Boreal Mixedwood Notes

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boreal mixedwood notes FAQs

What are BMW Notes?

The Boreal Mixedwood (BMW) Notes are a series of technical notes focussed on the ecology and silviculture of mixedwood sites and stands in northern Ontario. They provide an important foundation for the understanding and management of boreal mixedwoods. The notes cover a range of topics including autecology, site characteristics, silvicultural options, habitat, and disease and pest

Why were BMW Notes developed?

In 1993, the Boreal Mixedwood Silvicultural Guide Steering Committee recommended the development of a note series to communicate existing mixedwood information and the results of new research to forest managers. The decision of the Timber Class Environmental Assessment (1994) recognized the need for more information and management direction on boreal mixedwoods and directed MNR to develop a Mixedwood Silvicultural Guide. The BMW Notes provide an ecological context for mixedwood management and function as a companion document to the Boreal Mixedwood Silvicultural Guide (now under development). The Guide will provide specific management options and directions.

Who are the intended users of the BMW Notes?

The note series was designed primarily for forest management plan writers and policy developers in Ontario. The series will also be useful to resource managers in other jurisdictions and researchers and educators interested in mixedwood issues.

How can I use the BMW Notes?

Each note was written as a stand-alone publication and contains current information about a topic related to the ecology or silviculture of boreal mixedwoods. The notes can be used as a reference source for specific issues, or read as a whole to better understand the ecosystem-based philosophy of BMW management.

What's in the first release?

This first release contains the Table of Contents for all 48 proposed notes in Version 1.0, the 23 notes published to date, and a binder with section tabs to keep the notes together.

When can I expect the second release?

A second release of BMW Notes is planned for 2002 to complete Version 1.0. The Table of Contents outlines proposed titles and subject areas for these notes, many of which are presently under development (planning, researching, or writing).

How do I receive the second release?

If you wish to complete your BMW Notes binder, mail, fax, or e-mail the enclosed response sheet. Postal and e-mail addresses, as well as a fax number, are listed on the sheet.

If I have questions what should I do?

If you have questions about a specific note, contact the note author. Authors and contact information are provided at the bottom of the first page of each note.

If you have questions about the BMW Note Series or would like general information, contact

Silvicultural Guide Coordinator
Forest Management Branch - Ontario Ministry of Natural Resources
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Interim Table of Contents

Note: Bolded captions refer to tabs in the binder to which listed notes belong. Titles for Notes proposed for the second release are in italic. The second release is planned for December 2002. To receive the second release, please return the enclosed response sheet.

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PREAMBLE

About Boreal Mixedwood Notes

Welcome to *Boreal Mixedwood Notes,* a note series about the ecology, silviculture, and management of boreal mixedwood forests in Ontario. To address the limited availability of information about managing boreal mixedwood forest conditions in Ontario, the Boreal Mixedwood Silvicultural Guide Steering Committee (members listed in acknowledgements) decided in 1993 to develop *Boreal Mixedwood Notes.* The series was intended as an ecological primer on mixedwoods and as a method of communicating the results of field research and experimental trials to 'forest resource planners. The Boreal Mixedwood Notes Focus Group (members listed below) was charged with the development of the notes. The following sections describe the legislative context, purpose, and goals of the series, and how it is organized.

Legislative context, purpose, and goals

The Environmental Assessment Board, in its decision on the Class Environmental Assessment for Timber Management on Crown Land in Ontario (Koven and Martel 1994), directed the Ontario Ministry of Natural Resources (OMNR) to develop a silvicultural guide for boreal mixedwood forest conditions (Term and Condition 94d). The *Crown Forest Sustainability Act* provides the legal basis to manage Crown forests on a sustainable basis. It also provides for the preparation of the *Forest Operations and Silviculture Manual* (OMNR 1995), which describes the standards for silvicultural practices conducted on Crown land in the province. Some of these standards are included in a series of silvicultural guides, each one describing recommended forest practices for a particular forest type or region in Ontario. This information is used by forest managers when preparing a forest management plan. The Boreal Mixedwood Notes provide the ecological context and philosophy behind managing the province's boreal mixedwood forests. A forthcoming boreal mixedwood silvicultural guide will provide management interpretations for forest managers. Together these products will fulfill Term and Condition 94d.

Boreal Mixedwood Notes provide valuable background information that will link silvicultural research, technology transfer, and support agencies with those responsible for managing the forest on boreal mixedwood sites. The series has been designed to respond to operational needs.

The Focus Group hopes to accomplish the following goals with this series:

- to provide information about managing boreal mixedwood species on sites suitable for boreal mixedwood management
- to describe the successional changes on boreal mixedwood site types under different disturbance regimes
- to provide a reference tool for forest management planning teams and for operations staff involved in resource management
- to address the broad scope of information needed to manage boreal mixedwood forests on an ecosystem basis

The provincial Ecological Land Classification (ELC) program and the resulting forest ecosystem classifications will form the information framework to help us achieve our goals. However, there are still large information voids that will take time and effort to fill. The need for information will continue and change in response to our forest management questions.

How the series is organized

Boreal Mixedwood Notes provide summaries of information on specific topics using tables, graphs, and pictures to highlight important ideas. Specific features are designed to help users keep their series up-to-date and find information easily. Such features include:

- a 3-ring binder
- tabbed dividers that separate information into broad subject areas
- a guideword or guidewords to help users place new notes in the correct section
- updated table of contents with each release

As this series develops, landscape-level information will be written for the sections labelled:

- The Resource
- Ecosystems
- Landscape
- Environmental Considerations

Stand-level information will be written for sections labelled

- Economics
- Site
- Silvicultural Options
- Stand Dynamics
- Forest Health
- Habitat
- Planning

The Boreal Mixedwood Notes Focus Group

The Boreal Mixedwood Notes Focus Group oversees the production of this series. At the time of the initial release, the Focus Group included:

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OMNR's Strategic Directions and Statement of Environmental Values

The OMNR is responsible for managing Ontario's resources in accordance with the statues it administers. As the province's lead conservation agency, OMNR is steward of provincial parks, natural heritage areas, forests, fisheries, wildlife, mineral aggregates, fuel minerals, and Crown lands and waters, which make up 87% of the province's land base.

In 1991, OMNR released *Direction '90s,* which outlined the goal and objectives for the Ministry based on the concept of sustainable development, as expressed by the World Commission on Environment and Development (OMNR 1991). Within OMNR, policy and program development takes its lead from Direction '90s and its update, *Direction '90s, Moving Ahead 1995* (OMNR 1994). Those strategic directions are also considered in Ministry land use and resource management planning.

In 1994, the OMNR finalized its Statement of Environment Values (SEV) under the Environmental Bill of Rights (EBR). The SEV describes how the purposes of the EBR are to be considered whenever decisions that might significantly affect the environment are made in the Ministry.

The Ministry's SEV is based on Direction '90s because the strategic directions outlined therein reflect the purposes of the EBR. During the development of these notes, the Ministry has considered both Direction '90s, Direction '90s, Moving Ahead 1995 and its SEV. These notes are intended to reflect the directions set out in those documents and to further the objectives of managing our resources on a sustainable basis.

Further Information

Authors for *Boreal Mixedwood Notes* are solicited by the Focus Group. Authors include staff from the OMNR and other agencies with expertise in the area of boreal silviculture and ecology. Contributing agencies are acknowledged, and notes prepared under contract arrangement are so designated.

For more information about *Boreal Mixedwood Notes,* contact Silvicultural Guide Coordinator, Forest Management Branch, Ontario Ministry of Natural Resources, Suite 400, 70 Foster Dr., Sault Ste. Marie, ON P6A 6V5.

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Many people devoted their time and effort to developing this series. The members of the Steering Committee, the members of the Focus Group, and many others involved in the development and production of this series deserve thanks.

Staff of the Ontario Forest Research Institute's Technology Transfer Unit, Sault Ste. Marie and Northwest Science and Technology, Thunder Bay, designed and produced the notes; staff of the Communications Services Branch, Creative Planning and Production Section, Sault Ste. Marie, provided support and advice on publishing. Special thanks to Alf Aleksa for his efforts as the first Focus Group leader and Peter Nitschke, Interim Focus Group leader.

The Boreal Mixedwood Silvicultural Guide Steering Committee

The Boreal Mixedwood Silvicultural Guide Steering Committee contributed their knowledge, experience, and ideas throughout the initial discussions that led to this series. Some members continue to contribute their time and expertise by writing and reviewing manuscripts. The steering committee included:

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1995 • NUMBER 2

Definition of the Boreal Mixedwood Forest

by G. Blake MacDonald[1] and David H. Weingartner[2]

> *The complexity of the Boreal Mixedwood Forest requires a comprehensive set of definitions covering sites, stands, and forests.*

The Role of a Definition

The complexity of the Boreal Mixedwood Forest requires a comprehensive set of definitions covering sites, stands, and forests. Clear definitions will assist resource managers and planners in determining exactly which sites are good candidates for proactive mixedwood prescriptions. These definitions will also provide the basis for more accurate resource inventories.

The definitions developed here are intended to apply primarily within Ontario. However, the concepts underlying these definitions are relevant wherever mixedwood management is an issue.

Boreal Mixedwood Sites

*A **boreal mixedwood site** is an area with climatic, topographic, and edaphic conditions that favour the production of closed canopies dominated by trembling aspen* (Populus tremuloides) *or white birch* (Betula papyrifera) *in early successional stages, black spruce* (Picea mariana) *or white spruce* (Picea glauca) *in mid-successional stages and balsam fir* (Abies balsamea) *in late successional stages.*

The definition assumes that adequate supplies of seed or vegetative propagules are available to produce the characteristic dominant species at each stage. The abundance, diversity, and relative position of associated species at each successional stage depend on the disturbance type and pre-disturbance stand composition.

The Boreal Mixedwood Forest is defined in terms of characteristic site types to provide a stable frame of reference for a complex and dynamic forest. Boreal mixedwood sites typically have well-drained, fertile soils on mid-slope positions,

THE RESOURCE

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and exclude wet lowlands, dry sand plains, and shallow soils on bedrock outcrops (McClain 1981). The landforms are commonly upland ground moraines and terminal moraines (Day and Harvey 1981), and include soils of glacial, lacustrine, or alluvial origin on slopes of lake basins or river valleys (Weingartner and Basham 1979). Deep soils, medium to fine textures, and unrestricted drainage are essential elements of a mixedwood site.

The soil profile development on many boreal mixedwood sites is characteristic of the grey luvisol group. These are the fresh to moist, nutrient-rich sites with intermediate- to fine-textured calcareous soils (Pierpoint 1981). The organic litter breaks down rapidly and becomes incorporated into the mineral soil. Ground vegetation is typically abundant and species-rich. Mixedwood sites also include drier or less nutrient-rich soils with fine sandy to loamy, acid parent materials typical of the podzol group. These sites may support heavy shrub layers, but the diversity of herbaceous species tends to be reduced in favour of feathermosses (Pierpoint 1981).

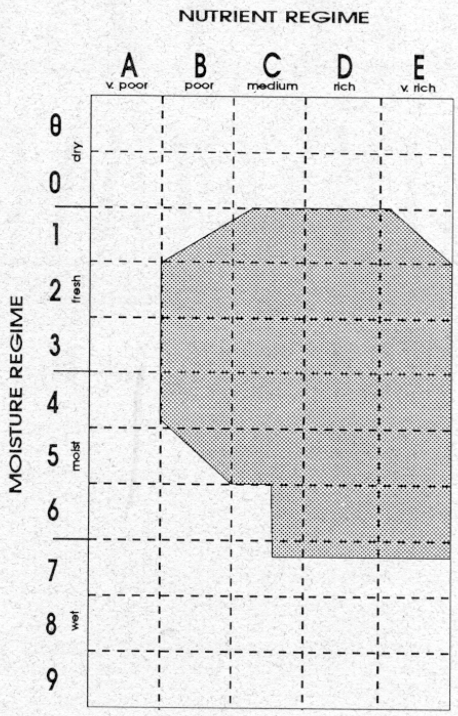

Figure 1. Boreal mixedwood sites are indicated by the shaded area on this moisture-nutrient matrix. (Adapted from Pierpoint 1981)

Figure 1. Boreal mixedwood sites are indicated by the shaded area on this moisture-nutrient matrix. *(Adapted from Pierpoint 1981)*

Figure 1 indicates the relative position of boreal mixedwood sites on a moisture-nutrient matrix. According to Corns (1988), this matrix is effective for classifying mixedwood sites. Moisture and nutrient regimes integrate many site characteristics, such as the slope position and the texture, depth, and parent material of the soil.

Climate is another aspect of site that strongly influences the nature of the Boreal Mixedwood Forest. Only species that are well adapted to low winter temperatures and short frost-free periods can be considered as defining species. Precipitation is largely dependent on longitude in northern Ontario, decreasing steadily from east to west. For example, the annual precipitation is 885 mm in Cochrane and only 623 mm in Kenora (Canada 1982). Sites that would otherwise be classified as boreal mixedwood in northwestern Ontario do not qualify because precipitation is inadequate for the establishment and good growth of spruce and fir.

Boreal Mixedwood Stands

A boreal mixedwood stand is a tree community on a boreal mixedwood site in which no single species exceeds 80% of the basal area.

Any of the defining or associated tree species qualifies as a canopy component (Tables 1 and 2). An associated species, such as jack pine *(Pinus banksiana)* in western Ontario or white pine

Table 1. The defining boreal mixedwood tree species

Common name	Scientific name
White spruce	*Picea glauca* (Moench) Voss
Black spruce	*Picea mariana* (Mill.) B.S.P.
Balsam fir	*Abies balsamea* (L.) Mill.
Trembling aspen	*Populus tremuloides* Michx.
White birch	*Betula papyrifera* Marsh.

(Pinus strobus) in the transition zone between the Boreal and the Great Lakes-St. Lawrence Forest Regions can be a dominant element of a boreal mixedwood stand. The definition imposes no constraint on the proportion of hardwood or softwood species necessary for a stand to be classified as mixedwood. It accommodates a stand composed of two or more hardwood species or two or more conifer species, provided the stand is established on a boreal mixedwood site. The implication is that the stand is a candidate for mixedwood management prescriptions because the site has the potential to increase its diversity of tree species in the future.

A boreal mixedwood *site* often supports only one tree species at a given successional stage. However, a boreal mixedwood *stand* must contain at least two species. The component species in the canopy often differ greatly in age or size (Day and Harvey 1981). A typical example is an overstory of trembling aspen coexisting with a younger understory of white spruce or balsam fir.

Several boreal mixedwood stands may occur on a single, uniform boreal mixedwood site. Stand composition at any point in time depends on the successional stage, which is controlled by the disturbance type and by the availability of seed or vegetative propaguies. Thus, a site can be classified as mixedwood while supporting a pure stand of trembling aspen, provided the site is capable of producing the other defining mixedwood tree species at later successional stages. Frequent disturbances, such as harvesting or fire, tend to keep mixedwood forests in early and mid-successional stages.

Typically, a disturbance on a boreal mixedwood site initiates a successional cycle by creating conditions suitable for the establishment of shade-intolerant species. Early successional trees such as trembling aspen and white birch usually become established with pioneer shrub species. As the hardwood trees close their canopy, the abundance of shrubs in the understory declines. Provided a

Table 2. The associated boreal mixedwood tree species

Common name	Scientific name
Jack pine	*Pinus banksiana* Lamb.
White pine	*Pinus strobus* L.
Red pine	*Pinus resinosa* Ait.
Eastern white cedar	*Thuja occidentalis* L.
Tamarack	*Larix laricina* (Du Roi) K. Koch
Largetooth aspen	*Populus grandidentata* Michx.
Balsam poplar	*Populus balsamifera* L.
White elm	*Ulmus americana* L.
Black ash	*Fraxinus nigra* Marsh.
Black willow	*Salix nigra* Marsh.

seed source exists, shade-intolerant pines may become established with the early successional hardwoods. The diffuse canopy provides a suitable regeneration environment for mid-tolerant conifers such as black spruce and white spruce, although significant mineral soil exposure is required to ensure establishment of spruce germinants. Balsam fir is the characteristic late successional species on boreal mixedwood sites; it tolerates the increasingly dense shade and establishes well on the undisturbed accumulations of litter and humus. Spruce-fir mixedwoods seldom endure as climax formations, because fire, windthrow, spruce budworm *(Choristoneura fumiferana)* epidemics, or other disturbances soon return these forests to the early successional stage. Thus, the complexity of the mixedwood mosaic is explained by spatial variations in site characteristics and disturbance types, which lead to temporal variations in successional patterns.

Although there are numerous potential combinations of canopy species in boreal mixedwood stands, composition and structure are most variable in the shrub and herb layers. This diversity reflects the high site productivity that is inherent to all boreal mixedwood forests. A secondary factor promoting herb-rich and shrub-rich understories in mixedwood stands is the greater transmission of light to the forest floor, compared to that occurring in pure conifer stands (Baldwin 1991).

Boreal Mixedwood Forests

The Boreal Mixedwood Forest of Ontario is the aggregate of all boreal mixedwood sites in the province. A ***boreal mixedwood forest*** *is the aggregate of all boreal mixedwood sites in any distinct area.*

Boreal mixedwood forests may contain intimate mixtures of several species or mosaics of small single-species stands. The emphasis on site provides geographical stability to these definitions, making them useful for inventory and management planning.

Performance Standards

The original definition of the Boreal Mixedwood Forest in Ontario was expressed in terms of sites that could support good growth of the five defining tree species (McClain 1981). While the meaning of “good growth” was not clarified, the reference to site capability was an important step in making the definition more useful for planning silvicultural prescriptions.

A height growth standard could be adopted as an estimator of site quality. While this satisfies timber production goals, it is less appropriate for other resource values. For example, wildlife habitat is evaluated by stocking, cover, or biomass production rather than by the height or volume of tree stems. Thus, the ability to maintain closed canopies of the defining species at maturity is proposed as the productivity standard in the definition of boreal mixedwood sites.

Relationship to Forest Ecosystem Classification Terminology

The forest ecosystem classification (FEC) systems in northern Ontario identify boreal mixedwood Vegetation Types (Jones *et al.* 1983; Sims *et al,* 1989), which are analogous to boreal mixedwood stands as defined in this note. A drawback to using Vegetation Types for management planning is that they change on a given site through natural forest succession.

The FEC Soil Types are simpler, more stable, and more relevant for identifying sites where long-term mixedwood management would be appropriate. Thus, the concept of Soil Type is compatible with the definition of boreal mixedwood site. The shallow soils and organic soils in the FEC descriptions can generally be excluded from the definition of mixedwood sites.

Subsequent notes in this series address the specific FEC types included in the Boreal Mixedwood Forest.

Management Implications

Sustainable development is best applied at large scales, with 12,000 ha being proposed as an approximate minimum extent (Webster 1993). Thus, a *boreal mixedwood forest* is a more relevant concept than a *boreal mixedwood stand* for sustainable resource management planning. The stand focus is most relevant for the operational application of silviculture.

The definition of a boreal mixedwood site emphasizes species replacement through several successional phases. The seral stages perform important ecological functions, including the maintenance of soil productivity (Gordon 1981) and the provision of wildlife habitat. Management prescriptions that recognize these values avoid the tendency to establish multiple rotations of monocultures on boreal mixedwood sites. However, the definition is intended to enlighten, not constrain. There may be valid reasons for maintaining pure stands of a preferred species on certain boreal mixedwood sites. Such cases are the subject of other silvicultural guides.

The definitions highlight the need for detailed site maps and successional information to help resource managers determine which sites should be managed under boreal mixedwood prescriptions. This information is also required to develop an accurate inventory of the Boreal Mixedwood Forest. Finally, there is a need to revise traditional forestry concepts, such as “working group”, “free-to-grow”, and “stocking”, to account for mixed-species crops.

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Boreal Mixedwood Management Philosophy

by David H. Weingartner[1] and G. Blake MacDonald[2]

> *Forest management on an ecosystem basis is the accepted model within the province.*

Introduction

In Direction '90s, the Ontario Ministry of Natural Resources (1991) promotes the following principles as the basis for the concept of "sustainable development": all life is connected; the resource economy is based on a diverse natural system; integrated management must account for environmental, social, and economic factors; development has limits; environmental damage must be prevented by anticipating and avoiding negative impacts; applied technologies required for sustainable development must be produced; and change will be a part of the process.

The Ontario Forest Policy Panel (1993) promoted the concepts of *sustainable development* and *adaptive ecosystem management* as two of the cornerstones in the forest policy framework. Forest management on an ecosystem basis is the accepted model within the province. Ecosystem management differs substantially from two earlier concepts: (1) **sustained yield** for timber production and (2) **multiple use (or integrated resource management)** for timber, fish and wildlife, and recreation. Conceptually, previous thought processes and perspectives are insufficient and require reformulation. For the *Boreal Mixedwood Forest*, a consistent philosophy to guide our actions is required. This report provides a philosophy (framework) aimed at helping focus our thoughts towards managing the boreal mixedwood forest on an ecosystem basis, to achieve sustainability.

Perspective

Perhaps the biggest challenge is developing a perspective on the boreal mixedwood forest, and our relationship to it, that facilitates implementing ecosystem management and sustainable development. Botkin (1990) suggests an organic perspective that involves accepting the open, dynamic nature of the ecosystem and recognizing that we are an integral part of it. From this perspective, we accept responsibility for the changes in the ecosystem that result from our actions.

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Berry (1990), and Drengson (1994) suggest that our hurried, consumer-oriented society has lost touch with the metaphysical or spiritual side of life, and that this loss has influenced our perspective on the natural world and our relationship to it. If we cannot appreciate a tree as a living entity, we lack a basic respect for life, and the tree becomes a mere commodity. Without respect for life in all its diversity and interconnectedness, a true commitment to ecosystem management and sustainability is unlikely; the ecosystem becomes a warehouse. Without respect for life, we will not accept responsibility for the ecosystem conditions we create, and the ecosystem will not remain functional.

Just accepting the organic view of the ecosystem is not enough: certain physical and biological aspects of the boreal mixedwood forest must be understood and considered before implementing ecosystem management. The concept of **diversity,** when considered in a broad sense, includes all the physical and biological aspects of the forest at a variety of levels. Diversity is important in an ecosystem because it adds redundancy to buffer the system against disturbance. In systems with low diversity, any disruption to a system component can have major repercussions, because of the limited alternatives available to compensate for the disturbance.

