STAND STRUCTURE DIFFERENCES RESULTING FROM POST-HARVEST SILVICULTURE IN BOREAL MIXEDWOODS

by

Daniel Corbett

A thesis submitted in partial fulfillment for the requirements of the degree of

Master of Science in Forestry

Lakehead University

Faculty of Forestry and the Forest Environment

April 2007

Library and
Archives Canada

Published Heritage
Branch

395 Wellington Street
Ottawa ON K1A 0N4
Canada

Bibliothèque et
Archives Canada

Direction du
Patrimoine de l'édition

395, rue Wellington
Ottawa ON K1A 0N4
Canada

Your file Votre référence
ISBN: 978-0-494-31851-5
Our file Notre référence
ISBN: 978-0-494-31851-5

NOTICE:
The author has granted a non-exclusive license allowing Library and Archives Canada to reproduce, publish, archive, preserve, conserve, communicate to the public by telecommunication or on the Internet, loan, distribute and sell theses worldwide, for commercial or non-commercial purposes, in microform, paper, electronic and/or any other formats.

The author retains copyright ownership and moral rights in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

AVIS:
L'auteur a accordé une licence non exclusive permettant à la Bibliothèque et Archives Canada de reproduire, publier, archiver, sauvegarder, conserver, transmettre au public par télécommunication ou par l'Internet, prêter, distribuer et vendre des thèses partout dans le monde, à des fins commerciales ou autres, sur support microforme, papier, électronique et/ou autres formats.

L'auteur conserve la propriété du droit d'auteur et des droits moraux qui protège cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

In compliance with the Canadian Privacy Act some supporting forms may have been removed from this thesis.

While these forms may be included in the document page count, their removal does not represent any loss of content from the thesis.

Conformément à la loi canadienne sur la protection de la vie privée, quelques formulaires secondaires ont été enlevés de cette thèse.

Bien que ces formulaires aient inclus dans la pagination, il n'y aura aucun contenu manquant.

Canada

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

In presenting this Thesis in partial fulfillment of the requirements for the degree of Master of Science in Forestry at Lakehead University in Thunder Bay, I agree that the University shall make it freely available for inspection.

This University Thesis is made available by my authority solely for the purpose of private study and research and may not be copied or reproduced in whole or in part (except as permitted by Copyright Laws) without my written authority.

Signature ________________________

Date ________________________

ABSTRACT

Corbett, D. 2007. Stand Structure Differences Resulting from Post-Harvest Silviculture in Boreal Mixedwoods. 122 p.

Co-supervisors: Kenneth M. Brown, Lakehead University, and Ian Thompson, Canadian Forest Service

Key Words: stand structure, coarse woody material, snags, silviculture, herbicide, site-preparation, chronosequence, boreal mixedwood, north east Ontario

Under the Ontario Forest Accord, several parcels of land have recently been designated as protected areas reducing the area available for forest management. As a result, forestry companies will likely have to intensify timber production using post-harvest silviculture on remaining industrial forestry land to yield the same volumes achieved from fewer operable hectares. I used a chronosequence approach (stands 15-57 yrs) to investigate the question: "Does post-harvest silviculture change forest composition and structural attributes at the stand level?"

I sampled overstory, standing dead-wood components, and woody debris of forty-three upland mesic stands in the Gordon Cosens Forest, Kapuskasing, Ontario. Stands were selected to address potential differences in structural attributes resulting from three silvicultural intensities (harvest with no silviculture, harvest with planting and with herbicide tending, and harvest with site preparation, planting, and application of herbicide), across the chronosequence.

A series of principal components analyses, discriminant function analyses, analyses of variance, and dummy variable regressions indicated differences in tree species composition and dead wood components resulting from treatment/age interactions.

I noted: higher spruce density in planted stands (1585 stems ha^{-1}) than in unplanted stands (902 stems ha^{-1}); higher white birch stem density in stands that were not herbicide treated (1027 stems ha^{-1}) than stands that were herbicide treated (243 stems ha^{-1}); lower balsam fir stem density in younger stands (774 stems ha^{-1}) than older stands (2909 stems ha^{-1}), higher 10.1-15 m snag density in older naturally regenerated stands (172 stems ha^{-1}) than older treated stands (17 stems ha^{-1}); higher volume of class 3 downed woody debris in stands treated intensively (89 m3 ha^{-1}) than in naturally regenerated stands (42 m3 ha^{-1}), primarily of large aspen.

My results clearly indicate silviculture modified species composition. I also found that the use of mechanical site preparation and herbicides to control competing vegetation resulted in delayed snag production and possibly in a reduction of coarse woody material in subsequent rotations. I conclude that broader use of post-harvest silviculture treatments could have important implications for stand structure attributes. My results apply to upland boreal mixedwood sites in northeastern Ontario.

TABLE OF CONTENTS

TABLES

Table Page

FIGURES

APPENDICES

ACKNOWLEDGEMENTS

Without a combined effort of my academic advisors, professional peers, friends, and family, this project would have never come to fruition. Dr. Ken Brown and Dr. Ian Thompson supervised the study and provided valuable support and guidance through the duration of the process. Dr. Han Chen also provided guidance on various aspects of the study. Dr. Mathew Leitch provided guidance and context throughout the study; special thanks are due to him for his creativity, patience, and grounded reality. A constructive review of a previous draft was provided by Dr. Doug Reid. My appreciation is extended to Doug, as well as to Dr. Andy Gordon, who served as the external reviewer.

My family and friends offered support, reassurance, and the optimistic view on matters when needed. The quality of my thesis, and the completion of this process through their support and knowledge. My wife supported my development, sacrificed her own pursuits, and patiently contributed to the final completion of this project through her support.

My field staff were a highly capable and motivating force in my field season completion. Field staff included Francois Simard, Michel Gagnon, Tina Godin, and Daniel Saurette. Financial support was provided by Tembec Ltd, The Forestry Research Partnership, The National Centres of Excellence, Sustainable Forest Management Network, Living Legacy Trust, and Upper Lakes Environmental Research Network, in grants to Dr. Ian Thompson.

INTRODUCTION

It has been proposed that conducting intensive forest practices on some parts of the landscape may increase the available land for conservation efforts while increasing fibre yield from a reduced area (Seymour and Hunter 1992, Wagner et al. 2004). Under the TRIAD model of forest management (Seymour and Hunter 1992), land-use zones would be designated for non-forestry use (primarily conservation), extensive forest management, and intensive forest management. Although these land-use designations potentially satisfy the multitude of land-use demands people have for the natural environment, increased intensive forestry practices may have negative effects on biodiversity (OFAAB 2002).

In Canada, planted forests are anticipated to play a vital role in assuring sustainable wood supply, sequestering carbon, and meeting societal needs for non-consumptive land-use. In Ontario, collaborations between environmental non-government organizations, the public, government, and forestry-based business sector led to the signing of a new provincial land-use strategy called the Ontario Living Legacy in 1999 (OMNR 1999). The Ontario Forest Accord was a companion document signed by the environmental community, government, and forest industry representatives. The Ontario Forest Accord was intended to help establish new protected areas, while taking into consideration the wood supply needs of the forest industry. Under the Accord, stakeholders agreed to set aside newly protected areas that would no longer be available for forestry. As a concession, all parties agreed the forest industry could use concepts from intensive forest management, such as intensive silviculture, to offset potential reductions in wood supply that resulted from the new protected areas (OFAAB 2002).

Potential Implications of Post-Harvest Silviculture

Post-harvest silviculture in the northern boreal forest includes varying degrees of intervention to change or enhance forest growth. Some examples include planting genetically enhanced stock of indigenous conifer species, spraying with herbicide, site-preparation, pre-commercial and commercial thinning or weeding, ditching, and fertilization. Intensive forestry in boreal Ontario is not yet similar to intensive forestry in Europe and some other jurisdictions, where species composition is highly controlled, tree health and growth are monitored, and regular measurements ensure forest stand models are accurate. Intensive forest management research is ongoing in many Canadian forest biomes, including the boreal forest of Ontario. One such example is the Limestone Lake plantations near Thunder Bay, where long-term sample plots have multiple measures, and there are many silvicultural research trials ongoing.

Most large forestry companies in Ontario are simply licensees on government-owned land. As such, there has traditionally been little incentive to invest in intensive silviculture when companies are not assured that they will realize results from their investment. This issue is often referred to as the lack of tenure on forest land. Ontario also enjoys a large managed landscape that, until recently, was still only being harvested for the first time. Silvicultural interventions were minimal until approximately 50 years ago when small tree-planting programs started, herbicide technology advanced, and forestry machinery became more readily available.

The Effects of Past Management Practices

In the current paradigm of forestry, land-use planners consider multiple land-use values in land-use planning, such as the Ontario Living Legacy Land Use Plan (OMNR 1999). If land-use planning were to go ahead with zones of intensive silviculture, there could be implications to biodiversity (OFAAB 2002). In order for resource planners to understand the implications of future forest management practices, land-use planners must first understand the legacy of past management practices on important issues like long-term biodiversity, and structural maintenance at the stand and landscape scale.

Forest structure is the arrangement of stand attributes including tree species composition, height, age, and diameter distribution of living and dead trees across the forested landscape. In the case of dead forest components, decay state is also an important attribute. In a similar fashion to forest structure, stand structure is the stand-level equivalent of the forest characteristics. Forest management practices such as post-harvest silviculture affect the forest landscape at the stand-level through modified stand-structure. The spatial organization and extent of stands at a diversity of ages, of variable species composition affects stand structure.

The Purpose of This Study

The question investigated through this study was "What are the effects of post-harvest silviculture management practices on forest stand structures?" I studied the relationship of post-harvest silviculture to stand structure by studying living vegetation, standing coarse woody material, and downed coarse woody material. This study makes use of a 55-year history of silviculture in a chronosequence study. The period associated with this chronosequence, 1947- 1985, represented the range of silvicultural conditions among stands that were 15 – 55 years old in 2000.

The specific questions that addressed the purpose of this study were:

- Does post-harvest silviculture such as planting, herbicide spray, and site preparation significantly alter species composition of live stems in post-harvest stands in comparison with natural regeneration following harvesting?
- Does post-harvest silviculture such as planting, herbicide spray, and site preparation significantly alter dead wood attributes in post-harvest stands in comparison with natural regeneration following harvesting?
- Does post-harvest silviculture significantly alter stand development such that future stands will lack important structural attributes such as snags and coarse woody debris in comparison with stands regenerating naturally following harvest?
- Is there a predictable gradient in response among individual tree species along the continuum of post-harvest silviculture practices from no treatment, to planting and herbicide spraying, to site preparation with planting and herbicide spraying?

Subsections of this thesis will present the relevant background information used to investigate the live and dead components, respectively. The results and discussion for living and dead forest components will be discussed separately

HISTORICAL CONTEXT AND LITERATURE REVIEW

Contextual History

Forestry underwent considerable changes in philosophy and technology in the late twentieth century. Technical changes are based on innovation. Innovation results from changes in philosophy that come from new knowledge and or new attitudes of the public (Farrel et al. 2000). Considerable and accepted changes in how society incorporates new knowledge and desired outcomes into practice are known as paradigm shifts. During the time period covered by this study, (approximately 1947-1989) the public has regarded the forest through three different paradigms.

During the earliest paradigm the forest was seen as an unregulated resource to be used for harvesting wood and game. This paradigm has been referred to as the exploitative stage. Later, the forest was seen as a regulated biological factory to be used to produce trees and animals. This paradigm has been called the biological factory stage. And most recently, the forest has been seen as a complicated multi-use ecosystem with intrinsic elasticity and resilience. This paradigm has been called the ecologically principled stage (Kimmins 2002).

Under each of these three paradigms, associated forestry practices were developed to provide society with forest resources in a way that satisfied philosophical direction from the public. During the exploitive phase, for example, harvesting was combined with the development of planting technology. In the biological factory stage, forestry incorporated silviculture and site preparation in various phases according to technological advances to ensure long-term productive forests. In the most recent stage, sometimes called the ecologically principled stage, managers incorporated practices other than clearcutting and high-grading to try to maintain structural and biological legacies from a pre-harvest stand. Some examples of more ecologically based forestry practices include leaving groups of seed trees, careful logging around advanced growth ("CLAAG"), snag retention, and site protection to ensure an ecologically sound use (Armson et al 2001). None of these latter practices were examined in this study.

Operational Developments

Near Kapuskasing, the Moonbeam nursery was established in 1947 and the first large scale tree planting was undertaken in 1952. Between 1955 and 1965, power saws completely replaced Swede saws. During the same era, horses were replaced by small tractors and eventually by wheeled skidders. In the 1970s, it became apparent that narrow tired skidders, operating during the frost-free season, were causing significant site damage with associated regeneration delays and problems. By the late 1970s, wide-tire technology for skidders was developed to reduce site damage during harvesting (Armson et al 2001).

At the same time, company trials and management direction at Spruce Falls focussed on improved and more efficient mechanization of harvesting. By 1984, Spruce Falls, Inc. had fully mechanized all operations on the study area with feller-bunchers, wide-tired skidders and delimber-toppers. Since feller-bunchers move trees with branches still on the stem, roadside delimbing became the norm. In the 1980s, the last live-in bush camp closed and the silviculture program was expanded.

Policy Development

Prior to 1980, the OMNR managed the forests, while the companies carried out logging, road building, and regeneration activities under their license and a formal Regeneration Agreement. In 1980, a Forest Management Agreement was signed and Spruce Falls was given the responsibility and authority to manage the Gordon Cosens Forest. The change in management responsibility represented a serious shift in accountability. It was no longer OMNR that provided forest license management on behalf of the people of Ontario. It was now the responsibility of forest companies to provide sound management of natural resources, from which they drew their profit. Additional costs of forest management planning required companies to optimize mechanical efficiency and forest growth, which solidified the move toward mechanization and the use of multiple silvicultural treatment techniques on a harvested area. This is not meant to imply that forest companies have increased silviculture investments or silvicultural control in harvest operations. In fact, some studies indicated that silvicultural investments have declined since companies assumed management responsibility through the 1980s and 1990s due to lack of tenure and public pressure (e.g., Wagner 2005).

The current forest management practices and policies are referred to as a ‘natural disturbance pattern emulation’ paradigm (OMNR 2001). Historically, wild fire was the dominant natural disturbance in the Kapuskasing area, although fire suppression has been used on the landscape since the 1950s. ‘Natural disturbance pattern emulation’ (NDPE) refers to attempts by researchers and practitioners to develop forest planning and practices that are similar spatially and in some cases structurally to natural disturbances such as fire. It is anticipated, though largely untested, that emulation of natural disturbance patterns may satisfy spatial and temporal requirements for key indicator species using a coarse filter approach (Hunter 1990). Under the coarse filter approach, a representative array of ecosystems in different age-classes should contain the majority of species in a region (Hunter 1990, Noss 1987). Maintenance of representative ecosystems will provide key structural elements in landscapes to provide for the essential functional relationships of most species.

Literature Review

Clarification of the Terminology of Intensive Forest Management

The term "intensive forest management" (IFM) is relatively new in Ontario, although most tools of IFM are based on well-established silvicultural concepts. Intensive forest management incorporates different tools to satisfy various situations, preferences, and needs. The terminology of intensive forest management will therefore differ depending on each situation (at the local level) and researchers will have to focus on what happens under a given suite of forest interventions, for each given situation (Bell et al. 2000). For the purposes of this study, discussion is limited to post-harvest silviculture systems to eliminate the ambiguity associated with the term intensive forest management.

Harvest and Transport

Chainsaws were used widely throughout the 1960s and 1970s but were replaced by feller-bunchers in the early to mid-1980s (Armson 2001, Armson et al. 2001).

Chainsaw and skidder operators had to delimb, cut, and stack harvested stems. Feller bunchers cut bunches of trees and set them in a pile for skidding and roadside delimbing. On this study area, feller-bunchers were always associated with roadside delimbing and, for the most part, most chainsaw operations involved on-site delimbing.

Log transportation evolved from horses to tractors to cable skidders throughout the historic time period associated with stand origins used in this study. Early operations that used tractors transported cut-to length wood to roadside on a sled. Trees had already been delimbed and the slash remained at or near the stump. Early skidder operations incorporated the use of cables to haul logs. Chainsaw operators would delimb harvested stems at the cutting site, and the skidder would transport all delimbed stems to roadside. Early skidder operations also left slash at or near the stump. Later, cable skidder operations pulled full-trees to roadside for delimbing that was done using a hydro-axe attachment on an excavator, leaving slash and tops near roadside. With the development of feller-bunchers in the late 1970s and early 1980s, forest companies gradually incorporated the use of grapple skidders for full-tree transport. Full-tree transport generally meant slash and tops were left at roadside after delimbing.

Site Preparation

Early site preparation was intended to redistribute on-site slash left after harvest and in some cases, to expose some mineral soil for planting. The primary method of early site preparation was by dragging attachments such as logs, rocks, or barrels through the harvest block with tractors or skidders (Armson 2001, Armson et al. 2001). Site preparation was also intended to knock over dangerous snags, non-crop species such as birch and aspen, and to otherwise prepare the site for planting crews. As feller-buncher technology and roadside delimbing developed, site preparation was used with a different purpose, to redistribute on-site slash. The new site preparation techniques aligned cut aspen, knocked-over uncut deciduous trees, and removed varying depths of organic layer to provide exposed mineral soil for planting (J. Leach, Tembec Ltd., pers. comm). In site preparation of the early 1980's, in some cases, all organic matter was removed intentionally, as the accepted practice of the day. The question of "how much organic soil to remove?" evolved with research, company experience, and regeneration successes or failures (Ryans and Sutherland 2001).

During the same period of forest harvesting technology development described above, planting and herbicide operations became more common. Planting conifer species in site prepared areas with applications of herbicide was an attempt to control post-harvest conditions, especially species composition. Such attempts sometimes resulted in high planted area densities and multiple herbicide applications. Company representatives refer to "stand conversions", where all sites were intended to be regenerated to pure merchantable conifer stands (A. Isabelle Tembec Inc., pers. comm.).

Planting and Herbicide Application

Planting techniques and technology have changed considerably throughout the period of the chronosequence studied. Planting has been used to assist in regenerating stands toward a high spruce content. Early planting operations relied on poorly stored and handled bare-root seedlings grown in southern Ontario and transported to

Kapuskasing in un-refrigerated trucks. This likely resulted in poor stock survival (Armson 2001, Armson et al. 2001).

Planting methods have changed over time. Planting tools have developed from broad-mouthed shovels, to narrow-bladed shovels, dibbles, potti-putkis, and back to thin-bladed planting shovels. Seedling spacing was originally selected by the tree-planter, who selected the best microsites for seedling planting. Planters were instructed to plant where a tree had previously grown (R. Isaac, Tembec Ltd., pers. comm.). Spacing later moved toward a more uniform pattern where line-planting was used to ensure that a high-quality seedling was planted at uniform spacing, regardless of the presence of natural regeneration. More recent planting operations have attempted to satisfy full site occupancy with one of several acceptable species. Under the current thinking, if a healthy natural seedling of an acceptable conifer species is located on or near a plantable microsite at the proper spacing, then the microsite is left for natural regeneration.

Herbicides have been used throughout the period of the chronosequence to control shade-intolerant, rapidly growing deciduous species. Trembling aspen (Populus tremuloides Michx.), balsam poplar (Populus balsamifera L.), white birch (Betula paperifera Marsh.) and many shrubs species such as mountain maple (Acer spicatum Lam.) and beaked hazel (Corylus cornuta Marsh) quickly recolonized harvested sites where they comprised a component of the preharvest stand (Brumelis and Carleton 1994, Hearnden et al. 1992). I assumed, therefore, that stands treated with herbicide had a broad-leaved component in the preharvest stand.

In many cases, naturally regenerated sites were simply left after cutting, regardless of the original stand type. Naturally regenerated stands may have been stands that simply received no post-harvest treatment, especially in early years when only a small proportion of harvested stands were treated. For example, on average, less than 30% of the harvested area in Ontario in the 1970's was treated, and even into the 1990s only about 50-60% of the harvested area was being treated (Carleton 2000 and OMNR unpubl. data). Currently on the Gordon Cosens Forest about 40% of harvested stands receive post-harvest silviculture.

Many stands that were harvested, planted, and herbicide sprayed (PS) would have been mixedwoods with higher components of deciduous than would have been the case if they were left as naturally regenerated stands. Planting and herbicide-spraying were used to give spruce a competitive advantage over deciduous regeneration (Hearnden et al. 1992). Site preparation was used in concert with planting and spraying to maximize the likelihood of regenerating a mixedwood or conifer stand with heavy slash loading, or numerous snags to a conifer dominated stand (A. Isabelle, Tembec Ltd., pers. comm.).

Effects of Post-Harvest Silviculture on Stand structure Components

Natural processes affected by early-intervention silviculture are stand establishment and competition (Rowland et al. 2005). The degree of stand control is dictated through silvicultural intensity (Smith et al. 1996, Rowland et al. 2005). With increasing intensity of silviculture, preferred species stems are artificially established and at a controlled density (Freedman et al. 1994).

Harvest Effect

Post-harvest species composition is often shifted toward mixedwood or broad-leaved species composition, especially on upland mesic sites (Groot and Horton 1994, Brumellis and Carleton 1988, Newton et al. 1992). Hardwood species that produce abundant seed and germinate quickly, such as white birch, are at an immediate competitive advantage in harvested blocks that have disturbed soil due to harvest operations (Harvey and Bergeron 1989). Some hardwood species that grow rapidly from stump sprouts and root-suckers, such as trembling aspen, are also at a competitive advantage (Newton et al. 1987). Aspen is more drought resistant than conifer species, giving it a competitive advantage over the more favoured conifer seedlings during times of drought stress in freshly harvested stands (Burns and Honkala 1990b).

Balsam fir (*Abies balsamea* (L.) Mill.) is a shade tolerant species but any of the primary deciduous competitor species can quickly over-top small seedlings or smother them with deciduous litter. Shade tolerant species such as balsam fir may take advantage of the new light availability and completely dominate the post-harvest stand if they are not damaged during harvest operations (Harvey and Bergeron 1989) or immediately out-competed by deciduous species. Maintaining mixtures of other tree species with balsam fir reduces the likelihood of budworm infestations, whereas balsam alone is highly susceptible to budworm attack (Buse and Bell 1992). White spruce (*Picea glauca* (Moench) Voss), is susceptible to smothering by deciduous litter, competition from deciduous saplings, and competition from dense grass and shrubs. In addition to these hazards, leaders and buds are may be whipped by small deciduous saplings in the wind. Sparse herbs and/or shrubs may assist in moderating microclimate in early establishment years but competition from beaked hazel and red raspberry may reduce height growth of white spruce by up to 50% in the first 5 years (Buse and Bell 1992). Black spruce (*Picea mariana* (Mill.) BSP.) germinants are susceptible to smothering by loose rapid growing sphagnum moss, but is generally considered shade tolerant (Sims et al. 1989). Deciduous competitors such as alnus spp., red raspberry (*Rubus idaeus* L. var. strigosus (Michx.) Maxim), and beaked hazel substantially reduce height growth and survival. Long term changes in canopy composition can permanently alter understory communities through changes in light transmittance (Freedman et al. 1994).

Planting Effect

Currently, plantations in Ontario focus on using genetically improved stock of locally suited species (Wagner et al. 2004). On the Gordon Cosens Forest, planted forests are targeted to have approximately 1600 seedlings/ha of black and white spruce after planting (J. Leach, Tembec Ltd., pers. comm.). Seedlings are mixed by planters during the planting operation. The seedling mix is approximately 75% black spruce and 25% white spruce grown at a local nursery, and/or grown at a contracted nursery using Kapuskasing seed stock. Both species are susceptible to water stress after planting, grazing by herbivores, and microsite effects such as soil compaction, and poor planting. Planting stock and planting method have undergone significant change throughout the period of this chronosequence (Armson et al. 2001, Armson 2001). Planting was used with herbicide treatments to ensure spruce would be dominant in the post-harvest stand

(Wagner 1994, Carleton 2000 and Hearnden et al. 1992), therefore I expected spruce planted stands should have a higher spruce density than stands that were not planted.

Herbicide Effects

Herbicide spray within the first 5 years after plantation establishment reduces the biomass of competing deciduous stems (Lautenschlager et al. 1998, MacKinnon and Freedman 1993, Buse and Bell 1992, VanWagner 1993). Near Kapuskasing, effective spray should reduce the density of trembling aspen, balsam poplar, and white birch in the post harvest stand (Carleton 2000 and Brumelis and Carleton 1988). White birch should be all but eliminated from treated sites due to high effectiveness of herbicides on this species (Buse and Bell 1992). Due to shade-intolerance of white birch, herbicide spray effects tend to persist after treatment. Herbicide spray is classed as good to excellent for controlling balsam poplar and trembling aspen (Buse and Bell 1992). Herbicide spray is effective for 2-5 years on aspen. Therefore, I expected to see aspen in the post-treatment stand, although delayed in its development. Herbicide treatments alter species composition, but seldom eliminate species (Freedman et al 1994). The 2-5 year delay allows establishment of the favoured spruce seedlings. Different herbicides have different degrees of effectiveness and cost associated with their application. Garlon and 2-4D herbicides were the main herbicides used prior to 1986. Glyphosate quickly replaced them due to its low cost and effectiveness against a broad range of broad-leaved species. Dead saplings and residual standing dead deciduous stems may have provided some shade to moderate the soil climate for planted seedlings.

Site-Preparation Effect

Aspen and balsam poplar regenerate aggressively from meristems on shallow lateral roots (Burns and Honkala 1990b), especially when the organic layer is disturbed during harvesting or site preparation (Fraser et al. 2003). Unless their entire root systems are removed, aspen and balsam poplar will aggressively regenerate via suckers.

Site preparation encourages suckering, which increases the need for herbicide spray one year after site preparation (Buse and Bell 1992). Exposed mineral soil is also a good substrate for aspen germination (Burns and Honkala 1990b). Seed viability is considered low in aspen after 1 year (Sims et al. 1989), so reproduction is mostly vegetative. Excessive soil moisture or drought can reduce sucker production (Burns and Honkala 1990b). White birch quickly colonizes any exposed mineral soil after site preparation (J. Leach, Tembec Ltd., pers comm., Buse and Bell 1992, Burns and Honkala 1990b). Seeds are viable in the forest floor for 1-2 years, so heavy seed production in the year of harvest may result in prolific seedling regeneration in the first few years following harvest. Birch relies most heavily on seed germination for regeneration, although coppice growth does occur. Balsam poplar reproduces both sexually and vegetatively, although vegetative reproduction is the most common case after harvest. Similar to aspen, balsam poplar produces root suckers when the root layer is disturbed during harvest. Balsam poplar also produces buds, roots, and shoots from cuttings (Burns and Honkala 1990b). Stem or branch parts buried during site preparation operations will also produce suckers. Seed is only viable for approximately 5 weeks, so balsam poplar regeneration does not rely heavily on seed production. Black spruce, white spruce, and balsam fir regeneration could be destroyed during site preparation (Archibald and Arnup 1993).

