shelterwood, underplantation, or mixed plantation. An important practice in pure plantations is to maintain high densities of young white pine until the trees reach about 6 m in height (Katovich and Mielke, 1993). This practice greatly improves the quality and growth of white pine (OMNR, 1998). Moreover, density creates competition and forces rapid height growth with minimal terminal diameter growth unfavorable to weevil. In addition, it causes natural lower branch mortality which favors rust control (Katovich and Mielke, 1993). Retaining more white pine trees could compensate for later blister rust mortality and increase the likelihood of maintaining any resistant trees on the site (Conklin et al., 2009).

4.4.3.6.1 Competing vegetation control

Restoration in high quality sites that are usually prone to vegetation competition requires application of silvicultural techniques to promote regeneration establishment and growth (Stiell et al., 1994). Restoration efforts on clearcut sites should also focus on early management of understory vegetation and the gradual reduction of overtopping cover from woody vegetation (Pitt et al., 2006, 2009). Stand tending is used for early control of competing vegetation which has positive effect on seedling growth by increasing resource availability and negative response on blister rust by altering its microclimate. Since white pines grow relatively slow for the first five years, early vegetation control is critical (Burgess and Wetzel, 2000; Burgess et al., 2002).

Thinning can also be done to remove competition from overtopping aspen and birch (Burgess et al., 2005). Plantation of tall seedlings (~ 50 cm) could be an option to reduce competition.

4.4.3.6.2 Pruning

In regenerating stands, pathological pruning of rust-infected or weevil-attacked twigs can reduce further infection or attacks (French, 1992; Lavallée, 1992). Most fatal blister rust cankers occur in the lower portions of the trees, thus repeated pathological pruning of lower branches can considerably reduce the likelihood of lethal cankers (Katovich and Mielke, 1993). If the rate of infection is above 8% when the trees reach their sixth year, systematic pruning of lower branches is recommended (CFS, 2012). According to Laflamme et al. (1998), pruning in Quebec should be performed yearly until trees reach 4.9 m height.

4.4.3.6.3 Dealing with browsing impact

Although browsing impact is not important in our study area (Uprety et al., submitted), damage severity could change with animal population cycles, availability of alternative food sources, or height of the surrounding vegetation (Krebs et al., 1995; Tester et al., 1997, Saunders and Puettmann, 1999). Eaten terminal shoots and branches cause forked stems, growth loss, and seedling mortality, which consequently delays canopy recruitment, and decreases wood quality (Pastor, 1992; OMNR, 1998; Latremouille et al., 2008). Browsing of lateral branches and buds is usually not detrimental to the health and survival of young white pine. Bud capping (a piece of paper wrapped and stapled around the terminal leader and bud of the tree) is the only method available to protect terminal leader (Ontario Woodlot Association, 2012). This should be done in the fall, before snow covers the ground. Keeping white-tailed deer and snowshoe hare populations under carrying capacity and growing and/or maintaining other preferred food sources are some other alternatives (OMNR, 1998).

4.5 Scenarios for white pine restoration and management

We propose five scenarios to meet the cultural needs for white pine, while taking into account site conditions and white pine autecology (Figure 4.2). There were a total of 198 727 stands in the study area according to the 4th decadal forest inventory of the Quebec Ministry of Natural Resources. Of these, 19 238 were not forested or had unproductive forests (water, islands, rock outcrops, peatlands, etc.). From the remaining 179 489 stands, only 4507 (2.5%) had white pine as 1st, 2nd or 3rd species in importance. However, the corresponding ecological types represented 168 858 stands (94%), thus showing enormous potential for white pine restoration on Kitcisakik's territory.

To develop the restoration and management scenarios, we focused on ecological types that were relatively abundant (i.e., comprising > 100 stands) and where white pine was currently found in ≥ 1% of the stands. Furthermore, we excluded ecological types with subhydric or hydric drainage, as they are susceptible to blister rust. The final list of 16 ecological types comprised 101 124 stands representing 56% of the productive forest stands (Table 4.2).

4.5.1 Scenario I: Scattered individuals of all ages

People from Kitcisakik need naturally-grown young, mature and old white pine trees for medicinal uses (Uprety et al. 2013). No silvicultural intervention is required for this scenario. This only calls for protection of existing white pines and encouragement of natural regeneration. Since scattered trees are enough for this purpose, ecological types that have white pine as a minor component should be targeted (Table 4.2). Mature and old trees have special medicinal properties after having been struck by lightning (Uprety et al. 2013). A special protection should therefore be given to such trees.

4.5.2 Scenario II: Supercanopy pines

Scattered supercanopy white pine trees are required as landmarks and as key habitat elements of some flagship species (bald eagle [*Haliaeetus leucocephalus* L.], black bear [*Ursus americanus* Pal.]). Therefore, in addition to protecting existing supercanopy trees, regeneration of scattered trees by promoting natural regeneration or by plantation should be planned so that future landmark trees will be present on all family hunting grounds. This can be done in all ecological types that support white pine as a minor component.

Table 4.2 Ecological types and suggested scenarios for white pine restoration and management. The light grey part of the table represents potential vegetation and the dark grey part represents the number and percentage of stands of each ecological type where white pine is currently found.

Ecological type (potential vegetation)	Code in inventory data	No. of stands	No. of stands with white pine as 1st component	2nd component	3rd component	Total stands with white pine	% stands with white pine	Scenarios*
Yellow birch, balsam fir, sugar maple on very thin deposits of varied texture with a xeric to hydric drainage	MJ10	296	20	2	19	41	13.85	I, V
Yellow birch, balsam fir, sugar maple on thin to thick medium deposits with a mesic drainage	MJ12	13253	88	45	246	379	2.85	I, II, V
Yellow birch, balsam fir on very thin deposits of varied texture with a xeric to hydric drainage	MJ20	1500	22	24	16	62	4.13	I, V
Yellow birch, balsam fir on thin to thick coarse deposits with a xeric to mesic drainage	MJ21	4459	58	47	131	236	5.19	I, II, V
Yellow birch, balsam	MJ22	39958	547	265	718	1530	3.82	I, II, V

fir on thin to thick medium deposits with a mesic drainage								
Balsam fir, paper birch on thin to thick coarse deposits with a xeric to mesic drainage	MS21	4856	83	35	121	239	4.92	I, II, V
Balsam fir, paper birch on thin to thick medium deposits with a mesic drainage	MS22	5490	21	22	19	62	1.13	II, V
White or red pine on very thin deposits of varied texture with a xeric to hydric drainage	RP10	222	100	61	4	165	74.32	III
White or red pine on thin to thick coarse deposits with a xeric to mesic drainage	RP11	273	149	48	11	208	76.19	III
White or red pine on thin to thick medium deposits with a mesic drainage	RP12	406	251	61	19	331	81.52	III
Balsam fir, eastern white cedar, on very thin deposits of varied texture with a xeric to hydric drainage	RS10	226	5	21	0	26	11.50	I, IV, V