> ***Without respect for life, we will not accept responsibility for the ecosystem conditions we create, and the ecosystem will not remain functional.***

The boreal mixedwood forest is one of the most diverse ecosystems in northern Ontario. Its diversity is evident in at least three aspects: sites, species, and genes. As a result of its diversity in sites and species, the boreal mixedwood forest appears unique in each location and at every successional stage.

The diversity of boreal mixedwood sites provides the structural framework for the boreal mixedwood forest on the landscape. These fertile sites can produce a wide variety of species and products not found on lower-quality sites. Four of the five tree species that define the boreal mixedwood forest—i.e., balsam fir (*Abies balsamea*), white birch (*Betula papyrifera*), trembling aspen (*Populus tremuloides*) and white spruce (*Picea glauca*)—attain commercial stature and abundance primarily on boreal mixedwood sites. A mixedwood site's capacity to produce a given level of a specific physical resource is not constant, but fluctuates as the system migrates down various successional pathways under biotic and abiotic influences.

Species diversity provides the basis for the variety of biotic communities visible across the landscape and gives the boreal mixedwood forest the resilience to maintain itself following disturbance. When insect infestation, disease epidemic, fire, or human activity eliminate individual species from stands locally, other species are available to fill the voids. Careful consideration must be given to the effect of human activity on the ecosystem and its components even when a diversity of species is present (Ontario Forest Policy Panel 1993).

Genetic diversity enables species to adapt to a changing environment (e.g., climate change) or synecological conditions. The Ontario Forest Policy Panel (1993) and several other sources (Hammond 1994, Maser 1994, Noss 1994) suggest the importance of gene pool maintenance as a component of biodiversity.

Landscape

The boreal mixedwood forest is visible at the landscape scale as a mosaic of stands of varied composition; it represents 45% to 50% of the productive forest land in northern Ontario (McClain 1981). The floral and faunal communities within the boreal mixedwood forest evolved as a result of the interaction of climate, soil development, disturbance history, and species migration. Unlike black spruce or jack pine forests, which tend to have low species diversity and which occur on a limited range of site conditions, mixedwood forests include a wide diversity of species and cover a broad range of sites.

> ***Unlike black spruce or jack pine forests, which tend to have low species diversity and which occur on a limited range of site conditions, the boreal mixedwood forest includes a wide diversity of species and covers a broad range of sites.***

The boreal mixedwood forest is associated with other boreal ecosystems and is part of larger continental and intercontinental systems. Ecosystem boundaries extend beyond provincial or national borders. For example, the seasonal habitat for many species of neotropical birds is in the boreal mixedwood forest, and insect infestation cycles move freely between the United States and Canada (Hodson 1941).

The extent of the landscape for management purposes may vary, as suggested by Allen and Hoekstra (1994), depending on what is to be sustained. From a species perspective, the landscape may be small for species that have a limited range; or the landscape may be extensive for species that have a large range. A variety of scales are required to conserve or manage the diversity of species present in the boreal mixedwood forest locally and provincially. Salwasser and Pfister (1994) suggest that ecosystem management at the landscape level requires cooperation. For the boreal mixedwood forest, it will require cooperation among a number of different forest user groups.

> ***A variety of scales is required to conserve or manage the diversity of species present in the boreal mixedwood forest locally and provincially.***

Temporal Scale

Stands develop and exist for a century or more, and forests exist for millennia, before climatic change and species migration transform them into new ecosystems. The challenge in managing the boreal mixedwood forest is to recognize and appreciate that the time scale in which we live and work is much shorter than the time scale of stand and forests. Individually, we rarely, if ever, see the full impact of our actions on the stands that we harvest and regenerate. Unless we contemplate and evaluate the consequences of our actions, the forest ecosystem's long-term survival will be jeopardized.

Over the past 50 years, human activity—specifically, harvesting and fire suppression—has increased the proportion of hardwood—softwood forest communities in the boreal mixedwood forest. In their regeneration audit, Hearnden *et al.* (1992) suggest that the loss of conifer dominance in the boreal forest of Ontario is not reasonable. There are significant economic and ecological reasons for maintaining conifers (spruce) in the boreal forest; however, the successional trends that occur on mixedwood sites must be recognized and appreciated as the natural responses to disturbance, and considered in long-term management planning and silvicultural operations. The increase of intolerant hardwoods results from their regeneration characteristics and ecological functions, and the harvesting methods applied.

A significant conifer (spruce) component may develop naturally in second-growth mixedwood stands following harvesting, but the successional time scale is several times greater than a human life span. As an example, simulations of aspen succession in the western United States (Bartos et al. 1983) indicate that aspen can dominate a site for centuries given the proper conditions. Models simulate reality with varying degrees of accuracy; what is important is what actually occurs within the ecosystem. Often succession depends on random influences that cannot be accounted for by models. For this reason, continuous monitoring of forest resources is required.

The two most fragile components of the boreal mixedwood forest appear to be infrequently occurring (rare) species and genes. In both cases, monitoring systems and methods are not currently in place; moreover, the monitoring systems now being contemplated may be inadequate to detect losses. Infrequently occurring species may be easily missed in monitoring programs and their habitat destroyed in forest operations. Genetic losses, because they are difficult to detect, often go unnoticed. The consequences of genetic losses may be a long-term decline in forest health resulting from biotic or abiotic stresses.

> ***Even with economically viable silvicultural systems that address the entire rotation, there will be instances when current costs to maintain or reconstruct ecosystem components will exceed the value of commercial products.***

Economics

The economics of silvicultural treatments was a main concern in a survey of mixedwood research and development needs (Weingartner and MacDonald 1994). The cost of regeneration, whether natural or artificial, appears to limit or exclude further silvicultural intervention. Perhaps as our knowledge of forest development increases, we can design appropriate regeneration systems for the boreal mixedwood forest that are ecologically and economically viable. Even with economically viable silvicultural systems that address the entire rotation, there will be instances when current costs to maintain or reconstruct ecosystem components will exceed the value of commercial products. These additional costs must be recognized if sustaining forest ecosystems is the first priority, as suggested by the Ontario Forest Policy Panel (1993).

Sustainable Development

To understand sustainable development, it is important to differentiate between economic growth and economic development. **Economic growth** increases economic welfare as a result of increased resource consumption, while **economic development** increases welfare as a result of an increase in product quality without a commensurate increase in resource consumption (Wetzel and Wetzel 1995). Exceeding the ecosystem's economic carrying capacity results in deterioration of both the ecosystem and the economy (Wetzel and Wetzel 1995). In the boreal mixedwood forest, the production of specific physical resources is not static but varies continuously; as a result, the economic carrying capacity also fluctuates.

All parts of the physical and biological systems are therefore unique in both time and space.

> ***All of us working in the boreal mixedwood forest have a responsibility to continually increase our knowledge and understanding of this ecosystem.***

Education

Education is a life-long process. As we begin to manage on an ecosystem basis, new knowledge and understanding are required. Knowledge—the accumulation of information (facts and figures)—in itself is of little value. However, understanding—recognition of the relationships among the facts and figures—can be applied to a variety of situations. All of us working in the boreal mixedwood forest have a responsibility to continually increase our knowledge and understanding of this ecosystem. Taking responsibility for education includes transferring this information to others, from the chainsaw operator to the legislator. Our understanding of the boreal mixedwood forest can then be applied toward the maintenance of the ecosystem and its biodiversity for the fulfillment of human needs.

Summary

On a global scale, humanity is recognizing the finite nature of the natural world and the importance of maintaining forest ecosystems for human survival. The boreal mixedwood forest, because of its diversity of plant and animal species on highly productive sites, is key to the long-term viability of northern communities. The ecosystem's sustainability depends on our recognizing and accepting responsibility for human activities in the boreal mixedwood forest, and basing management decisions on a thorough understanding of ecosystem processes.

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Distribution, Extent, and Importance of Boreal Mixedwood Forests in Ontario

by W.D. Towill*, R.O. Wiltshire**, and Janette C. Desharnais***

> *More than three quarters of the forest landbase in northern Ontario has the potential to support boreal mixedwood stands...*

Introduction

In Ontario, boreal mixedwood (BMW) site and stand conditions are distributed throughout the boreal and the boreal – Great Lakes-St. Lawrence (GLSL) forest transition zone (Rowe 1972). It has long been recognized that Ontario's BMW forests contribute much to the health of the boreal ecosystem in terms of productivity and forest diversity. However, mixedwoods continue to remain a poorly understood component of the boreal forest (Rowe 1972).

The purpose of this note is to define our current understanding of the distribution of boreal mixedwoods in Ontario and the extent of suitable boreal mixedwood soil/site conditions in both the boreal forest and the GLSL forest transition zone. The commercial importance of the boreal mixedwood to Ontario's economy is also briefly explored.

Definitions of a Boreal Mixedwood Site, Stand, and Forest

Before getting into details about distribution, extent, and importance, understanding the difference between a BMW site, stand, and forest is necessary. MacDonald and Weingartner (1995) defined boreal mixedwoods based on site, stand, and forest characteristics. Listed below, these definitions form the foundation for describing boreal mixedwoods in Ontario.

> "A **boreal mixedwood site** is an area with climatic, topographic, and edaphic conditions that favour the production of closed canopies dominated by trembling aspen (*Populus tremuloides* Michx.) or white birch (*Betula papyrifera* Marsh.) in early successional stages, black spruce (*Picea mariana* (Mill.) BSP) or white spruce (*Picea glauca* (Moench) A. Voss) in mid-successional stages, and balsam fir (*Abies balsamea* (L.) Mill.) in late successional stages."
>
> "A **boreal mixedwood stand** is a tree community on a boreal mixedwood site in which no single species exceeds 80% of the basal area."
>
> "**The boreal mixedwood forest** of Ontario is the aggregate of all boreal mixedwood sites in the

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> province. **A boreal mixedwood forest** is the aggregate of all boreal mixedwood sites in any distinct area."

However, other approaches have been used to define boreal mixedwoods. Pierpoint (1981) identified sites based on local moisture and nutrient regime relationships that could support a range of mixedwood stands. He not only described sites that could support the classic spruce-fir-aspen mixedwood stands (similar to those defined by MacDonald and Weingartner), but also identified other sites – some less nutrient rich, others somewhat drier or moister – that could support a range of mixedwood conditions.

Ontario's boreal mixedwood soil and site conditions have the potential to support highly productive stands (MacLean 1960, OMNR 1979). Boreal mixedwood sites are generally uplands (Day and Harvey 1981) and often associated with morainal, lacustrine, and glacio-fluvial deposits (McClain 1981, Sims and Uhlig 1996). Within boreal mixedwood sites, substantial variations exist in soil and site conditions due to local influences of climate, topography, slope, aspect, exposure, parent material, soil texture, depth and type of organic matter, as well as associated physical, chemical, and microbial soil properties (Chen and Popadiouk 2002). Mixedwoods are optimally adapted to mid-range climatic conditions for their defining species: white spruce, black spruce, balsam fir, white birch, and trembling aspen.

MacDonald and Weingartner's (1995) definition of a boreal mixedwood stand does not place restrictive definitions on the proportion of either hardwood or coniferous species necessary for a stand to be classified as mixedwood. Their definition embraces stands composed of two or more hardwood species, two or more coniferous species, or a mixture of hardwood and conifer species occurring on a boreal mixedwood site. Species presence and relative abundance in a mixedwood stand at a specific stage of stand development will vary with species autecology and stand history, including the type, intensity, and severity of disturbance and age since the last disturbance event. While a boreal mixedwood site often supports only one tree species at a particular stage of stand development, it ultimately must be capable of supporting the other defining mixedwood tree species in later successional stages.

Several boreal mixedwood stands may occur on a single, uniform boreal mixedwood site. As well, boreal mixedwood forests may contain intimate mixtures of several species or mosaics of small single-species stands (MacDonald and Weingartner 1995).

Geography and Extent of Distribution of Boreal Mixedwood Sites

Geographically, Ontario's Boreal Mixedwood Forest extends between the 48°N and 53°N latitudes (Figure 1). The southern boundary is difficult to discern due to the considerable admixture of species and the lack of distinct, persistent species associations in the GLSL transition zone (Hare 1950, Maycock and Curtis 1960, Sims and Uhlig 1996). The northern boundary coincides with the climatic indicators of potential evapotranspiration and mean July temperature (13°C isotherm) (Royal Comm. North. Environ. 1985). Deep, well-drained fresh to moist mineral soils occurring on upper slopes or crests of hills supporting mixtures of up to five tree species, where the mean annual temperature is 0 to 3°C and the mean annual precipitation is 700 to 950 mm, are typical of Ontario's boreal mixedwood forests (Rowe 1972, Sims and Uhlig 1996, Chen and Popadiouk 2002).

The *forest ecotone transition* between GLSL and the boreal forest region corresponds roughly to the 5°C mean annual isotherm east of Lake Superior and the 4°C annual isotherm to the west (Thompson 2001). This zone includes boreal species in addition to relict communities and individuals of red pine (*Pinus resinosa* Ait.), white pine (*Pinus strobus* L.), eastern hemlock (*Tsuga canadensis* (L.) Carr.), yellow birch (*Betula alleghaniensis* Britton), large-toothed aspen (*Populus grandidentata* Michx.) and red maple (*Acer rubrum* L.) resulting from post-glacial species migration, inter- and intraspecific competition, and climatic limits on species survival and reproduction (Maycock and Curtis 1960).

MacLean (1960) was one of the first in Ontario to consider how factors such as soil moisture, texture, nutrients, and structure interacted with other site conditions to affect the growth and development of boreal mixedwood stands. MacLean (1960) observed that the associated stand composition was the effect of stand disturbance (type, intensity, and severity) interacting with local physiography and soil moisture

Figure 1. *Ontario's boreal forest and boreal – Great Lakes-St Lawrence transition zone (in gray).*

regime. Extensive and broadly distributed areas of deep, fresh lacustrine deposits and tills normally support mixedwood stands. Dry tills associated with moist tills will usually support hardwood or mixedwood complexes, but dry tills associated with dry outwash deposits are commonly occupied by jack pine (*Pinus banksiana* Lamb.) and jack pine-dominated mixedwood stands. Boreal mixedwood sites typically exclude very moist to wet organic deposits, xeric to dry outwash glacio-fluvial deposits and shallow soils on bedrock outcrops (McClain 1981).

MacLean (1960) also recognized that the distribution and abundance of mixedwood tree species are often associated with various soil conditions, as outlined below:

Tree species	Preferred soil/site conditions
Trembling aspen	• Stratified outwash plain conditions underlain by clayey till • Deep, fresh to moist soils with high silt and/or clay content • Most influenced by subsoil conditions – more productive when finer-textured soils found lower in the profile (deeper-rooted species)
White birch	• Coarse textured, stony or very shallow soils over bedrock
Spruce and balsam fir	• As shallow-rooted species, these grow best on fine-textured soils overlaying coarse material

Extent of Boreal Mixedwood Forest Conditions

The joint government-industry Spruce-Fir-Aspen Forest Research Committee was one of the first to develop a definition for boreal mixedwood site and stand conditions (OMNR 1979). Their description closely resembles the definition subsequently developed by MacDonald and Weingartner (1995). The committee was also first to estimate the distribution and extent of boreal mixedwood cover types in Ontario using Dixon's (1963) original forest inventory for Ontario. At that time, Ontario's boreal forest consisted of 55% conifer, 32% mixedwood, 7% hardwood, and 6% reproducing forest. The committee surmised that the actual area of the production forest composed of mixedwood stand conditions included the area of the mixedwood and hardwood cover classes, and an additional 1.5% of the total production forest representing boreal mixedwood conditions in the stand initiation (reproduction) stage. A further 5-10% of the conifer cover type was also thought to be boreal mixedwood forests. The Spruce-Fir-Aspen Forest Research Committee concluded that between 45 to 50% of northern and central Ontario's productive forestland supported boreal mixedwood forests in the 1960s.

Armson (1988) subsequently used a 1986 compilation of Ontario's forest resource inventory (FRI) data to estimate the extent of the boreal mixedwood condition in the province. He assumed that approximately one-third of each of the poplar, white birch, and spruce working groups, respectively, represented boreal mixedwood forests. A working group is an aggregation of stands, including potential forest areas assigned to this category, having the same predominant species (i.e., species comprising 40% or more of the stand's total basal area), and managed under the same broad silvicultural system. This approach indicated that 18% (7 million hectares) of boreal Ontario's 38 million hectares of production forest were mixedwood stands in the mid-1980s. The volume of growing stock on those 7 million hectares was estimated at 1.0-1.5 billion cubic metres of wood.

These estimations of the extent of the boreal mixedwood resource were based on expert opinion and coarse inventory estimates. In this note, two alternative approaches are used to define the extent of mixedwoods in the boreal region and the GLSL transition zone in Ontario. The first (referred to as OLI-based) assesses the extent of potential boreal mixedwood site conditions. Data from either the Ontario Land Inventory (OLI – 1:250 000 scale) (OMNR 1977) or the Forestland Productivity Survey (FlaPS – 1:50 000 scale) conducted in south central Ontario in the early 1980s (OMNR 1981) are analyzed to quantify the aerial extent of boreal mixedwood site conditions. The classification of potential boreal mixedwood soil and site conditions follows the three broad classes defined by Pierpoint (1981).

The second approach (referred to as FRI-based) assesses boreal mixedwood stand conditions and uses forest unit summaries derived from both FRI and those in approved forest management plans currently in effect in the boreal forest region of Ontario to estimate the area of pure and mixedwood forest cover classes.

Boreal Mixedwood Soil and Site Conditions (OLI-based)

Moisture and nutrient regimes integrate many site characteristics, such as the slope position and the texture, depth, and parent material of the soil (Pierpoint 1981, MacDonald and Weingartner 1995, Towill *et al.* 2004). Pierpoint (1981) detailed three broad and recognizable soil moisture and nutrient regime conditions that could be used to classify the range of boreal mixedwood sites in Ontario (Figure 2). The three broad mixedwood site conditions included:

A) Deep, fresh to moist, nutrient-rich sites with intermediate to fine-textured, calcareous soils typical of the grey luvisol group

B) Moderately deep to deep, dry to fresh, less nutrient-rich soils with fine sandy to loamy, acid parent materials typical of the podzol group

C) Seepage enriched, deep, moist to wet mineral soils often overlain by thick organic layers (peaty-phase mineral soils)

The OLI is the only comprehensive, spatially explicit description of forest soil and site conditions between 44°N and 52°N latitude. Map units have been delineated using photo interpretation followed by systematic ground surveys to verify map unit (polygon) boundaries and associated land type unit soil-site descriptions. Land type unit descriptions for each polygon provide a full site description (e.g., bedrock type, terrain conditions, percent occurrence of different soil conditions occurring within the polygon) and detailed soils information (e.g., soil depth, texture, moisture regime, drainage class, calcareousness, percent exposed bedrock, depth of organic matter, percent surface coverage by organic deposits for each of the soils conditions described in the individual polygons).

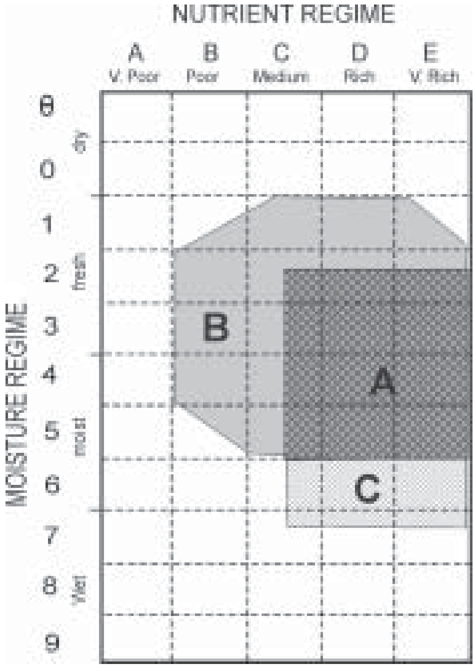

Figure 2. *Nutrient–moisture regime relationships for boreal mixedwood site conditions in Ontario (Pierpoint 1981) (A, B, C as defined in text).*

Maps from the FlaPS program (Heikurinen and Kershaw 1986) were used to determine the area of potentially suitable mixedwood soil conditions for portions of south-central Ontario where digital OLI. data were not available.

OLI and FlaPS map sheets were analyzed to determine the area of potential mixedwood sites in the productive Boreal Region and the GLSL transition zone in Ontario based on Pierpoint's mixedwood site groupings (1981). The analyses (Table 1) indicated that 78% (30 167 304 ha) of the productive and non-productive boreal forests (all ownerships) inventoried within and to the north of the active area of forest management ("Area of the

Table 1. Area summary (hectares) of potential suitable boreal mixedwood site conditions within the pre-1996 OMNR administrative regions in the boreal and the GLSL forest transition zone in Ontario.

	Regions			
Soil-site Conditions*	Northwest Region Boreal Forest Zone (OLI-derived) Area (ha)	Northeast Regon Boreal Forest Zone (OLI derived) Area (ha)	GLSL Forest Transition Zone (OLI/FlaPS derived) Area (ha)	All Areas (ha)
A: Deep, fresh to moist, nutrient rich, loams and fine textured soils[1]	6 721 648	3 034 495	195 715	9 951 858
B: Moderately deep to deep, dry to fresh, less nutrient rich, fine sands to loams[2]	16 234 959	1 652 255	4 128 106	22 015 320
C: Seepage enriched, very moist to wet mineral and/or peaty-phased soils[3]	2 503 065	20 882	307 935	2 831 882
Total area of potentially suitable mixedwood sites (ha)	25 459 672	4 707 632	4 631 756	34 799 060
Total area (ha)	28 501 847	10 100 000	6 320 000	44 921 847
Percentage of total area considered as suitable mixedwood sites (ha)	89%	47%	73%	77%

*Soil-site conditions from Pierpoint (1981).

[1] Includes: Northwest Region FEC Soil 'S'-types: S4, S5, S6, S9, S10, SS7 (Sims *et al.* 1997); Northeast Region FEC Soil 'S' -types: S9, S10, S11, S12; and Central Ontario FEC Soil 'S'-types: S4, S7, S8, S11, S12, S15 and S16 (Chambers *et al.*1997).