Mineral microsites created for planting may cause immediate desiccation of young seedlings if there is no shade for seedlings. Complete removal of the organic layer may moderate temperatures, as mineral soil does not maintain high surface temperature (Ryans and Sutherland 2001). Tree planters are instructed to select microsites with sparse shrub or grass cover with moderate ground temperature and moisture. Microsites that have mixed organic and mineral layers are another favourable condition, and sites with thick exposed organic layer should be avoided, as they are prone to periods of drying and high temperature (Ryans and Sutherland 2001). Balsam fir is highly susceptible to damage from machinery, so I expected site preparation to reduce balsam fir stem density. Black and white spruce trees are the only species planted after harvest on the study area.

Mechanical site preparation may allow more direct sunlight and increase soil temperatures, encouraging seedling establishment (Patterson et al. 2001). Leaving dead-standing snags may have helped partially shade seedlings to avoid desiccation and sun-scald (Seymour 1986). Site preparation generally helps seedling establishment by improving moisture conditions and modifying soil temperature. Site preparation may improve soil conditions through eliminating competing species, providing some berms and mounds for localized moisture pockets, and potentially mixing mineral and organic horizons (Ryans and Sutherland 2001). Soil temperature is controlled through partial removal of organic layers, controlling soil microtopography, and improving drainage on microsites.

Site preparation can have negative effects for planted seedlings. Removal of the insulative organic layer causes microsites to warm up faster in the spring. Premature warming could cause early flush of seedlings that could then be susceptible to frost damage (Sutton 1993). Removal of competing vegetation may also increase the potential of frost damage to early flushed seedlings. Any depressions left from site preparation could result in seasonal flooding and frost heaving (Ryans and Sutherland 2001). Site preparation in this study area was variable, as described above. Slash alignment or shear-blading removed parts or all the organic layer and left the mineral soil intact (Table 2).

Site preparation was also intended to align woody material and knock over residual stems left after harvest. Slash alignment improves accessibility of planting microsites for planters and partially removes the duff layer to make boot screefing easier (J. Leach, Tembec Ltd., pers. comm.). Site preparation increases coarse woody material volume on the ground and results in fewer residual stems left standing (Freedman et al. 1996). Coarse woody material and snags can be broken during site preparation operations, which provides extra entry points for micro-organisms and insects that assist in decomposition (Harmon et al. 1986).

If windrow piles are high and coarse woody material is suspended from the mineral and organic layers, coarse woody material and broken snags may become desiccated. Desiccation can temporarily slow the decay process (Harmon et al. 1986, Mackenson and Bauhus 1999) by creating unfavourable colonization conditions for fungi and insects responsible for decay. Normal forest floor microtopography is removed from the shear-bladed areas and concentrated in piles of coarse woody material in windrows. There is a risk that temporary removal of organic layers and coarse woody material will modify site quality by altering water retention capacity, organic bound nutrients, carbon storage, and acidity (Freedman et al. 1996 and Jurgensen et al. 1984).

Table 1. The effects of two intensities of site preparation on the vegetative and sexual reproduction of deciduous species (after Ryans and Sutherland, 2001, and Sutherland and Foreman, 1995).

	Vegetative Reproduction			Sexual Reproduction	
	From shoots	From roots		Wind-borne seed	Seed bank
Degree of Site Preparation	(e.g. beaked hazel, green alder, Labrador Tea, mountain maple, red osier dogwood, white birch, willow)	In organic layer (e.g., blueberry, blue-joint grass)	In mineral soil (e,g., prickly wild rose, poplar, wild red raspberry, willow)	(e.g., blue-joint grass, fireweed, poplar, white birch)	(e.g., blueberry, pin and choke cherry, prickly wild rose, red osier dogwood, wild red raspberry)
L layer and part of F layer removed or displaced (e.g., shallow screef)	Promotes	Promotes	Promotes	Promotes	Promotes strongly
LFH removed, mineral soil intact (e.g.,screef)	Discourages to Discourages strongly	Discourages	Promotes strongly	Promotes strongly	Discourages

The previous background information and field observations led to four questions for this study:

- Does post-harvest silviculture such as planting, herbicide spray, and site preparation significantly alter species composition of live stems in post-harvest stands in comparison with natural regeneration following harvesting?
- Does post-harvest silviculture such as planting, herbicide spray, and site preparation significantly alter dead wood dynamics in post-harvest stands in comparison with natural regeneration following harvesting?
- Does post-harvest silviculture significantly alter stand processes, such as mortality, such that future stands will lack important structural attributes such as snags and coarse woody debris in comparison with stands regenerating naturally following harvest?
- Is there a predictable gradient in response among individual tree species along the continuum of post-harvest silviculture practices from no treatment, to planting and herbicide spraying, to site preparation with planting and herbicide spraying?

METHODS

Study Area Description

The study area lies south of Kapuskasing, Ontario, Canada (49°25’N, 82°23’W) in the southern portion of the “Gordon Cosens Forest” (Ontario Ministry of Natural Resources (OMNR) Agreement 500600) (Figure 1). The study area is approximately 5140 km^2 of boreal forest within Ontario’s Clay Belt, a geological feature left approximately 10,000 years ago by post-glacial Lake Barlow-Ojibway. The topography is a flat to only slightly rolling plain of clay till, lacustrine clay, silt, and sand resulting from the glacial deposits and the movement of water within the former lake.

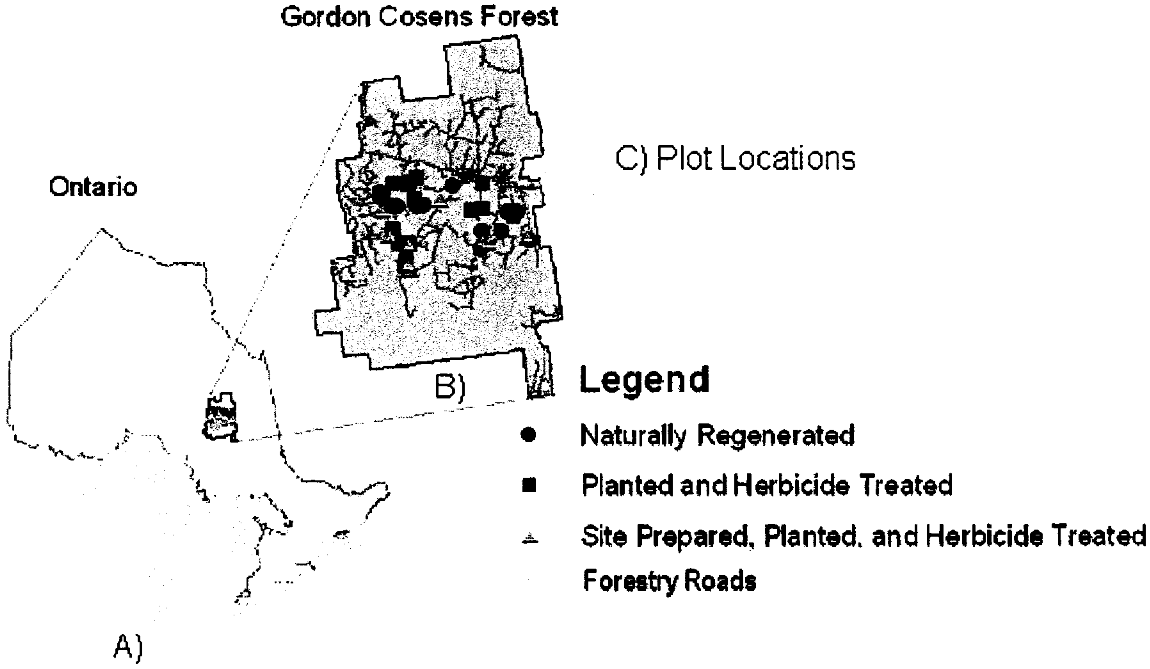


Figure 1. Location of the Gordon Cosens Forest study area in relation to Ontario and the Great Lakes A), and sample site locations (C) within the study area (B) by silvicultural treatment.

In post-glacial times, the predominant natural forest disturbance regime has been fire. Other agents of forest change have included spruce budworm (*Choristoneura fumiferana* (Lepidoptera: Tortricidae)), which affects predominantly balsam fir (*Abies balsamea*, L. Mill), forest tent caterpillar (*Malacosoma disstria* (Lepidoptera : Lasiocampidae)), which affects trembling aspen (*Populus tremuloides* Michx.), and windthrow. The pre-suppression fire return interval was estimated to average 250 years (Perera et al. 2000). Typical stand composition conformed with the definition of boreal mixedwood (Chen and Popadiouk 2002) on upland sites, and black spruce on lowland sites. The area was in site region 3E of the forest ecosystem classification system for the claybelt (Jones et al. 1983). Common tree species in site region 3E include included black spruce, trembling aspen, balsam fir, jack pine (*Pinus banksiana* Lamb.), white birch and eastern white cedar (*Thuja occidentalis* L.) with lesser amounts of tamarack (*Larix laricina* (DuRoi) K.Koch), balsam poplar, white spruce, and black ash (*Fraxinus nigra* Marsh.). Common ground covers include: feather mosses (e.g., *Pleurozium schreberi* (Brid.) Mitt, *Hylocomium splendens* (Hedw.)BSG.), sphagnum mosses (e.g., *Sphagnum wulfianum* Girg., *Sphagnum girgensohnii* Russ., and *Sphagnum magellanicum* Brid.), an herbaceous layer (e.g., *Cornus* sppl., *Vaccinium* sppl., *Lycopodium* sppl., *Equisetum arvense* L. , *Aster* sppl.), and a shrub layer (e.g., mountain maple, beaked hazel, and red alder *Alnus rugosa* (Du Roi) Spreng.).

Historic land use included fur trapping, hunting, and fishing by aboriginals, and trapping, agriculture, and commercial logging by settlers beginning in the 18th century. Spruce Falls Inc. (now Tembec Ltd.) has used silviculture techniques at varying intensities across the landscape to manage regeneration on logged sites for approximately 55 years. Common post-harvest silviculture interventions included planting (black spruce, white spruce), chemical tending (herbicides, especially 2,4-D and glyphosate), and site preparation (shear-blading). Forest operations have always focused on white spruce and black spruce.

Stand Selection

Field data were collected during the summers of 2002 and 2003. Sampling of live and dead forest components occurred in approximately 50 stands. Live stand components sampled included shrubs, small trees, and large trees. Dead components sampled included dead standing and downed woody material. Live and dead component sampling, which occurred at the same time in the same stands, are analyzed and discussed separately.

Study stands were selected from Forest Resource Inventory (FRI) maps through a series of queries using Arcmap 8.2 GIS software ™ (ESRI 2000). All available geographic information system (GIS) coverages were provided by Tembec (Spruce Falls Inc.), the sustainable forest license holder. Historic silviculture records were digitized and incorporated into the GIS maps to cover the period from 1945 to 2000.

The forest was broadly categorized into 'upland' or 'lowland' by grouping Ontario Forest Resource Inventory (FRI) codes (OMNR 1986) into an appropriate coverage. All areas not fitting the FRI description of upland were assumed to be lowland or non-forested. I limited my site selection to Forest Ecosystem Classification Operational Groups 6, 7, 8, and 9 (Jones et al 1983), which represent upland mesic conditions.

Stand ages were grouped into 10-year age classes from 20 to 120 years old. Age class groups were used to investigate availability of silviculturally treated stands within age classes. One study objective was to understand structural attributes of harvested stands across the history of post-harvest silviculture and so I selected stands up to 55 years of age that had been mechanically harvested. Post-harvest silvicultural treatment groups included natural regeneration (N), planted and herbicide sprayed (PS), and site preparation followed by planting and herbicide spray (SPS). Stand ages ranged from 12 to 52 years and the minimum stand size was 25 ha.

All stands included in this study were harvested using a clearcut silviculture system. The intensity of post-harvest forest management was assigned to 'treatments' used in this study based on level (or number of treatments) of post-harvest silviculture. The lowest intensity involved no post-harvest silviculture and the highest intensity incorporated site-preparation, planting, and chemical spraying of herbicides (Table 1). This provided the suite of post-harvest silvicultural tools that had been used on the Gordon Cosens Forest over the past 52 years.

Table 2. Descriptions of post harvest silviculture and acronyms used for levels of post-harvest silviculture intensity

Post-harvest silviculture	Acronym used
None	N = Natural Regeneration
Planted spruces (approximately 1600 stems ha^{-1}) and sprayed with herbicide	PS = Planted and Herbicide Sprayed
Site prepared (shear-blading) planted 1600 stems ha^{-1} spruces, and sprayed with herbicide	SPS = Site Prepared, Planted, and Sprayed

The basic components of post-harvest silvicultural treatments in this study are planting of crop trees, herbicide application, and mechanical site preparation, if required. Examples of similar interventions that were not addressed in this study but achieve similar objectives in other locations include chemical site preparation, alternative mechanical site preparation methods, aerial seeding, precommercial thinning, and cleaning. Although some of these silvicultural treatments were used in the study area, I focussed sampling effort on the most common treatment combinations used throughout the chronosequence time-period (Table 1).

Site preparation is an intervention that occurs between harvesting and planting to ensure availability of acceptable microsites for planting, reduce snags as a safety precaution, and to improve working conditions for tree planters. Its application depends on post-harvest site condition. When companies invest silviculture funds to plant trees, they generally spray with herbicides to reduce competition from 'weed' species to protect their investment. The use of herbicides always corresponded with planting in this study, so those two components are discussed together. Application of the different herbicide types (2-4D, Garlon, and Glyphosate) were recorded separately in the silviculture layers.

Design and Method of Forest Attribute Sampling

Sample plots were measured along systematic transects with a random start location in order to adequately sample the entire stand. Transect length and bearing were chosen in advance to ensure adequate stand coverage. Fifty to 100 corrected point distance sample points (Batcheler and Bell 1970, Laycock and Batcheler 1975) were measured in each stand. Points were located every 40 m along transects. If a sample point location fell in a lowland, the point was not used. Stand boundaries on the ground were not always as obvious as they appeared on the map. Point locations were acceptable if the sampling team could identify that they were still in the same treatment/age combination.

Corrected Point Distance Analysis

The corrected point distance sampling method (Batcheler and Bell 1970, Laycock and Batcheler 1975) as applied to trees is implemented as follows. From a marked point center, the distance to the nearest, or first, tree is measured and recorded. The first tree is then treated as a new point centre and the distance to its nearest neighbour is recorded. The second tree is treated as a new point centre and the distance to its nearest neighbour, the third tree, is recorded. I used the same distance measurement method for small trees, shrubs, and snags.

I limited the maximum search distance to 10 m for trees (greater than 10 cm dbh), small trees (greater than 3 m tall, less than10 cm dbh), and snags (dead trees greater than 2 m tall). I limited the maximum search distance to 5 m for shrubs (woody vegetation less than 3 m tall, but greater than 1 m tall). In cases where there were no measurable individuals, remaining records were recorded as no individuals. In cases of an individual with 2 or more stems, distance was measured to the clump center. Average height for the clump (H) was measured to the nearest decimeter using a percent slope clinometer, and average DBH was calculated based on measurements of all tree stems to the nearest millimetre using a diameter tape.

In the case of trees, small trees and snags, I recorded species, diameter, and height. In the case of shrubs, I recorded only species and height. In the case of snags, snag decay class was measured and recorded for each of the three snags measured using corrected point distance sampling. Intolerant hardwood species snag attributes, such as bark decay pattern, stem breakage, root rot, and branch pattern, made it necessary to adapt decay classes from Maser and Trapp (1984). The authors highlight characteristics of coastal conifer snags, which differ from shade-intolerant hardwood snags. Maser and Trapp's decay classification system assigns a decay classification (number 1-9) based on gross features of Douglas fir snags. I used a modification of the 9 decay-class definitions proposed by Maser and Trappe (1984) and recorded snag decay classes, based on similar characteristics, for species found in my study area. Characteristics that corresponded to decay classes used in this study reflected similar decay of gross features of northern conifer and deciduous species. Using a nine-class system allowed observers to accurately describe the physical traits of each snag. (see Appendix I: Boreal Decay Classification System).

Coarse Woody Material

Coarse woody material (CWM) was measured along transects in each stand using a systematic sample with random start. A 40 m nylon measuring tape was used to measure the distance between temporary sample points. With the tape held straight and tight along the forest floor, this line represented the left boundary for measurement. In the following description this will be called the boundary tape. A surveyor walked along the boundary tape with a 2 m tape extended from the boundary tape and recorded any portion of a piece of coarse woody material within 2 m of the boundary tape. Only the portion of coarse woody material that was within 2 m of the boundary tape was recorded, (e.g., if only 30 cm of a 10 m stem fell within 2 m of the boundary tape, then only 30 cm length was recorded). For each piece of coarse woody material; the average diameter (cm) at the midpoint of the log was recorded. Length was recorded for the entire log that fell within the 2 m. It was therefore possible to have coarse woody material pieces that were longer than 2 m if they were on any angle other than 90° to the boundary tape.

CWM was measured between two sample point locations at every third point. Decay classes (Maser and Trappe 1984) were recorded for CWM. This method was the same as Spruce Falls Inc.'s methods during the study period. Logs and stumps greater than 10 cm average diameter at the midpoint were considered as coarse woody material. Only pieces of coarse woody material shorter than 2 m high were included. Trees that had partially fallen but were greater than 1 m from the forest floor were not recorded as coarse woody material. In the case of coarse woody material that had a portion below 1 m from the forest and a portion above 1 m, only the portion below 1 m was recorded as coarse woody material.

Stem density (stems ha^{-1}) estimates were used for the analysis of standing forest components. Standing forest components were calculated to describe stem density per hectare by species, and stem density per hectare by diameter class and height class (Table 3). Measured and derived variables are presented in Appendix II. In the case of snags, the stem density per hectare by decay class (adaptation of Maser and Trapp 1984) was also calculated. Coarse woody material total volume and volume by decay class (Maser and Trappe 1984) were calculated from sample plots and reported in m^3/ha by stand.

Table 3. Class limits for tree heights and diameters.

Height class	Class limits (m)	Diameter class	Class limits (cm)
1	2 - 5	1	0 - 9.9
2	5.1 - 10	2	10 - 19.9
3	10.1 - 15	3	20 - 29.9
4	15.1 - 20	4	30 +
5	20.1 +		

Analysis

I wanted to test whether or not there were differences in stand structures due to silvicultural intensity. Stand-level values were calculated to reflect density or volume of specific aspects of stand structure, e.g., spruce tree density. For the rest of my methods, results, discussion, and conclusion sections, I will refer to the specific stand-level values as stand structure components, as they collectively contribute to overall stand structure (see Appendix II: Measured and Derived Variables).

Black spruce and white spruce stems were both analysed as "spruce tree density". This aggregation may seem unfortunate due to the limitations this policy had on the analysis. The different growth characteristics of these species and the potential that the species respond differently to treatment were lost. This aggregation was necessary, however, due to problems associated with the intermixing of species in study stands under natural and managed conditions. Preliminary analyses indicated highly variable species mixing, potential tree identification errors, and potential data recording errors. This uncertainty made it necessary to analyse the stand attributes using the most certain estimated parameter, which was spruce density.

During preliminary data analysis, I noted a potential difference between stands younger than 23 years, and stands 23 years or older. The potential difference I noted was reduced balsam fir stem density in stands < 23 years old. Further discussions with operational forestry staff indicated stands < 23 years old were harvested with heavy tracked machinery, such as a feller buncher. Stands 23 years or older were harvested with smaller machinery, such as a chainsaw by a motor-manual crew. I created age categories that would test whether or not the apparent stand composition difference was statistically significant.

Principal Components Analysis

I used principal components analyses (PCA) in Datadesk 6.01™ (Data Descriptions Inc. 1996) as a data reduction tool to eliminate redundant variables. Because I started the analysis with 68 variables and only 43 cases (Appendix II), I had to reduce the number of input variables for discriminant function analysis. I first conducted principal components analysis on groups of variables to investigate what variables had the highest eigenvalues. For example, I conducted individual PCA analysis on all tree species density values and found that some tree species consistently had very low eigenvalues because there were very few instances or highly variable density values. Tree species that had consistently low eigenvalues were then excluded from further analysis. I repeated the same process for all attributes of trees, snags, and coarse woody material (Appendix II). I then conducted principal components analysis of general attributes together such as tree species, diameter class, and height class in order to identify the most important variables for further analysis.

Discriminant Function Analyses

Using the subset of variables identified through principal components analysis, I used discriminate function analysis (DFA) in Systat 10.2 ™ (Systat Software Inc. 2002) to identify the subset of stand component variables that most clearly discriminate among silviculturally meaningful sub groupings of stands. In the DFA, I used forward step-wise analysis with tolerance set to 0.15 to remove. The model evaluated the probability of each variable and removed variables with probability greater than the maximum acceptable (P = 0.15). Variables with probability (*F*-to-remove) smaller than the maximum acceptable (P = 0.15) were automatically entered into the model. Canonical scores plots and tables of canonical scores were used to interpret effects of silvicultural treatment on stand structure components, investigate clustered data points, and describe gradients in the response variables.

This procedure was performed twice. In the first analysis, I grouped stands according to three silviculture treatment groups which I have abbreviated N, PS, and SPS. In the second analysis, I further subdivided each silviculture treatment group into "young" and "old" age classes. Thus, the second analysis was based on the 6 subgroups that are summarized in Table 4.

Table 4. Post harvest silviculture treatments, age ranges, and treatment codes by age class.

Age Class	Post-harvest silvicultural Treatment	Age Range (yrs)	Code
Young (<23 years)	Natural (N)	14 - 22	YN
	Planted and Sprayed (PS)	12 – 22	YPS
	Site Prepared, Planted and Sprayed (SPS)	12 – 22	YSPS
Old (≥23 years)	Natural (N)	23 – 53	ON
	Planted and Sprayed (PS)	23 – 48	OPS
	Site Prepared, Planted and Sprayed (SPS)	28	OSPS

Surprisingly, both rounds of DFA identified the same subset of five stand component variables. Of these, three are measures of living stand components, namely, spruce tree density, balsam fir tree density, and white birch tree density. The other two measure dead stand components, namely, 10.1 m to 15 m snag density and volume of class 3 coarse woody material.

Analysis of Variance

I then used analysis of variance (Eq. 1) and dummy variable regression analysis (Eq 2.) in Datadesk ™ (Data Descriptions Inc 1996) to investigate the effects of stand age and silvicultural treatment on each of the five stand component variables that had been identified by DFA. The ANOVA and dummy variable regression results are presented in two chapters. The first of these chapters focuses on the three most interesting living stand components; the second on the two most interesting dead stand components. The analysis of variance model is:

$$Y_{ijk} = \mu + T_i + Aj + TAij + \varepsilon_{k(ij)} \qquad \text{Eq. 1}$$

$$i = 1, 2, 3; \quad j = 1, 2; \quad k = 1, 2, 3, \ldots, r$$

where

Y_{ijk} = the measured response of the k^{th} replicate of the i^{th} level of silvicultural intensity and the j^{th} age class

μ = the overall mean

T_i = the fixed effect of the i^{th} silvicultural intensity treatment

Aj = the fixed effect of the j^{th} age category

$TAij$ = the fixed effect of the interaction between treatment and age category

$\varepsilon_{k(ij)}$ = the random effect due to error

Equation 1 shows the index *k* taking the values 1 through *r*. Here *r* represents the number of replicates in the treatment group and these vary from one treatment group to another.

Dummy Variable Regression

I used dummy variable regression to investigate trends in the data by treatment, using age as a continuous variable. The general dummy variable regression model is:

$$Y = \beta_0 + \beta_1 A + \gamma_1 D_1 + \gamma_2 D_2 + \alpha_1 D_1 A + \alpha_2 D_2 A \qquad \text{Eq. 2}$$

where

Y = either a) the total density in stems·ha^{-1} of the variable being modeled or
b) the volume of coarse woody material in m^3
A = stand age in years

D_1 and D_2 = dummy variables that code for silvicultural intensity as defined in Table 12
β_0, β_1 $\gamma_1, \gamma_2, \alpha_1, \alpha_2$ are constant coefficients to be estimated by the method of least squares.

Table 5. Dummy variable codes for silvicultural intensity treatment groups.

Silvicultural intensity treatment group	D_1	D_2
• natural regeneration (N)	0	0
• plant and herbicide spray (PS)	1	0
• site prepare, plant and herbicide spray (SPS)	0	1

RESULTS

For the purposes of general description or for the purposes of comparing my general findings to those in other studies, my general results are highlighted in Tables 6-11, and in Figure 2, a graph display of general species composition. Table 6 provides an overview of tree stem density, snag density, and volume of coarse woody material. The tables that follow provide additional detail with respect to the coarse components, following the pattern of Table 6. Since only two very young study stands had been treated with glyphosate, rather than 2-4 D, all herbicide treated stands were grouped into either ‘planted and sprayed’ or ‘site-prepared, planted and sprayed’. Tree attributes are presented first followed by snag attributes, and then coarse woody material attributes.

Table 6. Mean and standard deviation of total tree density, total snag density, and volume of coarse woody material per hectare by treatment/ age category.

Treatment/ Age Category	Count	Trees $\geq$ 3m Density (stems ha^{-1})		Snag Density (stems ha^{-1})		Volume of Coarse Woody Material (m^3 ha^{-1})	
	n	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S
YN	5	3039.7	1417.4	39.9	11.8	55.1	32.8
YPS	3	1282.5	656.9	57.4	27.2	80.0	53.3
YSPS	6	1436.3	715.3	46.7	42.3	128.4	69.4
ON	13	3091.0	960.3	111.8	112.4	66.5	21.2
OPS	15	3033.3	682.2	66.3	33.8	61.0	34.5
OSPS	1	2837.8	N/A	16.9	N/A	117.2	N/A
Grand Total	43	2702.0	1079.0	72.5	71.1	74.0	43.9

In Table 6 it is clear that younger silviculturally treated stands have lower stem densities, with the exception of naturally regenerated stands. Snag density is relatively consistent among all treatment – age categories with the exception of older natural stands, that have high snag density but also a high standard deviation. Volume of coarse woody material shows the highest values in stands that were treated with site preparation.

Table 7 provides an overview of species composition by stem density, by treatment – age category. For the purposes of general display, some species were grouped and referred to as pioneer species. The term pioneer species, in this case, refers to short-lived species that only rarely persist as part of a dominant stand canopy. The values in Table 7 are in stems ha^{-1}. The associated proportions are graphed in Figure 2.

Table 7. Mean and standard deviation of the density of trees (stems ha^{-1}) greater than 3 m tall by species and treatment-age category.