Balsam fir, eastern white cedar, on thin to thick coarse deposits with a xeric to mesic drainage	RS11	302	1	22	0	23	7.61	I, II, IV, V
Balsam fir, eastern white cedar, on thin to thick medium deposits with a mesic drainage	RS12	2901	22	124	0	146	5.03	II, IV
Balsam fir, black spruce on very thin deposits of varied texture with a xeric to hydric drainage	RS20	5520	9	85	0	94	1.70	I, IV, V
Balsam fir, black spruce on thin to thick coarse deposits with a xeric to mesic drainage	RS21	9086	107	102	5	214	2.35	I, II, IV, V
Balsam fir, black spruce on thin to thick medium deposits with a mesic drainage	RS22	12376	49	196	0	245	1.97	II, IV

* see figure 4.2

4.5.3 Scenario III: Mature pure stands of natural origin

Mature white pine stands should be managed as habitat for flagship species (moose [*Alces alces* L.], marten [*Martes americana* Sur.], fisher [*Martes pennanti* Erxl.],wolverine [*Gulo gulo* L.]). Pure or white pine-dominated mature stands are also required by the Kitcisakik Algonquin for resourcing (Uprety et al. 2013). In either case, stands should originate from natural regeneration, as plantations are not always favorable for wildlife (Roy et al., 2010), and are negatively perceived by aboriginal people.

The uniform shelterwood system could be used to restore white pine stands for wildlife habitat, as well as for resourcing purposes. Three of the 16 selected ecological types are dominated by white and red pines and white pine is currently present in 74%-82% of these ecological types (Table 4.2). Since these potential sites are spread evenly on the territory, it provides an opportunity to maintain white pine stands in all family hunting grounds, as well as near settlements.

4.5.4 Scenario IV: Timber production

Pure or white pine-dominated stands are required for timber production. Undercanopy plantations of pure white pine can be done in ecological types with spruce (*Picea* spp.), or eastern white cedar (*Thuja occidentalis* L.) as major components (Table 4.2). Pure white pine plantations can also be done in clearcut sites (but see section 4.4.3.6).

4.5.5 Scenario V: Mixed stands

Mixed stands are valued for aesthetic purposes, as habitat for wildlife, and for their potential to preserve biodiversity. Mixed plantations can be done in all ecological types that support white pine without the species being dominant or codominant.

Figure 4.2 White pine restoration and management framework for the Kitcisakik Algonquin territory.

ABORIGINAL NEEDS	Medicinal use	Orientation and habitat for flagship wildlife species	Resourcing and habitat for flagship wildlife species	Timber production	Others (aesthetic, biodiversity, etc.)
REQUIRED CHARACTERISTICS OF TREES AND STANDS	Scattered young and mature trees	Scattered supercanopy trees	Natural pure stands	Pure or white pine-dominated stands	Mixed stands
RESTORATION AND MANAGEMENT	Conservation of existing young and mature trees and natural regeneration of new trees	Conservation of existing supercanopy trees and natural regeneration or plantation of new trees	Conservation of existing natural stands and natural regeneration of new stands	Plantation	Natural regeneration or mixed plantation
SILVICULTURE	Not required / inappropriate	Scattered plantation	Uniform shelterwood	Under canopy mixed or pure plantation, or pure plantation in open sites	Mixed plantation
LOCATION	On every family hunting ground	On every family hunting ground	On sites where white pines are dominant or co-dominant. Near settlements (resourcing)	Near settlements	On every family hunting ground
SCENARIO*	**I**	**II**	**III**	**IV**	**V**

* See table 4.2

4.6 Conclusion

This paper addressed the call from the Kitcisakik Algonquin community for white pine restoration and management on its ancestral territory. The aim was not to restore white pine everywhere on the territory for industrial purposes, but rather to restore it in ways that would meet the cultural needs expressed by the Kitcisakik community. Four of the 5 proposed scenarios would have low impact on the forest industry as they aim at having scattered white pine individuals in the landscape (I, II, and V), as well as maintaining pure natural white pine stands (III). Scenario IV is labor intensive and costly. However, if done at a small scale in a cultural context, the people from Kitcisakik could contribute to site selection, preparation, management, and monitoring. The responsibility of some of the restoration and management operations on family hunting grounds could be given to community members through the *Aki* Department once guidelines and training are provided. Such community-based approaches have been shown to be efficient, have increased legitimacy, and be more sustainable (Ribot et al., 2006).

Aboriginal peoples' participation, and recognition and inclusion of their knowledge into restoration and management projects can contribute to build a strong partnership for successful implementation that significantly improves social acceptability, economic feasibility and ecological viability of restoration projects (Garibaldi and Turner, 2004; Higgs, 2005; Uprety et al., 2012). Therefore, a shift from "just another stakeholder" to "shared decision makers" (Stevenson and Webb, 2003) is possible. The approach presented here, where restoration and management scenarios take into account cultural needs and ecological constraints, could find wide application in diverse forest settings, as it could help meet the objectives of certification standards (e.g., Forest Stewardship Council – FSC) with regards to the rights and needs of indigenous people.

4.7 Acknowledgements

Thanks to Mélanie Desrochers (Centre for Forest Research, Université du Québec à Montréal) for helping with figure 4.1. The Chaire Desjardins en développement des petites collectivités, the Réseau de recherche et de connaissances relatives aux peuples autochtones (DIALOG), and the Centre de recherche sur la gouvernance des ressources naturelles et du territoire provided financial support for this project.

4.8 References

Abrams, M.D., 2001. Eastern white pine versatility in the presettlement forest. BioScience 51, 967-979.

Asselin, M., 1995. L'Abitibi-Témiscamingue : trois sous-régions, une région, in: O. Vincent (Ed.), Histoire de l'Abitibi-Témiscamingue, Institut québécois de recherche sur la culture, Québec, pp. 21-65.

Barrette, M., Bélanger, L., 2008. Reconstitution historique du paysage préindustriel de la région écologique des hautes collines du Bas-Saint-Maurice. Can. J. For. Res. 37, 1842-1854.

Bergeron, Y., Leduc, A., Li, T., 1997. Explaining the distribution of *Pinus* spp. in a Canadian boreal insular landscape. J. Veg. Sci. 8, 37-44.