[2] Includes: Northwest Region FEC Soil 'S' -types: S3, S7, S8, SS5, SS6; Northeast Region FEC Soil 'S'-types: S1, S2, S5, S7; and Central Ontario FEC Soil 'S' -types: S2, S3, S6, S7.

[3] Includes: Northwest Region FEC Soil 'S'-types: S11, SS8, SS9; Northeast Region FEC Soil 'S'-types: S11, S13, S14, S15, S16 (Taylor *et al.* 2000); and Central Ontario FEC 'S'-types S9, S13, S17, S18.

Undertaking") (38 601 847 ha) was potentially suitable mixedwood sites as previously defined by Pierpoint (1981). Whereas, 73% of the area defined by the GLSL transitional zone (4 631 756 of 6 320 000 ha), was classified as suitable boreal mixedwood sites based on the analysis of OLI and FlaPS coverage.

The most abundant soil-site condition in both areas, the Boreal Region (Figure 3) and the GLSL transition zone (Figure 4), consisted of moderately deep to deep, dry to fresh, less nutrient rich, fine sands to loams associated with morainal, glacio-fluvial and aeolian deposits. Approximately one-quarter of the potentially suitable mixedwood site conditions within the boreal consisted of deep, fresh to moist, nutrient rich, loams and fine-textured soils associated with former glacial lakes Agassiz, Barlow-Ojibway and Lake Superior. In contrast, only 3% (195 715 hectares) of those within the GLSL transition zone were loams and fine-textured soils. Seepage enriched, very moist to wet mineral and/or peaty-phase soils accounted for less than 5% of the suitable conditions in either area.

Boreal Mixedwood Cover Types (FRI-based)

The extent of mixedwood forest cover types within the boreal and the GLSL transition zone was assessed using descriptions of the current forest cover and growing stock. The description of the forest cover on each active management unit is derived from a summary of the FRI data. The FRI classifies a landbase into broad physical components: productive forest, non-productive forest, non-forested land, and water. Within forest stands, information is provided about tree species composition, stand age, stand height, stocking level, and site productivity class (OMNR 1996).

The area associated with specific mixedwood species assemblages across Ontario's landscape was assessed on both active and inactive management units. A 1995 version of the FRI database, also used in the "Forest Resources of Ontario 1996" report (OMNR 1996), was queried to determine the amount of pure and mixedwood stand conditions in the boreal and GLSL transition zones in all land ownership categories (private, parks, federal lands, provincial crown

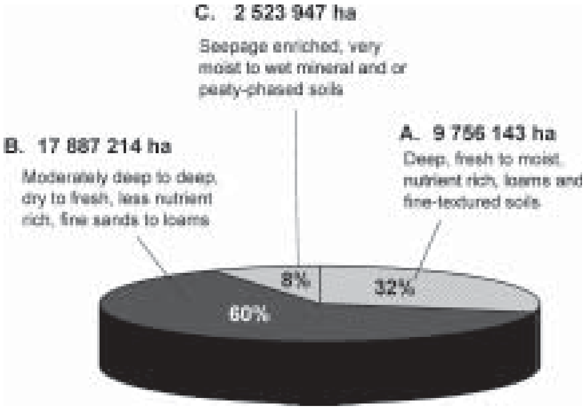

Figure 3. *Soil-site classification of potentially suitable mixedwood site conditions within the boreal zone in Ontario (hectares).*

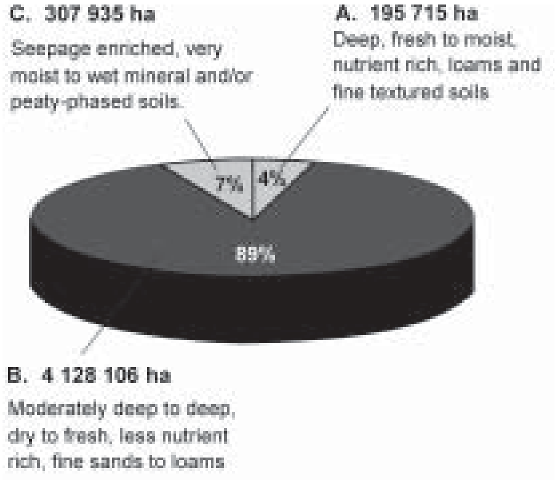

Figure 4. *Soil-site classification of potentially suitable mixedwood site conditions within the GLSL transition zone (hectares) in Ontario.*

forest and provincial protection forest reserve). This information was then used to compare and contrast similarities and differences in species composition and abundance within and between the broader landscapes associated with the OMNR administrative regions.

Table 2 provides a summary of the aerial extent of pure and mixedwood stands within the Northwest and Northeast Regions and the GLSL transition zone assessed from descriptions of the current forest cover and growing stock contained in approved forest management plans.

A total of 15 856 099 ha (45.7%) of mixedwood forest cover and 18 826 169 ha (54.3%) of non-mixedwood forest cover was determined to exist within the broader boreal and GLSL transition zone landscapes. The present Northwest and Northeast Regions each account for approximately 55 and 32% of Ontario's boreal mixedwood cover type and the GLSL transition zone supports an additional 13% (Figure 5).

Table 3 details the extent of the different mixedwood species assemblages. Dominant stand composition was defined as those stands whose stocking to a single boreal mixedwood defining species was greater than 0.7. Mixed species composition was defined as those stands where stocking to a single boreal mixedwood defining species was greater than 0.3 and less than 0.8 of normal stocking and where the balance of the species composition was made up of one or more of the other defining boreal mixedwood species. Breakdown of pure (conifer and hardwood) and mixedwood conditions by active management unit is presented in Appendices A and B.

Table 2. *Area summary (hectares) and percentage of pure and mixedwood stands in the boreal and Great Lakes-St. Lawrence transition forest for all land ownerships (including private, parks, federal lands, provincial crown forest and provincial protection forest reserve) in Ontario.*

Cover Type	Northwest Region		Northeast Region		GLSL Transition Zone		Total	
	area (ha)	%	area (ha)	%	area (ha)	%	area (ha)	%
Pure stands	12 110 770	58.06	5 521 298	51.95	11 94 101	37.37	18 826 169	54.28
Mixedwood stands	8 748 130	41.94	5 106 755	48.05	2 001 214	62.63	15 856 099	45.72
Total Area	20 857 900		10 628 053		3 195 315		34 681 268	

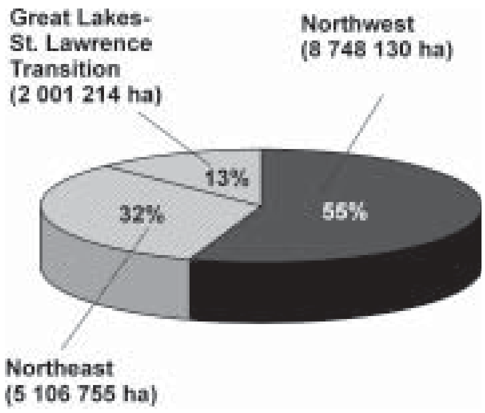

Figure 5. *Provincial distribution of boreal mixedwood cover by current OMNR administrative regions (all land ownership classes).*

Across Ontario, the two most prevalent boreal mixedwood cover types accounting for almost 50% of the mixedwood condition are either jack pine-dominated mixedwoods (4,203,505 ha) or those dominated by poplar (trembling aspen and balsam poplar) that occur on highly productive sites defined as having a site class of X, I, or II (3 783 658 ha). White birch and black spruce-dominated mixedwood cover types together account for an additional 28% of Ontario's boreal mixedwood condition. Poplar-dominated mixedwoods occurring on lower productivity soil/site conditions (site class III, IV) are the next most common mixedwood cover type (11%). This condition represents off-site stands occurring under extreme site conditions; i.e., shallow soils and those soils that are exceedingly wet or poorly drained. The balance of the mixedwood condition is represented by pure and mixed stands dominated by balsam fir, white spruce, white pine and extremely low productivity pure poplar stands.

Table 3. *Provincial distribution of boreal mixedwood cover by the presence of defining boreal mixedwood species and their associated site class (all land ownership classes).*

Forest Units	Total area (ha)	Area %
Bf* Dominant (SC X, I, II)	126 937	0.80
Bf Mix (SC X, I, II)	947 020	5.97
Bf Dominant (SC III, IV)	4 058	0.03
Bf Mix (SC III, IV)	40 789	0.26
Bw Mix (SC X, I, II)	1 315 517	8.30
Bw Mix (SC III, IV)	837 563	5.28
Pj Mix (SC X, I, II, III)	4 203 505	26.51
Po Mix (SC X, I, II)	3 301 959	20.82
Po Dominant (SC X, I, II)	481 699	3.04
Po Mix (SC III, IV)	1 690 352	10.66
Po Dominant (SC III, IV)	207 869	1.31
Pw Mix (SC X, I, II, III)	198 042	1.25
Sb Mix (SC X, I, II, III)	2 245 976	14.17
Sw Dominant (SC X, I, II, III)	59 937	0.37
Sw Mix (SC X, I, II, III)	194 876	1.23
Total	**15 856 099**	**100.00**

* Bf = Balsam fir, Bw = White birch, Pj = Jack pine, Po = Poplar, Pw = White pine, Sb = Black Spruce, Sw = White spruce, SC = Site Class (as defined by Plonski 1974)

The following trends are noted for three geographic areas in boreal Ontario and the GLSL transition zone:

Northwest:

- Jack pine-dominated mixedwoods represent nearly half the total area
- Poplar-dominated conditions and poplar mixedwoods make up a further 29% of the total
- Black spruce-dominated mixedwoods represent an additional 10% of the area.

North Central:

- Poplar-dominated cover types and poplar mixedwoods make up approximately one third of the total boreal mixedwood forest cover
- Jack pine-dominated mixedwoods are also common comprising almost 23% of the total area
- Black spruce-dominated mixedwoods constitute an additional 18% of the total area

Northeast:

- Black spruce- and poplar-dominated stands and poplar mixedwoods account for over 50% of the boreal mixedwood in the Claybelt area
- Poplar-dominated stands and poplar mixedwoods represent close to 40% of the boreal mixedwood forest in non-claybelt areas. In contrast, black spruce mixedwoods account for slightly more than 10%
- Jack pine-dominated mixedwoods are a common cover type in the non-claybelt conditions comprising almost 20% of the total area

GLSL Transition Zone:

- Boreal mixedwood cover types include two equally represented conditions: poplar-dominated stands or poplar mixedwoods (all site classes) and white birch mixes (all site classes)
- Jack pine mixes are the most common conifer mixedwood

Commercial Importance of Boreal Mixedwood Forest Conditions

Historic perspective

The forest industry in northern Ontario began in the mid-19th Century. Sawmilling preceded the pulp and paper industry for many decades (Armson 1988), but it never attained the commercial importance of the pulp and paper industry. White pine was both a desirable and sought after species for the lumber industry. The sawmill industry was essentially operated on a small scale and mostly to satisfy local needs. Tall, straight white pine boles were also much in demand in the European market for shipbuilding. The GLSL transition zone provided an important source of this valuable species for this purpose.

White spruce, black spruce, and jack pine have been logged extensively in northern Ontario since the late 1800s for pulpwood and sawlogs (Armson 1988). Jack pine was initially deemed a ‘scrub’ species and used for rough lumber, pit props, and railway tie blocks, but later became a component of the kraft pulpwood industry.

Because the pulpwood industry concentrated their harvesting efforts on forested lands supporting spruce and fir, significant logging in Ontario’s boreal mixedwoods only began following World War II. Access and transportation provided by the development of all-weather roads played an important role in the commercial utilization of the boreal mixedwood species (Opper 1981, Armson 1988). Roads were located preferentially on upland sites and with the onset of a forest inventory the forest industry began to utilize boreal mixedwood timber (Armson 1988).

Current timber use

The Canadian Council of Forest Ministers (CCFM 2000) recently acknowledged that boreal mixedwoods occur on the most productive sites in the boreal forest and contribute about a quarter of Canada’s annual harvest area (AHA).

In 1992, an econometric analysis of Ontario’s forest products industry was summarized in a report entitled *Ontario Forest Products and Timber Resources Analysis* (OMNR 1992). This report identified specific opportunities for the expansion of Ontario’s forest industry based on improvements in fibre utilization and the availability of unallocated hardwood fibre – much of it associated with boreal mixedwood conditions.

Key predictions from this report related to demand for Ontario wood fibre are:

- Fibre demand is projected to increase from 23.9 million m^3 to 30.8 million m^3 by 2021-2040
- Total hardwood fibre demand for pulp, oriented strand board (OSB), and medium density fibre (MDF) board products will increase 52% between 1990 and 2020
- Total softwood fibre demand for pulp and paper will increase 24% in the same period
- A shift in Ontario’s forest product sector was forecast with a greater emphasis on pulp and OSB production. Pulp will consume 56% of the province’s timber harvest (an increase of 15% from the 1980s) and OSB will utilize 6% (up 3% from the 1980s).

Actual harvest levels from Ontario’s forests are reported in Table 4.

Based on the *Forest Resources of Ontario* (OMNR 1996) boreal mixedwoods contributed 3 395.64 million m^3 gross total volume and 1 987.54 million m^3 net merchantable volume to the provincial growing stock annually. The Assessment of Ontario’s Forest Resources report for 1996 (OMNR 1997) also confirmed that a significant component of the potentially available hardwood resource identified in the 1992 study was already allocated and that in some regions, the conifer supply was fully utilized with future supplies forecast to decline. This is evidenced by the upgrading of existing processing facilities to improve fibre recovery and substitution of hardwood volume to help meet fibre demands. As such, new OSB and MDF mills have been a key factor in the increased utilization of boreal hardwoods.

The forecasted net Northwest and Northeast Region wood supply and demand situations (OMNR 2004b) are summarized below (Tables 5 and

Table 4. *Summary of harvest volumes as presented in the Ministry of Natural Resources Annual Reports on Forest Management (OMNR 2000, 2001, 2002, 2004a).*

Year	Region	Softwood (million m^3)	Hardwood (million m^3)	Total (million m^3)
1997 - 1998	Northwest	8 273 062	1 950 429	10 223 491
	Northeast	8 483 356	2 446 977	10 930 333
1998 - 1999	Northwest	7 826 729	1 908 759	9 735 488
	Northeast	7 608 319	2 829 712	10 438 031
1999 - 2000	Northwest	8 003 526	2 818 410	10 821 936
	Northeast	8 303 841	2 354 344	10 658 186
2000 - 2001	Northwest	8 014 988	1 997542	10 012 530
	Northeast	8 200 000	3 272 000	11 472 000

Table 5. *Ontario's Northwest Region wood demand and availability forecast for the year 2002 and beyond.*

Species subset	Volume demand (million m^3 yr^{-1})	Available harvest volume (million m^3 yr^{-1})	Projections
Conifer	10.250*	10.824*	· Strong dip (9.173 million m^3 yr^{-1}) in 2010-2020 decade, continuing until 2050-2060 · Then climb until 2080-2090 to 10.356 million m^3 yr^{-1}
Poplar	3.723*	3.644*	· Dip to 3.069 million m^3 yr^{-1} in the 2030-2040 decade · Then climb until 2080-90 to 3.872 million m^3 yr^{-1}
White birch	0.614	0.924	· Slow decline to 0.623 million m^3 yr^{-1} by 2090-2100

*The available harvest volume is lower than the demand for these species subsets.

Table 6. *Ontario's Northeast Region wood demand and availability forecast for the year 2002 and beyond.*

Species subset	Volume demand (million m^3 yr^{-1})	Available harvest volume (million m^3 yr^{-1})	Projections
Conifer	8.366	8.366	· Gradual decline in wood supply to 7 million m^3 yr^{-1} about 2030 · Recovery begins after 2070
Poplar	3.272	3.540	· Steady decline over next 15 years to 3 million m^3 yr^{-1} · Recovery begins about 2060
White birch	1.138	1.373	· Steady slow decline to 1 million m^3 yr^{-1} by 2070

6, respectively). These have been derived from the Strategic Forest Management Model selected management alternative outputs for approved or draft Forest Management Plans in each of the respective OMNR administrative regions.

The forecasted volume of tree species (or species groupings, e.g. spruce) to be harvested from each of the three broad cover classes has been projected using data from each management unit's approved forest management plan. The global picture for both the Northwest and the Northeast Regions are presented below (Tables 7 and 8).

Non-timber use

Ontario's boreal mixedwood forests contribute to diversity, ecosystem function, productivity and stability of the boreal landscape. In turn, they provide critical components of the habitat mosaic required by moose, woodland caribou, black bear, and white-tailed deer at all stages of stand development.

- Moose use boreal mixedwoods for security cover during calving in the spring, conifer-dominated boreal mixedwoods for the late winter habitat, and hardwoods and hardwood-dominated

Table 7. *Forecasted wood volume (million m^3) originating from each of three boreal forest stand types (hardwood/conifer/mixedwood) for the Northwestern Region (5-year period) (derived from approved Forest Management Plan).*

Stand type	Wood Volume by Species													
	Spruce		Pine		Other conifer		White birch		Poplar		Other Hdwd		All species	
	mill.m^3	%	mill.m^3	%	mill.m^3	%	mill.m^3	%	mill.m^3	%	mill.m^3	%	mill.m^3	%
Conifer	23.518	74	12.339	68	1.987	44	0.688	15	2.654	15	0.025	13	41.162	54
Hardwood	0.790	2	0.577	3	0.429	9	1.401	31	6.034	35	0.054	29	9.285	12
Mixedwood	7.470	24	5.182	29	2.151	47	2.422	54	8.389	49	0.110	58	25.724	34
Total	31.779	100	18.098	100	4.568	100	4.511	100	17.027	100	0.188	100	76.171	100

Table 8. *Forecasted wood volume (million m^3) originating from each of three boreal forest stand types (hardwood/conifer/mixedwood) for the Northeastern Region (5-year period) (derived from approved Forest Management Plan).**

Stand type	Wood Volume by Species													
	Spruce		Pine		Other conifer		White birch		Poplar		Other Hdwd		All species	
	mill.m^3	%	mill.m^3	%	mill.m^3	%	mill.m^3	%	mill.m^3	%	mill.m^3	%	mill.m^3	%
Conifer	19.972	82	8.604	79	2.041	66	0.908	20	1.976	13	0.026	8	33.659	57
Hardwood	1.084	4	0.583	5	0.295	10	1.969	42	9.339	59	0.121	38	13.399	23
Mixedwood	3.412	14	1.729	16	0.765	25	1.759	38	4.446	28	0.174	54	12.374	21
Total	24.468	100	10.917	100	3.102	100	4.637	100	15.761	100	0.320	100	12.374	100

*Data from Romeo Malette and Wawa forest unavailable. Algoma Forest inventory only included in "other hdwds" and "All species" due to differences in forest unit definitions.

mixedwoods for summer and early winter habitats (Timmermann 1998a).

- Black bears use the boreal mixedwood forest as a source of food during spring, summer, and fall. They also use it as escape cover and denning sites. Varied understory vegetation provides a good source of grasses, sedges, berries, nuts, and other soft-mast foods (Brown *et al* 1999).
- Woodland caribou utilize boreal mixedwood forests seasonally during the green food period where it occurs in association with open bogs, lakes and islands. The hardwood components of the boreal mixedwood forests provide caribou with a variety of deciduous buds and leaves (Timmermann 1998b).

The boreal mixedwood forest also provides critical breeding habitat for neo-tropical bird species, raptors, small mammals, gastropods, and insects. Wildlife affects the boreal mixedwood forest by shaping and directing succession on boreal mixedwood sites.

Recreational and resource-based tourism use of Ontario's boreal forests contribute greatly to local economies. In northern Ontario, forests and their associated wildlife populations support close to 1, 900 resorts, lodges and fishing/hunting camps (Hunt *et al.* in press). Tourism is strongly linked to the aesthetic quality of the surroundings, opportunities for remote fishing and recreational activities. Contribution to Ontario's Gross Domestic Product (GDP) by resource-based tourism industries and the sectors that supply goods and services to them directly or indirectly reached $1.2 billion annually during 2001 (OMTR 2003). Direct employment attributed to recreational and resource-based tourism within the boreal forest was 17, 525 jobs. Province-wide this tourism activity generated $554.6 million in taxes for all levels of government in 2001.

Summary

Analysis of site characteristics and forest cover types show that more than three quarters of the forest landbase in northern Ontario has the potential to support boreal mixedwood stands. At present, mixedwood stands occur on 45% of the area. With this amount of boreal mixedwoods currently on the landscape, and the potential for even greater amounts to occur, it's clear to see the contribution of boreal mixedwood stands to both consumptive and non-consumptive forest values in northern Ontario.

Increased mill demand for species such as white birch and trembling aspen and changes in mill technology have resulted in increased harvest levels of most boreal mixedwood tree species. Non-consumptive uses (or non-timber values) of the boreal mixedwood forest will increasingly limit harvest volumes. These pressures will emphasize the need for increased stand yields and improved utilization (Cormier 1996).

Boreal mixedwoods will continue to be a significant element of Ontario's boreal landscape. Managing mixedwoods on a 'multiple rotation' basis will require new approaches in predicting forest growth and yield for a variety of resource values: fibre, habitat, wildlife populations, and aesthetics. Criteria and indicators of sustainability must evolve to recognize the temporal and spatial variability of boreal mixedwoods and their diverse products and intrinsic values. The potential productivity and site capability of the boreal mixedwoods should be identified in all forest management and silviculture planning exercises to maintain and enhance the quantity, quality, and overall forest health of Ontario's extensive and diverse boreal mixedwood forest condition.

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Appendix A. Area of conifer, hardwood, and mixedwood cover types for active forest management units in the Northwest Region of Ontario.