Variable	Summary Statistic	YN	YPS	YSPS	ON	OPS	OSPS
Spruce	$\bar{X}$	291.9	850.2	611.0	241.3	927.3	211.4
	S	347.9	516.8	331.4	232.9	441.7	N/A
Balsam Fir	$\bar{X}$	452.8	213.5	237.5	1216.0	1285.0	107.6
	S	282.1	240.3	60.9	494.2	832.7	N/A
Jack Pine	$\bar{X}$	0.0	0.0	0.0	0.5	0.0	0.0
	S	0.0	0.0	0.0	1.2	0.0	N/A
Cedar	$\bar{X}$	0.4	3.0	1.9	85.1	32.6	25.3
	S	0.8	5.1	3.0	132.0	83.2	N/A
Larch	$\bar{X}$	77.9	8.9	11.6	7.5	5.1	85.4
	S	130.3	8.1	13.6	11.9	7.7	N/A
Aspen	$\bar{X}$	631.4	82.7	228.8	407.2	416.8	594.5
	S	389.4	130.6	255.1	338.4	282.1	N/A
White Birch	$\bar{X}$	280.6	19.3	85.6	405.5	10.2	88.4
	S	200.6	30.4	114.0	340.4	18.2	N/A
Balsam Poplar	$\bar{X}$	264.4	19.8	19.4	120.7	65.6	237.9
	S	279.9	25.6	25.2	82.7	65.1	N/A
Black Ash	$\bar{X}$	0.0	0.0	0.0	7.3	0.0	0.0
	S	0.0	0.0	0.0	23.5	0.0	N/A
Pioneer	$\bar{X}$	1040.4	85.1	240.6	599.9	290.7	1487.4
	S	781.5	61.8	225.8	471.6	192.0	N/A

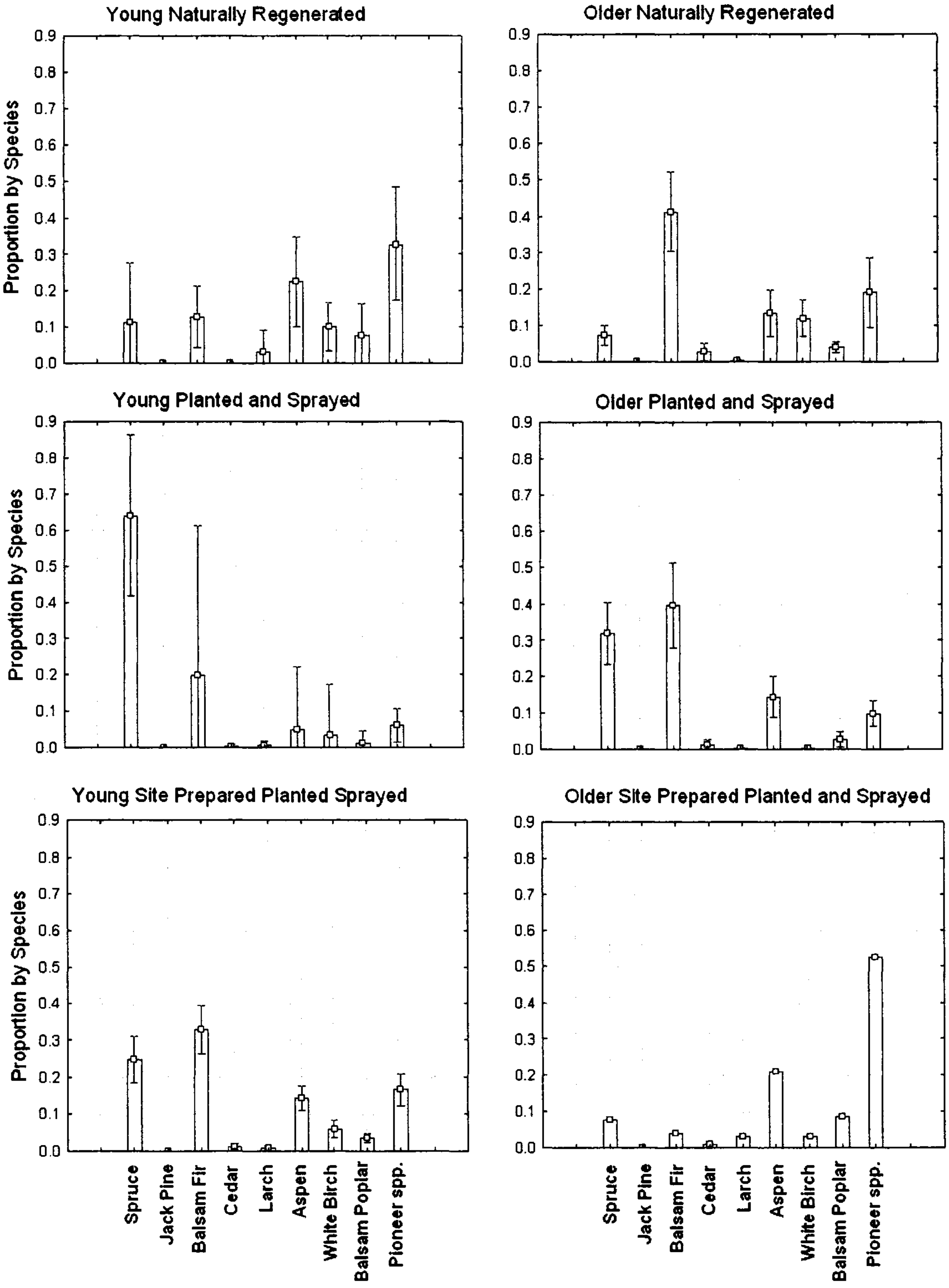


Figure 2. Sample stand species composition by treatment/age category, presented using proportion of total density (stems ha^{-1}) by species. Each bar graph shows mean and 95% confidence interval by tree species and treatment/age category.

Tree stem densities by height and diameter classes are presented in Table 8 to provide the final descriptive details with respect to living forest components in the general overview section. Additional attributes not specifically analysed for the purposes of this study are presented in Appendix IV and Appendix V.

Table 8. Mean and standard deviation of tree densities (stems ha^{-1}) by tree height class and diameter class, categorized by treatment/ age category.

Variable	Value	YN	YPS	YSPS	ON	OPS	OSPS	Total
Height Class 1	$\bar{X}$	1117.1	497.6	598.2	785.2	713.6	780.9	752.6
(3-5 m)	S	648.4	264.6	276.4	254.7	195.6	N/A	329.4
Height Class 2	$\bar{X}$	1208.9	757.2	749.5	1323.9	1554.9	1457.0	1274.5
(5.1-10 m)	S	883.9	530.9	514.7	664.9	505.0	N/A	647.5
Height Class 3	$\bar{X}$	613.6	28.2	98.3	1011.2	759.9	552.3	670.7
(10.1-15 m)	S	572.8	9.8	107.4	424.5	479.1	N/A	525.7
Height Class 4	$\bar{X}$	40.2	4.3	0.0	141.9	71.5	47.6	73.9
(15.1-20 m)	S	45.0	5.2	0.0	96.4	73.7	N/A	85.9
Height Class 5	$\bar{X}$	88.5	0.0	0.0	15.5	2.1	0.0	15.7
(>20 m)	S	195.4	0.0	0.0	27.6	5.8	N/A	68.0
Diameter Class 1	$\bar{X}$	1817.3	715.6	747.5	1627.6	1545.8	1418.9	1429.8
(<10cm)	S	706.5	277.4	331.1	460.8	288.4	N/A	538.9
Diameter Class 2	$\bar{X}$	1044.6	556.4	646.2	1387.7	1460.5	1361.8	1211.1
(10-20 cm)	S	849.6	388.9	372.0	484.0	284.0	N/A	546.0
Diameter Class 3	$\bar{X}$	94.2	9.3	44.0	197.8	86.6	38.1	108.6
(20.1-30 cm)	S	79.8	2.5	45.3	110.8	63.4	N/A	98.9
Diameter Class 4	$\bar{X}$	41.6	0.9	0.0	16.5	1.5	9.5	10.6
(30.1-40 cm)	S	77.4	1.6	0.0	27.2	3.9	N/A	31.1
Diameter Class 5	$\bar{X}$	70.6	5.0	8.4	48.1	7.8	9.5	27.2
(>40 cm)	S	114.2	8.7	10.5	46.2	11.7	N/A	50.0

Snag summary data are presented in Table 9 describing total snags per hectare and the various calculated sub-groups including height class, diameter class, softwood vs/ hardwood composition, and total large snag density.

Table 9. Mean and standard deviation of snag densities (stems ha^{-1}) by broad species group, height class, and diameter class, categorized by treatment/ age category.

Variable	Value	YN	YPS	YSPS	ON	OPS	OSPS	Overall
Snag Density/ha	$\bar{X}$	39.9	57.4	46.7	111.8	66.3	16.9	72.5
	S	11.8	27.2	42.3	112.4	33.8	N/A	71.1
Softwood	$\bar{X}$	4.5	3.2	2.5	27.0	18.8	1.8	15.9
	S	4.3	2.7	2.9	28.3	11.6	N/A	19.4
Hardwood	$\bar{X}$	35.4	54.2	44.2	84.7	47.5	15.1	56.6
	S	10.8	27.8	42.6	88.8	27.0	N/A	56.1
Height 2-5 m	$\bar{X}$	14.2	20.9	22.9	30.6	29.3	7.2	26.0
	S	5.1	21.2	20.0	17.1	18.2	N/A	17.4
Height 5.1-10.0 m	$\bar{X}$	18.3	34.6	19.2	25.5	27.4	5.4	24.5
	S	10.3	28.3	19.3	13.3	15.5	N/A	16.0
Height 10.1-15 m	$\bar{X}$	4.7	1.4	3.4	34.0	8.8	3.6	14.5
	S	3.3	1.4	3.4	53.9	5.2	N/A	31.8
Height 15.1-20 m	$\bar{X}$	1.2	0.5	1.0	3.5	0.7	0.0	1.6
	S	1.2	0.5	1.6	2.5	0.9	N/A	2.0
Height ≥ 20 m	$\bar{X}$	1.6	0.0	0.2	1.4	0.1	0.6	0.7
	S	3.5	0.0	0.4	1.3	0.4	N/A	1.5
10-20 cm DBH	$\bar{X}$	6.4	26.8	10.6	67.7	31.1	9.1	35.6
	S	5.6	30.9	7.6	85.7	26.9	N/A	54.2
20.1-30 cm DBH	$\bar{X}$	17.2	17.3	15.6	25.6	19.8	4.8	20.1
	S	13.2	22.2	18.8	33.2	16.8	N/A	22.6
30.1-40 cm DBH	$\bar{X}$	7.5	9.1	10.9	10.6	9.1	1.2	9.5
	S	5.6	11.2	14.8	7.7	5.6	N/A	8.1
≥ 40 cm DBH	$\bar{X}$	8.8	4.1	9.6	7.9	6.2	1.8	7.3
	S	5.0	3.6	6.9	7.4	6.4	N/A	6.4
Large (≥30 cm)	$\bar{X}$	16.3	13.3	20.6	18.5	15.4	3.0	16.7
	S	6.9	13.6	19.9	12.2	9.2	N/A	11.8

Snag density by species composition and decay class are presented in Table 10. There were generally fewer softwood snags per hectare than hardwood snags per hectare.

Table 10. Mean and standard deviation of tree density by species (stems ha^{-1}), categorized by treatment/ age category.

Variable	Value	YN	YPS	YSPS	ON	OPS	OSPS	Overall
Spruce Snags	$\bar{X}$	0.1	0.7	0.2	1.1	5.2	0.0	2.2
	S	0.1	0.7	0.3	1.1	8.5	N/A	5.4
Balsam Fir Snags	$\bar{X}$	0.6	0.1	1.4	18.8	9.3	0.0	9.2
	S	0.6	0.2	2.7	22.2	7.6	N/A	14.7
Cedar Snags	$\bar{X}$	0.1	0.2	0.2	0.9	1.9	0.4	1.0
	S	0.3	0.3	0.4	1.0	3.8	N/A	2.4
Larch Snags	$\bar{X}$	4.6	0.1	0.0	0.0	0.0	0.0	0.5
	S	10.2	0.2	0.0	0.1	0.0	N/A	3.5
Aspen Snags	$\bar{X}$	21.6	38.4	7.8	58.3	28.5	15.5	34.2
	S	18.1	28.4	9.1	73.6	23.6	N/A	46.2
Birch Snags	$\bar{X}$	4.8	14.0	15.5	19.3	13.1	0.1	14.1
	S	5.6	12.4	9.5	13.8	15.9	N/A	13.6
Balsam Poplar Snags	$\bar{X}$	7.7	3.8	21.7	13.1	4.4	0.9	9.7
	S	8.8	5.9	37.3	24.9	8.3	N/A	20.3
Decay Class 1	$\bar{X}$	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	S	0.0	0.0	0.0	0.0	0.0	N/A	0.0
Decay Class 2	$\bar{X}$	9.8	10.7	1.0	30.1	8.0	7.9	14.1
	S	8.2	17.7	1.6	40.8	6.4	N/A	25.1
Decay Class 3	$\bar{X}$	17.4	17.1	9.8	47.5	26.7	5.4	28.4
	S	6.2	12.2	11.6	61.8	20.7	N/A	38.2
Decay Class 4	$\bar{X}$	9.2	13.9	9.3	17.6	15.1	3.6	14.0
	S	8.3	17.1	7.7	11.5	10.6	N/A	10.8
Decay Class 5	$\bar{X}$	3.5	14.5	15.8	13.6	12.0	0.0	11.9
	S	4.5	19.5	24.2	6.6	8.6	N/A	11.9
Decay Class 6	$\bar{X}$	0.0	1.3	9.6	3.0	4.3	0.0	3.8
	S	0.0	1.1	17.1	2.7	4.5	N/A	7.2
Decay Class 7	$\bar{X}$	0.0	0.0	1.3	0.0	0.2	0.0	0.3
	S	0.0	0.0	1.8	0.0	0.5	N/A	0.8

The general pattern of decay class distribution indicates there were few new snags (Decay Class 1 and 2) in study stands, with the exception of older naturally regenerated (ON) stands. There were also fewer old snags (Class 6 and 7) in study stands with the exception of young site prepared, planted, and sprayed (YSPS) stands.

Volume of coarse woody material is presented by treatment - age category and decay class in Table 12. There was little Class 1 coarse woody material (CWM) in any treatment – age category. Young planted and sprayed (YPS) stands had the highest volume of Class 2 CWM. Young site prepared, planted, and sprayed (YSPS) stands had the highest volume of Class 3 and Class 4 CWM. Older site prepared, planted and sprayed (OSPS) stands had the highest volume of Class 5 CWM. The bottom row of Table 11 shows the total CWM volume by treatment – age category. YPS and OSPS stands had the highest mean volumes of coarse woody material.

Table 11. Mean and standard deviation of volumes (m3 ha^{-1}) of coarse woody material by decay class, categorized by treatment/ age category.

Variable	Value	YN	YPS	YSPS	ON	OPS	OSPS
Class 1 CWM	$\bar{X}$	0.1	0.0	0.0	0.2	0.1	0.0
	S	0.1	0.0	0.0	0.4	0.3	N/A
Class 2 CWM	$\bar{X}$	6.9	24.5	19.4	11.7	5.5	15.0
	S	4.0	41.7	29.2	10.0	4.3	N/A
Class 3 CWM	$\bar{X}$	16.6	24.9	53.9	21.3	17.7	41.6
	S	9.4	19.5	28.8	9.9	16.4	N/A
Class 4 CWM	$\bar{X}$	15.1	21.4	39.6	15.7	19.8	25.7
	S	14.9	5.8	17.6	10.6	11.4	N/A
Class 5 CWM	$\bar{X}$	16.4	9.2	15.3	17.6	17.9	35.0
	S	12.2	14.3	8.8	18.4	13.2	N/A
Total	Sum	55.1	80.0	128.3	66.5	61.0	117.2

To reduce this dataset to important predictor variables, I used principal components analysis and discriminant function analysis.

Principal Components Analysis

Principal components analysis (PCA) was used as a data reduction technique as described in the methods section. The data reduction exercise resulted in the final principal components analysis with results presented in Table 12. The eigenvalues and percent dispersion explained by factors are presented in Table 13.

Table 12. Component loadings from principal component analysis using 15 stand-level attributes.

Variable	Factor1	Factor 2	Factor 3	Factor 4	Factor 5
Spruce Tree Density	-0.430	0.213	-0.626	0.283	-0.002
Balsam Fir Tree Density	-0.038	0.106	0.101	-0.217	0.881
Aspen Tree Density	-0.343	0.293	0.597	-0.047	-0.281
White Birch Tree Density	-0.031	-0.079	0.475	-0.489	0.154
Balsam Poplar Tree Density	-0.035	0.258	0.615	-0.219	-0.281
5-10m Snag Density	0.735	0.349	-0.281	-0.067	0.084
10.1-15m Snag Density	0.704	0.542	0.058	0.156	0.067
15.1-20m Snag Density	0.818	0.330	0.112	0.114	-0.025
20.1-30cm DBH Snag Density	0.860	0.172	-0.095	0.040	0.067
30.1-40cm DBH Snag Density	0.542	-0.561	0.062	-0.342	0.049
>40 cm DBH Snag Density	0.621	-0.041	0.246	0.300	-0.279
Class 2 CWD Volume	0.512	-0.660	-0.159	-0.304	-0.177
Class 3 CWD Volume	0.297	-0.798	0.086	0.208	0.067
Class 4 CWD Volume	-0.070	-0.709	0.216	0.497	0.086
Class 5 CWD Volume	0.025	0.053	0.640	0.517	0.342

Table 13. Eigenvalues and percent variance explained by each of five eigenvectors identified by principal components analysis.

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Eigenvalues	3.787	2.664	2.021	1.317	1.215
Percent Variance Explained	25.24	17.76	13.47	8.78	8.10

The total percent variation explained by the first five factors is 73.35%. The rest of the variation is accounted for by the 10 eigenvectors that were not presented by the statistical software, during the statistical analysis. The 10 eigenvectors not presented only accounted for small proportions of variation, and were therefore not included in these results.

The variables identified through principal components analysis (Table 12) were then analysed using discriminant function analysis to identify which variables showed the strongest differences among treatment – age categories.

Discriminant Function Analysis (DFA)

DFA and Canonical Scores of Silvicultural Treatment Alone

Discriminant function analysis (DFA) identified five stand structure variables that allow meaningful discrimination among groups of stands that are defined by the three silviculture intensities studied. Although prediction is not a goal of this work, it is encouraging to note that 40 of 43 stands were correctly classified based on these five variables alone.

The five significant stand component variables are:

- spruce tree density
- balsam fir tree density
- white birch tree density
- 10.1 - 15 m tall snag density
- volume of class 3 coarse woody material

Eigenvalues, canonical correlations, and cumulative proportion of total dispersion indicate the first eigenvector accounts for most of the ability to discriminate among silvicultural treatments (Table 14).

Table 14. Eigenvalues, canonical correlations, and cumulative proportion of total dispersion by discriminant function.

Value	Eigenvector One	Eigenvector Two
Eigenvalues	3.478	0.950
Canonical Correlations	0.881	0.698
Cumulative Proportion of Total Dispersion	0.785	1.00

The locations of the three treatment group centroids in the space defined by the five selected stand component variables are presented in Table 15. The standardized canonical discriminant function coefficients for the first two linear discriminant functions are presented in Table 16. A plot of the 43 study stands in discriminant function space, coded by silviculture intensity group, is shown in Fig. 3.

The magnitudes of the standardized discriminant function coefficients (Table 16) show the relative importance of the independent variables in discriminating among the three groups of stands. Specifically, Table 16 shows that factor scores on the first discriminant function are most influenced by the levels of: white birch tree density, spruce tree density, volume of class 3 coarse woody material, and 10.1 to 15 m snag density. Consequently, stands that plot on the right hand side of Fig. 3 are relatively high in spruce tree density and class 3 coarse woody material volume and relatively low in white birch tree density and 10.1 to 15 m snag density.

Following the same reasoning, factor scores on the second discriminant function are most influenced by the levels of: volume of class 3 coarse woody material and balsam fir tree density. Thus, stands that plot high on Fig. 3 are relatively low in volume of class 3 coarse woody material and high in balsam fir tree density.

Table 15. Treatment group centroids in the five dimensions identified through discriminant function analysis by forest stand component.

		Treatment		
Forest Stand Component	Units	Natural (n=18)	Plant and Spray (n=18)	Site Preparation, Plant and Spray (n=7)
Spruce Tree Density	(Stems ha^{-1})	255	914	554
Balsam Fir Tree Density	(Stems ha^{-1})	1004	1106	219
White Birch Tree Density	(Stems ha^{-1})	371	12	86
10.1-15 m Snag Density	(Stems ha^{-1})	266	8	3
Volume of Class 3 Coarse Woody Material	m^3 ha^{-1}	20	19	52

The X-axis represents a clear gradient of regeneration method, with naturally regenerating stands to the left and artificially regenerated stands to the right. The Y-axis is less clear, but it represents the next best variables for discriminating among treatments (Table 16 and Figure 3). The degree of vertical overlap in the groups suggests there is similarity in some cases, among treatments, with respect to coarse woody material volume and balsam fir stem density among treatment groups.

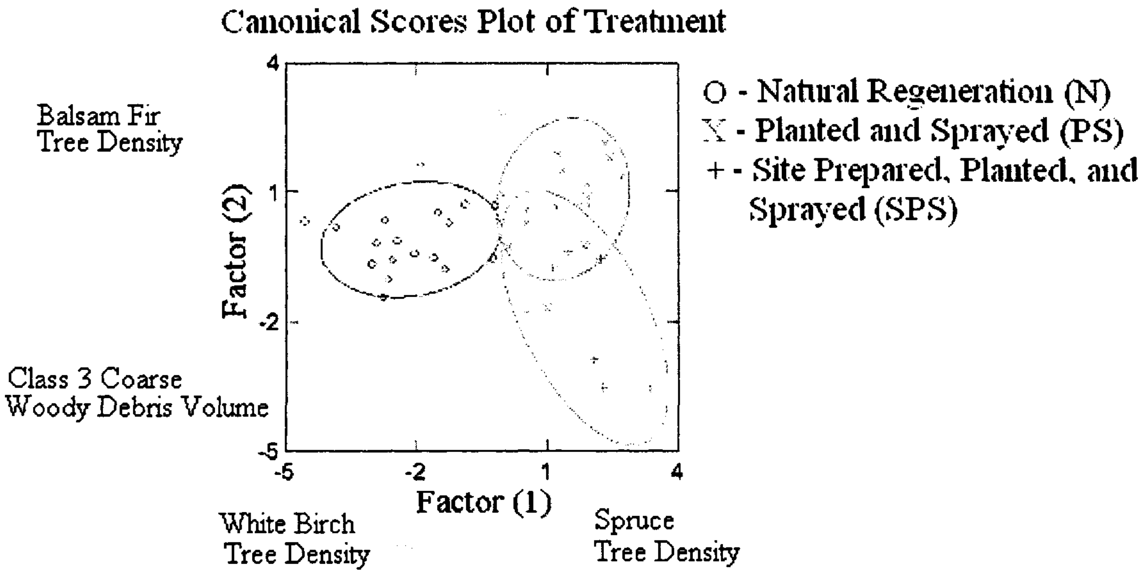


Figure 3. Canonical scores plot of the first two factors from discriminant analysis that identified five main factors that allowed positive discrimination 40 times out of a possible 43 stands near Kapuskasing 14-52 years old.

Table 16. Reported units and factor scores by stand structure component from canonical discriminant functions (standardized by within variances) for discriminant function analysis based on silvicultural treatment.

Forest Stand Component	Units	Factor 1	Factor 2
Spruce Tree Density	(Stems ha^{-1})	0.867	0.239
Balsam Fir Tree Density	(Stems ha^{-1})	-0.035	0.695
White Birch Tree Density	(Stems ha^{-1})	-0.970	-0.184
10.1m-15m Snag Density	(Stems ha^{-1})	-0.432	-0.037
Volume of Class 3 Coarse Woody Material	m^3 ha^{-1}	0.784	-0.739

DFA and Canonical Scores of Silvicultural Treatments with Age Categories

Discriminant function analysis (DFA) identified five stand structure variables that allow meaningful discrimination among groups of stands that are defined by the three silviculture intensities studied and two age categories. As described in the methods section, an age category variable was added to test for a discernable difference between stands that were regenerated before and after the advent of mechanized forest harvesting. The threshold age is 23 years. Age categories are associated with the full mechanization of forest operations and incorporation of harvest by feller-bunchers. Stands less than 23 years old are categorized as young (Y) stands. Stands greater than 23 years old are categorized as older (O) stands.

Although prediction is not a goal of this work, it is encouraging to note that 30 of 42 stands were correctly classified based on these five variables and two age classes. It is also encouraging to note that the most important discriminating variables are the same five stand structure variables identified in the previous analysis. The five significant stand component variables are:

- spruce tree density
- balsam fir tree density
- white birch tree density
- 10.1 - 15 m tall snag density
- volume of class 3 coarse woody material

Eigenvalues, canonical correlations, and cumulative proportion of total dispersion indicate the first eigenvector accounts for a high proportion of the ability to discriminate among silvicultural treatments (Table 17).

Table 17. Eigenvalues, canonical correlations, and cumulative proportion of total dispersion by eigenvector, as identified through discriminant function analysis.

	Eigenvector 1	Eigenvector 2	Eigenvector 3	Eigenvector 4
Eigenvalues	4.381	1.307	0.258	0.016
Canonical Correlations	0.902	0.753	0.453	0.124
Cumulative Proportion of Total Dispersion	.735	.954	.997	1.00

The locations of the three treatment group centroids in the space defined by the five selected stand component variables are presented in Table 18. Note that there are only five treatment – age categories because there was only one OSPS stand, excluding it from these analyses.

Table 18. Treatment group centroids of the five treatment/age category combinations by forest stand component identified through discriminant function analysis.

		Treatment – Age Category				
Forest Stand Component	Units	YN (n=5)	YPS (n=3)	YSPS (n=6)	ON (n=13)	OPS (n=15)
Spruce Tree Density	(Stems ha^{-1})	292	850	611	241	927
Balsam Fir Tree Density	(Stems ha^{-1})	453	213	237	1216	1285
White Birch Tree Density	(Stems ha^{-1})	281	19	86	406	10
10.1m-15m Snag Density	(Stems ha^{-1})	5	1	3	34	9
Volume of Class 3 Coarse Woody Material	m^3 ha^{-1}	17	25	54	21	18

The standardized canonical discriminant function coefficients for the first four linear discriminant functions are presented in Table 19. A plot of the 42 study stands in discriminant function space, coded by silviculture intensity group, is shown in Fig. 4. Note that older site prepared, planted, and herbicide-sprayed stands had to be omitted because there was only one stand in that age category, which would therefore not allow prediction of that treatment and age category.

Table 19. Reported units and factor scores by forest stand component from canonical discriminant functions (standardized by within variances) for discriminant function analysis based on silvicultural treatment and age category.