Bergeron, Y., Cyr, D., Drever, C.D., Flannigan, M., Gauthier, S., Kneeshaw, D., Lauzon, È., Leduc, A., Le Goff, H., Lesieur, D., Logan, K. 2006. Past, current, and future fire frequencies in Quebec's commercial forests: implications for the cumulative effects of harvesting and fire on age-class structure and natural disturbance-based management. Can. J. For. Res. 36, 2737-2744.

Boucher, J.-F., Bernier, P.Y., Margolis, H.A., Munson, A.D., 2007. Growth and physiological response of eastern white pine seedlings to partial cutting and site preparation. For. Ecol. Manage. 240, 151-164.

Boucher, Y., Bouchard, M., Grondin, P., Tardif, P. 2011. Le registre des états de référence : intégration des connaissances sur la structure, la composition et la dynamique des paysages forestiers naturels du Québec méridional. Mémoire de recherche forestière n° 161. Direction de la recherche forestière, Ministère des Ressources naturelles et de la Faune, Gouvernement du Québec, Québec.

Burgess, D., Wetzel, S., 2000. Nutrient availability and regeneration response after partial cutting and site preparation in eastern white pine. For. Ecol. Manage. 138, 249-262.

Burgess, D., Pinto, F., Wetzel, S., 2002. Some management implications from an eastern white pine regeneration experiment. Technology Transfer Note 28, Forestry Research Applications, Pacific Forestry Centre.

Burgess, D., Robinson, C., Wetzel, S., 2005. Eastern white pine response to release 30 years after partial harvesting in pine mixed wood forest. For. Ecol. Manage. 209, 117-129.

Burgess, D., MacAfee, K., Wetzel, S., Wang, B.S.P., 2011. Annotated bibliography of eastern white (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.): 1960–2007. Natural Resources Canada, Canadian Forest Service, Canadian Wood Fibre Centre, Ottawa.

Canadian Council of Forest Ministers (CCFM), 1992. Sustainable forest: A Canadian commitment. Canadian Council of Forest Ministers, Ottawa.

Canadian Council of Forest Ministers (CCFM), 2008. Measuring our progress: Putting sustainable forest management into practice across Canada and Beyond. Canadian Council of Forest Ministers, Ottawa.

Canadian Forest Service (CFS), 2012. White pine blister rust: knowledge, control and innovation. Canadian Forest Service, Laurentian Forestry Centre, Sainte-Foy, Quebec.

Conklin, D.A., Fairweather, M.L., Ryerson, D.E., Geils, B.W., Vogler, D.R., 2009. White pines, blister rust and management in the Southwest. R3-FH-09-01. Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Southwest Region.

Coulombe, C., Bélanger, G., Lavallée, R., Laflamme, G., 2004. A simple effective tool for controlling white pine weevil and blister rust on Norway spruce and Eastern white pine. Natural Resources Canada, Canadian Forest Service, Laurentian Forestry Centre, Sainte-Foy, Quebec.

Davis, T., 2000. Sustaining the forest, the people, and the spirit. State University of New York Press, Albany.

Delisle, S., 2011. Modèle prédictif d’occurrence du pin blanc sur le territoire des Anicinapek de Kitcisakik. Rapport de projet de fin d'études présenté à la faculté de foresterie, de géographie et de géomatique, Université Laval, Québec.

Doyon, F., Bouillon, D., 2003. Stratégie d’aménagement, de restauration et de conservation du pin blanc et du pin rouge dans l’Outaouais. Institut québécois d'aménagement de la forêt feuillue. Québec.

Engelmark, O., Bergeron, Y., Flannigan, M.D., 2000. Age structure of eastern white pine, *Pinus strobus* L., at its northern distribution limit in Quebec. Can. Field Nat. 114, 601-604.

Engle, L.G., 1951. Releasing white pine from oak and aspen. USDA For. Serv., Lake States For. Expt. Stn., Tech. Note No. 346.

French, D.W., 1992. White pine blister rust can be controlled, in: Stine, R.A., Baughman, M.J. (Eds.), Proceedings of the White Pine Symposium: History, Ecology, Policy and Management, September 16-18, 1992, Duluth, MN. Department of Forestry Resources, University of Minnesota, St. Paul, pp. 123-125.

Garibaldi, A., Turner, N., 2004. Cultural keystone species: implications for ecological conservation and restoration. Ecol. Soc. 9, 1.

Gillespie, A.R., Hocker, H.W., 1986. The influence of competition on individual white pine thinning response. Can. J. For. Res. 16, 1355-1359.

Gurnell, J., 1983. Squirrel numbers and the abundance of tree seeds. Mammal Rev. 13, 133-148.

Higgs, E.S., 1997. What is good ecological restoration? Conserv. Biol. 11, 338-348.

Hodge, J.C., Juzwik, J., Gross, H.L., Retnarkan, A., 1990. White pine blister rust and white pine weevil management: guidelines for white pine in Ontario. Ontario Ministry of Natural Resources, Ontario.

Hunt, R.S., Geils, B.W., Hummer, K.E., 2010. White pines, *Ribes*, and blister rust: integration and action. Forest Pathol. 40, 402-417.

Jiao, Y.M., Li, X.Z., Liang, L.H., Takeuchi, K., Okuro, T., Zhang, D.D., Sun, L.F. 2012. Indigenous ecological knowledge and natural resource management in the cultural landscape of China's Hani Terraces. Ecol. Res. 27, 247-263.

Katovich, S., Mielke, M., 1993. How to manage eastern white pine to minimize damage from blister rust and white pine weevil. NAFR-01-93. USDA Forest Service.

Katovich, S.A., O'Brien, J.G., Mielke, M.E., Ostry, M.E., 2004. Restoration and management of eastern white pine within high blister rust hazard zones in the Lake States, in: Sheppard W.D., Askew, L.G. (Eds.), Silviculture in Special Places, USDA For. Serv, Fort Collins, CO, RMRS-P-34, pp. 135-145.

Kotar, J., 1992. Managing white pine: Finding the proper niche, in: Stine, R.A., Baughman, M.J. (Eds.), Proceedings of the White Pine Symposium: History, Ecology, Policy and Management, Department of Forestry Resources, University of Minnesota, St. Paul, pp. 150-156.

Krebs, C., Boutin, S., Boonstra, R., Sinclair, A., Smith, J., Dale, M. and Turkington, R. 1995. Impact of food and predation on the snowshoe hare cycle. Science, 269: 1112-1115.