Forest Management Unit	Conifer		Hardwood		Mixedwood		Total
	ha	%	ha	%	ha	%	ha
Armstrong Forest	140 661	39	69 356	19	154 628	42	364 645
Black Sturgeon Forest	144 372	33	61 147	14	233 587	53	439 106
Brightsand Forest	243 917	86	22 441	8	17 681	6	284 039
Caribou Forest	358 350	87	0	0	52 785	13	411 135
Crossroute Forest	303 580	37	283 991	35	234 423	29	821 994
Dog River-Matawin Forest	287 095	42	57 001	8	338 943	50	683 039
Dryden Forest	39 760	37	7 620	7	60 967	56	108 347
English River Forest	255 518	60	14 883	4	152 063	36	422 464
Kenogami Forest	1 001 392	69	43 719	3	396 621	28	1 441 732
Kenora	173 163	38	51 098	11	226 549	50	450 810
Lac Seul Forest	442 760	69	18 610	3	179 431	28	640 801
Lake Nipigon Forest	208 512	29	61 631	9	444 120	62	714 263
Lakehead Forest	90 583	28	102 388	32	131 536	41	324 507
Nakina North Forest	200 891	78	18 206	7	38 726	15	257 823
Ogoki Forest	376 179	72	30 943	6	114 798	22	521 920
Pic River Ojibway Forest	39 550	22	23 208	13	116 492	65	179 250
Red Lake	136 414	94	7 970	6	0	0	144 384
Sapawe Forest	75 457	38	18 686	10	102 012	52	196 155
Spruce River Forest	371 430	63	41 099	7	173 745	30	586 274
Trout Lake Forest	634 063	94	38 046	6	0	0	672 109
Wabigoon Forest	370 001	80	85 306	18	6 201	1	461 508
Whiskey Jack Forest	337 721	70	949	0	142 950	30	481 620
TOTAL	6 231 369	59	1 058 298	10		31	10 607 925

Appendix B. Area of conifer, hardwood, and mixedwood cover types for active forest management units in the Northeast Region of Ontario.

Forest Management Unit	Conifer		Hardwood		Mixedwood		Total
	ha	%	ha	%	ha	%	ha
Algoma Forest	63 342	47	8 296	6	62 641	47	134 279
Big Pic Forest	340 172	68	68 895	14	93 538	19	502 605
Black River Forest	111 146	62	37 889	21	30 890	17	179 925
Cochrane / Moose River Forest	443 452	89	30 933	6	21 382	4	495 767
Gordon Cosens Forest	998 704	67	127 054	8	375 944	25	1 501 702
Hearst Forest	639 015	69	78 050	8	207 010	22	924 075
Iroquois Falls Forest	576 976	71	59 824	7	172 083	21	808 883
Magpie Forest	108 798	45	110 024	46	22 401	9	241 223
Nagagami Forest	192 197	62	77 370	25	38 366	12	307 933
Nighthawk Forest	219 956	72	46 436	15	37 106	10	303 498
Northshore Forest	93 165	24	47 036	12	249 422	64	389 623
Pineland-Martel Forest	231 168	53	96 871	22	110 593	25	438 632
Shiningtree Forest	120 661	53	67 853	30	39 743	17	228 257
Smooth Rock Falls Forest	272 705	87	21 065	7	21 440	7	315 210
Spanish River Forest	403 790	51	194 082	24	200 413	25	798 285
Sudbury Forest	95 072	28	79 262	23	167 745	49	342 079
Superior Forest	303 714	45	167 986	25	198 046	30	669 746
Temagami Forest	85 439	42	61 125	30	58 340	28	204 904
Temiskaming Forest	353 954	56	173 297	27	107 966	17	635 217
White River Forest	252 681	56	138 761	31	59 490	13	450 932
TOTAL	5 906 107	60	1 692 109	17	2 274 559	23	9 872 775

boreal
mixedwood
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1995 • NUMBER 5

Autecology of Trembling Aspen *(Populus tremuloides)*

by Bruce Miller[1]

The boreal mixedwood forest is defined in terms of sites that support the growth of five defining tree species. Trembling aspen is one of the defining species.

Physical Appearance

Trembling aspen is a medium- to large-sized tree that averages 21 m in height at maturity, but can reach as high as 34 m on some sites. It has a relatively small, diffuse crown and long, spreading branches (Sims et al. 1990). The branchlets and end buds are slender, shiny, and reddish-brown; buds are small (0.5 cm to 0.7 cm) and sharp-pointed (Bell 1991). The trunk has little taper and is essentially branchless below the crown. The bark is smooth, pale green to chalk white, with diamond-shaped indentations and dark patches, becoming rough and furrowed into ridges (Bell 1991).

The leaves are alternate on the branch, broadly egg-shaped to almost round, 3 cm to 5.5 cm in diameter, often wider than they are long, sharp-pointed at the tip, and rounded or squared at the base; margins are wavy, finely toothed, or almost entire; leafstalk is long, slender, flattened (Bell 1991), and usually longer than the leaf blade, which trembles in a breeze (Hosie 1969).

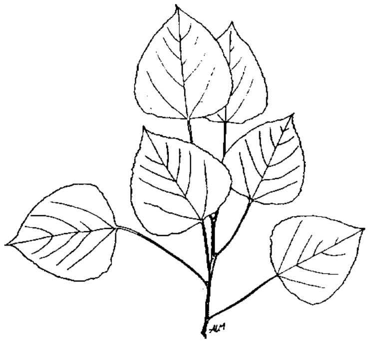

Figure 1. Typical aspen twig with leaves. (Adapted from Baldwin and Sims 1989)

Flowers of trembling aspen are typically imperfect (i.e., unisexual). Trees are dioecious, with individual trees entirely male or entirely female (Peterson and Peterson 1992). Pollination is accomplished by wind, and the fruit ripens in 4 to 6 weeks after flowering. The fruit is a one-celled capsule (approximately 6 mm long) containing many small seeds, each of which is surrounded by tufts of long, silky, white hairs (Bell 1991).

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Ontario

Habitat

Trembling aspen is the most widely distributed tree species in North America (Fowells 1965). In Ontario, it is common to both the Great Lakes-St. Lawrence and the Boreal Forest Regions, and occurs, to a limited extent, in the Deciduous Forest Region (Rowe 1972).

Within the commercial range of trembling aspen, the mean July temperature ranges from 16°C to 19°C, the mean annual precipitation from 635 mm to 864 mm, and the mean frost-free period from 80 days to 130 days (Davison et al. 1988). The northern limit of its range generally coincides with the 13°C July isotherm (Maini 1968, as quoted in Peterson and Peterson 1992). The key climatic gradients that affect the range of trembling aspen are temperature and moisture.

Stands dominated by trembling aspen typically occur on a wide range of soil/site conditions, including deep, dry to fresh coarse loamy soils; medium sands; fine sands; or silt soils (Sims et al. 1990). The best growth generally occurs on fresh to moist sandy loams that have good drainage and have some organic-matter content. Poorer growth is achieved on sands because of low moisture and nutrient levels, while clays with poor aeration limit the growth of trembling aspen (Fowells 1965). In the Clay Belt, however, trembling aspen is associated with nutrient-rich clays and silts. It is commonly found on morainal deposits, deep glaciofluvial deposits, and lacustrine soils. It does not associate with organic soils (Bell 1991).

Figure 2 shows a Vegetation Type Ordination that indicates the frequency of occurrence of trembling aspen, by moisture gradient and nutrient status, for the Northwestern Ontario Forest Ecosystem Classification (NWO FEC). Figure 3 shows a Site Type Ordination that indicates the frequency of occurrence of jack pine, by moisture gradient and nutrient status, for the Northeastern Ontario FEC (NE-FEC).

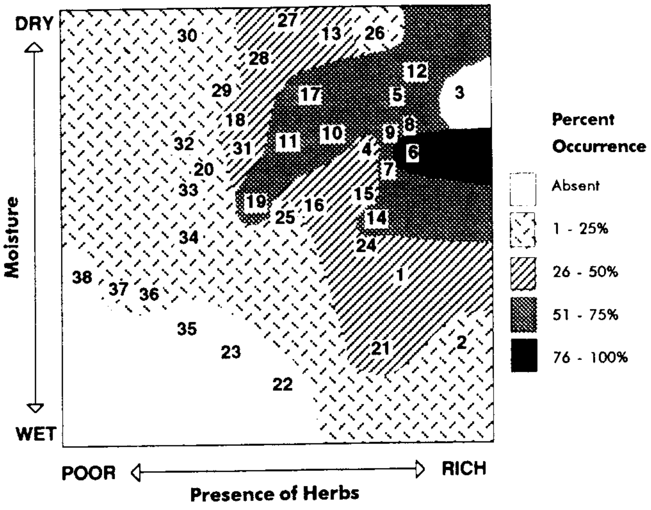

Figure 2. Frequency of occurrence of trembling aspen by NWO FEC Vegetation Type. (Numbers correspond to Vegetation Types.) (Adapted from Bell 1991 with permission)

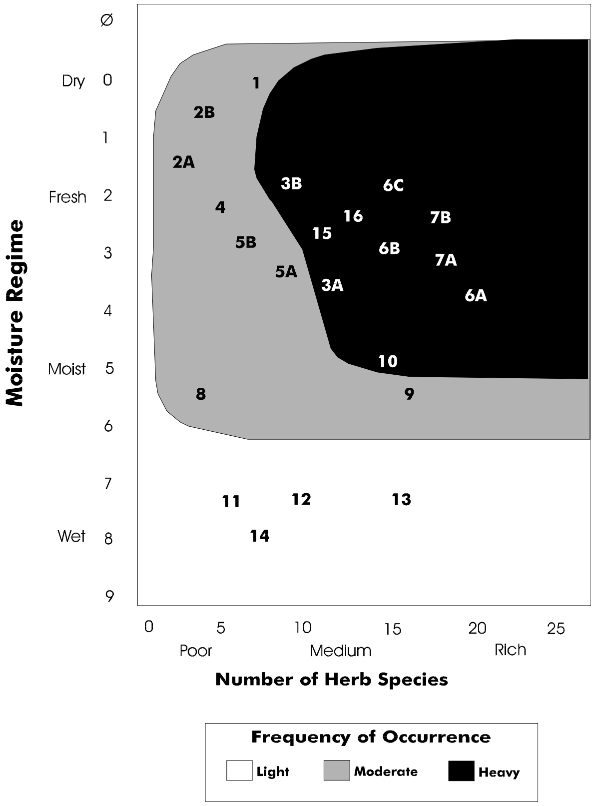

Figure 3. Frequency of occurrence of trembling aspen by NE-FEC Site Type. (Numbers correspond to Site Types.) (Adapted from Arnup et al. forthcoming with permission)

Trembling aspen grows on soils with a wide range of soil fertilities. Good aspen sites are those with high relative levels of calcium, magnesium, phosphorus, and nitrogen (Bell 1991), with calcium being the most important nutrient. In general, trembling aspen performs best on soils that contain 50% to 60% silt plus clay fractions, since these soils generally have higher calcium (free lime) contents than do coarser-textured sandy soils (Davison et al. 1988).

Due to its poor stomatal control, an adequate supply of soil moisture is crucial for the growth of trembling aspen (Davison et al. 1988). Moderately well-drained, very rapidly drained, or imperfectly drained soils support stands of intermediate vigour, while rapidly drained or well-drained soils produce good stands of trembling aspen (Sims et al. 1990). Best growth occurs on very fresh sites consisting of well-structured clay or silt loam.

Trembling aspen has poor to fair flood tolerance and can survive 2 to 3 weeks of flooding. Young seedlings or suckers are intolerant of prolonged flooding (Sims et al. 1990).

Phenology

Flower buds differentiate in the axils of leaves during the season before flowering occurs. Dates of flowering and leaf flush vary, depending on the clonal origin of the tree; however, flowering usually occurs in late April to early May, before the leaves have emerged (Sims et al. 1990). Fruit matures as the leaves expand and normally ripens during May and June. Seed dispersal occurs within a few days after ripening, generally from late May through mid-June in Northern Ontario (Heeney et al. 1975).

The earliest and latest flushing dates for clones in the same area may be 1 to 3 weeks apart, but flushing generally occurs in mid-May and early June. Leaf phenology is identical for all trees within the same clone. Clonal differences are most evident in the spring, when trees of some clones can be seen leafing out while adjacent trees are still dormant (Bell 1991).

Trembling aspen experiences both seasonally determinant growth (i.e., short-shoot elongation) and seasonally indeterminant growth (i.e., long-shoot elongation). Short shoots arise from preformed stem units in the winter bud, whereas long shoots involve the elongation of preformed stem units and a period of free growth during which new stem units begin and elongate simultaneously (Peterson and Peterson 1992).

Height growth begins in early June and continues until mid- to late August, depending on weather conditions. Short shoots elongate during a brief period in the spring, while long shoots continue elongation until the later part of the summer (Peterson and Peterson 1992). Radial growth begins about 1 week earlier than the initiation of height growth and continues for 2 to 3 weeks beyond the cessation of height growth (Sims et al. 1990).

The start of leaf fall, maximum leaf coloration, and the completion of leaf fall usually occur in late September to early October (Fowells 1965).

Reproduction

Most trembling aspen regeneration arises from asexual reproduction by root suckering, which results in stands of clones. Because the short period of seed viability rarely coincides with suitable environmental conditions that allow seedling establishment (Bell 1991), sexual reproduction by seed is not a significant means of regeneration for trembling aspen in nature, although it does occur (Davison et al. 1988).

Trembling aspen begins to bear seed between 10 and 20 years of age; however, flowers have been observed on suckers as young as 4 years (Bell 1991). The optimum age for the production of seed is between 50 and 70 years. Seed crops are produced annually, with good seed crops occurring every 2 or 3 years. Individual trees are capable of producing large quantities of seed (up to 1.6 million seeds in a single year). Seeds are extremely light, with an average of 5.5 million to 6.6 million seeds per kg (Bell 1991).

Under natural conditions, trembling aspen seeds are short-lived. However, the viability of fresh seed is high (95%), though this lasts for only 2 to 3 weeks. Should seedbed conditions be suitable during this period, seedling production can be prolific. Trembling aspen seeds are not dormant and will germinate immediately after dispersal. Moist seedbeds of mineral soil or humus with moderate temperatures, good drainage, and little competition from other vegetation are required for seed germination and seedling survival. Germination is completed within a few days (Bell 1991). Stands of seed origin are relatively rare, and often develop with difficulty (Sims et al. 1990).

Most regeneration occurs through suckering; however, stump sprouts and root collar sprouts may develop if the harvested trees are relatively young. Suckers arise from adventitious or dormant buds on roots located within 3 cm to 10 cm of the soil surface and are typically induced by damage to the stems or roots. Soil temperatures in excess of 20°C are required for maximum sucker production (Sims et al. 1990). Vegetative reproduction is inhibited by flooding immediately after disturbance.

Suckering results in the development of extensive clones of genetically identical trees; each clone varies in general form, suckering ability, phenology, growth rate, and disease susceptibility. Clones vary in size and can cover several hectares (Bell 1991).

Growth and Development

Trembling aspen may attain a height of 30 m and a diameter of 60 cm. It is a relatively long-lived species, reaching maturity in 80 to 120 years. However, stands tend to break up earlier as they mature and growth rates decrease. Holes develop in the canopy, increasing the exposure of the trees to wind, sunlight, and evaporation. Trembling aspen tends to be intolerant of sudden increases in stress, which cause a loss of vigour and an increased susceptibility to disease and insect attack, all of which in turn result in breakage and death of individual trees. This may occur in as short a time as 3 to 4 years (Peterson and Peterson 1992) and generally occurs between the ages of 55 and 90 years (Bell 1991). Following stand breakup, shrub vegetation, primarily beaked hazel and alder, increases and suppresses suckering (Bell 1991).

Trembling aspen grows rapidly after a major disturbance, such as fire, windthrow, or harvesting (Sims et al. 1990). The species is characterized by rapid early shoot growth, which may reach as much as 2 m in the first year for vigorous suckers supported by large pre-established root systems. Subsequent height growth averages between 30 cm and 60 cm annually, depending on the site. Seedling growth, however, is relatively slow for the first 2 to 3 years: growth generally averages less than 15 cm in the first year, and from 15 cm to 30 cm in the second year; under favourable conditions, seedlings may reach a total height of between 1 m and 1.3 m after 3 years (Graham et al. 1963).

Trembling aspen suckers grow rapidly following clearcutting. Sucker production is generally proportional to the severity of the cut (Fowells

1965). A clearcut, which removes all merchantable stems and most of the residual trees, creates the most desirable conditions for aspen sucker regeneration (Bell 1991).

Trembling aspen has a shallow and wide-spreading root system, which is supported by strong, vertically penetrating roots that originate near the base of the tree and by "sinkers" that arise from the lateral-root system (Peterson and Peterson 1992). Strong lateral roots can spread as far as 30 m from the tree base (Peterson and Peterson 1992). "Sinker" roots that descend from points on the lateral roots can reach depths of more than 2.7 m (Gifford 1966, as quoted in Peterson and Peterson 1992) but typically penetrate to a depth of between 1.0 m and 1.5 m into the soil. Excessive stoniness can affect lateral-root development and limit clonal expansion (Sims et al. 1990).

Height differences between adjacent clones can be as much as 6 m (Bell 1991). The best height growth occurs on well-drained, fresh to moist, calcareous soils with coarse loamy textures. Available soil moisture, spring soil temperatures, clonal origins, and genetics all affect height growth rates (Sims et al. 1990).

Trembling aspen is considered an early successional species typically replaced by more-tolerant species on drier soils, and by balsam fir and white spruce on fresh, fertile soils. On moist soils, in the absence of fire, trembling aspen is usually succeeded by balsam fir, black spruce, or eastern white cedar. Trembling aspen stands become dominated by shrubs after the stand becomes decadent and collapses, in the absence of a suitable seed source or advance reproduction (Davison et al. 1988).

Competition

Trembling aspen is considered a shade-intolerant species. It requires full sunlight for optimum growth and survival, and cannot reproduce successfully under its own shade. High light levels are required to stimulate sucker production and to ensure their continued, vigorous growth (Bell 1991). Suckers are more shade-tolerant than seedlings (Sims et al. 1990).

Relative Light Requirements for Trembling Aspen as Compared to Other Boreal Mixedwood Species

Species	Light Requirement Rating* (1=least, 5= greatest)
White birch	5.0
Jack Pine	5.0
Trembling Aspen	4.2
Black Spruce	3.5
Balsam Poplar	3.5
White Spruce	2.3
Balsam fir	2.0

*(Adapted from Bakuzis and Hansen 1959)

Trembling aspen is an aggressive pioneer species, readily invading burns (Fowells 1965). Fire kills the top of aspen, reducing auxin production and thereby stimulating prolific aspen suckering. The increased soil temperature promotes faster decomposition, increasing nutrient availability. Removal of the overstory increases light, which also improves sucker production.

Rapid early sucker growth gives trembling aspen an advantage over other tree species that regenerate from seed, as well as over competing grasses and herbs, following fire. Early spring fires that occur before leaf flushing result in the greatest stimulation of suckering (Bell 1991).

Damaging Agents

More than 300 insect species attack trembling aspen (Davison et al. 1988). The most prominent insect pest is the forest tent caterpillar (*Malacosoma disstria* Hbn.), which defoliates the trees about every 10 years, with infestation lasting for 3 to 5 years. Tree mortality may occur on poor sites; during severe, repeated attacks; and during dry growing seasons. Defoliation does not generally result in mortality, however; instead, it weakens the tree, leaving it more susceptible to other insect or fungal attacks (Davison et al. 1988).

The large aspen tortrix (*Choristoneura conflictana* [Wlk.]), a leaf-rolling insect, also defoliates trembling aspen. Its outbreaks tend to precede those of the forest tent caterpillar and tend to last for 2 to 3 years, until the forest tent caterpillar reaches outbreak proportions. Defoliation by the large aspen tortrix causes reduced radial increment, but seldom lasts long enough to cause appreciable mortality (Peterson and Peterson 1992). Infestations occur approximately every 10 years.

The Bruce spanworm (*Operophtera bruceata* [Hulst]) can cause both severe defoliation and reduced radial growth in trembling aspen. However, outbreaks of Bruce spanworm rarely last long enough to cause any permanent damage to the host trees, even if defoliation is severe (Peterson and Peterson 1992).

Insects of lesser importance that affect trembling aspen include the following: the aspen twinleaf tier (*Enargia decolor* Wlk.), which causes widespread and severe defoliation in Northwestern Ontario; the aspen leaf beetle (*Chrysomela crotchi* Brown) and the american aspen beetle (*Gonioctena americana* Schaef.), both of which defoliate predominantly aspen regeneration; and the aspen leafblotch miner (*Phyllonorycter ontario* Free.), which eats the insides of the leaves, primarily attacking young trees, and causes injury and foliar browning in June to early August (Sims et al. 1990).

Trembling aspen is the host to a variety of fungal diseases. The most important is the false tinder fungus (*Phellinus tremulae* [Bondart.]), which produces a yellowish-white trunk and butt rot with black zone lines. It is responsible for approximately 75% of all the observed decay in trembling aspen. False tinder fungus produces distinctive hoof-shaped conks, often with many occurring on a single tree. It is most prevalent in older stands (Sims et al. 1990).

Hypoxylon canker (*Hypoxylon mammatum* [Wahl.] Mill.), one of the most serious diseases that afflict trembling aspen in Canada, usually attacks poorly stocked stands. Hypoxylon cankers enlarge and eventually girdle the tree. This results in weakening of the stem at the point of infection, which is often broken by wind (Peterson and Peterson 1992).

Fungal diseases of lesser importance that affect trembling aspen include the following: shoot blight (*Napicladium tremulae* [Frank] Sacc.), which causes young shoots to fold, dry out at the tips, and die back; heart rot (*Radulodon americanum* [Morg.] Lloyd), which results in red-coloured heart rot in the main bole; butt rot (Pholiota spectabilis Fr.), which causes a stringy, yellow or yellow-brown butt rot of the roots and bases of older trees; leaf and twig blight (Pollaccia radiosa [Lib.] Bald. and Cif.), which is prevalent in young regenerating seedlings and saplings and causes blackening and wilting of foliage early in the growing season; and ink spot (Ciborinia whetzelii [Seav.] Seav.), which causes brown spots and holes in the leaves and may cause mortality in young trees if the infestation is severe (Sims et al. 1990).