Forest Stand Component	Units	Factor 1	Factor 2	Factor 3	Factor 4
Spruce Tree Density	(Stems ha^{-1})	0.850	0.354	0.294	0.523
Balsam Fir Tree Density	(Stems ha^{-1})	-0.268	0.843	0.430	-0.394
White Birch Tree Density	(Stems ha^{-1})	-1.003	-0.278	0.139	0.254
10.1m-15m Snag Density	(Stems ha^{-1})	-0.562	0.054	0.591	0.681
Volume of Class 3 Coarse Woody Material	m^3 ha^{-1}	0.858	-0.536	0.714	-0.114

The magnitudes of the standardized discriminant function coefficients (Table 19) show the relative importance of the independent variables in discriminating among the three groups of stands. Specifically, Table 19 shows that factor scores on the first discriminant function are most influenced by the levels of: white birch tree density, spruce tree density, volume of class 3 coarse woody material, and 10.1 to 15 m snag density. Consequently, stands that plot on the right hand side of Fig. 4 are relatively high in spruce tree density and class 3 coarse woody material volume and relatively low in white birch tree density and 10.1 to 15 m snag density.

Following the same reasoning, factor scores on the second discriminant function are most influenced by the levels of: volume of class 3 coarse woody material and balsam fir tree density. Thus, stands that plot high on Fig. 4 are relatively low in volume of class 3 coarse woody material and high in balsam fir tree density.

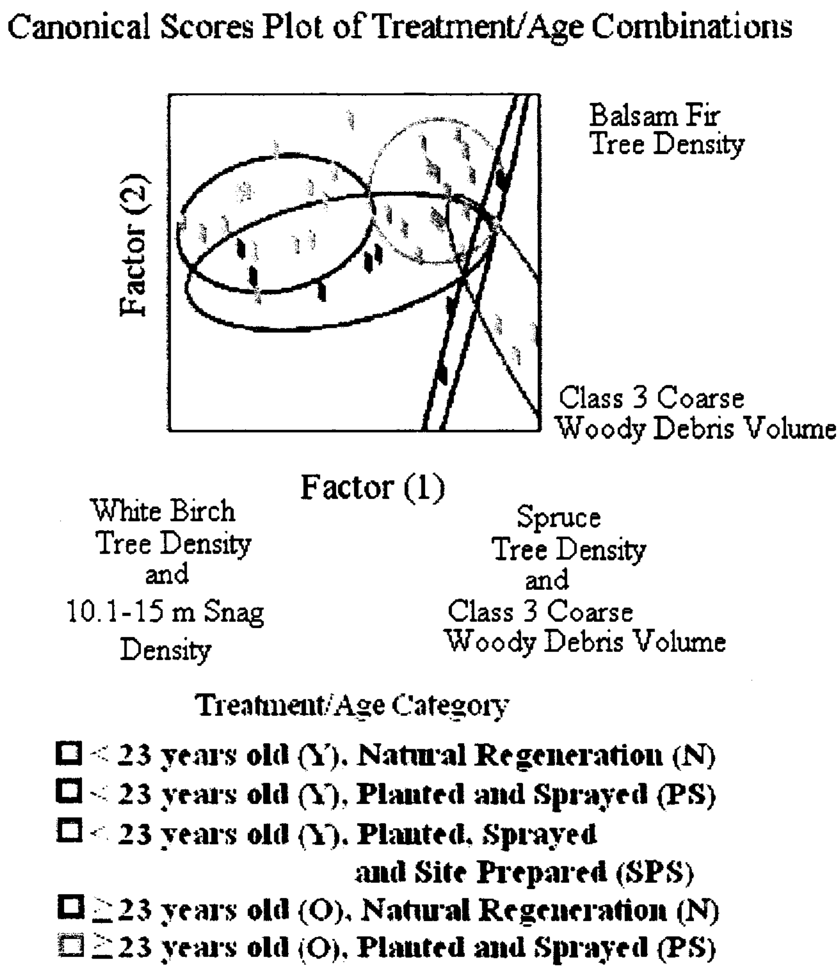


Figure 4. Canonical scores plot of the first two factors from discriminant analysis that identified five main factors that allowed positive discrimination 30 times out of a possible 42 stands near Kapuskasing 14-52 years old.

The degree of vertical overlap in the groups suggests there is some overlap of conditions with respect to coarse woody material volume and balsam fir stem density among treatment groups, with an age category introduced. Furthermore, stands that tend toward high balsam fir or high volume of class 3 coarse woody material are stands that had received silviculture. Silviculturally treated stands showed some separation in the canonical scores plot based on whether or not they were site prepared. Naturally regenerated stands showed little variation in volume of class 3 coarse woody material and balsam fir tree density, while silviculturally regenerated stands occupied a large range for volume of class 3 coarse woody material and balsam fir stem density. Old and young naturally regenerated (N) stands occupied approximately the same range of variability with respect to balsam fir stem density and coarse woody material volume (Figure 4).

Further analysis of 10.1-15 m snag density revealed that the oldest N-stands had high snag densities 49 and 53 years after disturbance. Naturally regenerated stands were the only silvicultural treatment group that had high densities of post-harvest origin snags (DBH $\geq$10 cm), likely due to high densities of post-harvest origin deciduous trees. Relative proportion of snag species composition indicated that the sum of relative proportions of aspen, white birch, and balsam poplar added to 92 % and 98 % of total snag density in the two high snag density stands. It was evident that the snags in 49-53 year old N stands were from the post-disturbance stand because the sum of relative proportion of class 2 and class 3 snags, indicating they were relatively new snags, added to 77% and 84% of total snag density,. Furthermore, diameter class distribution indicated diameter class 1 (10 - 20 cm dbh) accounted for 93% and 58% of total snag density, in the 49 and 53 year old stands, suggesting that relatively young trees were supplying the majority of snags.

LIVING FOREST STAND ATTRIBUTES

The following section focuses on the living stand component variables that were shown through the discriminant function analysis (DFA) to be meaningfully related to the separation of groups of stands that are defined by silvicultural intensity and age class. The specific questions asked via these analyses are:

1. What were the apparent effects of the three levels of silvicultural intensity and age class on each of the three living forest stand components identified through the DFA?
2. How were living stand-attributes modified by treatment and age category to produce these results?
3. Is there a predictable gradient in response among individual tree species along the continuum of post-harvest silviculture from no treatment, to planting and herbicide spraying, to site preparation with planting and spraying?

Analyses of Variance

Analyses of variance were performed on each of the three living stand component variables identified under the DFA. The general linear model is presented in Eq. 1. The three living forest attributes identified as having strong predictive influence in the discriminant function analysis were spruce tree density, balsam fir tree density, and white birch tree density. Mean and standard deviation of treatment-age category densities are presented in Table 20. Tables 21, 22, and 23 show ANOVA and post-hoc test results for specific living forest attributes identified through the discriminant function analysis. Figures 5, 6, and 7 show bar graphs of the treatment-age category values.

Table 20. Abbreviation, count, group means and standard deviations of living stand components identified through DFA by treatment/age category combination.

			Living Stand Components					
			Spruce Tree Density		Balsam Fir Tree Density		White Birch Tree Density	
Treatment/Age Combination	Abbreviation or No. code	Count *n*	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S
Young, Naturally Regenerated	YN - 11	5	291.9	347.9	452.8	282.1	280.6	200.6
Young, Planted and Sprayed	YPS - 12	3	850.2	516.8	213.5	240.3	19.3	30.4
Young, Site Prepared, Planted and Sprayed	YSPS - 13	6	611.0	331.4	237.5	60.9	85.6	114.0
Older Naturally Regenerated	ON - 21	13	241.3	232.9	1216.0	494.2	405.5	340.4
Older Planted and Sprayed	OPS - 22	15	927.3	441.7	1285.0	832.7	10.2	18.2
Older Site Prepared, Planted, and Sprayed	OSPS - 23	1	211.4	N/A	107.6	N/A	88.4	N/A
	Overall	43	579.8	463.6	919.1	728.2	174.1	263.0

Spruce Tree Density

Table 21. Analysis of variance, expected cell means, and least significant difference post-hoc test results indicating individual treatment effects for spruce tree density.

Analysis of Variance for Spruce Density

Source	*df*	Sums of Squares	Mean Square	F-ratio	*p-value*
Treatment (T)	2	2323470	1161730	8.7	≤ 0.001
Age class (A)	1	75532	75532	0.6	0.46
T*A	2	145129	72564	0.5	0.59
Error	37	4950010	133784		
Total	42	9026260			

Expected Cell Means of Spruce Tree Density

Level of T	Expected Cell Mean	Cell Count
N	266.6	18
PS	888.7	18
SPS	411.2	7

LSD Post Hoc Tests

	Difference	std. err.	p-value
PS - N	622.1	150.5	0.0002
SPS - N	144.6	219.7	0.515
SPS - PS	-477.5	228.9	0.044

Bar graphs of spruce tree density by treatment/ age class with 95% confidence intervals are presented in figure 5.

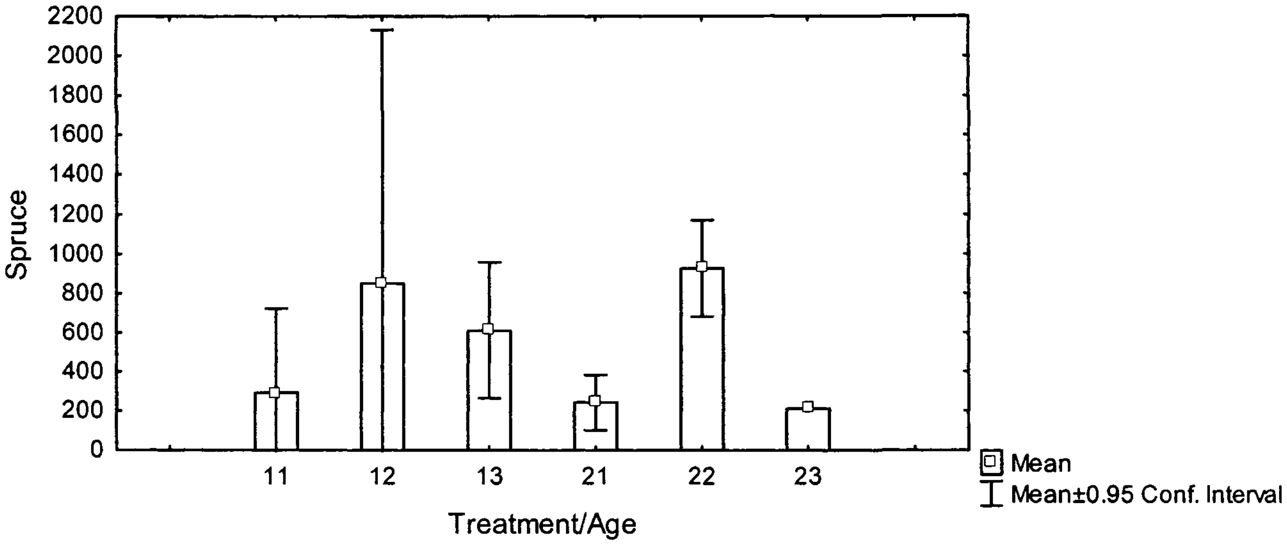


Figure 5. Spruce tree density by treatment/age class combination. Numerical codes are described in Table 20.

Balsam Fir Tree Density

Table 22. Analysis of variance, expected cell means, and least significant difference post-hoc test results indicating individual age effects for balsam fir tree density.

Analysis of Variance For Balsam Fir Density

Source	*df*	Sums of Squares	Mean Square	F-ratio	p-value
Treatment (T)	2	1224980	612488	1.7	0.19
Age class (A)	1	1576430	1576430	4.5	0.04
T*A	2	921226	460613	1.3	0.28
Error	37	13091100	353813		
Total	42	22271800			

Expected Cell Means of Balsam Fir Density

Level of A	Expected Cell Mean	Cell Count
Young	301.3	14
Old	869.5	29

LSD Post Hoc Tests

	Difference	std. err.	p-value
Old - Young	568.3	269.2	0.04

Bar graphs of balsam fir tree density by treatment/ age class with 95% confidence intervals are presented in figure 6.

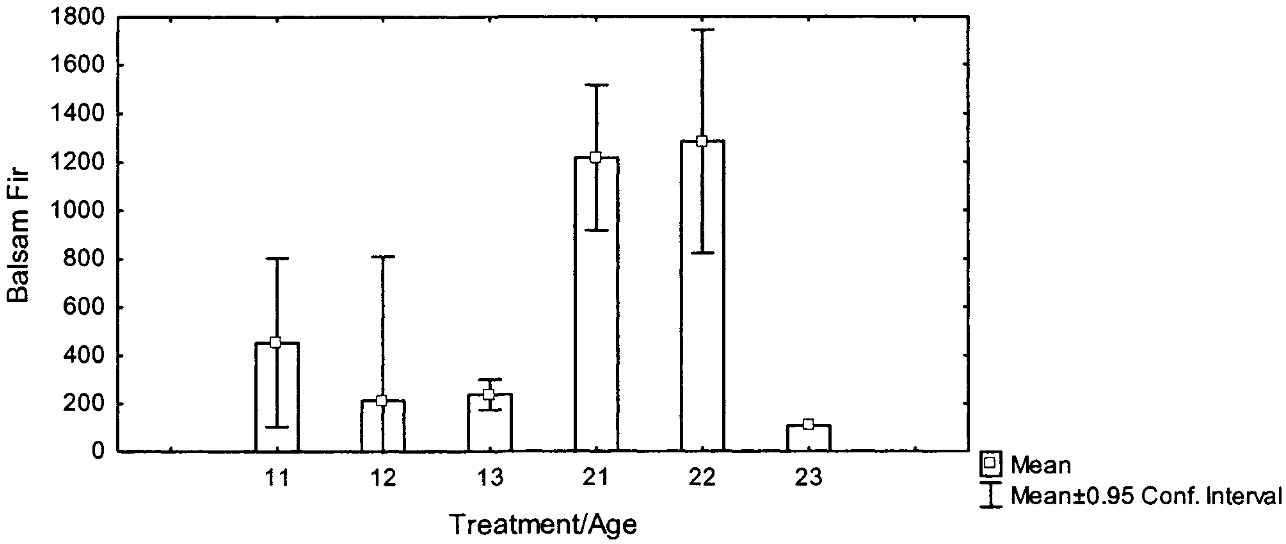


Figure 6. Balsam fir tree density by treatment/age class combination. Numerical codes are described in Table 20.

White Birch Tree Density

Table 23. Analysis of variance, expected cell means, and least significant difference post-hoc test results indicating individual treatment effects for white birch tree density.

Analysis of Variance of White Birch Density

Source	*df*	Sums of Squares	Mean Square	F-ratio	p-value
Treatment (T)	2	681443	340722	7.8	0.002
Age class (A)	1	7642	7642	0.2	0.68
T*A	2	29969	14985	0.3	0.71
Error	37	1622770	43859		
Total	42	2905010			

Expected Cell Means of White Birch Density

Level of T	Expected Cell Mean	Cell Count
N	343.1	18
PS	14.8	18
SPS	87.0	7

LSD Post Hoc Tests

	Difference	std. err.	p-value
PS - N	-328.3	86.2	0.0005
SPS - N	-256.1	125.8	0.05
SPS - PS	72.2	131.1	0.58

Bar graphs of white birch tree density by treatment/ age class with 95% confidence intervals are presented in figure 7.

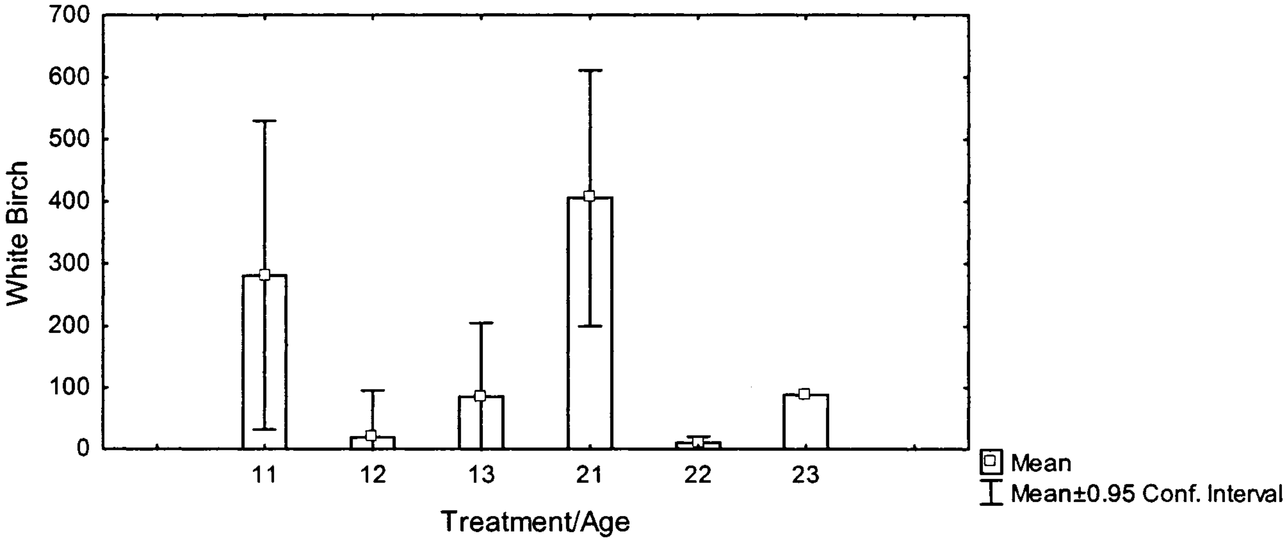


Figure 7. White birch tree density (Stems ha^{-1}) by treatment/age class combination. Numerical codes are described in Table 20.

Dummy Variable Regression Analyses

Scatter plots of spruce, balsam fir, and white birch-tree density against stand age are presented in Figures 7, 8, and 9. I show two versions of each scatterplot. In the a) version, the simple linear regression of tree density on stand age is superimposed. In the b) version, three "colored" regression lines are shown, where the individual colors correspond to the three silvicultural intensity groups (N, PS, and SPS). I used dummy variable regression to determine whether or not the trends suggested by the b)-versions of these plots (Figures 7, 8, 9) were statistically significant.

The general model is presented in Eq.2. Dummy variable codes for silvicultural intensity treatment groups are presented in Table 12. The full models are summarized in Tables 25, 27, 29 and the reduced models follow the full models in Tables 26, 28, 30.

The same models are illustrated in Figures 8, 9, and 10. These graphs were comparative rather than predictive.

Spruce Density

Dummy variable regressions indicate spruce tree density was significantly higher in planted and sprayed (PS) stands than naturally regenerated (N) almost immediately after the stand-originating disturbance (Table 25 and Figure 8 B), indicating that planting increased spruce tree density. Spruce tree density was not significantly different with age, for N and PS-stands, indicating spruce tree density is similar in older and younger stands. There is a significant treatment/age effect for site prepared planted, and sprayed (SPS) stands indicating older SPS stands have higher spruce density than young SPS stands.

Balsam Fir Density

Dummy variable regressions indicate balsam fir tree density was close to zero immediately after the stand-originating disturbance. Balsam fir tree density increased with age in all treatments (Table 27 and Figure 9 b), indicating older stands of all treatments have higher balsam fir density than younger stands.

White Birch Density

White birch tree density is significantly different between naturally regenerated (N) and planted and sprayed (PS) stands near the time of stand originating disturbance. Naturally regenerated (N) stand birch tree density is much higher than birch tree density in planted and sprayed (PS) stands (Table 39 and Figure 10 b). Age had no effect on the model, suggesting that naturally regenerated stands have significantly higher white birch tree density than planted stands, and the result is consistent throughout the time-period of the chronosequence. There is a significant treatment/age effect for site prepared planted, and sprayed (SPS) stands, indicating white birch density is higher in younger SPS stands than older SPS stands.

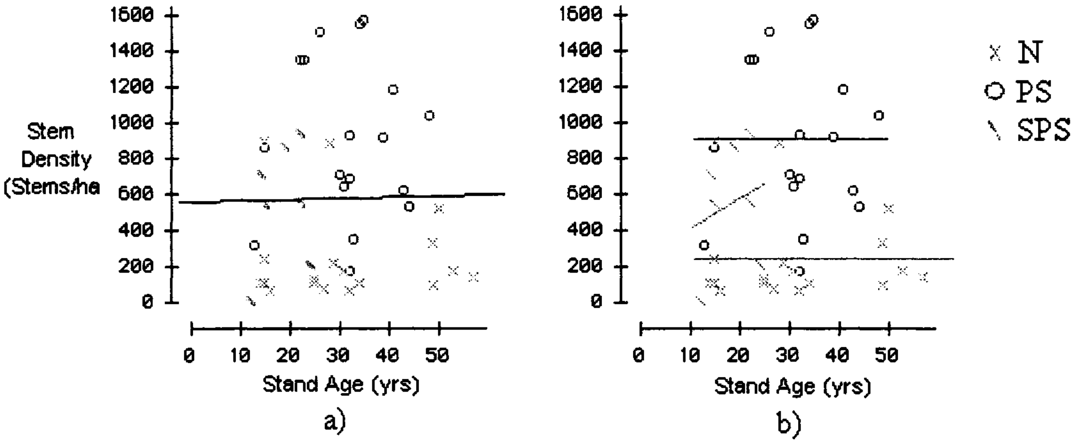


Figure 8. Scatter plots of spruce tree density vs. age. The overall regression of spruce stem density on age is superimposed on Fig. 8 a). Individual group regressions (full model) are superimposed on Fig. 8 b).

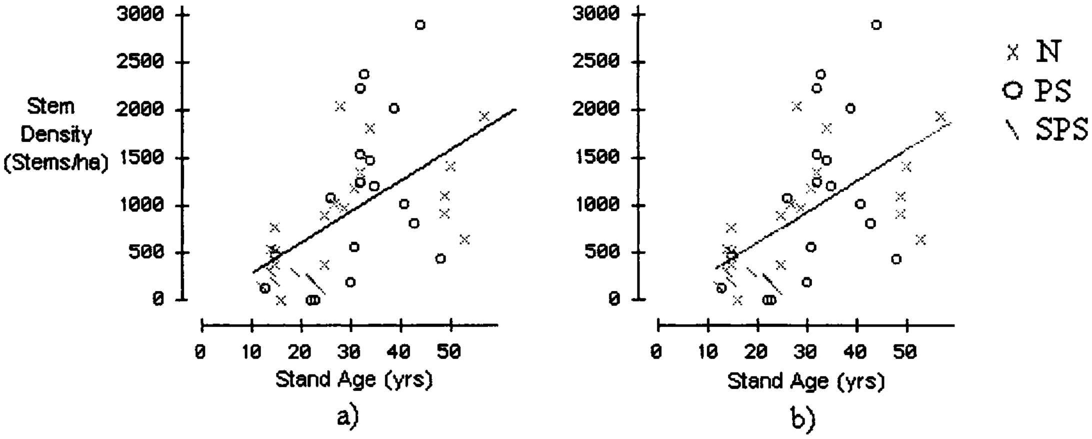


Figure 9. Scatter plots of balsam fir tree density vs. age. The overall regression of balsam fir stem density on age is superimposed on Fig. 9 a). Individual group regressions (full model) are superimposed on Fig. 9 b).

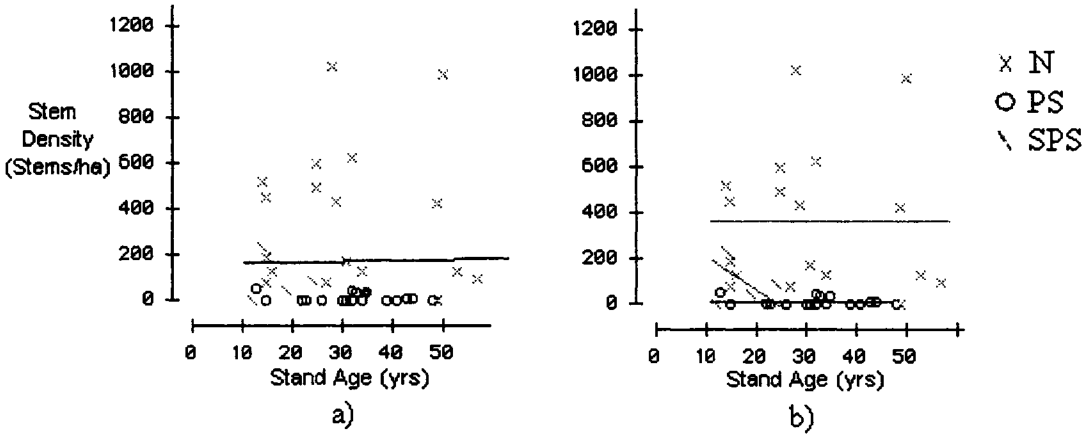


Figure 10. Scatter plots of white birch tree density vs. age. The overall regression of white birch stem density on age is superimposed on Fig. 10 a). Individual group regressions (full model) are superimposed on Fig. 10 b).

Table 24. Results of dummy variable regression of spruce tree density, silvicultural intensity treatments and stand age – the full model. Dummy variable codes for silvicultural intensity treatment are given in Table 5.

ANOVA Table

Source	Sum of Squares	*d.f.*	Mean Square	F-Test
Regression	3964050	5	792810	5.79
Residual	5062210	37	136816	

Coefficients Table

Variable	Coefficient	*s.e. of Coeff*	*t*-ratio	*p*-value
Constant	287.84	212.90	1.4	0.18
Age	-1.04	6.20	-0.2	0.87
D_1	614.74	378.40	1.6	0.11
D_2	-73.97	646.80	-0.1	0.91
D_1*Age	1.41	11.29	0.1	0.90
D_2*Age	19.63	33.10	0.6	0.56
$n = 43$	$R^2 = 43.9$	$R_a^2 = 36.3$	$\hat{\sigma} = 369.9$	$df = 37$

Table 25. Results of dummy variable regression of spruce tree density, silvicultural intensity treatments and stand age – the reduced model. Dummy variable codes for silvicultural intensity treatment are given in Table 5.

ANOVA Table

Source	Sum of Squares	*df*	Mean Square	F-test
Regression	3959390	2	1979690	15.6
Residual	5066870	40	126672	

Coefficients Table

Variable	Coefficient	*s.e. of Coeff*	*t-ratio*	*p-value*
Constant	254.51	83.05	3.1	0.004
D_1	659.92	118.00	5.6	≤ 0.0001
D_2*Age	16.49	8.36	2.0	0.05
$n = 43$	$R^2 = 43.9$	$R_a^2 = 41.1$	$\hat{\sigma} = 355.9$	$df = 40$

The regression models for spruce tree density in the three silvicultural intensity groups are presented immediately below.

Model 1 (natural regeneration): $y_{i1} = 254.51$

Model 2 (plant and spray with herbicide): $y_{i2} = 254.51 + 659.52$

Model 3 (site prepare, plant and spray with herbicide): $y_{i3} = 254.51 + 16.49\ \text{age}_i$

Table 26. Results of dummy variable regression of balsam fir tree density, silvicultural intensity treatments and stand age – the full model. Dummy variable codes for silvicultural intensity treatment are given in Table 5.