Laflamme, G., Blais, R., Desgagné, D. 1998. Control of *Cronartium ribicola* in *Pinus strobus* plantations, in: Jalkanen, R., Crane, P.E., Walla, J.A., Aalto, T. (Eds.), 1st IUFRO Rusts of Forest Trees Working Party Conference, Saariselkä, Finland. Finnish Forest Research Institute. pp. 299-303.

Lancaster, K.F., Leak, W.B. 1978. A silvicultural guide for white pine in the Northeast. Gen. Tech. Rep. NE-41. U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. Broomall, PA.

Latremouille, C., Parker, W.C., McPherson, S., Pinto, F., Fox, B., McKinnon, L., 2008. Ecology and management of white pine in the Lake Abitibi (3E) and Lake Temagami (4E) ecoregions of Ontario. Science Development and Transfer series no. 004. Ministry of Natural Resources, Ontario.

Lavallée, A., 1992. The spread of white pine blister rust in young white pine plantations. Info. Rep. LAU-X-101. Canadian Forestry Service, Laurentian Forestry Centre, Quebec.

Logan, K.T., 1966. Growth of tree seedlings as affected by light intensity. II. red pine, white pine, jack pine and eastern larch. Dep. For., Ottawa, Ont. Tech. Note 121.

Mason, L., White, G., Morishima, G., Alvarado, E., Andrew, L., Clark, F., Durglo, M., Durglo, J., Eneas, J., Erickson, J., Friedlander, M., James, L., Kenning, R., Leighton, A., Pierre, P., Raish, C., Shaw, B., Smallsalmon, S., Stearns, V., Teasley, H., Weingart, M., Wilder, S. 2012. Listening and learning from traditional knowledge and western science: A dialogue on contemporary challenges of forest health and wildfire. J. Forest. 110, 187-193.

Messier, C., Parent, S., Chengaou, M., Beaulieu, J. 1999. Juvenile growth and crown morphological plasticity of eastern white pine (*Pinus strobus* L.) planted along a natural light gradient: Results after six years. For. Chron. 75, 275-279.

Ontario Ministry of Natural Resources (OMNR), 1998. A silvicultural guide for the Great Lakes-St Lawrence conifer forest in Ontario. Queens's Printer, Ontario.

Ontario Woodlot Association, 2012. Protecting white pine from deer feeding (browsing) Available from: http://www.ont-woodlot-assoc.org/sw_protecting_pine_from_deer.html (accessed 4 December 2012).

Ostry, M.E., Laflamme, G., Katovich, S.A., 2010. Silvicultural approaches for management of eastern white pine to minimize impacts of damaging agents. Forest Pathol. 40, 332-340.

Parker, W.C., Noland, T.L., Morneault. A.E., (in press). Comparative mast seed production in unmanaged and shelterwood white pine (*Pinus strobus* L.) stands in central Ontario. New Forest DOI 10.1007/s11056-013-9366-8

Pastor, J., 1992. Browsing damage to white pine, in: Stine, R.A., Baughman, M.J. (Eds.), Proceedings of the White Pine Symposium: History, Ecology, Policy and Management, Department of Forestry Resources, University of Minnesota, St. Paul, pp. 137-144.

Pinto, F., 1992. Silvicultural practices in Ontario's white pine forests, in: Stine, R.A., Baughman, M.J. (Eds.), Proceedings of the White Pine Symposium: History, Ecology, Policy and Management, Department of Forestry Resources, University of Minnesota, St. Paul, pp. 170-178.

Pinto, F., Romaniuk, S., Ferguson, M., 2008. Changes to preindustrial forest tree composition in central and northeastern Ontario, Canada. Can. J. For. Res. 38, 1842-1854.

Pitt, D.G., Meyer, T., MacDonald, L., Buscarini, T., Thompson, D.G., 2006. Application of slow-release tablets to enhance white pine regeneration: growth response and efficacy against white pine blister rust. Can. J. For. Res. 36, 684-698.

Pitt, D.G., Morneault, A., Parker, W.C., Stinson, A., Lanteigne, L., 2009. The effects of herbaceous and woody competition on planted white pine in a clearcut site. For. Ecol. Manage. 257, 1281-1291.

Ribot, J.C., Agrawal, A., Larson, A.M., 2006. Recentralizing while decentralizing: How national governments reappropriate forest resources. World Develop. 34, 1864-1886.

Robbins, K., Jackson, W.A., McRoberts, R.E., 1988. White pine blister rust in the eastern Upper Peninsula of Michigan. North. J. Appl. For. 5, 263-264.

Rogers, L.L., Lindquist, E.L., 1992. Supercanopy white pine and wildlife, in: Stine, R.A., Baughman, M.J. (Eds.), Proceedings of the White Pine Symposium: History, Ecology, Policy and Management, Department of Forestry Resources, University of Minnesota, St. Paul, pp. 39-43.

Roy, C., Imbeau, L., Mazerolle, M.J., 2010. Transformation of abandoned farm fields into coniferous plantations: Is there enough vegetation structure left to maintain winter habitat of snowshoe hares? Can. J. Zool. 88, 579-588.

Saint-Arnaud, M., 2009. Contribution à la définition d'une foresterie autochtone : le cas des Anicinapek de Kitcisakik (Québec). Ph.D. thesis, Université du Québec à Montréal, Québec.

Saint-Arnaud, M., Asselin, H., Dubé, C., Croteau, Y., Papatie, C., 2009. Developing criteria and indicators for aboriginal forestry: mutual learning through collaborative research, in: Stevenson, M.G., Natcher, D.C. (Eds.), Changing the Culture of Forestry in Canada: Building Effective Institutions for Aboriginal Engagement in Sustainable Forest Management. Canadian Circumpolar Institute Press, pp. 85-105.

Saucier, J.-P., Bergeron, J.-P., Grondin, P., Robitaille, A., 1998. Les régions écologiques du Québec méridional (troisième version). L'Aubelle 124, S1-S12.

Saunders, M.R., Puettmann, K.J., 1999. Use of vegetational characteristics and browsing patterns to predict deer damage in eastern white pine (*Pinus strobus*) plantations. North. J. Appl. For. 16, 96-102.

Schroeder, H.W., 1992. The tree of peace: symbolic and spiritual values of the white pine, in: Stine, R.A., Baughman, M.J. (Eds.), Proceedings of the White Pine Symposium: History, Ecology, Policy and Management, Department of Forestry Resources, University of Minnesota, St. Paul, pp.73-83.

Smith, C.C., 1970. The coevolution of pine squirrels (*Tamiasciurus*) and conifers. Ecol. Monogr. 40, 349-371.