Frost resistance in trembling aspen is high, although not as high as in balsam poplar. Frost damage typically results in necrosis, the death of living tissue (Peterson and Peterson 1992). Young foliage is susceptible to late-spring frosts, although new foliage generally replaces the frost-killed leaves later in the season (Sims et al. 1990). Suckers tend to be more resistant to frost than are seedlings.

Frost cracking of the bole may occur in open-growing stands. These frost cracks are essentially freeze-killed areas of bark or wood where woody callus tissue develops to form burls or frost ribs (Peterson and Peterson 1992).

Wildlife Considerations

During winter months, porcupine, deer, moose, and hares browse on trembling aspen as a preferred food species. Aspen is the preferred browse species for both ruffed grouse and beaver.

Moose utilize young aspen stands for browse in the summer, winter, and autumn. In late winter, moose browse on aspen after more-palatable species have been heavily browsed. In spring and summer, use of the foliage of aspen has been reported (Timmermann and McNicol 1988). During autumn, moose utilize aspen litter, which is more digestible and higher in nutrient content than woody browse (Bell 1991).

Snowshoe hares feed on young aspen regeneration (Bell 1991). Buds, twigs, and bark of trembling aspen are principal food sources in winter. Deer utilize aspen stands in early or late summer for both browse and shelter. However, in winter, aspen stands do not provide cover or protection from deep snow (Peterson and Peterson 1992).

Trembling aspen is the primary food source for ruffed grouse. Aspen stands between 30 and 50 years of age are preferred. Ruffed grouse primarily consume aspen buds, leaves, and the catkins that occur in the upper branches of male trees. The most valuable ecosystem to ruffed grouse is one that has diversity as a result of succession following severe fire, windstorms, or harvesting (Peterson and Peterson 1992).

Beavers, like ruffed grouse, are primarily dependent on trembling aspen stands for food and construction materials. Aspen poles are utilized for dam and lodge construction (Bell 1991).

In addition, trembling aspen snags provide nesting sites for a number of cavity-nesting bird species (Peterson and Peterson 1992).

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*Readers who need further information will find the following key references most useful: Bell 1991; Fowells 1965; Sims et al. 1990. See also: Perala, D.A. 1990. *Populus tremuloides* Michx. quaking aspen. *In* Silvics of North America Vol. 2. Hardwoods. R.M. Burns, and B.H. Honkala (*tech. coords.*). US Dep. Agric., For. Serv. Washington, DC. Agric. Handbook 654 Vol. 2. p 555-569.

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boreal mixedwood Notes

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Autecology of White Birch *(Betula papyrifera)*

by Bruce Miller[1]

The boreal mixedwood forest is defined in terms of sites that support the growth of five defining tree species. White birch is one *of the defining species.*

Physical Appearance

White birch averages 16 m in height (Sims et al. 1990) at maturity, but can reach as high as 30 m (Haeussler and Coates 1986). It has a compact, open crown of spreading or ascending branches; twigs are slender, dark reddish-brown, and sometimes hairy; buds are greenish-brown and are blunt or sometimes pointed (Hosie 1969). The bark is thin and smooth; it is reddish-brown on young trees and later becomes white and papery, peeling easily into sheets with long horizontal streaks (Bell 1991).

As Figure 1 shows, leaves are alternate on the branches, egg-shaped or triangular, and about 7 cm long (Hosie 1969), with a tapered, sharply pointed tip; they are rounded to wedge-shaped or occasionally heart-shaped at the base. Margins are singly or doubly toothed, usually without teeth along the base, hairless above, and sparsely hairy in the vein angles on the underside (Bell 1991).

Figure 1. Typical white birch twig with leaves, and female catkin. *(Adopted from Baldwin and Sims 1989)*

Trees are monoecious: flowers are borne on catkins of the same tree. Cylindrical male catkins, formed in the year prior to seeding, are visible at the tips of the overwintering twigs. Mature male catkins are 3 cm to 5 cm in length (Safford et al. 1990).

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Habitat

White birch has a transcontinental range. In Ontario, white birch occurs throughout the Boreal Forest Region and the Great Lakes-St. Lawrence Forest Region, and extends, to a limited extent, into the Deciduous Forest Region (Rowe 1972). It does not occur in the area north of Lake Erie.

White birch is a cold-climate species that tolerates wide variations, in patterns and amounts of precipitation. In general, the climate where white birch is found can be characterized as one with short, cool summers and long, cold winters. It rarely grows where the average July temperature exceeds 21°C (Safford et al. 1990). It performs better in areas that are relatively humid, where moisture conditions are not limited (Sims et al. 1990).

In general, white birch is found on a range of soil textures, from gravelly sands to loams and organic soils. It occurs most often on deep, dry to fresh, coarse sandy, fine sandy, and coarse loamy soils, but is also found, to a lesser degree, on shallow sandy or coarse loamy soils; deep, moist, coarse loamy soils; and shallow, moist soils. White birch is found frequently on morainal deposits; moderately frequently on glaciofluvial, fluvial, and lacustrine deposits; and infrequently on organic soils (Sims et al. 1990).

White birch achieves its best growth on fresh, well-drained sandy loams, silty soils, and soils derived from limestone. Poor growth occurs on wet, poorly drained soils; extremely dry, shallow soils; or coarse sands and gravels on glacial outwash deposits (Bell 1991).

Figure 2 shows a Vegetation Type Ordination that indicates the frequency of occurrence of white birch, by moisture gradient and nutrient status, for the Northwestern Ontario Forest Ecosystem Classification (NWO FEC). Figure 3 shows a Site

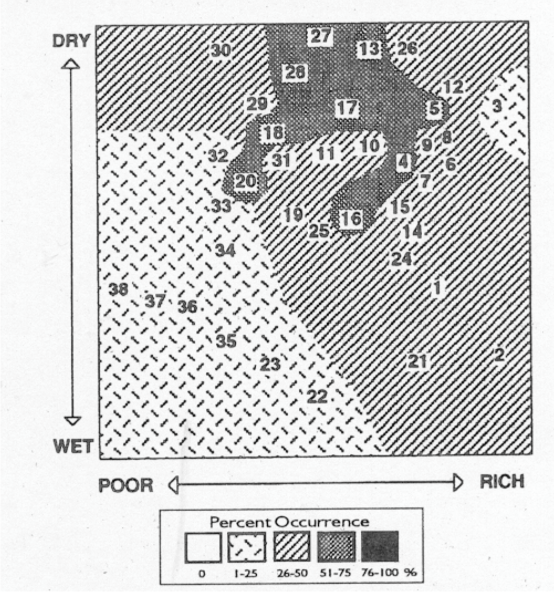

Figure 2. Frequency of occurrence of white birch by NWO FEC Vegetation Type. *(Numbers correspond to Vegetation* Types.) (Adapted from Bell 1991)

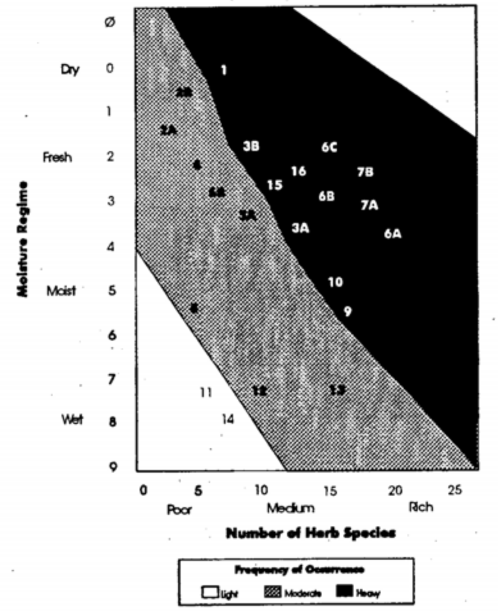

Figure 3. Frequency of occurrence of white birch by NE-FEC Site Type. *(Numbers correspond* to Site Types.) (Adapted from Arnup et al. forthcoming)

Type Ordination that indicates the frequency of occurrence of white birch, by moisture gradient and nutrient status, for the Northeastern Ontario FEC (NE-FEC).

White birch has moderate to fairly high nutrient requirements, especially for calcium and magnesium. It grows on a wide range of soils, from acidic to highly calcareous. It has a moderate acid tolerance and can grow on soils with a pH as low as 4.4 (Watson et al. 1980). It is tolerant of short-term flooding and of imperfectly drained conditions, but is rarely found on wet sites (Sims et al. 1990).

Phenology

Female flower induction occurs in late June or early July, in the year previous to seed release, during bud development. Male flowers are formed in late summer or early autumn and remain overwinter on the tree. Male flowers open in mid-April to early June after considerable elongation. Seeds develop between early August and mid-September, with seed dispersal occurring shortly there after (Safford et al. 1990).

Height growth generally begins early in the growing season while minimum temperatures remain below freezing, peaking in mid-June and gradually decreasing for the remainder of the summer. Radial growth occurs after maximum temperatures reach 21^{o}C and minimum temperatures are above freezing (Bell 1991). Diameter growth ends well before either moisture or temperature become limiting (Safford et at. 1990).

Reproduction

White birch reproduces both from seed and vegetatively following disturbance. Vegetative reproduction is important for persistence of the species; however, regeneration by seed is the most important means of regeneration (Sims et al. 1990). White birch begins to bear seed at approximately 15 years of age, with optimum seed production occurring between 40 and 70 years of age (Zasada 1971). Some seeds are produced in most areas every year, but on average, good seed crops occur every other year (Safford et al. 1990). Excellent crops occur every 2 to 4 years, with bumper crops occurring every 10 years. White birch seed is relatively light, ranging from 1.3 million to 9.1 million seeds per kg with an average of 3 million seeds per kg (Brinkman 1974).

The viability of fresh seed is highly variable, but usually ranges between 15% and 20%. Viability is usually highest during heavy seed years. Although seed may remain viable for up to 2 or 3 years under low moisture conditions, viability is rapidly lost under moist conditions in the forest floor (Brinkman 1974). It has been reported that between 20 and 400 seeds are required to produce a single 1-year-old seedling (Bell 1991).

Germination occurs in the year after seed dispersal. New germinants are sensitive to moisture, light, and seedbed conditions. As a result, significant mortality occurs within the first 2 years after germination (Sims et al. 1990). Best germination occurs on partially shaded, moist seedbeds of mixed mineral soil and organic material that have moderate surface temperatures. Disturbed mineral soils and recently burned areas also make good seedbeds for white birch (Leak et al. 1988). Occasionally, white birch will germinate on humus, but rarely will it do so on leaf litter (Safford et al. 1990). Following germination, full sunlight is required for survival.

White birch is capable of sprouting from the root collar and the stump after logging. Sprouting is most prolific can young trees, but sprouting vigour decreases with age. Trees between 40 and 60 years of age begin to lose their ability to sprout (Sims et al. 1990).

Growth and Development

White birch is a fast-growing, short-lived tree species, maturing as early as 60 years of age, but often surviving up to 140 years of age (Sims et al. 1990). In general, however, tree vigour and quality decline rapidly with age, resulting in crown dieback and mortality, usually between the ages of 60 and 90 years (Bell 1991). At maturity, white birch can reach heights in excess of 30 m and. diameters as large as 1 m at the base (Haeussler and Coates 1986); however, diameter ranges of 25 cm, to 30 cm and heights of 21 m are more common (Safford et al. 1990).

Seedlings average 10 cm in height in the first growing season and 1 m after 4 years (Fowells 1965; see also Safford et al. 1990). Sprouts generally grow more rapidly than do seedlings, reaching 60 cm in the first year; by the end of the fourth growing season, they are about twice the height of seedlings (Haeussler and Coates 1986).

In general, white birch has deep, penetrating roots and a high root-to-shoot ratio. It produces both stabilizing sinker roots and shallower feeder roots. Most roots occur within the top 20 cm to 30 cm of the soil, but readily adapt to variable soil depth conditions and to difficult site conditions (Perala and Alm 1989).

Competition

White birch is a shade-intolerant species that cannot reproduce from seed under its own shade, but can regenerate from basal sprouts after cutting. Although early seedling growth may be better in partial shade not exceeding 30% to 40% cover, young trees require full sunlight for continued optimum growth (Bell 1991).

Relative Light Requirements for White Birch as Compared to Other Boreal Mixedwood Species

Species	Light Requirement Rating * (1-least, 5=greatest)
White birch	5.0
Jack pine	5.0
Trembling aspen	5.0
Black spruce	3.5
Balsam poplar	3.5
White spruce	2.3
Balsam fir	2.0

*(Adapted from Bakuzis and Hansen 1959)

White birch is a pioneer species that frequently occurs in areas with a history of fire. In the natural succession, white birch persists in the overstory, but survives only one generation before it is replaced by species that are more shade-tolerant (Safford et al. 1990). In mature forests, it commonly occupies openings created by blowdown or other disturbances. On rich sites, it can tolerate more shade than on poorer sites (Damman 1964).

Heavy mortality generally occurs throughout the life of a white birch stand due to competition for light, moisture, and nutrients. Individual trees express dominance early in life; suppressed trees soon die, unless they are released. In sapling and pole sized stands, the growth response is proportional to the degree of release (Safford et al. 1990). However, in maturing stands (those beyond 60 years), white birch seldom responds to release (Safford et al. 1990).

White birch suffers from a condition known as post-logging decadence, which results from heavy cutting in mature, previously untreated stands. Symptoms include lowered vigour, reduced growth, dying back of the twigs and branches, and in many instances, eventual death of the trees. (Safford et al. 1990).

Due to the very thin, flammable bark on white birch, the species is extremely susceptible to being killed by fire. Even burns of moderate intensity will kill large trees (Safford et al. 1990). Regeneration results from sprouts on trees damaged or killed by, the fire and from seeds dispersed after the fire (Sims et al. 1990).

Damaging Agents

White birch is affected by a number of insects. The most destructive insect pest affecting white birch is the bronze birch borer *(Arrilis anxius)*, which can kill the trees after repeated attacks. Tiny white larvae tunnel through the bark, where they travel along and into the wood. Previously weakened trees are particularly vulnerable to attack by the bronze birch borer, resulting in extensive white birch decline (Safford et al. 1990).

The forest tent caterpillar *(Malacosoma disstria) is* at times a serious pest to white birch. The caterpillar causes complete defoliation of the trees, which results in reduced annual growth by as much as 85%. Repeated attacks can be especially injurious to white birch.

Although white birch suffers from heart rot, primarily *Phellinus ignarius and Pohlia oblique*, it is relatively resistant to stem decay when compared to, other deciduous species in Ontario. Decayed stem volume in trees less than 100 years of age is generally less than 5% (Basham 1991).

In addition to post-logging decadence (mentioned earlier), white birch suffers from a similar condition known as birch dieback. It is characterized by premature twig and branch dieback, which spreads from the crown downward. Climatic extremes and insect defoliation are considered to be the major causes of birch dieback (Sims et al. 1990).

Wildlife Considerations

Young stands of white birch and associate species - trembling aspen *(Populus tremuloides)*, balsam poplar *(Populus balsamifera), balsam fir (Abies balsamea), etc.* - provide prime browse for moose *(Alces alces)* and deer *(Odocoileus virginianus)*. Moose browse on white birch year-round (Timmermann and McNicol 1988), and the species may constitute up to 31% of the winter diet (McNicol and Gilbert 1980).

In addition to moose and deer, other wildlife species - including beaver *(Castor canadensis)*, porcupine *(Ereihizon dorsatum)*, snowshoe hare *(Lepus americanus)*, voles, birds, and other rodents - also feed on white birch (Sims et al. 1990). White birch is an important food source for beaver (Euler 1979). Porcupines feed on the cambium, while votes and other small rodents consume large quantities of seed. Snowshoe hares feed on the buds, twigs, and bark of seedlings (Jordan and Rushmore 1969). Birds eat buds, catkins, and seeds.

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Autecology of Balsam Poplar *(Populus balsamifera)*

by Bruce Miller [1]

> *The boreal mixedwood forest is defined in terms of sites that support the growth of five defining tree species. Depending on the site conditions, several tree species may grow in association with the five defining species. Balsam poplar is one of the associated species.*

Physical Appearance

Balsam poplar is a medium- to large-sized tree that averages 20 m in height at maturity, but can reach as high as 30 m. It has an open crown of thick, ascending branches, and stout, hairless red-dish-brown twigs. Buds are long (1.5 cm to 2.5 cm), sticky, fragrant, and sharp-pointed (Sims et al. 1990). On young trees, the bark is greenish-brown; as the tree ages, the bark turns dark greyish and becomes furrowed into rough, flat-topped ridges separated by irregular V-shaped crevices (Hosie 1969).

As Figure I shows, the leaves are alternate, egg-shaped to broadly lance-shaped, gradually tapering to sharp tips, 7.5 cm to 12.5 cm long, finely toothed along the margins, rounded at the base, shiny dark green on the upper surface, whitish-green below, and mostly hairless with a round leafstalk (Hosie 1969). Leaves do not flutter in a light breeze, as do those of trembling aspen (Bell 1991).

Figure 1. Typical balsam poplar twig with leaves. *(Adopted from Bell 1991)*

Trees are dioecious: male and female flowers are borne on catkins on separate trees. Flowers appear and mature in April and May before leaves emerge. Pollination is by wind (Sims et al. 1990).

Fruit, which are borne on capsules on the female catkins, are approximately 0.5 cm to 0.8 cm in length.

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Habitat

Balsam poplar has a transcontinental range and is found throughout Ontario, except in the Hudson Bay Lowlands. It grows most commonly in small, localized, mixed stands, in association with trembling aspen, balsam fir, white spruce, white birch, and black spruce (Sims et al. 1990).

The botanical range of balsam poplar is most closely related to climates of, the Boreal Forest Region (Rowe 1972), although it ranges from arctic to temperate climates (Bell 1991). Across its commercial range in Ontario, balsam poplar tolerates a wide range of temperature and precipitation conditions. Mean January temperatures range from –11°C to -13°C and July temperatures from 26°C to 32°C. Throughout its botanical range, the average annual precipitation varies from 170 mm to 1390 mm (Sims et al. 1990).

Balsam poplar occurs on alluvial bottoms, river flats, sandbars, lake margins, riverbanks, and lower slopes (Fowells 1965), as well as on depressional landscape positions where there is a significant amount of moisture and seepage. Stands dominated by balsam poplar are most commonly associated with lacustrine deposits and are less commonly found on morainal and fluvial materials. Balsam poplar occurs primarily on deep**,** fresh to moist, fine-textured soils, often with a calcareous C horizon. It rarely occurs on very shallow sods, deep organic soils, or very dry sandy soils (Sims et al. 1990).

Figure 2 shows a Vegetation Type Ordination that indicates the frequency of occurrence of balsam poplar, by moisture gradient and nutrient status, for the Northwestern Ontario Forest Ecosystem Classification (NWO FEC). Figure 3 shows a Site Type Ordination that indicates the frequency of occurrence of balsam poplar, by moisture gradient and nutrient status, for the Northeastern Ontario FEC (NE-FEC).

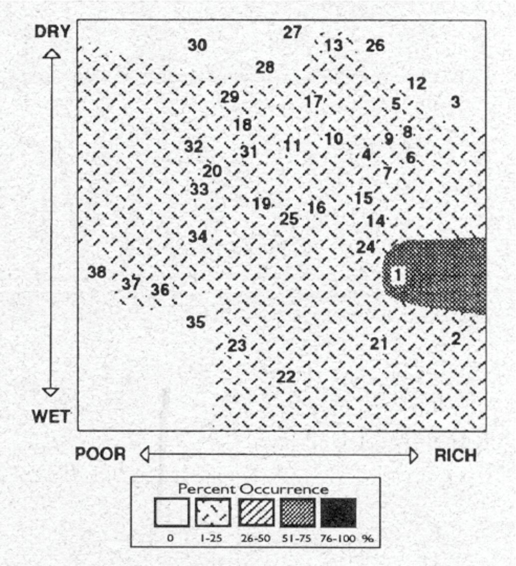

Figure 2. Frequency of occurrence of balsam poplar by NWO FEC Vegetation Type. (Numbers correspond to Vegetation Types.) *(Adapted from Bell 1991)*

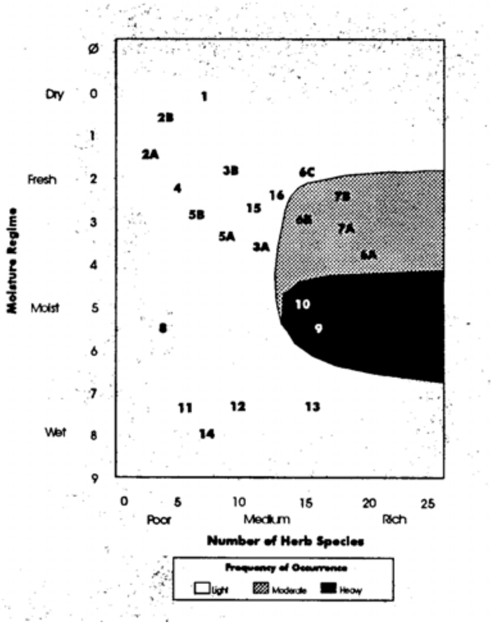

Figure 3. Frequency of occurrence of balsam poplar by NE-FEC Site Type. (Numbers correspond to Site Types.*) (Adapted from Arnup et al. forthcoming)*

Balsam poplar has moderate to high nutrient requirements, particularly for calcium and magnesium (Bell 1991). It does not tolerate acid soils, or forest humus forms that release nutrients slowly (Sims et al. 1990).

Although balsam poplar requires abundant moisture, it does not grow in areas that are extremely wet. Unlike trembling aspen, balsam poplar does not grow on dry exposed soils. But like trembling aspen, balsam poplar does develop into stands on peaty soils. Excellent development occurs on deep sandy soils and deep gravels that are subirrigated, indicating that soil texture is not as critical as abundant soil moisture for balsam poplar growth (Fowells 1965). Balsam poplar is highly tolerant of flooding; trees will produce new roots as required after flooding, especially when surface silt deposition occurs (Sims et al. 1990).

Phenology

Flowers mature in April and May before the leaves appear, but the date of flowering varies from year to year depending on climatic factors. In a Michigan study, the average date for flowering to begin was May, with full bloom reached on May 9. The average dates for swelling of the leaf buds, beginning of leaf expansion, and full leaf were May 2, May 13, and June 10, respectively (Fowells 1965).