ANOVA Table

Source	Sum of Squares	*df*	Mean Square	F-ratio
Regression	8737800	5	1747560	4.78
Residual	13534000	37	365784	

Coefficients Table

Variable	Coefficient	*s.e. of Coeff*	*t-ratio*	*p*-value
Constant	360.94	348.10	1.0	0.31
Age	20.52	10.14	2.0	0.05
D_1	-671.59	618.70	-1.1	0.28
D_2	-97.21	1058.00	-0.1	0.93
D_1*Age	23.99	18.46	1.3	0.20
D_2*Age	-22.97	54.12	-0.4	0.67
$n = 43$	$R^2 = 39.2$	$R_a^2 = 31.0$	$\hat{\sigma} = 604.8$	$df = 37$

Table 27. Results of dummy variable regression of balsam fir tree density, silvicultural intensity treatments and stand age – the reduced model. Dummy variable codes for silvicultural intensity treatment are given in Table 5.

ANOVA Table

Source	Sum of Squares	*df*	Mean Square	F-Test
Regression	8046890	2	4023440	11.3
Residual	14224900	40	355623	

Coefficients Table

Variable	Coefficient	*s.e. of Coeff*	*t-ratio*	*p-value*
Constant	182.73	271	0.67	0.50
Age	27.65	8.07	3.43	0.001
D_2*Age	-25.90	13.97	-1.85	*0.07*
$n = 43$	$R^2 = 36.1$	$R_a^2 = 32.9$	$\hat{\sigma} = 596.3$	$df = 40$

The regression models for balsam fir tree density in the three silvicultural intensity groups are presented immediately below.

Model 1 (natural regeneration): $y_{i1} = 0 + 27.65\ age_i$

Model 2 (plant and spray with herbicide): $y_{i2} = 0 + 27.65\ age_i$

Model 3 (site prepare, plant and spray with herbicide): $y_{i3} = 0 + (27.65 - 25.90)\ age_i$

Table 28. Results of dummy variable regression of white birch tree density, silvicultural intensity treatments and stand age – the full model. Dummy variable codes for silvicultural intensity treatment are given in Table 5.

ANOVA Table

Source	Sum of Squares	*df*	Mean Square	F-ratio
Regression	8737800	5	1747560	4.78
Residual	13534000	37	365784	

Coefficients Table

Variable	Coefficient	*s.e. of Coeff*	*t-ratio*	*p*-value
Constant	360.94	348.10	1.0	0.31
Age	20.52	10.14	2.0	0.05
D_1	-671.59	618.70	-1.1	0.28
D_2	-97.21	1058.00	-0.1	0.93
D_1*Age	23.99	18.46	1.3	0.20
D_2*Age	-22.97	54.12	-0.4	0.67
$n = 43$	$R^2 = 42.7$	$R_a^2 = 34.9$	$\hat{\sigma} = 212.2$	$df = 37$

Table 29. Results of dummy variable regression of white birch tree density, silvicultural intensity treatments and stand age – the reduced model. Dummy variable codes for silvicultural intensity treatment are given in Table 5.

ANOVA Table

Source	Sum of Squares	*df*	Mean Square	F-Test
Regression	1232720	2	616358	14.7
Residual	1672290	40	41807.3	

Coefficients Table

Variable	Coefficient	*s.e. of Coeff*	*t-ratio*	*p-value*
Constant	368.60	*47.71*	7.73	< 0.0001
D_1	-356.87	67.82	-5.26	< 0.0001
D2*Age	-15.14	4.8	-3.15	0.003
$n = 43$	$R^2 = 42.4$	$R_a^2 = 39.6$	$\hat{\sigma} = 204.5$	$df = 40$

The regression models for white birch tree density in the three silvicultural intensity groups are presented immediately below.

Model 1 (natural regeneration): $y_{i1} = 368.60$

Model 2 (plant and spray with herbicide): $y_{i2} = 368.60 - 356.87$

Model 3 (site prepare, plant and spray with herbicide): $y_{i3} = 368.60 - 15.14\text{age}_i$

DISCUSSION OF LIVING FOREST STAND ATTRIBUTES

Within the following sub-sections of this report, I provide a brief overview of pertinent literature and then focus on tree species density differences that resulted from harvest and silviculture intensity in my study. I initially focus discussion on individual living stand components identified through statistical analyses, and compare my results with those found by other authors. To provide an overall discussion, I then summarize with a combined living forest dynamics discussion at the end of this chapter. Although living and dead components were examined together, dead-wood attributes are addressed in a later section.

Greene et al. (1999) reviewed regeneration dynamics of commercial North American boreal forest tree species. Dynamics of boreal mixedwoods have been well documented by Popadiouk et al. (2003), Chen and Popadiouk (2002), Brassard and Chen (2006), and Kuuluvainen (2002). In most cases, authors reviewed dynamics that followed natural disturbances. Several studies and generally accepted textbooks indicated post disturbance regeneration and stand development pattern depended on site and plant interactions (Bergeron 2000, Chen and Popadiouk 2002, Oliver and Larson 1996, Perrera et al. 2000). Chen and Popadiouk (2002) reviewed the four commonly accepted stages of boreal forest development: stand initiation, stem exclusion, canopy transition, and gap dynamics. Most stands in my study were within the stem exclusion phase of forest development and some of the older stands were nearing the end of this phase.

The effects of silviculture on forest regeneration have also been reviewed in Smith et al. (1996) and Wagner and Colombo (2001), where they reviewed aspects of regeneration, as well as silviculture and site preparation effects on regeneration in Ontario. Carleton (2000) provided an excellent description of post-harvest forest development in managed landscapes. Sutherland and Foreman (1995) provided a comprehensive description of site-preparation effects on different sites in northwestern Ontario.

The intent of forest practices used in the historic period associated with this chronosequence, was the production of spruce trees. Planting was expected to increase spruce density in early successional stands, as hypothesized by Thompson et al. (2003) and suggested by Carleton (2000), and Erdle and Pollard (2002), and found by Freedman et al. (1994). The significant increase in spruce tree stem density that resulted from planting confirmed that herbicide treated plantations were successful in the study area. Hearnden et al. (1992) reported on regeneration success in Ontario's managed forest based on the Ontario Independent Forest Audit in 1991. They concluded in order to regenerate conifer dominated stands, some planting and vegetation management may be necessary. They also found that after clearcutting, deciduous species tend to dominate the regenerating stand. The shift from conifer-dominated forest to deciduous-dominated forest following clearcutting has been well-documented by Carleton and MacLellan (1994), Carleton (2000), and Hearnden et al. (1992), among others.

Species composition shift is of concern to forest companies because they traditionally operated in a softwood dominated market while, at the same time, ecologists express concern that the deciduous-dominated managed landscape may not provide sufficient conifer dominated stands to support wildlife needs (e.g., Thompson et al. 2003). Because of concern for wood supply, forest companies used herbicide to temporarily control deciduous content of regenerating stands. In this study, herbicide exerted the greatest control over white birch tree density. According to Carleton (2000), silvicultural interventions that attempted to reduce the deciduous component of managed stands are successful. They do not, however, generally regenerate monocultures of the planted species (Rowland et al. 2005). According to silvicultural staff with 25 years experience on the study area: "The best way to regenerate a fine textured mixedwood boreal forest stand is to clearcut, plant spruce, and spray herbicide, at least once" (J. Leach, Tembec Ltd., pers. com).

MacKinnon and Freedman (1993) reported that although species abundance may have been significantly altered from their preharvest densities, no species was eliminated from their study plots. Erdle and Pollard (2002) confirmed that few plantations were strict monocultures in terms of tree species, in a study examining the effects of plantations at the landscape scale in New Brunswick. However, Betts et al. (2005) argue that although Erdle and Pollard (2002) concluded plantations were not necessarily monocultures, Pollard and Erdle (2002) also stated that defining biodiversity by tree species alone is of limited applicability. Betts et al. (2005) cite many examples from New Brunswick where other structural attributes (e.g., snags, coarse woody debris; Freedman et al. (1994), birds (Parker et al. 1994), amphibians (Waldick et al. 1999), herbaceous plants (Ramovs and Roberts 2003), and bryophytes (Ross-Davis and Frego 2002) showed reduced stand-level diversity in softwood plantations compared to in uncut forests or naturally regenerating stands.

Spruce Tree Density

Post-harvest silviculture treatment was a significant predictor of spruce density as suggested by the ANOVA models of spruce density (Table 21, and Figure 8). All planted stands in this study were treated with herbicide within 1-3 years after harvest. The significant increase in spruce tree density that resulted from planting was an expected result because planting and spraying a stand was intended to result in higher stem density of spruce. Herbicide likely increased the success of planted conifer regeneration, as suggested by Hearnden et al. (1992), MacKinnon and Freedman (1993), and Bell (1991). Herbicides effectively altered species composition toward more conifer dominated stand development by selectively killing or retarding growth of broad-leaf plants, as intended. My results are similar to those reported by many authors (e.g., Bell 1991, Lautenschlager et al. 1998, Freedman et al. 1994, MacKinnon and Freedman 1993, Rowland et al. 2005).

Herbicide use, especially when used in conjunction with planting, is known to give conifers a competitive advantage over deciduous competing species (Bell 1991, MacKinnon and Freedman 1993, Rowland et al. 2005). In my study, the delay in deciduous regeneration caused by herbicide application helped to explain the high density of spruce trees that became established in PS and SPS stands, but not in N stands (Figure 5). Deciduous species may have prevented establishment of spruce of the stems by out-competing spruce for growing space, nutrients, or water and taking a dominant stand position, a lack of seed source may have made spruce regeneration impossible, or inhospitable seedbeds may have resulted post-harvest preventing spruce from seeding in. Further, Brumellis and Carleton (1988), who also found low spruce stem density in post-harvest stands that were not planted, attributed that result to a modified C/N ratio in their study stands. Increased C/N ratio was caused by effects of mechanization, such as duff disturbance or creating raised microsites. The disturbed forest floor and availability of raised microsites encouraged deciduous competitor species. However, Brumellis and Carleton (1988) investigated lowland spruce, which I did not examine in this study, and I did not test for C/N ratios. Carleton and MacLellan (1994) also found forest harvesting shifted species composition toward hardwood dominated species composition rather than conifer dominated species composition. They attributed the species composition shift to disturbance type, as their study focused on comparison of post-logged conditions to post-fire conditions.

Because the effect of planting and spraying was statistically significant at age zero, based on my dummy regression results, I infer the effect of planting and spray immediately affected stand initiation and future composition. In my study, planting and effective herbicide use helped control long term stand development by ensuring that spruce gained a dominant stand position from early age. My results were similar to those in MacKinnon and Freedman (1993), Lautenschlager (1998) and Bell et al. (1997), although they were focussed on jack pine and effects of different competition control methods. The delay in aspen regeneration that resulted from herbicide application was apparently enough to allow spruce to become established. Spruce density remained constant over age in both N and PS stands.

The high variability in spruce densities among planted stands was likely a result of variable planting success and variable amounts of competition in PS and SPS stands as previously suggested by Hearnden et al. (1992). With one exception, young, naturally regenerated stands displayed far less variability in spruce tree density. The one exceptional stand density was attributed to high density of advanced regeneration in spruce, although this explanation was pure speculation. Older N stands had slightly more variability in spruce tree density than young stands due to competition from balsam fir. Spruce density did not change in N and PS stands within the time-period of the chronosequence (Table 21 and 25, Figure 8). This result implied that any spruce trees that would reach 3 m within the time period associated with this chronosequence had done so by the time they reached my minimum sampling age of 14 years. In other words, the spruce tree density was not significantly higher in older stands than in younger stands, in this study, likely due to variable post-silviculture development (Carleton 2000).

Analysis of naturally regenerated showed no age effect because spruce only made up a small proportion of stand density irrespective of age., and the density did not increase with age. Naturally regenerated stands also showed high variance in spruce tree density, likely due to variable seed source availability post-harvesting and regeneration success. In SPS stands, spruce tree density was low (Figure 5 and 8). Although spruce trees were planted and sprayed in SPS stands, I believe spruce tree density was lower than expected due to competition mortality or retarded growth due to early competition from grasses or another type of early seedling mortality as suggested by Bell (1991), and supported by Ryans and Sutherland (2001). Another possible explanation is that windrows of coarse woody material occupied a significant proportion of plantable area at the time of treatment, thus limiting the number of stems that could be planted per hectare. There was no evidence supporting this hypothesis in the literature, although personal observation of senior forestry staff supported this hypothesis. As initial planting density was intended to be the same in SPS and PS stands, and SPS stands did not achieve the same densities as PS stands, there must have been a difference in early seedling mortality or availability of plantable microsites.Spruce tree density was most important in separating silviculturally treated stands from untreated stands in the discriminant function analysis (Figure 3 and 4, Factor 1). Young naturally regenerated stands may not have the same spruce composition because microsites may have been colonized by deciduous species and balsam fir, or other ground vegetation such as shrubs or grass. The importance of spruce density that resulted from planting and herbicide confirmed the importance of silviculture in maintaining spruce in young regenerating forests following clearcutting, as proposed by Thompson et al. (2003), Freedman et al. (1996), Hearnden (1992), and Carleton (2000). Planting, as expressed through spruce tree density, exerted strong influence on stand structure and species composition.

Balsam Fir Tree Density

The apparent operational difference between stands less than 23 years old, and stands 23 years old or greater, was most apparent in balsam fir tree density (Table 22 and 27, Figures 6 and 9). The operational difference between age categories corresponded with an operational shift into fully mechanized operations with feller-bunchers, skidders, and roadside delimbing. The operational shift affected all treatment types and therefore resulted in a higher densities of balsam fir in older stands studied in this chronosequence. Balsam fir tree density was much lower in stands that had been harvested with machinery because it is a thin-barked species and is therefore susceptible to machinery damage, as supported by (Burns and Honkala 1990a). The importance of operational mechanization, including site preparation, in reducing balsam fir stem density has also been suggested by Buse and Bell (1992), Foreman and Sutherland (1995) and discussed by Carleton (2000). The mechanical damage theory is supported by low balsam fir stem densities in mechanically harvested stands of all treatments. More specifically, stands that had been site prepared showed an almost complete absence of balsam fir. YSPS stands had consistently low balsam fir densities in all stands, and had clearly received the most disturbance due to use of site-preparation. Further support for this result came from examination of the density of balsam fir shrubs; again YSPS stands had consistently low balsam fir stem densities, likely due to effects of mechanized harvest and site preparation.

Balsam fir tree density was most strongly implicated as a predictor variable in planted and sprayed stands (Figure 3 and 4) because advanced regeneration of balsam fir took advantage of herbicide release and became a dominant component of post-harvest stands (Carleton 2000, Harvey and Bergeron 1989). The effects of mechanization is also visible in the minor differences found between younger (<23 yrs old) and older (≥ 23 yrs old) naturally regenerated (N) stands in the canonical scores plot (Figure 3 and 4). Although there is significant overlap between the two age categories with respect to balsam fir tree density, younger N-stands (harvested with feller-buncher) had lower balsam fir stem density than older N stands. It is likely that mechanical damage exerted strong influence on balsam fir tree density in the discriminant function analysis and enhanced the ability to discriminate among treatment/age combinations.

Although my study was not specifically designed to test the effects of large, heavy tracked machinery, balsam fir showed strong correlations between my results (e.g., Tables 22 and 27, and Figures 4, 6, and 9) and the change in equipment used in the forest that happened approximately 23 years ago. Advanced regeneration of balsam fir was either controlled by mechanical site preparation or encouraged by herbicide (Figure 4) in silviculturally treated stands. I therefore suggest that increased mechanization has an increasingly negative effect on balsam fir tree density, and that herbicide release, in the absence of heavy mechanization, has a positive influence on balsam fir tree density.

My results for balsam fir are similar to those of Haeussler et al. (2002) who reported increased disturbance-intensity decreased abundance of some species such as balsam fir. The decreased abundance of some species allowed site occupation and increased density of other species (e.g., *Prunus* spp., *Alnus* spp., and *Rubus* spp.). Haeussler et al. (2002) concluded that increased disturbance intensity allowed a shift from residual and resprouting understory to ruderal species regenerating from seeds and spores.

At Kapuskasing, older stands had been harvested with chainsaws and the harvested wood was transported by cable skidders. Localized forest floor disturbance allowed the persistence of balsam fir advanced regeneration that now constitutes part of the dominant/codominant canopy in older stands. As a shade tolerant species, balsam fir is capable of showing growth response to very small canopy gaps (Messier et al. 1999). Balsam fir is considered a sub-climax to climax species (Sims et al. 1989), so it is expected to take a more dominant stand position as the stand matures and earlier successional species die through competition mortality (Chen and Popadiouk 2002), or as the spruce component dies off and, in the absence of fire, balsam fir can take advantage of canopy gaps.

White Birch Tree Density

Herbicide treated stands consistently had low white birch stem density, while. naturally regenerated stands had high white birch stem density and variance (Tables 23 and 29, and Figure 7 and 10), as also described by Carleton (2000) and Hearnden et al. (1992). There was a significant difference in white birch tree density between herbicide sprayed (PS and SPS) and non-herbicide-sprayed (N) stands due to the effectiveness of herbicide spray, particularly on white birch trees (Figures 3, 4, Factor 1). Lautenschlager et al. (1998) tested effects of a number of different herbicides on broad-leaved competition and found glyphosate to be effective at reducing white birch In the time period following herbicide application, it is likely that any subsequent white birch that regenerated was out-competed by other species such as aspen and various shurbs.

Messier et al. (1999) suggest that white birch requires large gaps to grow under a canopy. Trees that died in younger stages (initiation and early exclusions) due to interspecific and intraspecific competition were small and did not create a gap large enough for birch to regenerate below the canopy. Therefore, due to shade intolerance, I did not expect white birch stem density to increase within the historic period associated with the chronosequence. However, white birch can become established after a stand has begun to regenerate, according to Popadiouk et al. (2003). In their study of unmanaged boreal mixedwoods, they found white birch in older stands that were in the gap dynamics stage of development. These latter authors also found that white birch seedlings can regenerate on rotting logs and that white birch can survive for a long time in the shade by resprouting. However, I attribute their finding to their use of stands that had not been herbicide treated.

High density of white birch in untreated stands supports Bell (1991) who indicates reduced birch in heavily treated stands. Naturally regenerated stands showed high variance in white birch stem density, likely due to site differences and from competition by other species. White birch tree density was higher in more recently site prepared stands than in the oldest (26 – 28 year old) stands (Table 29, Figure 10 b) because recent site preparation with bulldozers may have left more exposed or mixed mineral soil microsites. The exposed or mixed organic/mineral microsites encouraged post-herbicide white birch tree regeneration. Ryans and Sutherland (2001) suggested that mechanical mixing of organic and mineral layers in site preparation can improve microsites for some deciduous species and since birch quickly colonizes exposed mineral soil, it is a reasonable expectation that more abundant mineral microsites suited to white birch lead to higher birch stem density.

My results with respect to living forest components can be summarized as follows:

- Planting promoted an increase in spruce tree density. Consequently, PS and SPS stands were distinguished from N stands due to their higher spruce tree density.
- The protection of advanced regeneration had a strong effect on stand structure in regenerating stands. The regenerating stands had more balsam for when advanced balsam fir regeneration was left intact, than if it was damaged by machinery.
- Herbicide strongly affected species composition of regenerating stands. The species composition shift most noticeable in my study was an almost complete elimination of white birch in herbicide treated stands.

- There was a predictable gradient in response among individual tree species along the continuum of post-harvest silvicultural treatments based on spruce, white birch, and balsam fir. Spruce density was most strongly influenced by tree planting. White birch density was strongly affected by herbicide spray. Balsam fir density was strongly affected by heavy machinery use, especially mechanical site preparation.

Carleton and MacLellan (1994) found coniferous species more widespread in post-fire stands, whereas hardwoods (aspen) were more frequently found in post-logged stands. They attributed this finding to the disturbance of the organic layer and newly created raised microsites. In earlier succession stands, sites tend to be dominated by balsam fir and aspen, then by aspen and spruce mixes, and then (in gap phase) by spruce and balsam fir (Chen et al. 2002, Casperson 2004). Popadiouk et al. (2003) found stem densities similar to my study for spruce and balsam fir, but also had evidence of birch in gap-phase boreal mixedwoods. Their study was different from mine in that they investigated the Ontario Permanent Sample Plot (PSP) data. Permanent sample plots were established in stands of all ages, broad soil groups, and stand development stages, and their analysis did not include managed stands. They also found jack pine in PSP's. There was very little jack pine in my study area because I focused on fine-textured fresh boreal mixedwood sites, where jack pine did not commonly dominate species composition. The presence of jack pine and old white birch in the permanent sample plot data are evidence of the range of conditions captured within the permanent sample plot program, that were not captured in this study. My study stands were restricted to upland mesic sites in an attempt to standardize site conditions as much as possible. My study investigated only managed stands. The history of silviculture in my study area only allowed sampling in stands up to the age associated with large (>10 cm) stem exclusion stage.

FOREST STAND DEAD WOOD ATTRIBUTES

The following section focuses on the dead stand structures identified as significant to my ability to discriminate among silvicultural treatments and age categories through the discriminant function analysis (DFA). The specific questions that further addressed the detailed component of this study were:

1. What were differences in dead stand components among post-harvest silvicultural intensities?

2. If there were differences in dead stand components identified through discriminant function analysis, how were dead stand structures different among post-harvest silviculture treatments?

3. Could post-harvest silviculture practices significantly alter stand attributes such that future stands will lack important dead structural attributes such as snags and coarse woody debris in comparison with natural regeneration following harvesting?

The purpose of this investigation was to understand clearly what treatments had the greatest effect on each dead forest component identified through the discriminant function analysis (Figures 3, 4 and Table 15, 16, 18, 19). Analysis of variance was used to test for differences between two age categories and three treatments.

Analyses of Variance

Analyses of variance were performed on each of the three living stand component variables identified under the DFA. These analyses were based on the two-factor ANOVA linear model given in Eq. 1.

The two living forest attributes identified as having strong predictive influence in the discriminant function analysis were density of 10.1-15 m tall snags, and volume of class 3 coarse woody material. Mean and standard deviation of treatment-age category densities are presented in Table 30. Tables 31 and 32 show ANOVA and post-hoc test results for specific dead forest attributes identified through the discriminant function analysis. Figures 11 and 12 show bar graphs of the treatment-age category values.

Table 30. Abbreviation, count, group means and standard deviations of dead stand components identified through DFA by treatment/age category combination.

			Dead Stand Components			
			10.1-15 m Snags		Class 3 Coarse Woody Material	
Treatment/Age Combination	Abbreviation or No. Code	Count	$\bar{X}$	S	$\bar{X}$	S
Young, Naturally Regenerated	YN - 11	5	4.7	3.3	16.6	9.4
Young, Planted and Sprayed	YPS - 12	3	1.4	1.4	24.9	19.5
Young, Site Prepared, Planted and Sprayed	YSPS - 13	6	3.4	3.4	53.9	28.8
Older Naturally Regenerated	ON - 21	13	34	53.9	21.3	9.9
Older Planted and Sprayed	OPS - 22	15	8.8	5.2	17.7	16.4
Older Site Prepared, Planted, and Sprayed	OSPS - 23	1	3.6	N/A	41.6	N/A
	Total	43	14.5	31.8	24.8	20.0

10.1- 15 m Snags

Table 31. Analysis of variance, expected cell means, and least significant difference post-hoc test results indicating no treatment or age category effects for 10.1-15 m snags.

Analysis of Variance for 10.1-15m Snags

Source	*df*	Sums of Squares	Mean Square	F-ratio	*p-value*
Treatment (T)	2	1508	754	0.8	0.46
Age (A)	1	734	734	0.8	0.39
T*A	2	1015	507	0.5	0.59
Error	37	35289	954		
Total	42	42578			

Bar graphs of 10.1-15 m snag density and 95% confidence interval are presented in Figure 11.

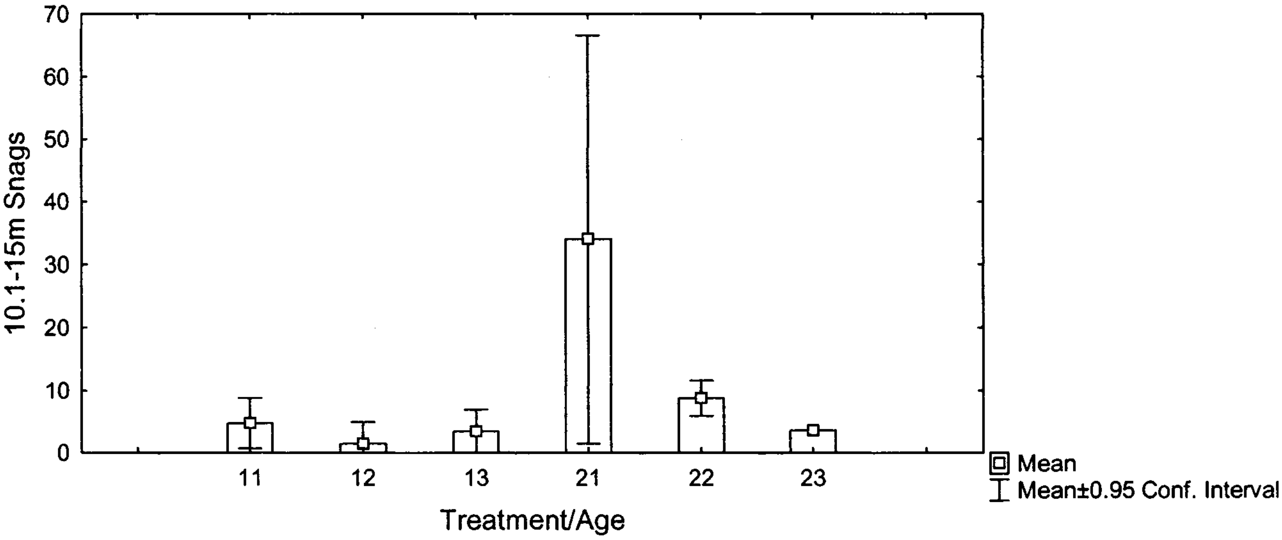


Figure 11. Density of 10.1-15m snags by treatment/age class combination. Numerical codes are described in Table 30.

Class 3 Coarse Woody Material

Table 32. Analysis of variance, expected cell means, and least significant difference post-hoc test results indicating individual treatment effects for volume of class 3 coarse woody material.

Analysis of Variance for Volume of Class 3 Coarse Woody Material

Source	*df*	Sums of Squares	Mean Square	F-ratio	*p-value*
Treatment (T)	2	2369	1185	4.3	0.02
Age (A)	1	117	117	0.4	0.52
T*A	2	322	161	0.6	0.56
Error	37	10227	276		
Total	42	16857			

Expected Cell Means for Volume of Class 3 Coarse Woody Material

Level of T	Expected Cell Mean	Cell Count
N	19.0	18
PS	21.3	18
SPS	47.8	7

LSD Post Hoc Tests

	Difference	*std. err.*	*p-value*
PS - N	2.3	6.8	0.74
SPS - N	28.8	10.0	0.006
SPS - PS	26.5	10.4	0.015

Bar graphs displaying volume of class 3 coarse woody material with 95% confidence intervals by treatment/ age class are presented in Figure 12.