Steen-Adams, M.M., Langston, N., Mladenoff, D.J., 2007. White pine in the northern forests: An ecological and management history of white pine on the Bad River Reservation of Wisconsin. Environ. Hist. 12, 614-648.

Steen-Adams, M.M., Mladenoff, D.J., Langston, N.C., Liu, F., Zhu, J., 2011. Influence of biophysical factors and differences in Ojibwe reservation versus Euro-American social histories on forest landscape change in northern Wisconsin, USA. Landscape Ecol. 26, 165-1178.

Stevenson, M.G., Webb, J., 2003. Just another stakeholder? First Nations and sustainable forest management in Canada's boreal forest, in: Burton, P.J., Messier, C., Smith D.W., Adamowicz, W.L., (Eds.), Towards Sustainable Management of the Boreal Forest, NRC Research Press, Ottawa, Ontario, Canada, pp. 65-112.

Stiell, W.M., 1959. Seeding and planting red pine and white pine. Tech. Note No. 80. Can. Dept. Nor. Aff. and Nat. Resour., For. Br. For. Res. Div. Ottawa.

Stiell, W.M., 1978. Characteristics of eastern white pine and red pine, in: Cameron, D.A. (comp.). White and Red Pine Symposium. Dept. Environ, Can. For. Serv., Sault Ste. Marie, ON, pp. 7-51.

Stiell, W.M., Berry, A.B., 1985. Limiting white pine weevil attacks by side shade. For. Chron. 61, 5-9.

Stiell, W.M., Robinson, C.F., Burgess, D., 1994. 20-year growth of white pine following commercial improvement cut in pine mixedwoods. For. Chron. 70, 385-394.

Tester, J.R., Starfield, A.M., Frelich, L.E., 1997. Modeling for ecosystem management in Minnesota pine forest. Biol. Conserv. 80, 313-324.

Tikina, A.V., Innes, J.L., Trosper, R.L., Larson, B.C., 2010. Aboriginal peoples and forest certification: a review of the Canadian situation. Ecol. Soc. 15, 33.

Trosper, R.L., 2007. Indigenous influence on forest management on the Menominee Indian Reservation. For. Ecol. Manage. 249, 134-139.

Trosper, R.L., Parrotta, J.A. (Eds.), 2012. Traditional forest-related knowledge: Sustaining communities, ecosystems and biocultural diversity. World Forest XII, IUFRO, The Christensen Fund and Springer.

Uprety, Y., Asselin, H., Bergeron, Y., 2013. Cultural importance of white pine (*Pinus strobus* L.) to the Kitcisakik Algonquin community of western Quebec, Canada. Can. J. For. Res. 43, 544-551.

Uprety, Y., Asselin, H., Bergeron, Y., Mazerolle, M.J., submitted. White pine (*Pinus strobus* L.) regeneration dynamics at the species' northern limit of continuous distribution.

Uprety, Y., Asselin, H., Bergeron, Y., Doyon, F., Boucher, J.-F., 2012. Contribution of traditional knowledge to ecological restoration: Practices and applications. Ecoscience, 19, 225-237.

Van Arsdel, E.P., 1969. Environment in relation to white pine blister rust infection, in: Hoff, R.J., McDonald, G.I., (Program Coordinators). Biology of Rust Resistance in Forest Trees: Proceedings of a NATO-IUFRO Advanced Study Institute. USDA For. Serv., Washington DC, Misc. Pub. No. 1221. pp. 479-493.

Van Arsdel, E.P., Riker, A.J., Kouba, T.F., Suomi, V.E., Bryson, R.A., 1961. The climatic distribution of blister rust on white pine in Wisconsin. Stn. Pap. 87. U.S. Department of Agriculture, Forest Service, Lake States Forest Experiment Station, St. Paul.

Wendel, G.W., Smith, H.C., 1990. *Pinus strobus* L., Eastern white pine, in: Burns, R.M., Honkala, B.H. (Eds.), Silvics of North America, Vol. 1, Conifers, U.S.D.A. For. Serv. Agric. Handbk. 654, Washington, D.C.

White, M.A., Brown, T.N., Host, G.E., 2002. Landscape analysis of risk for white pine blister rust in the Mixed Forest Province of Minnesota, U.S.A. Can. J. For. Res. 32, 1639-1650.

Wyatt, S. 2008. First Nations, forest lands, and “aboriginal forestry” in Canada: from exclusion to comanagement and beyond. Can. J. For. Res. 38, 171-180.

Wyatt, S., Merrill, S., Natcher, D., 2011. Ecosystem management and forestry planning in Labrador: how does aboriginal involvement affect management plans? Can. J. For. Res. 41, 2247-2258.

Zambino, P.J., 2010. Biology and pathology of *Ribes* and their implications for management of white pine blister rust. Forest Pathol. 40, 264-291.

Zenner, E.K., Puettmann, K.J., Krueger, J.A., 2005. Early growth responses of naturally regenerated eastern white pine (*Pinus strobus* L.) to partial release from juvenile aspen and pathological pruning. North. J. Appl. For. 22, 27-34.

CHAPTER V

GENERAL CONCLUSION

Under the new paradigm of sustainable forest management, industry and governments increasingly recognize the importance of including different interests and perspectives from various stakeholders in the planning process. One of the key stakeholders in sustainable forest management are aboriginal communities whose concerns, knowledge and values have received growing attention in recent years (Trosper and Parrotta 2012). Aboriginal perspectives and traditional knowledge should be taken into account in forest management, together with ecological knowledge (Stevenson 2005). This doctoral dissertation has advanced this approach of forest management by providing a concrete example of how aboriginal perspectives and ecological knowledge can be integrated into a culturally-adapted restoration and management scenario.

5.1 White pine as a cultural keystone species

The cultural importance of tree species and forest stands to aboriginal people from Canada has so far received little attention from scholars compared to other cultural groups around the world (Berkes and Davidson-Hunt 2006). We documented the cultural and spiritual importance and the traditional ecological knowledge relating to white pine in the Kitcisakik Algonquin community of western Quebec (chapter II). We showed the interaction between white pine trees and forests, and cultural and spiritual life of aboriginal people. Besides cultural and spiritual significance, people from Kitcisakik obtained several other tangible and intangible benefits from white pine. By using a framework developed by Garibaldi and Turner (2004) we concluded that white pine is a cultural keystone species to the Kitcisakik Algonquin community. This might be a reason why people from Kitcisakik are concerned about white pine decline and have been calling for its restoration and sustainable management on their ancestral territory. Their suggestions regarding restoration options, like targeting sites that previously supported white pine or using mixed plantations, closely matched ecological knowledge. Traditional knowledge and science should be used in complementarity (Rist et al. 2010) and we thus recommended that the intrinsic ecological worth and cultural and spiritual significance of white pine as perceived by the Kitcisakik Algonquin community should be included in forest restoration and management.