Seed-bearing capsules develop and mature from late May to mid-June, when the leaves are approximately two-thirds grown. Seed dispersal occurs immediately thereafter, when seed capsules split to discharge tiny seeds with long, silky hairs (Bell 1991).

Reproduction

For balsam poplar, unlike trembling aspen, both seeding and suckering are important means of reproduction (Sims et al. 1990). Seed reproduction is most important in the colonization of areas where the species did not occur before; but it is much less important than vegetative reproduction in regenerating fire-killed or logged stands (Bell 1991). Mineral soils are best for seed reproduction, while root sucker regeneration benefits from the removal of the forest floor (Peterson and Peterson 1992).

Balsam poplar begins to bear seed between 8 and 10 years of age, with good crops being produced annually (Bell 1991). Seeds initially have high viability, but this usually declines within a few days after dispersal. Seeds are dispersed by wind and water, with most seed concentrated in an area of 100 m to 200 m around the parent tree (Sims et al. 1990).

If seedbed conditions are favourable and moisture is not limiting, germination occurs immediately after seed dispersal, which usually takes place between May and early July (Fowells 1965). Because seeds remain viable for only a few days, if conditions are not favourable at this time, germination will fail to occur. The best seedbeds are moist mineral soil surfaces (Zasada and Phipps 1990). Newly germinated seedlings are susceptible to desiccation and rain damage.

In general, vegetative reproduction is more important than seed reproduction. Balsam poplar regenerates from basal (stump) sprouts, buried branch parts, and root suckers (Sims et al. 1990). However, stump sprouts do not appear to result in tree-for-tree replacement (Peterson and Peterson 1992). Balsam poplar is easily propagated from rooted stem cuttings (Bell 1991).

Growth and Development

Balsam poplar can survive as long as 200 years (Zasada and Phipps 1990). In its juvenile years, balsam poplar is characterized by rapid height growth that allows it to establish and maintain dominance over competing vegetation. This early rapid growth lasts for 40 to 50 years, during which time balsam poplar can reach heights of 25 m and diameters of more than 45 cm (Bell 1991). It occasionally reaches heights of 30 m and diameters of 1 m, especially on moist, fertile sites. On such sites, balsam poplar may even outperform trembling aspen in height growth. It reaches commercial size relatively quickly, usually within 40, years (Sims et al. 1990).

Table 1. Relative light requirements for balsam poplar as compared to other boreal mixedwood species

Species	Light Requirement Rating * (1-least, 5=greatest)
White birch	5.0
Jack pine	5.0
Trembling aspen	4.2
Black spruce	3.5
Balsam poplar	3.5
White spruce	2.3
Balsam fir	2.0

**(Adapted from Bakuzis and Hansen 1959)*

Balsam poplar has a shallow, wide-spreading root system (Hosie 1969). Root suckers arise from roots located within 2 cm of the soil surface, or from exposed roots (Sims et al. 1990). Root suckers are most prolific 2 years after a light to moderate burn.

Competition

Balsam poplar is less tolerant of shade than are most of its common associates - white spruce *(Picea glauca)*, balsam fir *(Abies balsamea)*, and eastern white cedar *(Thuja occidentalis)* - but has about the same shade tolerance as trembling aspen *(Populus tremuloides)* and white birch *(Betula papyrifera)*. It does not grow in association with other species unless it is the dominant species. It forms dense stands under older trees, but will eventually die out unless it is given full sunlight (Fowells 1965). Table 1 compares the shade tolerance of balsam poplar with that of its common associates.

Balsam poplar is considered a pioneer to early successional species that readily invades exposed, moist mineral soils - such as recently deposited alluvium along streams and valleys that are subjected to overflow (Zasada and Phipps 1990) - if a seed source is available (Bell 1991). Although it will seed in on upland burns, such sites are more likely to be invaded by trembling aspen and white birch.

Following burning in stands dominated by balsam poplar, suckers generally become dominant. With age, these stands begin to become open and are succeeded by more-tolerant or longer-lived trees, such as white spruce, balsam fir, eastern white cedar, and black ash *(Fraxinus nigra)*. In Alberta, balsam poplar often invades trembling aspen stands, but is eventually replaced by white spruce (Fowells 1965).

Damaging Agents

When young, balsam poplar has relatively thin bark and is easily killed by fire. Mature trees, however, are less easily killed by fire, because they possess thick, fire-resistant bark. In addition, fires are generally light in stands dominated by balsam poplar, due to the low fuel loadings associated with this species (Fowells 1965).

The primary insects that affect balsam poplar are the forest tent caterpillar *(Malacosoma disstria)* and the poplar and willow borer *(Crytorhynchus lapathi).* The forest tent caterpillar feeds on the foliage of balsam poplar if the latter is interspersed with trembling aspen and the foliage of trembling aspen has been depleted. The poplar and willow borer, an introduced weevil, is considered the most serious insect pest affecting balsam poplar and willow. It can cause significant mortality in stands of saplings that are 20 to 40 years old (Sims et al. 1990).

Diseases that affect balsam poplar include leaf *spot (Mycosphaerella* populorum), which causes brown spots to appear on the leaves in late August, but has little influence on the growth of the trees; shoestring root rot *(Armillaria ostoyae),* which is common in mature stands and, causes weakened stems that are susceptible to breakage; and trunk rot *(Phellinus trenulae* [formerly *P. igniarius or Fomes ignarius]),* which is the most common decay found in mature stands, although it does not contribute significantly to mortality and decline in, balsam poplar stands (Fowells 1965).

Wildlife Considerations

Balsam poplar is an important browse species for moose, particularity in the winter months when more-palatable food sources have been exhausted (Bell 1991).

Beaver utilize balsam poplar for dam and lodge construction and as a food source. Although snowshoe hares utilize balsam poplar, they use it less often than they do trembling aspen.

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Autecology of White Spruce

(Picea glauca)

by Bruce Miller[1]

> *The boreal mixedwood forest is defined in terms of sites that support the growth of five defining tree species. White spruce is one of the defining species.*

Physical Appearance

White spruce can grow as tall as 28 m, but averages approximately 17 m in height at maturity. It has a uniform, conical crown, with branches that spread or droop slightly and extend to the ground. The bole is distinctly tapered, with thin, scaly bark that is light greyish-brown. The inner bark is silvery-white to reddish. Branches, which are usually without hairs, are whitish-grey to yellowish, with persistent, woody leaf bases (Hosie 1969).

As Figure 1 shows, the needle-like leaves are broad, about 2 cm long, stiff, with blunt ends, straight, four-sided in cross-section, and green to bluish-green (often with a whitish bloom); they are strongly aromatic when crushed (Hosie 1969).

The needles are attached to the branchlet in a spiral fashion and form a cylindrical rather than a flattened spray (Bell 1991).

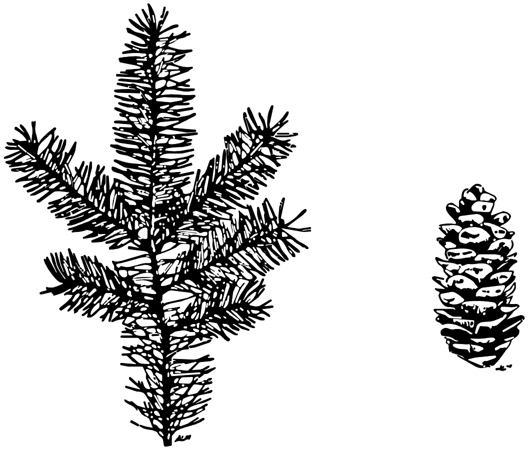

Figure 1. Typical white spruce twig and cone. *(Adapted from Bell 1991)*

Trees are monoecious: male and female flowers occur on separate branches of the same tree. Male flowers are tiny, conelike, deciduous, and short-lived; they are situated at the end of the previous year's growth. Female flowers are erect red cones with numerous spirally arranged scales that also develop at the end of the previous year's growth (Bell 1991). Flowers appear in mid-May to early June.

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Within the mature female cones, seeds are enclosed by woody scales. Cones are 3.5 cm to 5 cm long, cylindrical, and stiff, with smooth margins. They open in the autumn of the year in which they develop.

Habitat

White spruce has a transcontinental distribution (Neinstaedt and Zasada 1990). In Ontario, the commercial range of the species extends throughout the Great Lakes-St. Lawrence and the Boreal Forest Regions (Rowe 1972). White spruce rarely occurs in pure stands, but is a common component of the boreal mixedwoods, in association with balsam poplar *(Populus balsamifera), black* spruce *(Picea mariana),* balsam fir *(Abies balsamea),* eastern white cedar *(Thuja occidentalis),* and tamarack *(Larix laricina)* on deep, imperfectly or poorly drained sites, and with jack pine *(Pinus banksiana),* balsam fir, trembling aspen *(Populus tremuloides),* and white birch *(Betula papyrifera)* on deep, well- to moderately well-drained sites (Arnup et al. 1988).

White spruce is one of the hardiest conifers in North, America, surviving as far north as Alaska (Neinstaedt and Zasada 1990). Within its natural range, the frost-free season varies between a range of 20 to 25 days in remote northern locations and a range of 130 to 160 days further south (Neinstaedt and Zasada 1990). Within its commercial range in Ontario, the frost free period varies from 80 to 150 days and mean annual precipitation ranges from 635 mm to 991 mm (Arnup et al. 1988).

White spruce grows on a narrower range of soil textures than does black spruce. Its best development occurs on alluvial soils along the banks of streams or lakes and at the edges of swamps, on moist sandy loams, and on calcareous lacustrine silts and silt loams. On dry sandy podzolic soils, the species is usually of minor importance

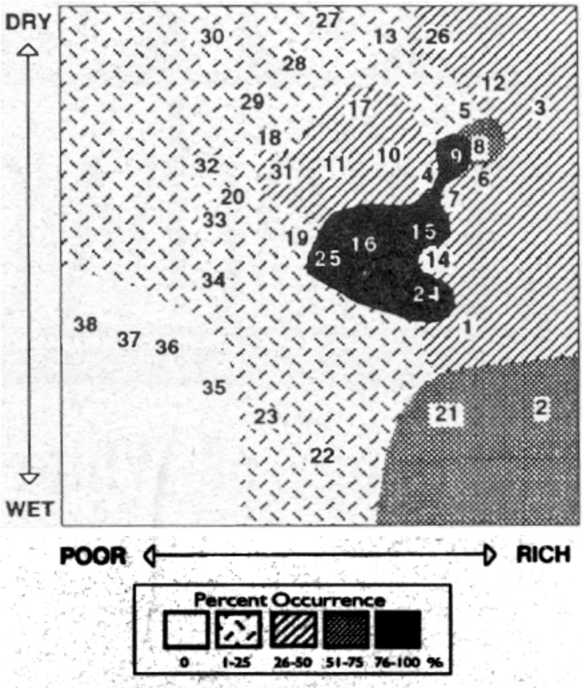

Figure 2. Frequency of occurrence of white spruce by NWO FEC Vegetation Type. (Numbers correspond to Vegetation Types.) *(Adapted from Bell 1991)*

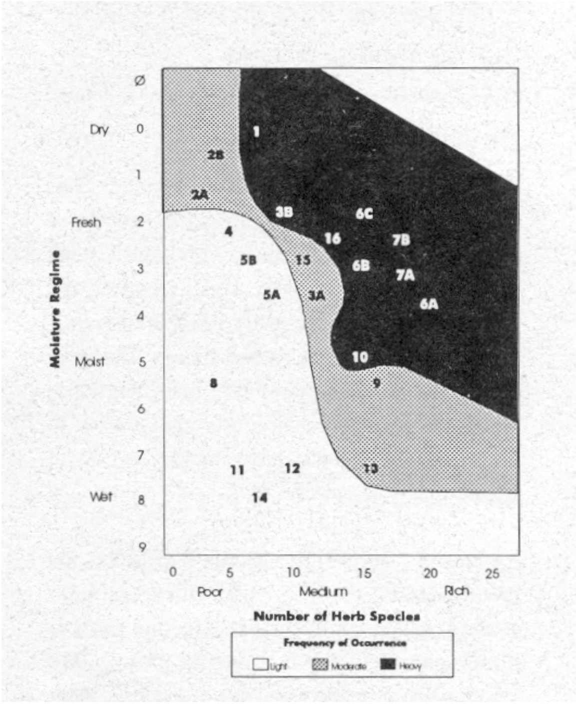

Figure 3. Frequency of occurrence of white spruce by NE-FEC Site Type. (Numbers correspond to Site Types.) *(Adapted from Arnup et al. forthcoming)*

(Neinstaedt and Zasada 1990). White spruce does not appear as a dominant species on wet organic soils or on very shallow soils (Sims et al. 1990).

Figure 2 shows a Vegetation Type Ordination that indicates the frequency of occurrence of white spruce, by moisture gradient and nutrient status, for the Northwestern Ontario Forest Ecosystem Classification (NWO FEC). Figure 3 shows a Site Type Ordination that indicates the frequency of occurrence of white spruce, by moisture gradient and nutrient status, for the Northeastern Ontario FEC (NE-FEC).

The species tolerates a wide range of soil moisture conditions, but growth is significantly reduced on very dry and poorly drained soils where soil water is not well aerated (Arnup et al. 1988). The best growth occurs on well-drained silty soils with adequate moisture (Watson et al. 1980). White spruce is moderately tolerant to flooding; however, mature trees will experience mortality after prolonged periods of flooding.

Phenology

The timing of bud break, flushing, flowering, leader development, bud set, and hardening of the new growth varies greatly in different parts of white spruce's range. In addition, there are considerable differences in the timing of flushing among individuals within a local population. These differences are related to genetic variability and soil fertility (Arnup et al. 1988).

White spruce flushes in late May, approximately 5 to 10 days earlier than black spruce, and is quite susceptible to damage by spring frosts. Regrowth of the damaged leaders rarely occurs following frost damage. Shoot elongation, which is very rapid following leaf flush, is completed in early July to late August, depending on the location and climatic conditions (Bell 1991). In the juvenile stage of its life cycle, white spruce experiences a period of free or indeterminate growth, during which the species is capable of flushing and growing continuously if, environmental conditions are favourable (Stiell 1976). The date of flushing becomes progressively later as the tree ages.

Flower bud initiation begins in late July during the year preceding the season of seed production, after shoot elongation ceases (Eis 1967). Flowering occurs over a period of 3 to 5 days in late May to early June, prior to the flushing of the vegetative buds (Sims et al. 1990). Male flowers are abundant in the middle portion of the crown, while female flowers occur in the upper crown (Arnup et al. 1988).

Reproduction

Natural stands of white spruce generally do not produce seed in quantity until 40 years or older; however, cones have been observed on trees as young as 10 years of age. Cones are generally produced every year, but good crops occur every 2 to 6 years (Nienstaedt 1957). However, the periodicity of good cone crops varies from one part of Ontario to another (Arnup et al. 1988). Excellent seed years are related to hot, dry summers at the time of bud differentiation (Nienstaedt 1981).

Cones are light brown when ripe, but can vary from green to reddish brown. Seed yields in Ontario average approximately 310,000 viable seeds per hectolitre of cones or 370,000 viable seeds per kilogram (Arnup et al. 1988). Seeds are generally viable for 1 year, but if conditions remain extremely dry, they may maintain their viability for up to 2 years.

Cones ripen from mid-August to late September (Nienstaedt 1957) of the year in which flowering occurs and open within a few days of maturation. The seeds are dispersed by wind and gravity, and overwinter in the forest floor.

Germination occurs in mid-June to late July when seedbeds are warm and moist.

Good seedbeds include exposed, humus-rich mineral soils; decayed wood; and mineral/organic soil mixtures (Sims et al. 1990) that have an adequate but not excessive moisture supply (Nienstaedt 1957) throughout the first season of growth. Seedbeds that dry out easily, such as poorly decomposed humus, litter, and feathermoss, are detrimental to white spruce during the first season (Fowells 1965) and can contribute to seedling mortality (Arnup et al. 1988).

White spruce does not reproduce by layering in Ontario; however, cuttings of seedlings can be rooted in the greenhouse. Cuttings from older trees are difficult to root (Arnup et al. 1988).

Growth and Development

White spruce trees 30 m in height and 60 cm to 90 cm in diameter are not uncommon throughout the range (Neinstaedt and Zasada 1990). In the absence of fire and disease, white spruce may reach ages of 250 to 350 years (Nienstaedt 1957), but mature white spruce stands in the boreal forest more commonly range in age from 75 to 125 years (Arnup et al. 1988).

White spruce is considered a slow-starting species. Seedlings often take several years after planting to assume a rapid or reasonable rate of height growth. This period of minimal height growth, known as check, can persist for 2 to 15 years. It results from the tree's inability to exploit the rooting zone rather than from physical damage (Sutton 1968). In later stages of stand development, however, white spruce will often outperform black spruce and balsam fir. In mixedwood stands, white spruce is semitolerant of shade and moisture stress. It may remain in the understory in a suppressed state until the hardwood overstory component becomes decadent (Arnup et al. 1988), after which white spruce exhibits dominance in the stand. This generally occurs at stand ages between 80 and 100 years (Zasada and Argyle 1983).

White spruce is a deeper-rooted species than black spruce. However, it is characteristically described as a "shallow-rooted" or "plate-rooted" species with many wide-spreading lateral roots. Rooting is generally restricted to the top 30 cm of the soil profile, but deep taproots and sinker roots are common. Root form and rooting depth are highly variable, depending on the soil texture, moisture regime, and soil fertility (Arnup et al. 1988). Due to the shallow-rooting nature of the species, windthrow may cause severe mortality, especially in mature and overmature stands.

White spruce is adapted to establishment after major disturbance and often colonizes newly exposed fluvial silts; it is also capable of invading established stands that are in the process of breaking up (Arnup et al. 1988). However, it does not appear to proceed toward a single-species climax type. In its older phases of growth, it grows in mixed associations, often of fire origin, with balsam fir, trembling aspen, balsam poplar, and white birch. These mixedwood stands vary in age, species composition, and structure (Arnup et al. 1988). Overmature mixedwood stands are characterized by a few widely spaced individual white spruce emerging over a dense understory of balsam fir and hardwoods. In the absence of fire, this association tends to form a self-perpetuating all-aged stand that prevents the reproduction of other species (Day and Harvey 1981).

Competition

White spruce is semitolerant of shade and can reproduce and grow in partial shade if moisture is adequate. Up to 5 years of age, good growth occurs in as little as 45% of full sunlight (Logan 1969). However, after the age of 10 years, full sunlight is required for optimum growth (Bell 1991). Table 1 compares the shade tolerance of the white spruce with that of its common associates.

Relative Light Requirements for White Spruce as Compared to Other Boreal Mixedwood Species

Species	Light Requirement Rating * (1-least, 5=greatest)
White birch	5.0
Jack pine	5.0
Trembling aspen	4.2
Black spruce	3.5
Balsam poplar	3.5
White spruce	2.3
Balsam fir	2.0

**(Adopted from Bakuzis and Hansen 1959)*

White spruce will persist in spruce-aspen stands and still respond to release by removal of the aspen overstory. Best response occurs for trees that have their crowns in direct contact with or immediately below those of aspen. For best results, white spruce should be released while young and vigorous, generally between 20 and 40 years of age. Trees older, than 75 years of age respond poorly to release from trembling aspen (Bell 1991). Where advance growth is well established and of sufficient size, satisfactory new stands will usually develop when the mature overstory is removed (Arnup et al. 1988).

Because of their slow initial height growth, white spruce seedlings are unable to compete with dense growths of perennials, bracken ferns, or shrubs, or with a dense understory of hardwood trees. However, a sparse overstory that reduces light intensity but increases humidity and soil moisture is beneficial to seedlings (Arnup et al. 1988). Light to moderate ground covers of herbs and graminoids also help to protect. young seedlings from exposure and frost in open plantations (Stiell 1976).

Young white spruce are affected by grass competition, particularly from sod on compacted soils. Seedlings are either shaded out by the rapidly growing grasses or smothered during the winter by dead grass that is being compressed by snow (Arlidge 1967). This can be a problem on rich clay soils (Arnup et al. 1988).

Damaging Agents

The principal insect pest in natural white spruce stands is the spruce budworm *(Choristoneura fumiferana)*. Stands with a significant component of balsam fir are most susceptible. In mature stands, serious outbreaks occur after several years of early summer drought (Arnup et al. 1988). Mortality exceeding 60% has been reported after a few years of heavy infestation.

Other insect pests that affect white spruce include the yellow-headed spruce sawfly *(Pikonena alaskensis)*, which attacks mainly young plantations and mature open-grown trees, but is not a problem in closed stands; the green-headed spruce sawfly *(Pikonema dimmockii)* and the balsam fir sawfly *(Neodiprion abietis)*, both of which cause damage similar to that caused by the yellow-headed spruce sawfly; the white pine weevil *(Pissodes strobe)*, which attacks and kills the leaders; the black army cutworm *(Actebia fennica)* and the spruce climbing cutworm *(Syngrapha alias)*, both of which can cause severe mortality in plantations, and june-bug *(Phyllophagus* spp.) larvae, which feed on the roots and can cause mortality and growth losses in nurseries and plantations (Arnup et al. 1988).

The spruce budworm, the spruce seedworm *(Cydia strobilella)*, the spruce cone maggot *(Strobilomyia neanthracina)*, and cone borers cause significant losses in seed and cone yields, particularly When crops are light.

Root rots, primarily the shoestring root rot *(Armillaria ostoyae)*, causes significant damage in young plantations. Dry or nutrient-poor soils increase the likelihood of infection. Mature trees, however, are relatively free from root and butt rots (Arnup et al. 1988).

Seedlings are commonly damaged by or suffer mortality from frost heaving, flooding, summer heating, sun scorching, and physical damage from ice loading and deep snow (Sutton 1969).

Wildlife Considerations

Few animals utilize white spruce. Moose *(Alces alces)* and deer *(Odocoileus virginianus)* rarely browse on white spruce. Mature stands of white spruce are used for late-winter cover by moose (Timmermann and McNicol 1998).

Red squirrels *(Tamiasciurus hudsonicus)* occasionally eat the new growth on white spruce, particularly during years of cone failure. Seeds are eaten by birds, squirrels, chipmunks, moles, and mice.