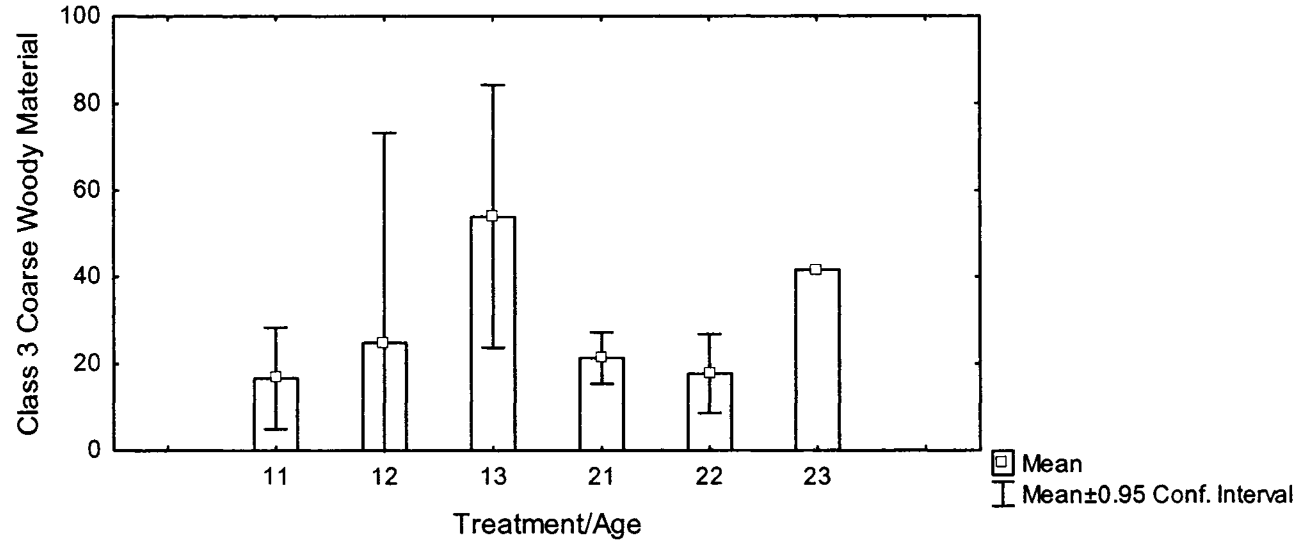


Figure 12. Volume of class 3 coarse woody material (in m^3) by treatment/age class combination. Numerical codes are described in Table 30.

Dummy Variable Regression Analyses

Scatter plots of 10.1-15m snag density and volume of class 3 coarse woody material against stand age are presented in Figures 13 and 14. I show two versions of each scatterplot. In the a) version, the simple linear regression of tree density on stand age is superimposed. In the b) version, three "colored" regression lines are shown, where the individual colors correspond to the three silvicultural intensity groups (N, PS, and SPS). I used dummy variable regression to determine whether or not the trends suggested by the b)-versions of these plots (Figures 13 and 14) were statistically significant. The general model is presented in Eq.2.

Dummy variable codes for silvicultural intensity treatment groups are presented in Table 5. The full models are summarized in Tables 34 and 36 and the reduced models follow the full models in Tables 35 and 37. The same models are illustrated in Figures 13 and 14. These graphs were comparative rather than predictive.

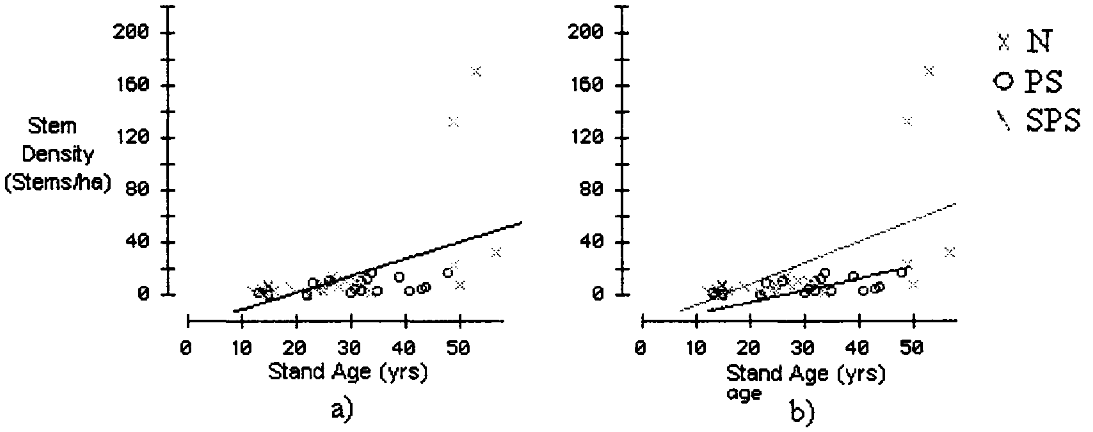


Figure 13. Scatter plots of 10.1-15 m snag density, for forest stands near Kapuskasing 14-52 years old, showing overall general linear model (a) and subdivided by treatment with dummy variable regression, Eq. 1, superimposed (b).

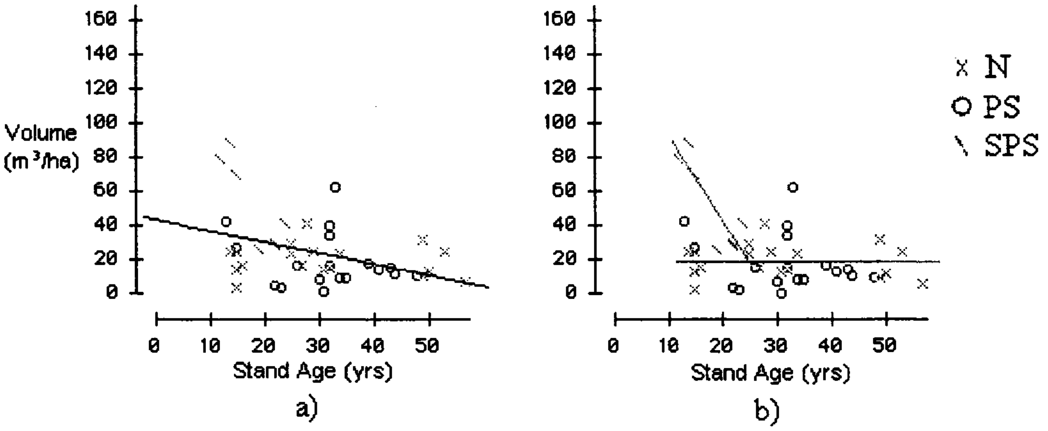


Figure 14. Scatter plots of intact coarse wood volume, for stands near Kapuskasing 14-52 years old, showing overall general linear model (a) and subdivided by treatment with dummy variable regression, Eq. 1, superimposed (b).

Table 33. Results of dummy variable regression of 10.1-15m snag density, silvicultural intensity treatments and stand age – the full model. Dummy variable codes for silvicultural intensity treatment are given in Table 5.

ANOVA Table

Source	Sum of Squares	*df*	Mean Square	F-Test
Regression	17695	5	3538.9	5.26
Residual	24884	37	672.5	

Coefficients Table

Variable	Coefficient	*s.e.* of Coeff	*t*-ratio	*p*-value
Constant	-35.23	14.93	-2.4	0.02
Age	1.95	0.43	4.5	$\leq$ 0.0001
D_1	35.10	26.53	1.3	0.19
D_2	41.20	45.35	0.9	0.37
D_1* Age	-1.71	0.79	-2.2	0.04
D_2* Age	-2.09	2.32	-0.9	0.37
$n = 43$	$R^2 = 41.6$	$R_a^2 = 33.7$	$\hat{\sigma} = 25.93$	$df = 37$

Table 34. Results of dummy variable regression of 10.1-15m snag density, silvicultural intensity treatments and stand age – the reduced model. Dummy variable codes for silvicultural intensity treatment are given in Table 5.

ANOVA Table

Source	Sum of Squares	*df*	Mean Square	F-Test
Regression	16064	2	8032.1	12.1
Residual	26514	40	662.9	

Coefficients Table

Variable	Coefficient	*s.e.* of Coeff	*t*-ratio	*p*-value
Constant	-24.46	10.34	-2.4	0.02
Age	1.64	0.35	4.8	$\leq$ 0.0001
D_1*Age	-0.69	0.25	-2.8	0.01
$n = 43$	$R^2 = 37.7$	$R_a^2 = 34.6$	$\hat{\sigma} = 25.75$	$df = 40$

The regression models for 10.1-15m snag density in the three silvicultural intensity groups are presented immediately below.

Model 1 (natural regeneration): $y_{i1} = -24.46 + 1.64\ \text{age}_i$

Model 2 (plant and spray with herbicide): $y_{i2} = -24.46 + (1.64 - 0.69)\ \text{age}_i$

Model 3 (site prepare, plant and spray with herbicide): $y_{i3} = -24.26 + 1.64\ \text{age}_i$

Table 35. Results of dummy variable regression for volume of class 3 coarse woody material, silvicultural intensity treatments and stand age – the full model. Dummy variable codes for silvicultural intensity treatment are given in Table 5.

ANOVA Table

Source	Sum of Squares	*df*	Mean Square	F-Test
Regression	9694	5	1938.8	10.00
Residual	7163	37	193.6	

Coefficients Table

Variable	Coefficient	*s.e.* of Coeff	*t*-ratio	*p*-value
Constant	21.75	8.01	2.7	0.01
Age	-0.06	0.23	-0.2	0.81
D_1	9.72	14.23	0.7	0.50
D_2	120.69	24.33	5.0	≤ 0.0001
D_1* Age	-0.34	0.42	-0.8	0.43
D_2* Age	-4.88	1.25	-3.9	0.00
$n = 43$	$R^2 = 57.5$	$R_a^2 = 51.8$	$\hat{\sigma} = 13.91$	$df = 37$

Table 36. Results of dummy variable regression for volume of class 3 coarse woody material, silvicultural intensity treatments and stand age – the reduced model. Dummy variable codes for silvicultural intensity treatment are given in Table 5.

ANOVA Table

Source	Sum of Squares	*df*	Mean Square	F-Test
Regression	9432	2	4715.8	25.40
Residual	7425	40	185.6	

Coefficients Table

Variable	Coefficient	*s.e.* of Coeff	*t*-ratio	*p*-value
Constant	19.46	2.27	8.6	≤ 0.0001
D_2	122.99	22.61	5.4	≤ 0.0001
D_2* Age	-4.94	1.20	-4.1	0.0002
$n = 43$	$R^2 = 56.0$	$R_a^2 = 53.7$	$\hat{\sigma} = 13.62$	$df = 40$

The regression models for volume of class 3 coarse woody material in the three silvicultural intensity groups are presented immediately below.

Model 1 (natural regeneration): $y_{i1} = 19.46$
Model 2 (plant and spray with herbicide): $y_{i2} = 19.46$
Model 3 (site prepare, plant and spray with herbicide): $y_{i3} = (19.46 + 122.99) - 4.94\ \text{age}_i$

10.1-15m Snag Density

There is a no treatment effect for 10.1-15 m snag density, and there is no interaction effect due to age with treatment (Table 31 and Figure 11), with age treated as a categorical variable. There was a positive age effect for naturally regenerated (N) stands and planted and sprayed (PS) stands (Table 34 and Figure 13). This indicates the two models had significantly different age effects, but both treatments had higher snag densities in older stands than younger stands.

Class 3 Coarse Woody Material

According to the ANOVA results, silviculture treatments resulted in different volumes of coarse woody material. Post-hoc analysis results indicated the difference was that SPS stand volumes were significantly higher than N and PS stands. Dummy variable regression indicated the volume of class 3 coarse woody material was significantly different in naturally regenerated (N) stands and site prepared, planted, and sprayed (SPS) stands almost immediately after the stand-originating disturbance (Table 36 and Figure 14). This suggests SPS stands have higher volume of residual coarse woody material after harvest due to pre-disturbance stand condition or due to treatment. There was also a significant treatment/age effect for site prepared planted, and sprayed (SPS) stands indicating age had a strongly negative effect on class 3 coarse woody material volume in SPS stands compared to N and PS stands.

DISCUSSION OF FOREST STAND DEAD WOOD ATTRIBUTES

Coarse woody material management is an important consideration in forest management because dead woody material is a necessary habitat component for many vertebrate and invertebrate species (Thompson et al. 2003, Harmon et al. 1986, Payer and Harrison 2000, Freedman et al 1996). Further, in many ecosystems, coarse woody material provides a substrate for forest regeneration (e.g., Greene et al. 1999, Simard et al. 1998). One highly discussed implication of IFM practices on forested landscapes is a potential reduction of coarse woody material due to harvesting and stand management (Sturtevant et al.1997, Hansen et al 1991, Fleming and Freedman 1998). The short term effects of intensive forest management on dead woody material are dependent on the nature of the preharvest stand, the management techniques applied, and the length of planned rotation (Rowland et al. 2005).

In my study, total above ground coarse woody material volume includes standing snags and downed woody material. My results with respect to dead forest components can be summarized in the following two statements:

- Competition management affected stand development and mortality in silviculturally treated stands. The net effect of competition management was a time-lag in the generation of post-harvest origin snags and subsequent coarse woody material.
- Site preparation caused an increase in the decay rate of coarse woody material due to modified coarse woody material position and stem damage. As a result, sites that received competition management and site preparation may show low volumes of coarse woody material for an extended time period, even though their coarse woody material volume is high immediately after harvest.

My results agree with studies by Pedlar et al. (2002) and Hely et al. (2000), who found that total coarse wood volume is highest immediately after a stand initiating disturbance. As snags fall and coarse woody material decomposes, the volume of coarse woody material decreases until a low-point occurs just before the post-disturbance stand reaches the stem exclusion stage. As the post-disturbance stand reaches stem exclusion stage, coarse woody material volume begins to increase again due to competition related mortality in the post-disturbance stand (Rowland et al. 2005, Spies et al. 1988). Sturtevant (1997) suggested the low-point in total coarse woody material volume occurs near approximately age 55 in mixed balsam fir-spruce stands in Newfoundland. Many authors suspect shortened rotations that result from intensive forest management practices will have a cumulative effect, eventually reducing total coarse woody material in subsequent rotations (Thompson et al 2003, Carleton 2000, Bergeron et al 1999, Hansen et al 1991, Spies et al 1988)

10.1-15 m Snag Density

Stands from all silvicultural groups had similar ranges of snag density values and were not significantly different, with the exception of two N stands. The two outlier N stands had high densities of 10.1-15 m aspen snags. However, high densities of 10.1-15 m snags in the two outlier stands were an extremely important result. An investigation of plot level data associated with the two outlier stands revealed mostly 10–14 cm DBH aspen snags, indicating stem mortality had occurred in stems with diameters that met the minimum diameter criteria. I used 10 cm as a minimum diameter limit when measuring snags because it was minimum stem sized used by Tembec in their own dead woody material surveys. Ten cm is commonly used as a minimum diameter criterion because stems <10 cm decay quickly and contribute minimally to habitat quality (Bull 1983, Thompson et al. 2003, Sturtevant 1997).

It is likely that many small diameter snags (<10 cm) were generated due to competition mortality in young stands, however, they were not included in measurements due to my minimum diameter criterion. The two outlier N-stands helped to confirm that there were likely many snags generated due to stem exclusion in younger stands, but they were not identified in my sampling. The hypothesis of early stem mortality was confirmed by contemporary forest dynamics theory (e.g., Oliver and Larson 1996) which states that stem density is generally very high in the stand initiation phase and then decreases through a series of stem exclusion pulses due to competition mortality.

Planted and sprayed stands did not show competition related mortality during the timeframe associated with the chronosequence because density management (planting and spraying) reduced competition from "non-crop" species, such as aspen (Buse and Bell 1992, Hearnden et al 1992). Live-tree densities in silviculturally treated stands did not result in sufficient competition to generate 10.1-15 m snags within stand ages studied in this chronosequence. I therefore believe large-stem mortality will proceed at later ages in silviculturally treated stands.

Greif and Archibold (2000) used sub-plots of their larger temporary sample plots to measure all living and dead stems between 10 cm and 2 cm DBH. They found 2-16% of the stems in their study stands were dead standing snags, even at smaller diameters. Standing dead stem density percentages were also used by Ferguson and Archibald (2002), who found overall 18%, 1 %, 15%, and 16% of stems were dead in 0-60 year old, 61-80 year old, 81-100 year old, and >100 year old stands, respectively. The upper limit of Greif and Archibold (2000)'s values corresponded with those of Ferguson and Archibald (2002). I attribute the lower limits of snag density (2 %), presented by Grief and Archibold (2000) to differences in sampling methods. Greif and Archibold used fixed area plots that capture all attributes, including whether or not plots fell in or included anomalies of very high or low stem density. I anticipate that the low percentage mortality values reported by Greif and Archibold (2000) could be attributed to canopy gaps where all remaining trees had sufficient growing space and nutrients (Messier et al. 1999), and were therefore alive.

The characteristics of the two outliers also identified that stand density changes in older N stands was a result of large (>10 cm) stem competition mortality, usually between aspen and birch stems, rather than spruce or balsam fir stems. These results are similar to those of Casperson (2004) who found that early successional species have higher rates of mortality than late successional species. In my study, the lack of 10.1-15 m snags from immediately after harvest until approximately 49 years after harvest (Figure 13) was an important result. Low snag densities confirmed that, even after stands naturally regenerated, they did not produce 10 cm dbh snags in any significant numbers until age 49 in N stands. This result was also found by Sturtevant (1997), who calculated that although there were log-sized (8 cm) trees in managed stands at age 26, stands did not generate self-thinned coarse woody material (of 8 cm) until 48 years after disturbance. Sturtevant's estimate was based on site index curves and the length of time it took for stands to reach crown closure and a quadratic mean diameter of 8 cm. For ease of explanation, competition mortality between acceptable-sized trees will be referred to as snag generation phase, as suggested by Sturtevant (1997). Snag generation phase is one of several stem exclusions (Chen and Popadiouk 2002, Oliver and Larson 1996) that occur in pulses in even-aged stands.

The fact that there was a higher density of snags in older N-stands, in my study, indicated that the pulse of mortality had begun to affect trees as large as 10 cm dbh, my minimum dbh criteria for snags. However, PS stands did not have any outliers with similar snag densities, so if there were pulses of mortality in PS-stands, they apparently had not begun to affect 10 cm dbh trees in the time-period associated with this chronosequence. This result suggests that PS stands do not have the same level of inter- or intra-specific competition as occurred in N stands, in the time period associated with this chronosequence, and silviculturally treated stands in this study had not reached a snag generation phase. There may have been large-scale stem exclusions when trees were smaller, but they were not 10 cm DBH at the time of mortality.

In my results, I assumed most snags with DBH greater than 10 cm, in stands <49 years old were mostly a result of residual stems that remained after harvest. Preharvest origin was evident due to snag size and/or state of decay. My result was similar to Sturtevant (1997) who noted that white birch and smaller balsam fir were left standing after harvest in their study area. In this study, some stems of trembling aspen, white birch, and balsam fir were left standing after harvest. The fact that snag density increased significantly over age in N stands (Table 34) confirms that snag density was positively influenced by the lack of silviculture. This leads to the conclusion that N stands experienced stem exclusion earlier than PS stands, likely due to reduced deciduous competition density in PS stands.

Since spruce trees were planted and given a competitive advantage over deciduous competitor species with herbicide, the spruce trees out-competed birch and aspen trees at a very young age. Herbiciding of aspen stems causes a temporary (5-10 year) delay of aspen regeneration (Buse and Bell 1992). By the time aspen started to re-colonize stands, the planted spruce were already well established and held a dominant or co-dominant canopy position. Young shade intolerant aspen stems died through competition mortality as they grew among planted spruce (Casperson 2004), but before they attained 10 cm. Hence, in PS stands, generation of snags will be considerably delayed in years compared to N stands.

Class 3 Coarse Wood Volume

It is likely that most class 3 coarse woody material (CWM) in N and PS stands originated from residual balsam fir, birch, and aspen that died shortly after harvest operations. Carleton (2000) reported on the fate of residual stems after harvest and suggested there was usually high mortality. These results are similar to those of other authors who found that aspen are prone to pathogen attack, often due to logging damage, desiccation, and top breakage due to stem form (e.g., Alban and Pastor 1993). Residual balsam fir are also documented as being prone to desiccation and logging damage (Ryans and Sutherland 2001, Brumelis and Carleton 1988, Carleton 2000).

I suggest that class three coarse woody material (CWM) exerted strong influence on the model (Figures 3 and 4) because it indicated how much living and dead volume was left on site from preharvest origin. Most CWM was a result of preharvest trees left on site after harvest operations, similar to Sturtevante (1997). Stands that had high densities of deciduous trees or balsam fir in the preharvest species composition were candidates for site preparation. Therefore such stands might be expected to have the highest coarse wood volume immediately after harvest (Figure 14).

Class 3 coarse woody material is assumed to be coarse woody material with one of two types of preharvest origin. The first subcategory of class 3 coarse woody material of preharvest origin consists of living trees that were left behind after harvest and died shortly thereafter. The second subcategory consists of snags that were present in the harvested stand and were still sufficiently durable to be classified as class 3 coarse woody material (Hely et al. 2000). Post-disturbance stands had only begun to produce minimum acceptable sized snags within the later ages of this chronosequence (45-50 years) due to competition related mortality. I therefore concluded it was unlikely that Class 3 CWM originated from the post-disturbance stand, since piece size and abundance of new snags was too small to contribute significantly to volume of class 3 coarse woody material. This designation of preharvest and post harvest origin was also used by Siitonen et al. (2000).

Silvicultural treatments produced significantly different volumes of class 3 coarse woody material. SPS stands had a high volume of coarse woody material in 14 - 17 year old stands (Figure 14). Site preparation was used to knock over residual aspen and white birch stems after harvest. Coarse woody material was aligned in windrows, and at least some of the organic soil was removed between windrows (Ryans and Sutherland 2001 and confirmed by J. Leach, pers. comm.). The use of site preparation therefore implied the stand had a lot of residual stems and downed logging debris that had to be aligned before planting. However, in slightly older stands (18-28 yrs old), SPS stand coarse woody material volume was comparable with N and PS stands (Figure 14) due to fast decay rates of deciduous species (Alban and Pastor 1993, Lambert et al. 1980). Fractured or damaged boles often decay faster than intact boles due to increased surface area and entry points for microorganisms that cause decay (Harmon et al. 1986). Therefore, I attribute rapid decay rates to species of coarse woody material and to mechanical effects such as fracture and close contact with the forest floor that enhanced the rate of decay.

The volume of class 3 coarse woody material remained relatively constant (15-30 m3 ha^{-1}) throughout the rest of the chronosequence, from 28-52 years, thus the lack of significant age effect in N stands. Krankina et al. (1999) concluded that coarse woody material can store carbon for significant periods of time in boreal forests, depending on climate. With faster decay rates in SPS stands, I conclude that in time, the decay rate of coarse woody material in SPS stands will result in lower residual volumes of coarse woody material in SPS stands than in stands that have not been treated with site preparation.

In the case of SPS stands, it is particularly important to discuss rate of coarse woody material deposition because of the likely enhanced decay rate in these stands. Live stem densities of all species were low in SPS-stands compared to N and PS stands of similar ages because site preparation killed balsam fir trees, and herbicide spray killed deciduous trees. I expect similar spruce densities in PS and SPS stands because they were planted at the same planting density

If there is an enhanced decay rate, then preharvest-origin coarse woody material will be completely decayed within a short time-period after harvest. If there is also reduced or delayed coarse woody material deposition due to competition control, then there may be low coarse woody material volume on SPS sites for an extended time period, due to altered stand dynamics. Therefore, SPS stands may not begin to generate coarse woody material through snag generation for at least another 25 years.

DYNAMICS OF DEAD FOREST COMPONENTS

Snag densities were low in all stands until competition related mortality began to generate high densities of snags through stem exclusion. The only silviculture treatment that generated a relatively high snag density was natural regeneration. Pre-harvest origin coarse woody debris volumes are relatively constant in N and PS stands. And finally, coarse woody material in SPS stands had faster decay rates due to effects of bulldozers knocking-over, crushing, breaking, and piling coarse woody material. The difference in decay rate due to site preparation results in reduced residence time for any coarse woody material in site-prepared stands.

Taken together, these results suggest that silviculturally treated stands will undergo an extended period during which coarse woody material volume is low. The length of this period is increased by site preparation treatments since these treatments accelerate decay rates and thus reduce the residence time of pre-harvest coarse woody material. It is therefore important to assess silvicultural intensity by condition and species composition of trees left standing, if the desire is to manage for continuous supply of coarse woody material at the stand level. If these stands are harvested at a young age, say at 80 years, and subsequently treated again as SPS stands, I would expect that the next generation stand will have an even lower level of coarse woody material.

The lack of post-harvest origin snags in PS and SPS-stands will have a long-term effect on overall stand structure with respect to coarse woody material if these stand types make up a large proportion of forest stands. Naturally regenerated stands have a faster class 2/class 3 coarse woody material deposition rates than silviculturally treated stands, because they already have 10.1-15m tall snags post-harvesting.

Silviculture has not been practiced on this forest long enough to test whether or not the suggested slower recruitment of coarse woody material will occur as a result of post-harvest treatments. My analysis of tree and snag density dynamics that result from silvicultural interventions indicate an apparent time-lag in post-harvest snag development in silviculturally treated stands due to density management, which controls competition related mortality. Since naturally regenerated and silviculturally treated stands have similar ranges of values of coarse woody material at the oldest ages sampled, and few post-harvest snags being generated by silviculturally treated stands at the same age, lower coarse woody material volume is anticipated in silviculturally treated stands than in naturally regenerated stands in the future. These significant alterations to living and dead forest dynamics could sacrifice essential stand structure components, essential to biological processes.

CONCLUSIONS

My results indicate there is a potential low point or prolonged low level of coarse woody material volume in upland forests that receive post-harvest silviculture. Stands that receive more intensive silviculture (i.e. site preparation) could have the lowest coarse woody material volumes, in spite of having the highest initial volumes of coarse woody material after disturbance. Stands that are treated with density management may have a prolonged time-period of low coarse woody material volume because of reduced interspecific and intra-specific competition in stands. Reduction of competition in silviculturally treated stands slows the onset of the post-harvest origin snag generation stage. Delayed or reduced generation of post-harvest origin snags will have a negative effect on volume of high quality, post-harvest origin, coarse woody material. The low levels of dead stand structures coupled with reduced stand competition, have implications for planning long term abundance of quality coarse woody material at the stand level and at the forest level. Potentially reducing volume of coarse woody material on highly productive sites through intensive forest management practices could have long term effects on stand-level biodiversity by modifying dead stand structure component dynamics.