5.2 Regeneration dynamics of white pine

Chapter III fulfilled an important research gap about white pine regeneration dynamics at the species' northern limit of continuous distribution. We recorded low, but continuous white pine regeneration. We found that recruitment success was strongly influenced by competitive and inhibitory effects of mature balsam fir, and that regeneration was more abundant than expected on moister substrates. The occurrence of blister rust and weevil was much lower than expected based on the risk maps produced by the Ministry of Natural Resources. We also showed that remnant stands had a significant effect on the spatial distribution of white pine regeneration in logged areas. Hence, the northern limit of continuous distribution could support white pine restoration if mesic to moist sites are targeted, but only under moderate shade so as to minimize the risk of blister rust occurrence.

5.3 Culturally-adapted white pine restoration and management

Chapter IV presented culturally- and ecologically-adapted white pine restoration and management scenarios for the Kitcisakik ancestral territory by taking into account cultural needs (Chapter II) and ecological constraints (Chapter III) at the species' northern limit of continuous distribution. We showed a high potential for restoration using simple silvicultural techniques separated into five scenarios aiming at fulfilling different cultural needs on different ecological types.

5.4 Future perspectives

This study suggested culturally- and ecologically-adapted scenarios to restore and sustainably manage white pine at its northern limit of continuous distribution. The scenarios do not take into account the effect of climate change and this should be investigated. Further research will also be needed to develop tools to integrate the roles and responsibilities of the various stakeholders present on the territory (aboriginal people, forestry companies, government officials, outfitters, etc.). Site selection and the spatial scale of restoration efforts are two important issues that should be addressed jointly by the stakeholders. Experimental logging and plantations could help test the different scenarios with respect to their economic feasibility and to their potential to effectively meet the needs of aboriginal people. Experimental plantations could also be tested north of the present northern limit of continuous distribution, as assisted migration might be necessary to cope with climate change.

Some of the scenarios presented here would require important investments, not only financial, but also in time. The new forestry legislation in Quebec introduced the concept of "proximity forestry", that could allow aboriginal people to play a greater role in forest management, in accordance with their knowledge, needs, and views.

Future research endeavors should aim at developing tools to help decision-making and favor integrated management in an intercultural context.

5.5 References (for General Introduction and General Conclusion)

Abrams, M.D. 2001. Eastern white pine versatility in the presettlement forest. *BioScience*, 51: 967-979.

Ahlgren, C.E. 1976. Regeneration of red and white pine following wildfire and logging in northeastern Minnesota. *Journal of Forestry,* 74: 135-140.

Anonymous. 1993. Flora of North America Vol. 2. Flora of North America Editorial Committee, Oxford University Press, New York, pp. 379-380.

Asselin, M. 1995. L'Abitibi-Témiscamingue : trois sous-régions, une région. *In* Histoire de l'Abitibi-Témiscamingue. *Edited by* O. Vincent. Institut québécois de recherche sur la culture. pp. 21-65.

Belyea, R.M. and Sullivan, C.R. 1956. The white pine weevil: a review of current knowledge. *Forestry Chronicle*, 32: 58-67.

Bergeron, Y., Leduc, A. and Li, T. 1997. Explaining the distribution of *Pinus* spp. in a Canadian boreal insular landscape. *Journal of Vegetation Science,* 8: 37-44.

Berkes, F. 2008. Sacred Ecology. Second edition, Routledge, New York.

Berkes, F. and Davidson-Hunt, I.J. 2006. Biodiversity, traditional management systems, and cultural landscapes: Examples from the boreal forest of Canada. *International Social Science Journal,* 58(187): 35-47.

Berkes, F., Colding, J. and Folke, C. 2000. Rediscovery of traditional ecological knowledge as adaptive management. *Ecological Applications*, 10(5): 1251-1262.

Boucher, J. F., Bernier, P. Y., Margolis, H. A. and Munson, A.D. 2007. Growth and physiological response of eastern white pine seedlings to partial cutting and site preparation. *Forest Ecology and Management*, 240: 151-164.

Buchert, G.P. 1994. Genetics of white pine and implications for management and conservation. *Forestry Chronicle*, 70: 427-434.

Burgess, D. and Wetzel, S. 2000. Nutrient availability and regeneration response after partial cutting and site preparation in eastern white pine. *Forest Ecology and Management*, 138: 249-262.

Burgess, D., Robinson, C. and Wetzel, S. 2005. Eastern white pine response to release 30 years after partial harvesting in pine mixed wood forest. *Forest Ecology and Management*, 209: 117-129.

Cheveau, M., Imbeau, L., Drapeau, P. and Bélanger, L. 2008. Current status and future directions of traditional ecological knowledge in forest management: A review. *Forestry Chronicle,* 84(2): 231-243.

Colombo, S.J. 2008. Ontario's forests and forestry in a changing climate. Climate Change research Report 12, Ontario Ministry of Natural Resource, Ontario.

Daoust, G. and Beaulieu, J. 2004. Genetics, breeding, improvement and conservation of *Pinus strobus* in Canada. In: Breeding and Genetic Resources of Five-Needles Pines: Growth, Adaptability and Pest Resistance, United States Department of Agriculture, Proceedings RMRS-P-32. pp. 3-11.

Delwaide, A. and Filion, L. 1999. Dendrosérie du pin blanc (*Pinus strobus* L.) et de la pruche de l'est (*Tsuga canadensis* L. [Carr.]) dans la région de Québec. *Géographie physique et Quaternaire,* 53: 265-275.

Dovčiak, M., Reich, P.B. and Frelich, L.E. 2003. Seed rain, safe sites, competing vegetation, and soil resources spatially structure white pine regeneration and recruitment. *Canadian Journal of Forest Research,* 33: 1892-1904.

Doyon, F. and Bouillon, D. 2003. Stratégie d'aménagement, de restauration et de conservation du pin blanc et du pin rouge dans l'Outaouais. Institut québécois d'aménagement de la forêt feuillue (IQAFF), 10 pp.

Engelmark, O., Bergeron, Y. and Flannigan, M.D. 2000. Age structure of eastern white pine, *Pinus srtobus* L., at its Northern distribution limit in Québec. *Canadian Field-Naturalist*, 114 (4): 601-604.