Snowshoe hares *(Lepus americanus)* will browse white spruce seedlings extensively when their populations are at a peak (Nienstaedt 1957). Practically all seedlings will be browsed by hares. After repeated browsing, seedlings as tall as 0.9 rn may be killed (Rowe 1955).

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boreal mixedwood notes

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Autecology of Black Spruce (*Picea mariana*)

by Bruce Miller [1]

> *The boreal mixedwood forest is defined in terms of sites that support the growth of five defining tree species. Black spruce is one of the defining species.*

Physical Appearance

Black spruce averages 15 m in height at maturity but can reach as high as 26 m (Bell 1991). It develops a straight trunk with little taper, and has a narrow, conical, and often compact crown. It has drooping branches with upturned ends, and the crown often develops a characteristic club-like shape. The outer bark is thin and scaly, and is dark brown to greyish-brown; thinner bark is deep, dark olive green (Hosie 1969).

As Figure 1 shows, the stiff, blunt leaves are broad, needle-shaped, and generally less than 2 cm long; they are distinctly four-sided in cross-section. They are dark bluish-green in colour, often with a powdery whitish coating (Bell 1991), and they lack lustre (Hosie 1969). The needles are arranged around the branchlet, which is covered with dense, short hairs and has persistent, raised, woody leaf bases (Hosie 1969).

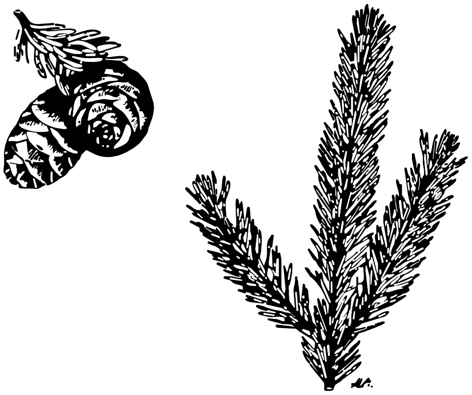

Figure 1. Typical black spruce twig with cone. *(Adapted from Bell 1991)*

Trees are monoecious, with male and female flowers occurring on different branches of the same tree, at the end of the previous year's growth. Male flowers are tiny, conelike, deciduous, and short-lived. Female flowers, however, are ovate, persistent, erect red cones with numerous spirally arranged scales.

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Small, winged seeds are enclosed by the woody scales of the mature female cones which are generally 1.5 cm to 3.0 cm in length, semi-serotinous, and egg-shaped to roundish; the scales are toothed to frayed along the margins. Cones remain on the branches for many years and periodically open in late winter to release seeds.

Habitat

Black spruce is one of the abundant conifers in northern North America (Viereck and Johnston 1990). Its commercial range extends throughout most of the Boreal and the Great Lakes-St. Lawrence Forest Regions in Ontario (Rowe 1972). However, its botanical range stretches considerably beyond its commercial range, (Arnup et al. 1988).

The frost-free season, within the natural range of the species, varies from 60 days in remote northern locations to 140 days in the southeastern part of the range (Viereck and Johnston 1990). Within its commercial range in Ontario, the frost-free season varies from 80 to 150 days. Mean annual precipitation ranges from 635 mm to 991 mm (Arnup et al. 1988).

Black spruce grows on an extremely wide range of sites, from dry sands and gravels to nutrient-deficient, sphagnum-dominated organic soils and from well-drained, fine-textured mineral soils to well-decomposed organic soils that are rich in shrubs and herbs (Arnup et al. 1988). Black spruce can be found on virtually any combination of soil texture, soil depth, and moisture regime.

Figure 2 shows a Vegetation Type Ordination that indicates the frequency of occurrence of black spruce, by moisture gradient and nutrient status, for the Northwestern Ontario Forest Ecosystem Classification (NWO FEC). Figure 3 shows a Site Type Ordination that indicates the frequency of occurrence of black spruce, by moisture gradient and nutrient status, for the Northeastern Ontario FEC (NE-FEC).

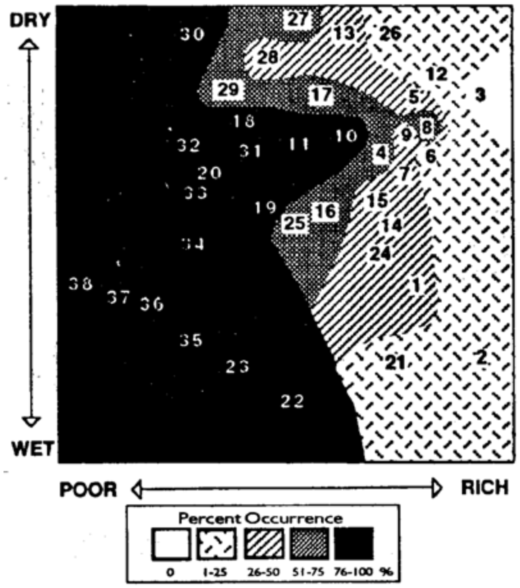

Figure 2. Frequency of occurrence of black spruce by NWO FEC Vegetation Type. (Numbers correspond to Vegetation Types.) *(Adapted from Bell 1991)*

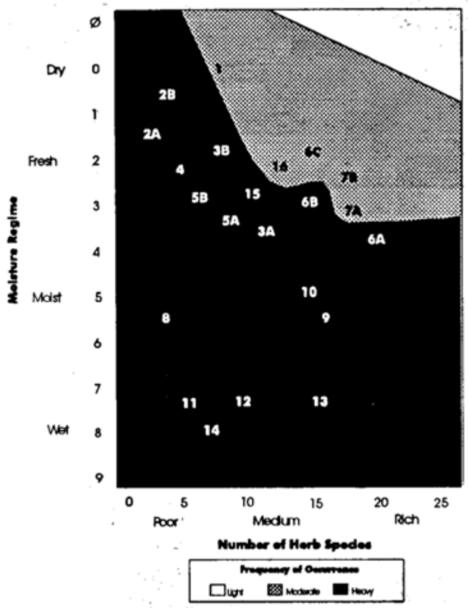

Figure 3. Frequency of occurrence of black spruce by NE-FEC Site Type. (Numbers correspond to Site Types.) *(Adapted from Arnup et al. forthcoming)*

Black spruce is tolerant of low fertility and high acidity. Availability of nitrogen has been correlated to the growth of black spruce, particularly on organic soils. Feathermosses such as *Pleurozium* are important for nitrogen cycling in black spruce stands (Arnup et al. 1988) because they accumulate and mineralize nitrogen.

The species is tolerant of a wide range of soil moisture conditions, as evidenced by its broad range of distribution across dry to wet soil conditions. Better stands occur where slopes are gentle and moisture is abundant (Heinselman 1957). Growth declines on dry mineral soils, and on organic soils where the water table is close to the soil surface (Arnup et al. 1988). Prolonged submergence of roots by flooding for more than 48 days may kill seedlings and mature trees. Short durations of floods are usually tolerated (Sims et al. 1990).

Phenology

Overwintered vegetative buds begin to swell during mid-April to late May, with bud break and leaf flushing occurring in late May to early June (after the risk of late frost has passed). Reproductive buds flush approximately one week earlier. April growth begins in mid-June and continues until early August, with radial growth beginning about 2 weeks earlier and ending in late August (Arnup et al. 1988). The timing of bud break, flushing, leader development, bud set, and hardening of new growth varies with local climate conditions (Bell 1991).

Female flower primordia are usually initiated the year preceding the season of seed production. This process begins in mid-May and extends to late June, depending on local environmental factors such as site and microclimate (Arnup et al. 1988). Male flowers appear in late July or early August and are most prolific during years with warm, dry springs and summers. Black spruce cones persist on the tree after they ripen.

Reproduction

Black spruce produces persistent, semi-serotinous cones that turn purple as they ripen in late August to mid-September; later, they turn brown and finally grey. Cones first appear at between 10 and 20 years, and most stands over 25 years of age bear cones regularly. However, the optimum age for cone production is between 50 and 150 years. Good cone crops occur at intervals of 1 to 4 years, with heavy crops occurring every 2 to 6 years (Heinselman 1957).

Although the cones begin to open in late September to early November, most of the annual seedfall occurs from early spring to mid-summer of the following year. Because of the semi-serotinous nature of the cones, some seedfall occurs each year, regardless of the size of the cone crop (Haavisto 1978). Healthy cones contain 30 to 45 viable seeds, which are generally dispersed within the first 4 years. Seed viability decreases significantly in the fifth year. Seeds remain viable after fire when released from the cones. On the ground, seeds are typically viable for 10 to 16 months (Fraser 1976).

Unsaturated, moist seedbeds are required for black spruce seeds to germinate. Under ideal conditions, germination begins 10 days after seed deposition and is completed within 3 weeks (Bell 1991). Mineral soils provide a suitable seedbed for the germination of black spruce as long as moisture is not limiting. However, silts or fine loamy soils can be susceptible to frost heaving, and silts and clays are susceptible to desiccation when exposed (Arnup et al. 1988). Sphagnum mosses, particularly those with a compact surface, make a good seedbed, but sometimes these mosses can outgrow the young seedlings. Feathermosses, however, often die and dry out when exposed following harvesting; therefore, they make a poor seedbed (Arnup et al. 1988).

Black spruce reproduces vegetatively through layering of the lower branches, especially on wet organic soils. However, layering also occurs on mineral soils and may account for as much as 50% of the reproduction on mineral soils in boreal areas. Layering occurs when the lower branches come in contact with and are covered by accumulating moss or litter. Once the branches are covered, roots are formed from dormant buds near the terminal bud scars of the branches (Sims et al. 1990). Layering is often the main method of natural regeneration in wet sphagnum bogs and on very dry, shallow upland sites where conditions are adverse for seedling establishment (Arnup et al. 1988).

Growth and Development

Black spruce is a relatively long-lived, slow-growing tree species. Under normal conditions, it ranges in height from 12 m to 24 m and attains an average diameter of about 20 cm. The maximum age for black spruce is 250 years. However, black spruce usually succumbs to various agents long before reaching this maximum age (LeBarron 1948).

The average height of black spruce seedlings in year 1 is about 2.5 cm; in year 2, they average 5 cm to 13 cm; during year 3, they reach 20 cm to 38 cm (Arnup et al. 1988). In general, better early height growth is achieved on organic layers or burned duff on mineral soils.

Black spruce is a shallow-rooted species that develops an extensive, strong fibrous lateral root system. Heavy clay soils tend to restrict root depth, while in loamy or sandy soils, rooting depth tends to be greater. On upland mineral soils, many of the fine roots tend to be located along the interface between the organic humus (LFH) layer and the mineral soil (A Horizon), where much of the nutrition, particularly nitrogen, is supplied (Arnup et al. 1988). This shallow rooting habit renders individual trees prone to windthrow.

With the exception of white spruce, black spruce grows more slowly than its associates - trembling aspen *(Populus tremuloides)*, tamarack *(Larix laricina)*, and jack pine *(Pinus banksiana)* - on similar soils. It experiences free and indeterminate growth in the first several years of its life cycle, with elongation and radial growth continuing as long as environmental variables are favourable. This free growth diminishes and ceases between 5 and 10 years of age (Logan and Pollard 1975); thereafter, annual growth is controlled by preformed, overwintered buds (Sims et al. 1990).

The life cycle of a natural black spruce stand consists of four developmental phases (Heinselman 1981): an initial *establishment phase*, of very slow growth, which lasts roughly 10 years; a *canopy development phase*, between 10 and 50 years, of continuing overstory development accompanied by the expansion of a feathermoss ground cover; *a maturation phase*, between 50 and 120 years, during which overstory growth slows and black spruce and balsam fir seedlings become abundant in the understory; and a *senescence phase*, between 120 and 200 years, which is marked by death of the first-generation trees. The length of each phase depends on site productivity, stand health, stand density, local climate and other factors (Heinselman 1981).

Black spruce does not show a tendency to progress toward a single-species climax type. Successional trends in upland stands are generally recognized to be very different from those on peatlands. On upland sites, black spruce generally becomes established by acting as a primary colonist after fire or other catastrophic destruction such as windthrow, ice storms, or insect and fungal attack. In the absence of catastrophe, black spruce stands tend to develop into secondary balsam fir or spruce-fir associations (Arnup et al. 1988).

Competition

Black spruce is considered a shade-intolerant species; it grows best in full sunlight but is capable of surviving for long periods at low light intensifies. Seedlings may survive when exposed to as little as 10% of full sunlight, but growth will be significantly reduced under such conditions (Heinselman 1957). In well-stocked even-aged stands with low light intensities, advance regeneration is usually lacking under the main canopy. However, these stands commonly develop an understory of saplings once the stands begins to open up due to advanced age (Arnup et al. 1988). Table 1 compares the shade tolerance of black spruce with that of its common associates.

Table 1. Relative light requirements for black spruce as compared to other boreal mixedwood species

Species	Light Requirement Rating* (1=least, 5=greatest)
White birch	5.0
Jack pine	5.0
Trembling aspen	4.2
Black spruce	3.5
Balsam poplar	3.5
White spruce	2.3
Balsam fir	2.0

(Adapted from Bakuzis and Hansen 1959)

Speckled alder (*Alnus rugosa)* is considered a serious competitor on better-drained organic sites and on some poorly drained mineral soils. Black spruce is able to survive for long periods of time under alder, and eventually overtop it, but growth is significantly diminished and understocking results. Heavy leaf-falls from speckled alder can also smother black spruce seedlings (LeBarron 1948). A speckled alder canopy affects height growth for black spruce layers less than it does that for black spruce seedlings.

On some sites, a light covering of aspen suckers and shrubs will protect black spruce from late-spring or early-summer frosts. However, trembling aspen will usually outgrow black spruce unless the site is very unfavourable for aspen (Heinselman 1957).

On sites with heavy grass competition, snow and ice can compress the grass litter, crushing black spruce seedlings. Bluejoint grass *(Agropyron repens)* is especially problematic, but sedges may also result in poor stocking of natural-origin black spruce (Arnup et al. 1988).

Severely suppressed black spruce does not respond quickly to release. Complete removal of an aspen or alder overstory frequently results in an invasion by grasses or sedges, especially on fine-textured mineral soils. Sun scald of the advance regeneration may result from sudden opening of a stand, either from windthrow or forest harvesting (Miller 1936).

Damaging Agents

Black spruce is relatively free of insect pests and diseases (Arnup et al. 1988). The principal insect pest that has a significant effect on black spruce is the spruce budworm *(Choristoneura fumiferana).* Spruce budworm can defoliate black spruce when it is growing among heavily infested white spruce and balsam fir.

White pine weevil *(Pissodes strobi),* yellow-headed spruce sawfly *(Pikonema alaskensis),* european spruce sawfly *(Gilpinia hercyniae),* black army cutworms *(Actebia fennica),* and sawyer beetles *(Monochamus* spp.) also affect black spruce (Arnup et al. 1988). However, the amount of damage caused by these species is relatively minimal (Sims et al. 1990).

Except for root rots and decays, black spruce is relatively disease-free (Arnup et al. 1988). Cone and needle rusts occur frequently; however, damage is generally light. The major root rot fungi include tomentosus root rot *(Inonotus tomentosus)* and shoestring root rot *(Armillaria ostoyae).* Heart rot *(Phellinus pini)* occurs occasionally (Sims et al. 1990).

Eastern dwarf mistletoe *(Arceuthobium pusillum)* occurs primarily in the northwest, and sporadically elsewhere in Ontario. It is the only mistletoe species that occurs on black spruce. Although trees of any age can be deformed or killed by the mistletoe, mortality is generally highest among seedlings and saplings (Sims et al. 1990).

Wildlife Considerations

Black spruce is not the preferred food species for most animals. However, snowshoe hare *(Lepus americanus)* sometimes feeds on seedlings and saplings, and can cause significant damage in plantations.

Moose *(Alces alces)* occasionally browse the leaders of black spruce; however, it is not a preferred browse species. Black spruce stands provide late-winter cover for moose (Timmermann and McNicol 1988).

Spruce grouse *(Canachites canadensis)* utilize black Spruce cover types extensively for food and cover (Bell 1991). In addition, black spruce stands provide summer habitat for other bird species, such as ruby- crowned kinglet *(Regulus calendula)* and magnolia warbler *(Dendroica magnolia*) (Bell 1991).

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boreal mixedwood notes

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boreal mixedwood notes
1995 • NUMBER 10

Autecology of Balsam Fir *(Abies balsamea)*

by Bruce Miller [1]

> *The boreal mixedwood forest is defined in terms of sites that support the growth of five defining tree species. Balsam fir is one of the defining species.*

Physical Appearance

Balsam fir is a small-to medium-sized conifer tree that averages less than 15 m in height at maturity. It is characterized by a dense, symmetrical, spirelike crown. The branches are usually distinctly whorled, whereas finer branchlets are opposite, arranged in flat sprays (Sims et al, 1990), and minutely hairy (Bell 1991). Dead branches persist below the live crown for many years (Hosie 1969). On young trees, the bark is smooth, greyish, and has raised resin blisters; with age, the bark becomes broken into irregular brownish scales (Hosie 1969).

As shown in Figure 1, the leaves are needlelike, 2 cm to 3 cm long, flattened, with a blunt or minutely notched tip and two white bands beneath; they are un-stalked and are arranged on the branch spirally, but twisted at the base to appear in two rows, giving a flattened appearance (Bell 1991). Leaves are shiny and dark green (Hosie 1969).

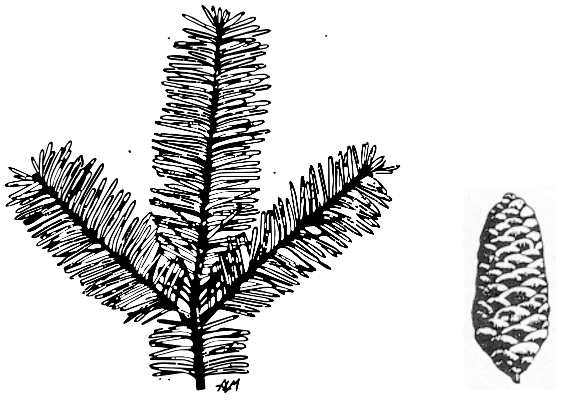

Figure 1. Typical balsam fir twig and cone.
(Adapted from Bell 1991)

Trees are monoecious, with male and female flowers occurring on the same tree. Female flowers, which appear toward the end of May, are upright, fleshy cones 5 cm to 10 cm long, with broadly rounded cone scales. Male flowers are tiny, conelike, deciduous, and short-lived; they hang from the bases of the previous year's needles.

ECOSYSTEMS

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The fruit of balsam fir are winged seeds enclosed by the woody scales of the mature female cones. The scales and the seeds fall away from the central stalk, which persists on the branch (Bell 1991).

Habitat

Balsam fir occurs throughout Ontario, except in the Hudson Bay Lowlands. It grows in cold, moist climates associated with the Boreal Forest Region of Ontario (Rowe 1972). It flushes relatively early in the growing season. As a result, seedlings are moderately susceptible to frost, while saplings and mature trees tend to be frost-resistant.

Balsam fir occurs on a wide range of soils, including deep, fresh fine sands, coarse loams, silts, and clays; and deep, moist to wet sands, coarse loams, and clays. It occurs less frequently on shallow soils, but when it does so, it occurs primarily on coarse loamy parent materials. Soils are primarily derived from morainal and lacustrine materials, with minor occurrences on glaciofluvial outwash deposits. Balsam fir is found most commonly on level terrain or upper mid-slope positions and only occasionally on lower or toe slope positions (Sims et al. 1990).

Figure 2 shows a Vegetation Type Ordination that indicates the frequency of occurrence of balsam fir, by moisture gradient and nutrient status, for the Northwestern Ontario Forest Ecosystem Classification (NWO FEC). Figure 3 shows a Site Type Ordination that indicates the frequency of occurrence of balsam fir, by moisture gradient and nutrient status, for the Northeastern Ontario FEC (NE-FEC).

Although balsam fir grows on soils with a wide range of acidities, its optimum growth occurs on soils with a pH between 4.0 and 6.0 (Bakuzis and Hansen 1965). It is occasionally found on organic

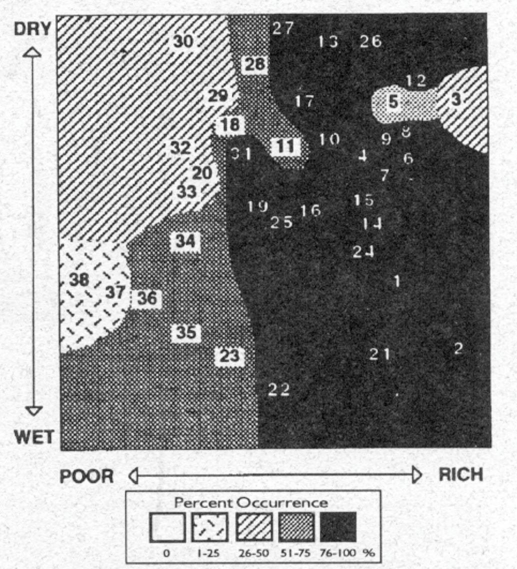

Figure 2. Frequency of occurrence of balsam fir by NWO FEC Vegetation Type. (Numbers correspond to Vegetation Types.) *(Adapted from Bell 1991)*

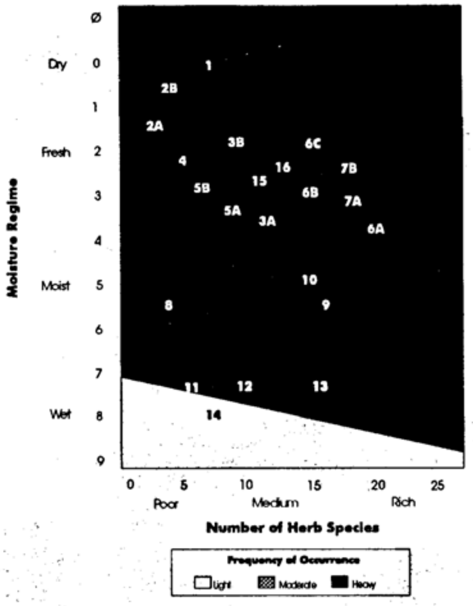

Figure 3. Frequency of occurrence of balsam fir by NE-FEC Site Type. (Numbers correspond to Site Types.) *(Adapted from Arnup et la. forthcoming)*

soils, as well as on gravelly sands; however, growth on such soils is slow, and trees typically have poor form (Sims et al. 1990).