My results apply to upland mesic sites in northeastern Ontario. My study stands were treated with specific silviculture. The effects of those silviculture activities may be similar to other types of silviculture interventions. These results should therefore be applied with discretion under alternate management scenarios and geography

Management Implications

Modified stand dynamics could have adverse effects on processes that we do not yet understand, such as the role of small and large woody material in forest floor carbon and nutrient dynamics, and the importance of these aspects in soil maintenance. Short rotation forestry and use of roadside delimbing could reduce soil structural components and nutrient availability on post-harvest silviculturally treated sites. Hence, plantation variability creates uncertainty in achieving desired future forest conditions. If companies have a stated desirable future forest condition that they intend to use for wood supply planning, it is necessary to ensure stands are developing toward that future forest condition. Therefore, monitoring historic silviculture through retrospective observation is important to future wood supply and landscape planning.

On the other hand, harvesting without post-harvest silviculture increases the deciduous component in stands compared to that of the original forest. Therefore it is useful to use some untreated areas within the landscape planning process for maintaining landscape level diversity. However, landscape planners must be reminded that too much harvesting without silviculture will cause a large-scale change in forest composition from conifer dominated, to mixed or deciduous dominated, for the next rotation.

Recommendations:

Intensive forest management should concentrate on improving site occupancy on landscape and stand scales as my results, and those of other authors, clearly indicate significant structural differences and dynamics that result from intensive post-harvest silviculture. The proper use of prescribed burning with retention patches may be a more natural silvicultural tool and may be an alternative to the use of herbicide. Land use planning that incorporates zones of intensive forest management should consider site-occupancy of abandoned farm-land and roadsides for zones of intensified forest management, as recently suggested by Newmaster et al. (2006). In northeastern Ontario, under-used areas that are currently non-forested, or under-forested can benefit from establishment of intensive forestry plantations.

If intensive forest management is to be planned on large forested areas, it would be wise to consider the size of operational blocks. Appropriately sized, or appropriately organized, operational blocks may mitigate potentially negative effects of intensive forest management on habitat availability by placing operational blocks within a matrix of more diverse stands. Another important consideration in the land-use planning process is that if intensive forestry practices only target highly productive sites, they leave only less productive sites for alternate uses, such as habitat.

From a silvicultural perspective, preharvest assessments are necessary to understand site productivity, yield relationships, and in order to accurately plan for the most effective regeneration method for the desired future forest condition. Data should be consistently collected to describe sites prior to treatment in order to track silviculture effectiveness under many conditions. For example, companies should collect preharvest data before the site is harvested, report pre-harvest yield estimates, compare with post-harvest yield, and be very deliberate in planning for desired future forest condition. In addition to being responsible for preharvest assessments, forest companies should be required to either digitally document their historic silviculture or provide it to the government for future planning. In order to ensure their future wood supply is growing as expected; forest management companies need to track silviculturally treated areas, and perhaps untreated areas. Assembly of Ontario Ministry of Natural Resources historic datasets, with a similar type of analysis would improve the number of plots with which to make conclusions. Though the historic datasets were intended to reflect different projects, an overall investigation of their results would show broader patterns of interactions of silviculture with forest dynamics. A combination of retrospective observation and prospective monitoring programs will improve our understanding of silviculture, stand regeneration, and wood supply estimates, stand dynamics, and ultimately planning for coarse woody material.

LITERATURE CITED

Alban, D. H. and J. Pastor. 1993. Decomposition of Aspen, Spruce, and Pine Boles on 2 Sites in Minnesota. Canadian Journal of Forest Research 23: , 1744-1749.

Archibald, D. J. and R. W. Arnup. 1993. The management of black spruce advance growth in northeastern Ontario. Ontario Ministry of Natural Resources, Timmins, Ont. VMAP Technical Report No. 93-05.

Armson, K. A. 2001, Ontario Forests: A Historical Perspective, Fitzhenry and. Whiteside Limited, Markham ON, pp. 233

Armson, K. A., W. R. Grinell, and F. C. Robinson. 2001. History of Reforestation in Ontario. Part One, pp3. In Regererating the Canadian Forest: Principals and Practices for Ontario. Editors: R. G. Wagner and S. J. Colombo. Fitzhenry and Whiteside Limited Marham Ontario. Copyright © Queens Printer of Ontario 2001 650 pp.

Batcheler, C. and D. Bell. 1970. Experiments in Estimating Density from Joint Point- and Nearest-Neighbour Distance Samples. Proceedings of the New Zealand Ecological Society 17: , 111-117.

Bell, F. W. 1991. Critical silvics of conifer crop species and selected competitive vegetation in northwestern Ontario. Forestry Canada, Ottawa, Ont., and Ontario Ministry of Natural Resources, Thunder Bay. COFRDA Rep. 2310 and Northwest. Ont. For. Tech. Dev. Unit Tech. Rep. 19.

Bell, F. W., R. A. Lautenschlager, R. G. Wagner, D. G. Pitt, J. W. Hawkins, and K. R. Ride. 1997. Motormanual, mechanical and herbicide release affects early successional vegetation in northwestern Ontario. Forestry Chronicle 73: , 61-68.

Bell, F. W., D. G. Pitt, M. Irvine, W. C. Parker, L. J. Buse, N. Stocker, W. D. Towill, H. Chen, F. Pinto, K. Brown, D. Deyoe, T. McDonough, G. Smith, and M. Weber 2000. Intensive Forest Management in Ontario: Summary of a 1999 Science Workshop, Sault Saint Marie Ontario 1999.Ontario Ministry of Natural Resources Science Development and Transfer Series no. 003.

Bergeron, Y. 2000. Species and Stand Dynamics in the Mixed Woods of Quebec's Southern Boreal Forest. Ecology 81:6 1500-1516.

Bergeron, Y., B. Harvey, A. Leduc, and S. Gauthier, S. 1999. Forest management guidelines based on natural disturbance dynamics: stand- and forest-level considerations. Forestry Chronicle. 75: , 49–54.

Betts, M. G., A. W. Diamond, G. J. Forbes, K. Frego, J. Loo, B. Matson, M. Roberts, M. A. Villard, R. Wissink, and L. Wuest. 2005. Plantations and biodiversity: A comment on the debate in New Brunswick. Forestry Chronicle 81: , 265-269.

Brassard, B. W. and H. Y. H. Chen. 2006. Stand structural dynamics of North American boreal forests. Critical Reviews in Plant Science 25: , 115-137.

Brumelis, G. and T. J. Carleton. 1988. The vegetation of postlogged black spruce lowlands in central Canada. I. Trees and tall shrubs. Canadian Journal of Forest Research 18: ,1470-1478.

Bull, E. L. 1983. Longevity of snags and their use by woodpeckers. In: Davis, J. W., G. A. Goodwin, and R. A. Ockenfels. coords. Snag habitat management: proceedings of the symposium. Gen. Tech. Rep. RM-99. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 64-67.

Burns, R. M. and B. H. Honkala. (Editors). 1990a. Silvics of North America. Vol. 1. Conifers. U.S. For. Serv. Agric. Handb. 654.

Burns, R. M. and B. H. Honkala. (Editors). 1990b. Silvics of North America. Vol. 2. Hardwoods. U.S. For. Serv. Agric. Handb. 654.

Buse, L. J. and F. W. Bell. 1992. Critical silvics of selected crop and competitor species in northwestern Ontario. Thunder Bay, ON: Northwestern Ontario Forest Technology Development Unit. Ontario Ministry of Natural Resources. 138 pp.

Carleton, T. J. and P. MacLellan. 1994. Woody vegetation responses to fire versus clear-cutting logging: A comparative survey in the central Canadian boreal forest. Ecoscience 1:2 141-152.

Carleton, T. J. 2000. Vegetation responses to the managed forest landscape of central and northern Ontario. In Ecology of a managed terrestrial landscape: Patterns and processes of forest landscapes in Ontario. Edited by A.H. Perera, D.L. Euler, and I.D. Thompson. University of British Columbia Press, Vancouver, B.C. pp. 178–197.

Caspersen, J. P. 2004. Variation in stand mortality related to successional composition. Forest Ecology and Management. 200: , 149-160.

Chen, H. Y. H. and R.V. Popadiouk. 2002. Dynamics of North American boreal mixedwoods. Environmental Reviews 10: , 137-166.

Data Descriptions Inc. 1996. Datadesk 6.0.1™ (Windows) Copyright ® 1996, Data Description Inc.

Erdle, T. and J. Pollard. 2002. Are plantations changing the tree species composition of New Brunswick's forest? Forestry Chronicle 78: , 812-821.

ESRI 2002. Arcmap™ 8.2, Copyright 1999 2002, ESRI ® Inc.

Farrell, E. P., E. Fuhrer , D Ryan, F. Andersson, R. Huttl, and P. Piussi. 2000. European forest ecosystems: building the future on the legacy of the past. Forest Ecology and Management. 132:1, 5-20

Ferguson S. H. and D. J.Archibald. 2002. The ¾ power law in forest management: how to grow dead trees. Forest Ecology and Management 169: , 283-292.

Fleming, T. L. and B. Freedman 1998. Conversion if natural, mixed-species forests to conifer plantations: Implications for dead organic matter and carbon storage. Ecoscience 5:2, 213-221

Fraser, E. C., S. M. Landhäusser, and V. J. Lieffers. 2003. The effects of mechanical site preparation and subsequent wildfire on trembling aspen regeneration. New Forests 25: , 49-66.

Freedman, B., S. Woodley, and J. Loo. 1994. Forestry practices and biodiversity, with particular reference to the Maritime Provinces of eastern Canada. Environmental Reviews 2: , 33-77.

Freedman, B., V. Zelazny, D. Beaudette, T. Fleming, S. Flemming, G. Forbes, J. S. Gerrow, G. Johnson, and S. Woodley. 1996. Biodiversity implications of changes in the quantity of dead organic matter in managed forests. Environmental. Reviews 4: , 238-265.

Greene D.F., J. C. Zasada, L. Sirois, D. Kneeshaw, H. Morin, I. Charron, and M.-J.Simard. 1999. A review of the regeneration dynamics of North American boreal forest tree species Canadian Journal of Forest Research 29: , 824-839.

Greif G.E. and O. W. Archibold. 2000. Standing dead tree component of the boreal forest in central Saskatchewan. Forest Ecology and Management 131: , 37-46.

Groot, A. and B. J. Horton. 1994. Age and size structure of natural and second-growth peatland Picea mariana stands. Canadian Journal of Forest Research 24:2 , 225-233.

Haeussler, S., L. Bedford, A. Leduc, Y. Bergeron, and J. M. Kranabetter. 2002. Silvicultural disturbance severity and plant communities of the southern Canadian boreal forest. Silva Fennica. 36: , 307-327.

Hansen, A. J., T. A. Spies, F. J. Swanson, and J. L. Ohmann. 1991. Conserving biodiversity in managed forests: Lessons form natural forests. BioScience 41: , 382-392.

Harmon, M. E., J. F. Franklin, F. J. Swanson, P. Sollins, S. V. Gregory, J. D. Lattin, N. H. Anderson, S. P. Cline, N. G. Aumen, J. R. Sedell, G. W. Lienkaemper, K. Cromack, and K. W. Cummins. 1986. Ecology of coarse woody debris in temperate ecosystems. Advances in Ecological Research 15: , 133-302.

Harvey, B. D. and Y. Bergeron. 1989. Site patterns of natural regeneration following clear-cutting in northwestern Quebec. Canadian Journal of Forest Research 19: 1458-1469.

Hearnden, K. W., S. V. Millson, and W. C. Wilson. 1992. A report on the status of forest regeneration by the Ontario Independent Forest Audit Committee. Ontario Ministry of Natural Resources, Queen's Printer for Ontario, Canada.

Hely C., Y. Bergeron, and M. D. Flannigan. 2000. Coarse woody material in the southeastern Canadian boreal forest: Composition and load variations in relation to stand replacement. Canadian Journal of Forest Research 30: , 674-687

Hunter Jr., M. L. 1990. Wildlife, Forests, and Forestry: Principals of Managing Forests for Biological Diversity. Prentice Hall, Inc., Englewood Cliffs, NJ.

Jones, R. K., G. Pierpoint, G. M. Wickware, J. K. Jeglum, R. W. Arnup, and J. M. Bowles. 1983. Field guide to forest ecosystem classification for the Clay Belt, Site Region 3E. Ontario Ministry of Natural Resources, Toronto, Ontario, Canada

Jurgensen, M. F., M. J. Larsen, S. D. Spano, A. E. Harvey, and M. R. Gale. 1984. Nitrogen fixation associated with increased wood decay in Douglas-fir residue. Forest Science 30: , 1038-1044.

Kimmins, J. P. 2002. Future shock in forestry. Where have we come from; where are we going; is there a right way to manage forests? Lessons from Thoreau, Leopold, Toffler, Botkin and Nature. Forestry Chronicle 78: , 263-271.

Krankina, O. N., M. E. Harmon, and A.V. Griazkin. 1999. Nutrient stores and dynamics of woody detritus in a boreal forest: modeling potential implications at the stand level. Can. J. For. Res. **29**: , 20–32.

Kuuluvainen, T. 2002. Natural variability of forests as a reference for restoring and managing biological diversity in boreal Fennoscandia. Silva Fennica 36: , 97-125.

Lambert, R.L., G. E. Lang, and W. A. Reiners. 1980. Loss of mass and chemical change in decaying boles of a subalpine balsam fir forest. Ecology, **61**: 1460–1473.

Lautenschlager, R. A., F. W. Bell, R. G. Wagner, and P. E. Reynolds. 1998. The Fallingsnow Ecosystem Project: Documenting the consequences of conifer release alternatives. Journal of Forestry 96: , 20-27.

Laycock, W. and C. Batcheler. 1975 Comparison of Distance Measurement Techniques for sampling Tussock Grassland Species in New Zealand. Journal of Range Management 28:3, 235-239.

Mackensen, J. and Bauhus, J. 1999. The decay of coarse woody debris. Australia National University, Department of Forestry, National Carbon Accounting System, Technical Report No. 6.

MacKinnon, D. S. and B. Freedman 1993. Effects of Silvicultural Use of the Herbicide Glyphosate on Breeding Birds of Regenerating Clearcuts in Nova Scotia, Canada. The Journal of Applied Ecology 30:3, 395-406.

Maser, C. and J. M. Trappe (Technical Editors) 1984. The seen and unseen world of the fallen tree USDA Forest Service Pacific Northwest General Technical Report 164

Messier, C., R. Doucet, J-C. Ruel, Y. Claveau, C. Kelly, and M. J. Lechowicz. 1999. Functional ecology of advance regeneration in relation to light in boreal forests. Canadian Journal of Forest Research 29: , 812-823.

Newmaster, S. G., F. W. Bell, C. R. Rosenboom, H. A. Cole, and W. D. Towill. 2006 Restoration of floral diversity through plantations on abandoned agricultural land. Canadian Journal of Forest Research 36: , 1218-1236

Newton, M., M. L. McCormack Jr., R. L Sajdak, and J. D. Walstad. 1987. Forest vegetation problems in the Northeast and Lake States/Provinces. In Forest Vegetation Management for Conifer Production, ed. J. D. Walstad and P. J. Kuch. Wiley, New York. Pp 77-104

Newton, M., E. C. Cole, M. L. McCormack, and D. E. White. 1992. Young spruce-fir forests released by herbicides II: Conifer response to residual hardwoods and overstocking. Northern Journal of Applied Forestry 9: , 130-135.

Noss, R. F. 1987. Corridors in real landscapes: A reply to Simberloff and Cox Conservation Biology 1:2, 159–164.

Oliver, C. D. and Larson, B. C. 1996. Forest stand dynamics. Update ed. John Wiley and Sons, Inc., New York, N.Y. 520 p.

OFAAB 2002. Room to grow: final report of the Ontario forest accord advisory board on implementation of the accord. Ontario Forest Accord Advisory Board. Queens Printer for Ontario. 28 p.

OMNR 1986. Forest Resource Inventory of the Gordon Cosens Forest (Sustainable Forest Licence # 500600)

OMNR 1999. Ontario's living legacy land use strategy. Ontario Ministry of Natural Resources. Queens Printer for Ontario. 136 p.

OMNR 2001. Forest management guide for natural disturbance pattern emulation. Ontario Ministry of Natural Resources. Queen's Printer for Ontario. 40 p.

Parker, G., D. G. Kimball, and B. Dalzell. 1994. Bird communities breeding in selected spruce and pine plantations in New Brunswick. Canadian Field Naturalist 108: , 1-9.

Patterson J, D. DeYoe, S. Millson, and R. Galloway. 2001. Handling and planting of seedlings. In: Wagner RG, Colombo SJ (eds) Regenerating the Canadian Forest – principals and practice for Ontario. Fitzhenry & Whiteside Ltd., Markham, Ontario, pp 325-341

Payer, D. C. and D. J. Harrison. 2000. Structural differences between forests regenerating following spruce budworm defoliation and clear-cut harvesting: implications for marten. Canadian Journal of Forest Research 30: , 1965-1972.

Pedlar J. H., J. L.Pearce, L. A. Venier, and D. W. McKenney. 2002. Coarse woody material in relation to disturbance and forest type in boreal Canada. Forest Ecology and Management 158: , 189-194

Perera, A., D. Euler, I. D. Thompson. 2000. Ecology of a Managed Terrestrial Landscape: patterns and processes of forest landscapes in Ontario. University of British Columbia Press.

Popadiouk, R. V., H. Y. H. Chen, C. Bowling, and S. Vasiliauskas. 2003. Compositional and structural characteristics of Ontario's boreal mixedwoods. OMNR, Northeast Science and Information, Timmins, Ontario. Queen's Printer for Ontario. NESI TR-045.

Ramovs, B. and M. Roberts. 2003. Understory vegetation and environment responses to tillage, forest harvesting and conifer plantation development. Ecological Applications 13: , 1682-1700.

Ross-Davis, A. L. and K. A. Frego. 2002. Comparison of three managed forest types in the Acadian forest: diversity of forest floor bryophyte community and habitat features. Canadian Journal of Botany 80: , 21-23.

Rowland E. L., A. S. White, and W. H. Livingston. 2005. A Literature Review of the Effects of Intensive Forestry on Stand structure and Plant Community Composition at the Stand and Landscape Levels, Maine Agricultural and Forest Experiment Research Station, Miscellaneous Publication 754

Ryans, M. and B. Sutherland. 2001. Site preparation – mechanical, in: Wagner R.G., Colombo S.J. (Eds.), Regenerating the Canadian forest – principals and practice for Ontario, Fitzhenry & Whiteside Limited, Markham, ON, 2001, pp. 177-199.

Seymour, R. S. 1986. Stand dynamics and productivity of northeastern forests-biomass harvesting considerations. In Proceedings. 1986 Symposium on Productivity of Northern Forests Following Biomass Harvesting. USDA Forest Service NE-GTR 115. 63-68.

Seymour, R. S. and M. L. Hunter. 1992. New forestry in eastern spruce-fir forests: Principals and applications to Maine. Maine Agricultural Experiment Station Miscellaneous Publication 716.

Simard, M-J., Y. Bergeron, and L. Sirois. 1998. Conifer Seedling Recruitment in a Southeastern Canadian Boreal Forest: The Importance of Substrate. Journal of Vegetation Science, 9:4, Key Issues in Disturbance Dynamics in Boreal Forests. 575-582.

Siitonen, J., P. Martikainen, P. Punttila, and J. Rauh. 2000. Coarse woody material and stand characteristics in mature managed and old-growth boreal mesic forests in southern Finland. Forest Ecology and Management 128: , 211-225

Sims, R.A., W.D. Towill, K.A. Baldwin, and G.M. Wickware. 1989. Field guide to ecosystem classification for northwestern Ontario. Ontario Ministry of Natural Resources. Queens Printer for Ontario. 191 p.

Smith, D.M., B. C. Larson, M. J. Kelty, and P. M. S. Ashton. 1996. The Practice of Silviculture: Applied Forest Ecology. 9th edition. John Wiley & Sons, New York, 537 p.

Spies, T. A., J. F. Franklin, and T. B. Thomas. 1988. Coarse woody debris in Douglas-fir forests of western Oregon and Washington. Ecology 69: , 1689-1702.

Sturtevant B. R., J. A. Bisonette, J. N. Long, and D. W. Roberts. 1997. Coarse woody material as a function of age, stand structure, and disturbance in the boreal forest. Ecological Applications 7:2, 702-712

Sutherland, B.J., and Foreman, F.F. 1995. Guide to the use of mechanical site preparation equipment in northwestern Ontario. Natural Resources Canada, Canadian Forest Service, Great Lakes Forestry Centre, Sault Ste. Marie, Ont. NODA/NFP Rep. 4113.

Sutton, R. F. 1993. Mounding site preparation: A review of European and North American experience. New Forests 7:2

Systat Software Inc. 2002. Systat 10.2 Data.$^{(TM)}$, Copyright 2002, Systat Software Inc.

Thompson I. D, J. A. Baker, and M. Ter-Mikaelian 2003. A review of the long-term effects of post-harvest silviculture on vertebrate wildlife, and predictive models, with an emphasis on boreal forests in Ontario, Canada. Forest Ecology and Management 177: , 441-469

Van Wagner, C. E. 1993. Prescribed fire in the Great Lakes-St. Lawrence and Deciduous forests of Ontario: problems and potential. Ontario Ministry of Natural Resources, Central Region Science and Technology Development Unit. North Bay, ON. Technical Report No. 23 / VMAP Technical Report No. 93-02. 68 pp.

Wagner, R.G. 1994. Toward integrated forest vegetation management. Journal of Forestry 92:11, 26-30.

Wagner, R. G. 2005. Forest regeneration trends: Dinosaurs, political correctness, and the future. pp. 36-42 In Colombo, S.J. (Compiler). The Thin Green Line: A Symposium on the State-of-the-Art in Reforestation Proceedings, July 26-28, 2005, Thunder Bay, Ontario, Canada. Forest Research Information Paper 160. Ontario Ministry of Natural Resources, Sault Ste. Marie, Ontario. (Invited paper)

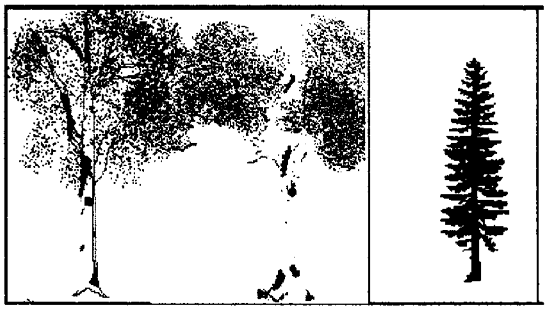
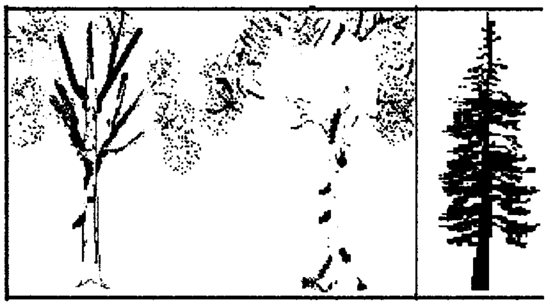
Wagner, R. G. and S. J. Colombo. 2001. Regenerating the Canadian forest – principals and practice for Ontario. Fitzhenry & Whiteside Limited, Markham, ON, 2001.

Wagner R. G., M. Newton, E. C. Cole, J. H. Miller, and B. D. Shiver. 2004. The role of herbicides for enhancing forest productivity and conserving land for biodiversity in North America. Wildlife Society Bulletin 32:4, 1028-1041.

Waldick R. C., B. Freedman and R. J. Wassersug. 1999. The consequences for amphibians of the conversion of natural, mixed-species forests to conifer plantations in southern New Brunswick. Canadian Field Naturalist 113: , 408-418.

APPENDICES

APPENDIX I. Images and descriptions used for decay classes of standing snags in this study. Adaptations of Maser and Trappe's 1984 snag classification system intended to reflect similar decay state, but as expressed in northern species.

Decay Class~	**Description**	**Images of the trees** (self descriptive)
This box will describe general tree characteristics and what common wildlife user groups are associated with each class.	*This box will describe key diagnostics of each decay class which may help in classification.*	*Images have crucial features (to classification) highlighted red for quick identification. Always use personal judgment and local knowledge where it exists. Adjustments between species can be made based on local knowledge.*
Class One (1) **Living tree that could show signs of poor health or damage leading to poor health.** Used by many wildlife user groups for shelter, food production, and/or breeding. Small or large stick nests may be present. ***(Not used in this study)***	***Features:*** Crown die-back, Newly broken top, Frost crack(s), Insect damage, Mechanical damage, Small excavated holes or signs of insect feeding by birds Roots stable	
Class Two (2) **Recently dead tree showing signs of damage or cause of death.** Commonly used by: wood boring insects, primary excavators (strong excavators), fungi, and insectivores. Small or large stick nests.	***Features:*** Retained Dead Leaves/Twigs/Buds Dry/cracking bark, Dark stain on bark, Hard heartwood, Signs of fungal, infection in exposed wood (grey) Roots stable	

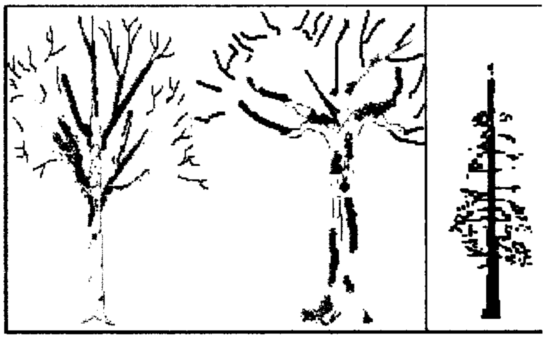
Class Three(3)

Dead tree showing signs of decay or loss of structural characteristics.

Used by wood boring insects, primary excavators and cavity users (smaller).
Larger stick nests.

Features:

No leaves/twigs, (small branches intact) Fungal Fruiting Bodies, Loosened/ cracked bark, fungal infection under bark, Wood dark where exposed, Hard heartwood, Roots stable



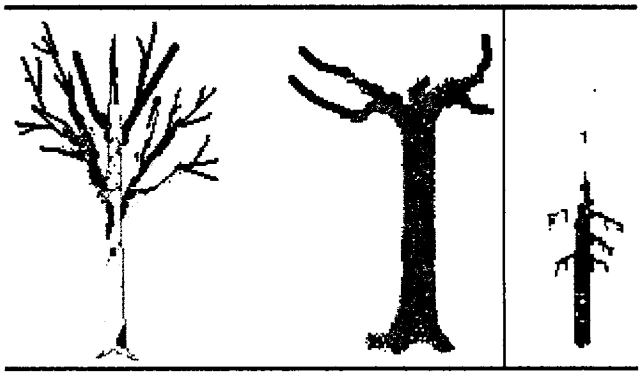
Class Four (4)

Dead tree showing signs of advanced decay.

Used by insects, primary and secondary excavators (larger) and larger secondary users, fungi, insectivores, raptors (hunting perch)
Large stick nests and excavated dens.