Foster, S. and Duke J.A. 2000. A field guide to medicinal plants and herbs of eastern and central North America. Houghton Mifflin Company, New York.

Francis, J.K. 1979. Species-site suitability of shortleaf, white and Virginia pine. In: Proceedings of the Workshop on Management of Pines of the Interior South. USDA Forestry Service, Technical Publication SA-TP-2, Southeast Area State and Private Forestry, Atlanta, GA, pp. 63-71.

Frelich, L.E. 1992. The relationship of natural disturbances in white pine stand development. In: Stine, R. A. and Baughman, M. J. (Eds.), Proceedings of the White Pine Symposium: History, Ecology, Policy and Management, September 16-18, 1992, Duluth, MN. Department of Forestry Resources, University of Minnesota, St. Paul, pp. 27-37.

Garibaldi, A. and Turner, N. 2004. Cultural keystone species: Implications for ecological conservation and restoration. *Ecology and Society*, 9(3): 1.

Gouvernement du Québec. 2010. Loi sur l'aménagement durable du territoire forestier. Trente-neuvième législature, première session. Éditeur officiel du Québec.

Hall, R.I., Duff, K.E. and Quinby, P.A. 1994. A 10,000 year vegetation history of the Temagami Region of Ontario with special emphasis on white pine. Ancient Forest Research Report No. 4.

Heckman, S.T. 1992. White pine management on the Menominee and its evolutionary process. In: Stine, R. A. and Baughman, M. J. (Eds.), Proceedings of the White Pine Symposium: History, Ecology, Policy and Management, September 16-18, 1992, Duluth, MN. Department of Forestry Resources, University of Minnesota, St. Paul, pp. 157-167.

Heinselman, M.L. 1981. Fire intensity and frequency as factors in the distribution and structure of northern ecosystems, in: Proceedings of the Conference Fire Regimes and Ecosystem Properties. U.S. Forest Service General Technical Report WO-26, pp. 7-57.

Holla, T.A. and Knowles, P. 1988. Age structure analysis of a virgin white pine, *Pinus strobus*, population. *Canadian Field-Naturalist,* 102: 221-226.

Hunt, R.S. 2003. White pine blister rust. *Recent Research Development in Mycology,* 1: 73-85.

IPCC. 2007. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp.

Jacobson, G.L. 1992. A 7000 year history of white pine. In: Stine, R. A. and Baughman, M. J. (Eds.), Proceedings of the White Pine Symposium: History, Ecology, Policy and Management, September 16-18, 1992, Duluth, MN. Department of Forestry Resources, University of Minnesota, St. Paul, pp. 19-26.

Kriebel, H.B. 2004. Genetics and breeding of five-needle pines in the eastern United States. In: Breeding and Genetic Resources of Five-Needles Pines: Growth, Adaptability and Pest Resistance, United States Department of Agriculture, Proceedings RMRS-P-32.

Lancaster, K.F. and Leak, W.B. 1978. A silvicultural guide for white pine in the Northeast. Gen. Tech. Rep. NE-41. U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. Broomall, PA.

Latremouille, C., Parker, W.C., McPherson, S., Pinto, F., Fox, B. and McKinnon, L. 2008. Ecology and management of white pine in the Lake Abitibi (3E) and

Lake Temagami (4E) ecoregions of Ontario. Science Development and Transfer series no. 004. Ministry of Natural Resources, Ontario, 79 pp.

Lavallée, A. 1986. Zones de vulnérabilité du pin blanc à la rouille vésiculeuse au Québec. *Forestry Chronicle,* 62: 24-28.

Leroux, J., Chamberland, R., Brazeau, E. and Dubé, C. 2004. Au pays des peaux de chagrin : Occupation et exploitation territoriale à Kitcisakik (Grand-Lac-Victoria) au XX[e] siècle. Presses de l'Université Laval, Quebéc.

Liu, K.B. 1990. Holocene paleoecology of the boreal forest and Great Lakes-St. Lawrence Forest in Northern Ontario. *Ecological Monographs*, 60(2): 179-212.

Major, J. E., Mosseler, A., Barsi, D.C., Clouthier, A. and Campbell, M. 2009. Impact of three silvicultural treatments on weevil incidence, growth, phenology, and branch level dynamics of *Pinus strobus* from large and small populations. *Canadian Journal of Forest Research*, 39: 12-25.

Ontario Ministry of Natural Resources (OMNR). 1998. A silvicultural guide for the Great Lakes-St Lawrence conifer forest in Ontario. Queens's Printer, Ontario.

Ontario Ministry of Natural Resources (OMNR). 2008. State of the resource reporting. Regional report: White pine in the lake Abitibi and lake Temagami ecoregions of Ontario. Ministry of Natural Resources, Ontario, 10 pp.

Ostry, M.E., Laflamme, G. and Katovich, S.A. 2010. Silvicultural approaches for management of eastern white pine to minimize impacts of damaging agents. *Forest Pathology,* 40: 332-340.

Palmer, M.A., Falk, D.A. and Zedler, J.B. 2008. Foundations of Restoration Ecology. Society for Ecological Restoration International. Island Press.

Parker, W.C., Colombo, S.J., Flannigan, M.D., Cherry, M.L., Greifenhagen, S., McAlpine, R.A., Papadopol, C.S., and Scarr, T. 2000. Third millennium forestry: What climate change might mean to forests and forest management in Ontario. *Forestry Chronicle*, 76: 445-463.

Perrow, M.R. and Davy, A.J. 2002. Handbook of Ecological Restoration Vol 1. Cambridge University Press.

Pinto, F. 1992. Silvicultural practices in Ontario's white pine forests. In: Stine, R. A., Baughman, M. J. (Eds.), Proceedings of the White Pine Symposium: History, Ecology, Policy and Management, September 16-18, 1992, Duluth, MN. Department of Forestry Resources, University of Minnesota, St. Paul, pp. 170-178.

Pinto, F., Romaniuk, S. and Ferguson, M. 2008. Changes to preindustrial forest tree composition in central and northeastern Ontario, Canada. *Canadian Journal of Forest Research,* 38: 1842-1854.

Pitt, D.G., Morneault, A., Parker, W.C., Stinson, A. and Lanteigne, L. 2009. The effects of herbaceous and woody competition on planted white pine in a clearcut site. *Forest Ecology and Management,* 257: 1281-1291.

Price, R.A., Liston, A. and Strauss, S. H. 1998. Phylogeny and systematics of *Pinus*. In: Richardson, D.M. (Ed.), Ecology and biogeography of *Pinus*. Cambridge University Press, Cambridge, UK, pp. 49-68.

Ramakrishnan, P.S. 2009. Linking traditional ecological knowledge with modern approaches. Biodiversity and Climate Change in the Himalayas, International Centre for Integrated Mountain Development, Kathmandu.

Richard, P. J. H. 1995. Le couvert végétal du Québec-Labrador il y a 6000 ans BP : essai. *Géographie physique et Quaternaire*, 49: 117-140.

Rist, L., Shaankar, R.U., Milner-Gulland, E.J. and Ghazoul. J. 2010. The use of traditional ecological knowledge in forest management: An example from India. *Ecology and Society,* 15(1): 3.

Rogers, L.L. and Lindquist, E.L. 1992. Supercanopy white pine and wildlife. In: Stine, R.A. and Baughman, M.J. (Eds.), Proceedings of the White Pine Symposium: History, Ecology, Policy and Management, September 16-18, 1992, Duluth, MN. Department of Forestry Resources, University of Minnesota, St. Paul, pp. 39-43.

Saint-Arnaud, M., Asselin, H., Dubé, C., Croteau, Y. and Papatie, C. 2009. Developing criteria and indicators for aboriginal forestry: mutual learning through collaborative research. In: Stevenson, M.G. and Natcher D.C. (Eds.), Changing the Culture of Forestry in Canada: Building Effective Institutions for Aboriginal Engagement in Sustainable Forest Management, Volume I. Canadian Circumpolar Institute Press.

Saucier, J.-P., Bergeron, J.-P., Grondin, P. and Robitaille, A. 1998. Les régions écologiques du Québec méridional (troisième version). L'Aubelle 124: S1-S12.

Schroeder, H.W. 1992. The tree of peace: symbolic and spiritual values of the white pine. In: Stine, R.A. and Baughman, M.J. (Eds.), Proceedings of the White Pine Symposium: History, Ecology, Policy and Management, September 16-18, 1992, Duluth, MN. Department of Forestry Resources, University of Minnesota, St. Paul, pp.73-83.

Schulte, L. A., D. J. Mladenoff, T. R. Crow, L. C. Merrick, and D. T. Cleland. 2007. Homogenization of northern US Great Lakes forests due to land use. *Landscape Ecology*, 22:1089-1103.

Shebitz, D. 2005. Weaving traditional ecological knowledge into the restoration of basketry plants. *Journal of Ecological Anthropology,* 5: 51-68.

Simard, M.-J., Bergeron, Y. and Sirois, L. 2003. Substrate and litterfall effects on conifer seedling survivorship in southern boreal stands of Canada. *Canadian Journal of Forest Research,* 33: 672-681.

Stearns, F. 1992. Ecological characteristics of white pine. In: Stine, R.A. and Baughman, M.J. (Eds.), Proceedings of the White Pine Symposium: History, Ecology, Policy and Management, September 16-18, 1992, Duluth, MN. Department of Forestry Resources, University of Minnesota, St. Paul, pp.10-18.

Steen-Adams, M.M., Langston, N. and Mladenoff, D.J. 2007. White pine in the Northern Forests: An Ecological and Management History of White Pine on the Bad River Reservation of Wisconsin. *Environmental History*, 12: 614-648.

Stevenson, M. 2005. Traditional knowledge and sustainable forest management. Sustainable Forest Management Network. Edmonton, Alberta, 18 pp.

Stiell, W.M., Robinson, C.F. and Burgess, D. 1994. 20-year growth of white pine following commercial improvement cut in pine mixedwoods. *The Forestry Chronicle*, 70: 385-394.

Terasmae, J. and Anderson, T.W. 1970. Hypsithermal range extension of white pine *(Pinus strobus* L.) in Quebec, Canada. *Canadian Journal of Earth Sciences*, 7: 406-413.

Tester, J.R., Starfield, A.M. and Frelich, L.E. 1997. Modeling for ecosystem management in Minnesota pine forest. *Biological Conservation*, 80: 313-324.

Trosper, R.L. and Parrotta, J.A. (eds). 2012. Traditional forest-related knowledge: Sustaining communities, ecosystems and biocultural diversity. World Forest XII, IUFRO, The Christensen Fund and Springer.

Uprety, Y., Asselin, H., Dhakal, A. and Julien, N. 2012a. Traditional use of medicinal plants by aboriginal people of boreal Canada: Review and perspectives. *Journal of Ethnobiology and Ethnomedicine,* 8: 7.

Uprety, Y., Asselin, H., Bergeron, Y., Doyon, F. and Boucher, J.-F. 2012b. Contribution of traditional knowledge to ecological restoration: Practices and applications. *Ecoscience,* 19: 225-237.

Wendel, G.W. and Smith, H.C. 1990. *Pinus strobus* L., Eastern white pine. In: R.M. Burns and B.H. Honkala (Eds.), Silvics of North America, Vol. 1, Conifers, U.S.D.A. For. Serv. Agric. Handbk. 654, Washington, D. C.

Wetzel, S. and Burgess, D. 2001. Understorey environment and vegetation response after partial cutting and site preparation in *Pinus strobus* L. stands. *Forest Ecology and Management*, 151: 43-59.

Weyenberg, S.A., Frelich, L.E. and Reich, P.B. 2004. Logging versus fire: how does disturbance type influence the abundance of *Pinus strobus* regeneration? *Silva Fennica,* 38(2): 179-194.

White, M.A., Brown, T.N. and Host G.E. 2002. Landscape analysis of risk factors for white pine blister rust in the Mixed Forest Province of Minnesota, U.S.A. *Canadian Journal of Forestry Research*, 32: 1639-1650.

Whitney, G.G. 1987. An ecological history of the Great Lakes forest of Michigan. *Journal of Ecology*, 75: 667-684.

Williams, D.W., Long, R.P., Wargo, P.M., and Liebhold, A.M. 2000. Effects of climate change on forest insect and disease outbreaks. In: Mickler, R., Birdsey, R. A. and Hom, J. (Eds.) Responses of Northern U.S. Forests to Climate Change. Springer-Verlag, New York, N.Y. Ecol. Stud. Vol. 139. pp 455-494.

Woodley, E. 1991. Indigenous ecological knowledge systems and development. *Journal of Agriculture and Human Values,* 8: 173-178.

Wyatt, S., Merrill, S. and Natcher, D. 2011. Ecosystem management and forestry planning in Labrador: how does aboriginal involvement affect management plans? *Canadian Journal of Forest Research,* 41: 2247-2258.

Zambino, P.J. 2010. Biology and pathology of *Ribes* and their implications for management of white pine blister rust. *Forest Pathology,* 40: 264-291.