Features:

No small branches, Few large branches, Scars fungal fruiting bodies,
Up to 50 % of bark missing, Wood showing signs of decay (white rot) where exposed, Roots stable



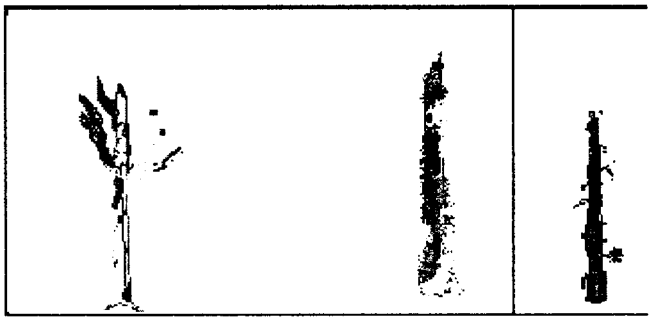
ClassFive(5)

Dead Tree showing advanced stages of decay.

Used by fewer insects, primary and secondary excavators (larger) and larger secondary users. Weak excavators, amphibians, fungi, insectivores, raptors (hunting perch) Large excavated dens.

Features:

Few large branches (if any)
<50% of bark remaining
Wood starting to become orange to dark brown color, Spongy Heartwood if not hollow, Roots becoming weak.
Becoming unstable



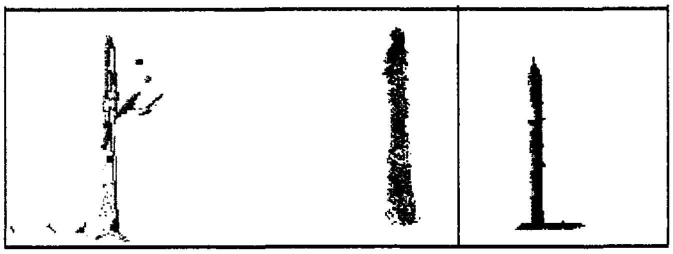
Class Six (6)

Dead Tree in advanced stages of decay.

Used by fewer insects, Unstable for primary and secondary excavators (larger) and larger secondary users. Weak excavators, amphibians, fungi, insectivores, raptors (hunting perch) display posts, singing perches

Features:

No Branches
< 25% of bark remaining
Fibrous wood (breaks off in squares) (Orange) Wood falling off in large pieces
Unstable Roots
Large holes at branch and conk holes
Excavated holes broken through, exposing large



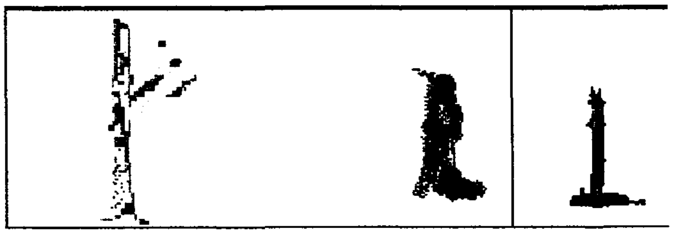
Class Seven (7/8)

Unstable Decayed tree

Used by fewer insects, Unstable for primary and secondary excavators.
Weak excavators, amphibians, fungi, microbial communities, insectivores.

Features:

No Branches, No bark
Fibrous wood (falls away in strands (stringy) (Orange) Wood falling off in large/ small pieces. Unstable roots and tree base. Gross features unrecognizable. Excavated holes

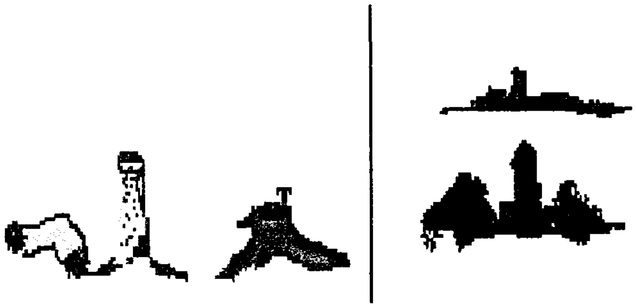


Class Nine (9)

Downed Woody Debris
"Extremely Important"
Used by Insects, Amphibians, birds, ground dwelling small mammals, microbial communities and fungi.
Shelter, food, host, display/drumming logs.

Features: < 2m

Detached from decaying standing stem or stem shorter than 2m due to decay. Various stages of decay classified by another system. Use system for classifying ground debris



APPENDIX II. Criterion and Acronym for measured and derived variables by component.

Measured Variables	Criterion	Group Acronym	Attribute Acronym
Trees			
	Diameter at breast height >10 cm, height >3m	T	
	Distance to first tree	T	Dist1
	Distance from first to second tree	T	Dist2
	Distance from second to third tree	T	Dist3
	Diameter at breast height (1.3 m) of first tree	T	DBH1
	Diameter at breast height (1.3 m) of second tree	T	DBH2
	Diameter at breast height (1.3 m) of third tree	T	DBH3
	Height of first tree	T	H1
	Height of second tree	T	H2
	Height of third tree	T	H3
	Species of first tree	T	Sp1
	Species of second tree	T	Sp2
	Species of third tree	T	Sp3
Small Trees			
	Diameter at breast height <10 cm, height >3m	ST	
	Distance to first small tree	ST	Dist1
	Distance from first to second small tree	ST	Dist2
	Distance from second to third small tree	ST	Dist3
	Height of first small tree	ST	H1
	Height of second small tree	ST	H2
	Height of third small tree	ST	H3
	Species of first small tree	ST	Sp1
	Species of second small tree	ST	Sp2
	Species of third small tree	ST	Sp3

Appendix II continued…

Measured Variables	Criterion	Group Acronym	Attribute Acronym
Shrubs			
	Height <3m, >1m	Sh	
	Distance to first shrub	Sh	Dist1
	Distance from first to second shrub	Sh	Dist2
	Distance from second to third shrub	Sh	Dist3
	Height of first shrub	Sh	H1
	Height of second shrub	Sh	H2
	Height of third shrub	Sh	H3
	Species of first shrub	Sh	Sp1
	Species of second shrub	Sh	Sp2
	Species of third shrub	Sh	Sp3
Snags			
	Diameter at breast height >10 cm, height >2m	Sn	
	Distance to first snag	Sn	Dist1
	Distance from first to second snag	Sn	Dist2
	Distance from second to third snag	Sn	Dist3
	Diameter at breast height (1.3 m) of first snag	Sn	DBH1
	Diameter at breast height (1.3 m) of second snag	Sn	DBH2
	Diameter at breast height (1.3 m) of third snag	Sn	DBH3
	Height of first snag	Sn	H1
	Height of second snag	Sn	H2
	Height of third snag	Sn	H3
	Species of first snag	Sn	Sp1
	Species of second snag	Sn	Sp2
	Species of third snag	Sn	Sp3
	Decay class (2 - 9) of first snag	Sn	Dc1
	Decay class (2 - 9) of second snag	Sn	Dc2
	Decay class (2 - 9) of third snag	Sn	Dc3
Coarse Woody Material (CWM)			
	Minimum diameter 10 cm, minimum 10 cm long	CWM	
	Coarse woody material length	CWM	L
	Coarse woody material diameter	CWM	Dia
	Coarse woody material decay class (1 - 5)	CWM	DC

Appendix II continued…

Derived Variables	Stand structure Component	Range
Height Class	Trees	
	HC1	3 - 5 m
	HC2	5.1 - 10 m
	HC3	10.1 - 15 m
	HC4	15.1 - 20 m
	HC5	20.1 - 25 m
	Snags	
	HC1	2 - 5 m
	HC2	5.1 - 10 m
	HC3	10.1 - 15 m
	HC4	15.1 - 20 m
	HC5	20.1 - 25 m
Diameter Class		
	Trees	
	DBHC1	< 10 cm
	DBHC2	10.1 - 20 cm
	DBHC3	20.1 - 30 cm
	DBHC4	30.1 - 40 cm
	DBHC5	> 40 cm
	Snags	
	DBHC1	10.1 - 20 cm
	DBHC2	20.1 - 30 cm
	DBHC3	30.1 - 40 cm
	DBHC4	> 40 cm
Stem Density by Species	Trees ≥ 3m tall	Derived stem densities by species were calculated by multiplying total tree stem density by proportion of occurrences of the species, in the data. e.g., total tree density = 1000/ha and spruce comprised 33.3 % of measured stems, then spruce density was calculated as: 1000 (stems ha^{-1}) * 33.3% = 333 spruce ha^{-1}
	Spruce	
	Balsam fir	
	Jack pine	
	Larch	
	Cedar	
	White birch	
	Trembling aspen	
	Black ash	
	Balsam poplar	
	Early Pioneers species groups such as cherry, willow, alder, mountain ash.	

Appendix II continued…

Derived Variables	Stand structure Component	Range
Coarse Woody Material	Dead Standing Decay Class	Derived decay class densities were calculated by multiplying total snag stem density by proportion of occurrences of the decay class, in the data. e.g., total snag density = 100 DC2 comprised 33.3 % of measured stems, then DC2 density was calculated as: 100 (stems ha^{-1}) * 33.3% = 33.3 DC 2 snags/ ha
	DC2	
	DC3	
	DC4	
	DC5	
	DC6	
	DC7	
	DC8	
	Dead Down Decay Class	
	DC1	Derived decay class volumes were calculated by multiplying total CWM volume by proportion of occurrences of the decay class, in the data, similar. to the density examples above, however using volume/ha as the reported unit.
	DC2	
	DC3	
	DC4	
	DC5	
Dummy Variable	Dummy Variable Regression	
	D1	Evaluates 1 when treatment is Plant and Spray
	D2	Evaluates 1 when treatment is Site Preparation, Plant, and Spray

Appendix III. Dummy variables and codes by case for all samples.

Case #	Stand Name	Stand Age Years	Treatment/ Age Code	Treatment Code	D1 Code	D2 Code	untreat Code	Young Code
1	629	13	12	2	1	0	0	1
2	823	15	12	2	1	0	0	1
3	96	22	12	2	1	0	0	1
4	939	23	22	2	1	0	0	0
5	609	26	22	2	1	0	0	0
6	708	30	22	2	1	0	0	0
7	305	32	22	2	1	0	0	0
8	554	32	22	2	1	0	0	0
9	612	31	22	2	1	0	0	0
10	613	32	22	2	1	0	0	0
11	707	33	22	2	1	0	0	0
12	423	34	22	2	1	0	0	0
13	324	41	22	2	1	0	0	0
14	413	35	22	2	1	0	0	0
15	426	43	22	2	1	0	0	0
16	79	39	22	2	1	0	0	0
17	108	44	22	2	1	0	0	0
18	153	48	22	2	1	0	0	0
19	217	15	11	1	0	0	1	1
21	631	15	11	1	0	0	1	1
22	274	15	11	1	0	0	1	1
23	503	16	11	1	0	0	1	1
24	25	25	21	1	0	0	1	0
25	463	14	11	1	0	0	1	1
26	392	27	21	1	0	0	1	0
27	610	28	21	1	0	0	1	0
28	319	57	21	1	0	0	1	0
29	824	29	21	1	0	0	1	0
30	304	32	21	1	0	0	1	0
31	303	31	21	1	0	0	1	0
32	376	34	21	1	0	0	1	0
33	201	25	21	1	0	0	1	0
34	316	50	21	1	0	0	1	0
35	414	49	21	1	0	0	1	0
36	663	49	21	1	0	0	1	0
37	131	53	21	1	0	0	1	0
38	334	12	13	3	0	1	0	1
39	296	14	13	3	0	1	0	1
40	785	15	13	3	0	1	0	1
41	830	19	13	3	0	1	0	1
42	112	22	13	3	0	1	0	1
43	132	22	13	3	0	1	0	1
44	322	24	23	3	0	1	0	0

Appendix IVa. Stand-level summary data used for analyses. Generic tree summaries.

Case #	Stand Age Years	Treatment Code	Trees > 10cm DBH (stems ha^{-1})	Trees > 3m Density (stems ha^{-1})	Hardwood Trees (stems ha^{-1})	Softwood Trees (stems ha^{-1})
1	13	2	37	551	80	467
2	15	2	490	1474	102	1369
3	22	2	156	1822	417	1391
4	23	2	643	3000	1599	1401
5	26	2	647	3360	628	2610
6	30	2	415	1457	540	912
7	32	2	1183	2960	1000	1503
8	32	2	1112	3029	299	2523
9	31	2	450	2739	1153	1245
10	32	2	1129	3525	204	2925
11	33	2	1081	3268	325	2748
12	34	2	1148	3622	382	3042
13	41	2	1154	2648	213	2227
14	35	2	1232	3640	651	2821
15	43	2	1129	2628	755	1779
16	39	2	953	3837	711	2959
17	44	2	953	3849	268	3549
18	48	2	1164	1940	376	1505
19	15	1	622	3337	1882	790
21	15	1	1129	2619	666	1600
22	15	1	462	4042	1755	959
23	16	1	26	814	497	96
24	25	1	631	2975	1281	615
25	14	1	375	4386	2153	670
26	27	1	829	3458	1326	1140
27	28	1	927	5543	1684	2942
28	57	1	1320	2633	388	2193
29	29	1	861	2595	839	1258
30	32	1	1135	3151	1597	1492
31	31	1	879	2791	422	1723
32	34	1	1104	2429	367	1985
33	25	1	980	4082	2250	1475
34	50	1	1627	3777	1399	1976
35	49	1	902	2532	962	1476
36	49	1	1257	1776	656	1027
37	53	1	529	2442	335	858
38	12	3	14	181	7	175
39	14	3	202	1797	368	1022
40	15	3	194	1186	277	764
41	19	3	374	2304	1025	1222
42	22	3	417	1566	733	792
43	22	3	261	1584	376	1196
44	24	3	389	2838	1557	430

Appendix IVb. Stand-level summary data used for analyses. Total volume of coarse woody material, total snag density, and softwood/hardwood breakdown of snags by case.

Case #	Stand Age Years	Treatment Code	Total CWM m^3/ha	Total Snags (stems ha^{-1})	SWD Snags (stems ha^{-1})	HWD Snags (stems ha^{-1})
1	13	2	132	82	5	77
2	15	2	82	28	5	23
3	22	2	26	62	0	62
4	23	2	12	43	16	27
5	26	2	52	145	36	109
6	30	2	43	75	14	61
7	32	2	138	80	17	63
8	32	2	38	72	12	60
9	31	2	53	24	11	12
10	32	2	101	46	9	37
11	33	2	120	75	25	50
12	34	2	42	60	3	57
13	41	2	49	22	10	12
14	35	2	59	44	22	22
15	43	2	83	36	15	21
16	39	2	34	62	20	42
17	44	2	49	107	23	84
18	48	2	43	106	50	57
19	15	1	80	40	6	35
21	15	1	12	46	11	34
22	15	1	64	51	3	48
23	16	1	31	42	1	41
24	25	1	70	99	8	91
25	14	1	89	20	1	19
26	27	1	55	65	4	61
27	28	1	88	41	7	35
28	57	1	66	102	35	67
29	29	1	86	56	9	47
30	32	1	115	50	8	42
31	31	1	47	68	9	59
32	34	1	72	84	21	63
33	25	1	56	42	11	31
34	50	1	37	54	38	17
35	49	1	59	85	33	52
36	49	1	43	288	92	196
37	53	1	71	420	78	341
38	12	3	227	124	0	124
39	14	3	188	25	2	23
40	15	3	142	61	8	54
41	19	3	73	43	2	40
42	22	3	87	14	3	10
43	22	3	53	14	0	14
44	24	3	117	17	2	15

Appendix IVc. Stand-level summary data used for analyses. Snag density by decay class by case.

Case #	Stand Age Years	Treatment Code	Decay 2 Snags (stems ha^{-1})	Decay 3 Snags (stems ha^{-1})	Decay 4 Snags (stems ha^{-1})	Decay 5 Snags (stems ha^{-1})
1	13	2	0	10	33	37
2	15	2	1	10	9	7
3	22	2	31	31	0	0
4	23	2	0	27	11	5
5	26	2	12	84	12	24
6	30	2	0	14	33	22
7	32	2	10	23	18	17
8	32	2	2	18	19	24
9	31	2	10	7	2	3
10	32	2	5	13	12	12
11	33	2	8	37	12	18
12	34	2	23	24	9	4
13	41	2	8	9	2	2
14	35	2	17	15	9	4
15	43	2	6	17	10	3
16	39	2	5	25	11	12
17	44	2	11	28	34	23
18	48	2	1	61	33	6
19	15	1	12	22	4	2
21	15	1	0	11	23	11
22	15	1	22	22	5	2
23	16	1	8	21	11	2
24	25	1	8	47	17	17
25	14	1	7	10	3	0
26	27	1	17	22	16	9
27	28	1	11	16	6	8
28	57	1	18	45	22	15
29	29	1	17	17	10	8
30	32	1	10	18	8	10
31	31	1	9	34	11	12
32	34	1	5	29	23	23
33	25	1	13	15	9	6
34	50	1	9	16	18	9
35	49	1	33	27	10	13
36	49	1	131	92	37	28
37	53	1	110	241	44	19
38	12	3	0	1	11	64
39	14	3	0	3	4	13
40	15	3	3	26	23	8
41	19	3	3	23	11	5
42	22	3	0	6	3	1
43	22	3	0	0	3	3
44	24	3	8	5	4	0

Appendix IVd. Stand-level summary data used for analyses. Tree density by species by age class. (Cases 1-25)

Case #	Stand Age Years	Treatment Code	Spruce Stems/ha	Jack Pine Stems/ha	Balsam Fir Stems/ha	Cedar Stems/ha	Larch Stems/ha	Aspen Stems/ha	White Birch Stems/ha	Balsam Poplar Stems/ha	Pioneer Species Stems/ha
1	13	2	324	0	141	0	2	4	54	0	26
2	15	2	869	0	482	0	18	11	4	11	81
3	22	2	1357	0	18	9	7	233	0	49	149
4	23	2	1361	0	18	8	13	898	0	31	669
5	26	2	1512	0	1098	0	0	514	0	41	195
6	30	2	715	0	192	0	5	158	0	221	166
7	32	2	182	0	1256	65	0	877	49	19	513
8	32	2	941	0	1560	0	22	78	0	188	240
9	31	2	652	0	572	0	20	819	0	61	614
10	32	2	693	0	2233	0	0	118	0	11	470
11	33	2	366	0	2377	0	6	213	43	27	237
12	34	2	1559	0	1483	0	0	255	0	118	206
13	41	2	1190	0	1037	0	0	196	0	16	208
14	35	2	1585	0	1225	11	0	396	42	40	341
15	43	2	630	0	832	317	0	664	10	43	132
16	39	2	927	0	2032	0	0	498	0	115	264
17	44	2	542	0	2909	88	11	219	10	30	42
18	48	2	1055	0	450	0	0	348	0	24	63
19	15	1	252	0	532	0	6	1107	80	582	778
21	15	1	902	0	391	0	307	355	198	0	466
22	15	1	121	0	774	2	62	987	459	156	1481
23	16	1	69	0	11	0	15	246	137	38	298
24	25	1	114	0	392	93	16	383	601	58	1318
25	14	1	115	0	555	0	0	461	529	546	2180

Appendix IVe. Stand-level summary data used for analyses. Tree density by species by case. (Cases 26-44)

Case #	Stand Age Years	Treatment Code	Spruce Stems/ha	Jack Pine Stems/ha	Balsam Fir Stems/ha	Cedar Stems/ha	Larch Stems/ha	Aspen Stems/ha	White Birch Stems/ha	Balsam Poplar Stems/ha	Pioneer Species Stems/ha
26	27	1	86	0	1037	16	0	783	86	292	1071
27	28	1	897	0	2045	0	0	340	1027	133	1102
28	57	1	150	0	1945	92	0	73	99	217	57
29	29	1	228	3	981	10	36	174	439	112	613
30	32	1	76	0	1366	50	0	789	633	37	200
31	31	1	178	3	1191	334	17	140	178	32	718
32	34	1	111	0	1825	49	0	171	133	34	95
33	25	1	144	0	896	410	24	1182	500	235	691
34	50	1	526	0	1433	16	0	231	998	100	471
35	49	1	343	0	1111	22	0	442	432	71	111
36	49	1	104	0	918	0	5	549	7	100	92
37	53	1	179	0	666	13	0	38	138	148	1259
38	12	3	21	0	147	0	6	2	2	1	2
39	14	3	720	0	298	4	0	62	243	0	469
40	15	3	546	0	205	0	14	9	218	5	190
41	19	3	874	0	311	0	37	453	51	9	568
42	22	3	557	0	227	7	1	613	0	60	101
43	22	3	948	0	237	0	12	234	0	42	112
44	24	3	211	0	108	25	85	595	88	238	1487

Appendix IVf. Stand-level summary data used for analyses. Snag density by height class and diameter class, by case. (Cases 1-25)

Case #	Stand Age Years	Treatment Code	2-5 m Snags Stems/ha	5.1-10 m Snags Stems/ha	10.1-15m Snags Stems/ha	10-20cm DBH Snags Stems/ha	20.1-30 cm DBH Snags Stems/ha	30.1-40 cm DBH Snags Stems/ha	DBH> 40 cm Snags Stems/ha
1	13	2	42	36	3	12	42	22	6
2	15	2	20	6	2	6	10	6	7
3	22	2	0	62	0	62	0	0	0
4	23	2	16	16	11	11	5	5	21
5	26	2	72	60	12	85	48	12	0
6	30	2	44	28	3	6	53	6	11
7	32	2	41	24	12	31	22	16	11
8	32	2	29	38	4	18	39	16	0
9	31	2	10	9	5	14	7	1	1
10	32	2	25	17	4	12	24	9	1
11	33	2	32	29	13	18	29	16	13
12	34	2	19	20	17	27	11	12	11
13	41	2	7	11	3	15	3	2	2
14	35	2	20	19	4	29	9	4	2
15	43	2	16	12	6	16	4	8	8
16	39	2	17	31	14	43	9	11	0
17	44	2	57	43	6	48	32	18	9
18	48	2	34	54	17	96	5	3	2
19	15	1	15	14	9	14	3	8	15
21	15	1	11	34	0	0	34	0	11
22	15	1	20	14	7	8	19	14	10
23	16	1	17	21	3	3	25	11	3
24	25	1	34	52	4	35	20	31	13
25	14	1	7	7	5	6	5	4	4

Appendix IVg. Stand-level summary data used for analyses. Snag density by height class and diameter class by case. (Cases 26-44)

Case #	Stand Age Years	Treatment Code	2-5 m Snags Stems/ha	5.1-10 m Snags Stems/ha	10.1-15m Snags Stems/ha	10-20cm DBH Snags Stems/ha	20.1-30 cm DBH Snags Stems/ha	30.1-40 cm DBH Snags Stems/ha	DBH> 40 cm Snags Stems/ha
26	27	1	28	17	15	18	24	19	4
27	28	1	12	20	7	15	16	7	2
28	57	1	26	37	34	71	11	5	15
29	29	1	28	12	11	21	20	7	8
30	32	1	19	19	11	25	13	9	3
31	31	1	27	24	11	31	23	10	4
32	34	1	27	45	3	38	22	16	9
33	25	1	14	13	9	12	12	10	8
34	50	1	22	22	8	35	9	6	4
35	49	1	35	19	24	68	9	6	2
36	49	1	48	106.8	133	268	17	0	2
37	53	1	78	112.7	172	244	135	13	28
38	12	3	61	55	4	17	52	40	16
39	14	3	13	10	0	4	6	6	9
40	15	3	28	25	7	19	10	12	20
41	19	3	18	18	7	17	20	3	3
42	22	3	9	3	2	5	3	2	4
43	22	3	8	5	0	3	3	3	5
44	24	3	7	5	4	9	5	1	2

Appendix Va. Stand-level summary data not-used for analysis. Main pioneer species, presented for detailed description of pioneer aggregate.

Case #	Stand Age Years	Treatment Code	Mountain Maple stems ha^{-1}	Green Alder stems ha^{-1}	Red Alder stems ha^{-1}	Pin Cherry stems ha^{-1}	Willow stems ha^{-1}
1	13	2	0	0	4	14	8
2	15	2	0	0	4	0	77
3	22	2	0	0	14	0	135
4	23	2	0	0	0	0	669
5	26	2	0	49	73	0	73
6	30	2	4	0	0	0	162
7	32	2	415	28	14	14	42
8	32	2	0	0	207	8	25
9	31	2	0	0	341	0	263
10	32	2	385	0	11	0	75
11	33	2	121	0	73	0	42
12	34	2	17	77	103	0	9
13	41	2	0	0	208	0	0
14	35	2	34	78	56	11	151
15	43	2	0	0	94	9	19
16	39	2	0	0	166	0	98
17	44	2	21	0	11	0	11
18	48	2	0	0	59	0	4
19	15	1	0	279	385	10	51
21	15	1	0	25	328	0	113
22	15	1	321	750	257	68	85
23	16	1	0	0	221	0	74
24	25	1	840	0	239	109	113
25	14	1	19	1298	246	38	560
26	27	1	961	0	31	13	66
27	28	1	152	466	299	17	135
28	57	1	39	13	0	0	0
29	29	1	370	39	89	30	46
30	32	1	14	0	48	0	61
31	31	1	595	8	42	12	60
32	34	1	0	0	76	19	0
33	25	1	32	143	182	32	207
34	50	1	151	10	241	0	40
35	49	1	41	6	47	0	17
36	49	1	0	0	92	0	0
37	53	1	1225	16	8	0	10
38	12	3	0	0	0	0	2
39	14	3	0	0	406	19	44
40	15	3	0	23	122	0	36
41	19	3	0	0	57	28	476
42	22	3	14	0	28	18	41
43	22	3	0	0	12	6	95
44	24	3	737	0	114	13	599

Appendix Vb. Stand-level summary data not-used for analysis. Snag Height Class 4 and 5, shown as an example of why some attributes are not presented.

Case #	Stand Age Years	Treatment Code	Height Class 4 15.1-20m Snags stems ha^{-1}	Height Class 5 >20 m Snags stems ha^{-1}
1	13	2	1	0
2	15	2	1	0
3	22	2	0	0
4	23	2	0	0
5	26	2	0	0
6	30	2	0	0
7	32	2	2	0
8	32	2	1	0
9	31	2	0	0
10	32	2	0	0
11	33	2	0	0
12	34	2	3	1
13	41	2	1	0
14	35	2	1	0
15	43	2	2	0
16	39	2	0	0
17	44	2	0	0
18	48	2	1	0
19	15	1	2	0
21	15	1	0	0
22	15	1	3	8
23	16	1	0	0
24	25	1	9	0
25	14	1	1	0
26	27	1	3	2
27	28	1	2	0
28	57	1	5	0
29	29	1	3	2
30	32	1	2	1
31	31	1	3	3
32	34	1	5	4
33	25	1	4	2
34	50	1	2	0
35	49	1	6	1
36	49	1	0	0
37	53	1	53	3
38	12	3	4	0
39	14	3	1	1
40	15	3	1	1
41	19	3	0	0
42	22	3	0	0
43	22	3	0	0
44	24	3	0	1