Balsam fir is intolerant of prolonged flooding (flooding that lasts more than a few weeks) but is tolerant of short-duration flooding. Flooding for more than six weeks has been known to kill mature trees (Sims et al. 1990).

Phenology

Initiation of the bud primordia occurs in late July and continues until late August in the year before seed release. Female flower buds begin to swell in early April and burst between late April and mid-May, approximately 10 days before vegetative bud burst (Bell 1991), in the year of seed production. Male buds burst somewhat before female buds, in early May. Pollen is shed between mid-May and early June. Cones ripen in mid- to late August (Smith 1984) and begin to disintegrate in September, releasing the majority of the seed in October (Bell l991). Vegetative buds usually flush after the flowering buds (Frank 1990).

Rapid shoot elongation occurs, generally between mid-June and mid-July; it usually ceases in late July or early August, but may continue until late August in some locations (Bell 1991). Radial growth begins toward the end of May and terminates in late August or early September (Bakuzis and Hansen 1965). Needle flush occurs simultaneously with pollen release, usually between mid-May and early June (Bakuzis and Hansen 1965).

Reproduction

Male and female flowers occur on the same tree. Male flowers cluster along the undersides of 1-year-old twigs and generally occur lower in the crown than do female flowers. Female flowers are generally found in the uppermost part of the crown, where they occur singly or in clusters on the upper side of the previous year's growth, although male and female flowers can occasionally be found on the same branchlet.

Seed production may begin on trees as young as 15 years, although regular production does not usually start until trees are between 20 years and 30 years old (Frank 1990). Good seed crops occur every 2 to 4 years, with light crops occurring in the intervening years. Dominant and codominant trees produce the best cone crops; open-grown trees produce better crops than those that are crowded (Fowells 1965). In a good seed year, balsam fir stands may produce in excess of 6 kg/ha of seed. In general, balsam fir produces more seed than do competing conifer species growing in the same stands. Seed yield for balsam fir ranges from 66,100 to 208,300 seed/kg, averaging 130,000 seed/kg.

The optimum age for seed production is 40 years, at which time seed viability also peaks; thereafter, seed viability declines (Sims et al. 1990). Seed viability is approximately 30% in natural stands. Increased viability can be achieved through stratification of the seed. Although natural seeding in the fall allows the seed to stratify over the winter, few viable seeds remain in the forest floor longer than 1 year (Sims et al. 1990).

Pollination and seed dissemination occur via wind. Although seeds can be disseminated to a maximum distance of 160 m, most seeds fall directly below the tree (Sims et al. 1990).

Provided moisture is sufficient, almost any type of seedbed - mineral soil, rotten logs, or shallow duff - is satisfactory for the germination of balsam fir (Frank 1990). Under natural conditions, germination and early establishment are best on medium-textured mineral soils, beneath a forest cover with a crown closure of 80% or less (Fowells 1965; Sims et al. 1990; Bell 1991). Lower germination occurs on coarse sands, which are usually too dry; fine-textured mineral soils, which are susceptible to frost heaving; and thick litter layers in excess of 8 cm (Benzie et al. 1983). However, balsam fir has greater germination success on undisturbed duff than does white spruce, black spruce, or jack pine.

The most common mode of reproduction for balsam fir is through seed. Although balsam fir can reproduce by layering when lower branches make contact with moist soil, this is not an important means of regeneration for the species unless the tree has adopted a prostrate growth habit in response to adverse climatic conditions. Such conditions are found in northern climates and in mountainous regions (Frank 1990).

Growth and Development

Although individual trees can achieve ages of 200 years, balsam fir is a relatively short-lived species. At maturity, balsam fir averages 40 cm in dbh and 15 m in height, although it can reach more than 75 cm in dbh and 27 m in height (Frank 1990). Balsam fir may achieve - heights of 15 m in 50 years (Sims et al. 1990).

Balsam fir seedlings are reported to be inherently slow-growing during the first 5 to 6 years, even under full sunlight, reaching 30 cm in height in 5 years and 90 cm in 9 years. Once established, seedlings can achieve height growths of up to 30 cm per year under optimum conditions. However, less vigorous trees may average only 1 cm per year. Under full sunlight, balsam fir grows at a rate comparable to that of white spruce on the same site (Sims et al. 1990).

Early height growth of balsam fir is controlled by the amount of overhead shade present in the stand. Seedlings can grow in dense shade (as little as 10% of full sunlight) for the first 6 to 8 years and will survive for many years. However, after this period, best growth occurs in approximately 45% or more of full sunlight (Logan 1969; Benzie et al. 1983).

High ground-surface temperatures, drought, and frost heaving are the principal causes of seedling mortality. Drought-caused mortality is generally high in late July and early August. In the fall and winter, mortality may result from smothering by hardwood leaf litter, physical damage by ice and/or snow, or extreme cold.

The roots of balsam fir are shallow and wide-spreading. It develops strong, slightly branched lateral roots in the surface humus. Seedlings frequently develop a heavy central root that appears to be a taproot, but then splits at the bottom of the humus layer into a number of laterals that remain in the organic layer. Due to the shallow rooting habit of balsam fir, trees are vulnerable to windthrow when exposed. Root grafting is common among, balsam fir (Johnston 1986).

Competition

Balsam fir is considered a subclimax to climax species and is extremely shade-tolerant (Sims et al. 1990). It is able to regenerate and survive at low light levels for long periods of time - up to 50 years or more (Bakuzis and Hansen 1965) - and trees are capable of responding to release late into life. The rate of recovery is related to the duration of suppression (Hatcher 1960), but can also be influenced by climatic and soil-fertility factors. Table 1 compares balsam fir's shade tolerance with that of its common associates.

Balsam fir tends to develop into uneven-aged stands, partly due to its shade tolerance and its quick response to release. Suppressed trees in the understory will grow quickly when openings and clearings created by blowdown, disease, or other disturbances occur in mature stands. Following harvesting, it has been observed that younger, smaller advance-growth seedlings responded faster and better to release than did older, taller seedlings (Sims et al. 1990).

Table 1. Relative light requirements for balsam fir as compared to other boreal mixedwood species

Species	Light Requirement Rating* (1=least, 5=greatest)
White birch	5.0
Jack pine	5.0
Trembling aspen	4.2
Black spruce	3.5
Balsam poplar	3.5
White spruce	2.3
Balsam fir	2.0

*(Adapted *from Bakuzis and Hansen 1959)*

When released, balsam fir attains a growth rate comparable to that of nonsuppressed seedlings. Under an aspen-birch overstory, balsam fir will achieve fair growth. However, it will reach pulpwood size considerably faster if released. Release is best conducted when balsam fir is still young and vigorous. Complete release, however, is not desirable, as the potential for spruce budworm *(Choristoneura fumiferana)* damage increases significantly. A birch overstory can reduce mortality caused by spruce budworm (Johnston 1986).

Competing vegetation can delay balsam fir reproduction for 30 to 50 years. Establishment and early growth rates depend on degree of vegetative competition. Raspberry (*Rubus* spp.), which invades quickly after harvesting, can suppress small balsam fir advance growth and retard regeneration by overtopping the seedlings.

Among the shrub species, mountain maple *(Acer spicatum)* is balsam fir's most serious competitor. Mountain maple has site requirements similar to those of balsam fir, produces prolific regeneration, and is somewhat more shade-tolerant than balsam fir (Bakuzis and Hansen 1965).

Beaked hazel *(Corylus cornuta)* also presents serious competitive problems for balsam fir, because of the former's tremendous regeneration potential (Bakuzis and Hansen 1965). However, balsam fir seedlings are usually capable of becoming established in dense thickets of beaked hazel (Hsiung 1951).

Damaging Agents

The most serious insect pest affecting balsam fir is the spruce budworm, which utilizes balsam fir as its preferred food source. Spruce budworm causes heavy damage in stands that contain mature balsam fir or have a high proportion of balsam fir in relation to other species. Spruce budworm outbreaks result in defoliation of the trees, which in turn causes reduced tree growth, widespread tree mortality, loss of wood production, and significant forest-fire hazard (MacLean 1984).

Balsam fir is host to a variety of decaying fungi, which can cause widespread damage and mortality. These include shoestring root rot *(Armillaria ostoyae)*, brown cubical butt rots *(Polyporus balsameus, Meulius himantiodes, and Coniophora puteana)*, and trunk rot fungus *(Haematostereum sanguinolentum).*

Although shoestring root rot is not responsible for extensive mortality, reduced growth and increased windthrow in drought- or nutrient-stressed trees are substantial. The brown cubical butt rots infect individual trees through root or basal wounds that result in weakened trees, reduced wood quality, and increased likelihood of windthrow. Trunk rot fungus causes decay in the upper portions of the living trees, resulting in significant cull (Sims et al. 1990).

In addition, stem cankers produced by *Nectria* spp. can cause dieback of the tree. However, *Nectria* cankers are not considered economically important (Sims et al. 1990).

Wildlife Considerations

Balsam fir plays an important role in wildlife habitat for many animal species, including large herbivores, small mammals, carnivores, and birds.

Although balsam fir is not the preferred browse species for moose *(Alces alces),* it is utilized when other preferred browse species are in limited supply (Zach et al. 1982). Browsing generally occurs in winter and spring, with little use of the species in summer or autumn (Timmermann and McNicol 1988). Balsam fir stands also provide important late-winter cover, as well as shade during warm summer months.

Deer *(Odocoileus virginianus),* like moose, utilize balsam fir stands for cover in the late winter and during warm summer months. Well-stocked stands provide protection from predators (Johnston 1986).

Small mammals such as red-backed vole *(Clethrionomys gapperi),* meadow vole *(Microtos pennsylvanicus),* and deer mouse *(Permyscus maniculatus)* are common inhabitants of balsam fir stands. Carnivores, including fisher *(Martes pennanti),* marten *(M. americana),* Canada lynx *(Lynx canadensis),* and timber wolf *(Canis lupus),* also frequent balsam fir stands (Benzie et al. 1983).

During summer months, various songbird species utilize balsam fir stands. Species such as Cape May warbler *(Dendroica tigrina),* the blackpoll warbler *(D. triata),* and the black-burnian warbler *(D. fusca)* particularly prefer balsam fir stands for habitat. In addition, spruce grouse *(Dendragapus canadensis)* and ruffed grouse *(Bonasa umbellus)* utilize balsam fir

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boreal mixedwood notes

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Autecology of Jack Pine (Pinus banksiana)

by Bruce Miller [1]

> *The boreal mixedwood forest is defined in terms of sites that support the growth of five defining tree species. Depending on the site conditions, several tree species may grow in association with the five defining species. Jack pine is one of the associated species.*

Physical Appearance

Jack pine averages, 19 m in height at maturity, but can reach as tall as 30 m. It has a sparse, variable crown with spreading or ascending branches and a tapered trunk (Hosie 1969). The branches are yellowish-green, becoming dark greyish-brown as the tree ages. The bark is thin; it is reddish-brown to grey on young stems and becomes dark brown and flaky or platy as the tree ages.

As Figure 1 shows, jack pine leaves are needlelike, straight or slightly curved, somewhat twisted, stiff, sharp-pointed, light yellowish-green, distinctly spreading apart, in clusters of two, with toothed edges, and have a persistent basal sheath. They are generally 2.0 cm to 3.5 cm in length (Hosie 1969).

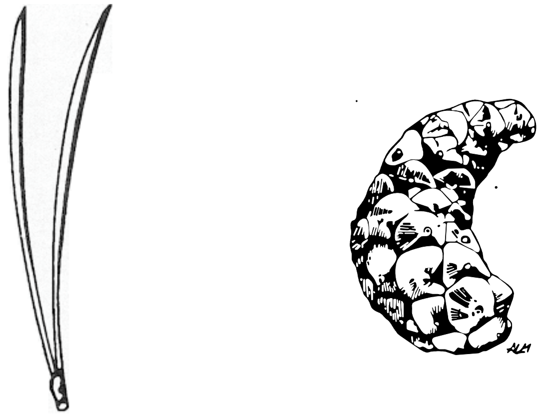

Figure 1. Typical jack pine needles and cone. (Adapted from Bell 1991)

Jack pine is dioecious, with male and female flowers occurring on separate branches of the same tree. Male flowers - which are tiny, conelike, deciduous, and short-lived - occur at the base of the current year's growth. Female flowers are erect cones, 2.5 cm to 7.5 cm long, with numerous spirally arranged scales. Flowering occurs in mid- to late May (Bell 1991).

ECOSYSTEMS

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Winged seeds are encased by the woody scales of the mature female cone. Cones are egg-shaped to conical and can be straight or curved. They usually remain closed, and may persist on the tree for as long as 25 years (Sims et al. 1990).

Habitat

Jack pine, the most widely distributed Canadian pine, occurs primarily in the Boreal Forest Region (Rowe 1972), but also forms a considerable part of the Boreal/Great Lakes-St. Lawrence Transition Forest (Galloway 1986). It is typically found in extensive, even-aged stands that have developed after fire.

The natural range of jack pine is characterized by long, frigid winters and short, warm to cool summers with low rainfall (Galloway 1986). Average January temperatures vary from –29°C to -4°C, while July temperatures range from 13°C to 22°C. The number of frost-free days across the natural range of jack pine varies from 50 to 173 days, but is usually from 80 to 120 days (Rudolph and Laidly 1990).

In Ontario, jack pine grows on a variety of soil types, ranging in texture from coarse sands to clays, with moisture regimes varying from dry to very moist (Galloway 1986). It grows most commonly on level to gently rolling sand plains, usually of glacial, outwash, fluvial, or lacustrine origin. It occurs less commonly on eskers, sand dunes, rock outcrops, and bald rock ridges (Rudolph and Laidly 1990).

Although jack pine is occasionally found on shallow, coarse loamy soils, it occurs most frequently on deep, dry to fresh, coarse sandy soils and on deep, fresh, fine sandy to coarse loamy soils. It is seldom found on fine-textured silts and clay soils, although it usually obtains its best growth on such soils. When growing on such sites, it is rarely the dominant species (Bell 1991) and is usually overtaken by other species.

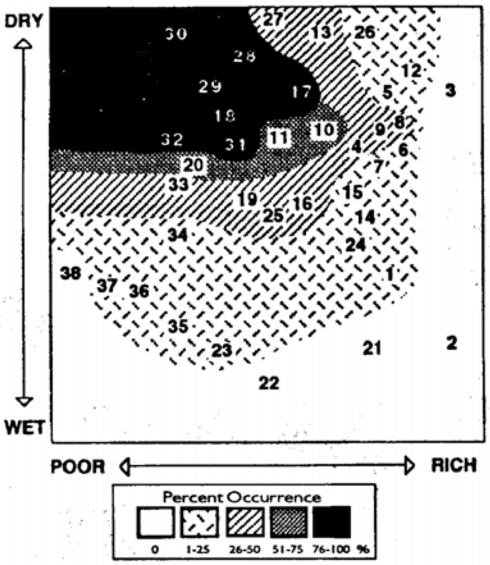

Figure 2. Frequency of occurrence of jack pine by NWO FEC Vegetation Type. (Numbers correspond to Vegetation Types.) *(Adapted from Bell 1991)*

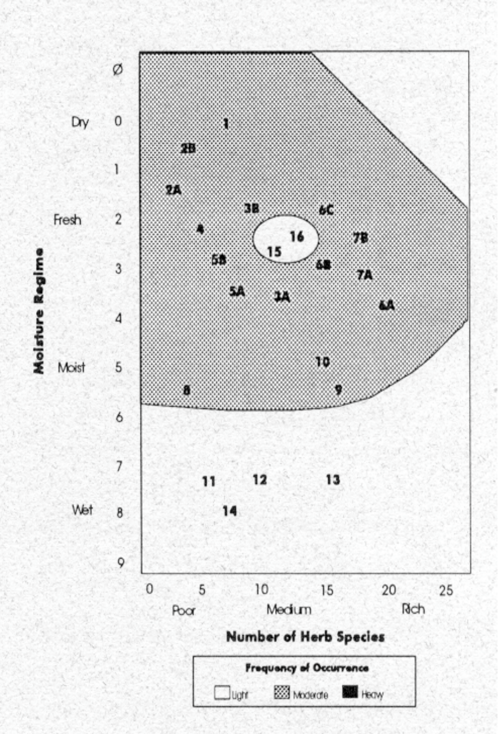

Figure 3. Frequency of occurrence of jack pine by NE-FEC Site Type. (Numbers correspond to Site Types.) *(Adapted from Arnup et al. forthcoming)*

Figure 2 shows a Vegetation Type Ordination that indicates the frequency of occurrence of jack pine, by moisture gradient and nutrient status, for the Northwestern Ontario Forest Ecosystem Classification (NWO FEC). Figure 3 shows a Site Type Ordination that indicates the frequency of occurrence of jack pine, by moisture gradient and nutrient status, for the Northeastern Ontario FEC (NE-FEC).

Jack pine has relatively low nutrient requirements (Rudolph and Laidly 1990) and is usually found on sites that have a low nutrient status (Bell 1991). The optimum soil pH for good growth of jack pine is between 4.5 and 7.0; however, the species will grow satisfactorily on calcareous soils (pH 8.2) if a normal mycorrhizal association is present (Rudolph and Laidly 1990).

Soils associated with stands dominated by jack pine most commonly have moisture regimes that are moderately fresh, fresh, moderately dry, or dry. However, this species can maintain itself on very dry sandy or gravelly soils where other species can barely survive. Its best growth occurs on well-drained loamy or very fine sands where the mid-summer water table is 1.2 m to 1.8 m below the soil surface (Rudolph and Laidly 1990). Occasionally, it can be found on poorly drained soils (Cayford et al. 1967).

Jack pine withstands a broad range of precipitation regimes. It is highly tolerant of, and well adapted to, summer droughts that exceed 30 days. It has a moderate tolerance to flooding, enduring short periods of inundation. However, it is intolerant of prolonged flooding (Sims et al. 1990).

Phenology

Jack pine usually flowers in mid-May to early June, with female primordia laid down well in advance (several weeks) before the primordia of the male flowers. Conelets are visible by late May, and pollination occurs shortly thereafter. By late July or early August, the conelets cease to grow for the season. Cones ripen during the second growing season, in late August or early September. The cones are serotinous, usually remaining closed and persistent on the tree for many years (Fowells 1965).

The vegetative buds of jack pine usually flush in mid-May to early June; however, the date of flushing fluctuates depending on local climate conditions. By the end of June, 80% of the annual height growth is completed. However, if moisture conditions are favourable during late summer, a second period of shoot elongation occurs, through production of late shoots, lammas growth, or prolepsis (Rudolph and Laidly 1990).

Temperatures in excess of 4.4°C in the upper 10 cm of the soil surface are required for root development in jack pine (Sims et al. 1990). Root growth usually begins within a week of the onset of shoot growth and ceases when the temperature drops below 7°C for 6 successive days or more (Bell 1991).

Reproduction

Jack pine produces serotinous cones that usually do not open until subjected to temperatures of at least 50°C. However, cones open and disperse seed readily when placed within 30 cm of exposed ground surfaces that receive full sunlight. Seedfall usually begins in the fall of the year after flowering and continues intermittently for several years (Fowells 1965). Seed dissemination is primarily via wind (Bell 1991).

Cone production occurs as early as 3 years of age. However, seed production normally begins at age 5 to 10 for open-grown trees and at age 10 to 25 for those in closed stands. Seed production is best when trees are between 40 and 50 years of age (Fowells 1965). Good seed crops occur every 3 to 4 years, with light crops in intervening years. Total crop failures are rare (Rudolph 1983).

Well-developed, vigorous trees can produce between 1000 and 1200 cones per year, although 300 to 500 are more common (Fowells 1965). Approximately 50 seeds per cone are produced, and average seed yield is approximately 286,000 seeds/kg (Eyre and LeBarron 1944). Viability is generally high, ranging from 24% to 95%. Viability is highest during the first 6 years, but some seeds remain viable for up to 25 years (Cayford and McRae 1983).

Jack pine seeds have no requirement for stratification and generally germinate within 15 to 60 days after dispersal when air temperatures are above 17°C and moisture is adequate. However, some seeds may germinate for up to 3 years after dispersal (Rudolph 1983). Germination is best on exposed, moist mineral soils. Mixed humus and mineral soil seedbeds are also suitable for the germination of jack pine (Sims et al. 1990), but increased competition may result (Benzie 1977).

Seedlings are vulnerable to heat, drought, freezing temperatures, frost heaving, insect and rodent damage, and being smothered beneath fallen leaf or grass litter (Sims et al. 1990).

In nature, jack pine does not reproduce vegetatively (Rudolph and Laidly 1990).

Growth and Development

Early stand growth is rapid in the initial 40 years after a major disturbance, such as fire, windthrow, or harvesting (Sims et al. 1990). Soon thereafter, jack pine shows a marked reduction in its height growth and diameter growth, depending on site and vegetation density (Galloway 1986). On dry, shallow, coarse-textured soils, height growth may slow at an earlier age. On deeper, fresh soils, height growth continues to 60 or 80 years (Sims et al. 1990). Jack pine has been known to grow to a height of 32 m and a diameter of 71 cm, although heights of up to 24 m and diameters of 46 cm are more common (Bell 1991).

Under good growing conditions, jack pine seedlings can reach breast height in 4 to 6 years and a height of 6 m in about 18 years. Merchantable trees (13 cm dbh) are generally produced in about 30 years. Jack pine may reach ages of 175 years, but usually matures in 60 to 80 years on most sites.

In the first year, jack pine develops a taproot that extends 15 cm to 30 cm deep. By year 7, the taproot can reach 60 cm in depth, with lateral roots stretching up to 4.9 m in length (Rudolph and Laidly 1990). Jack pine has a deeper rooting system than does black spruce *(Picea Mariana)*, white spruce *(Picea glauca)*, or balsam fir *(Abies balsamea)* growing on the same soils. As a result, jack pine generally, suffers little windthrow before maturity - except on shallow soils, where losses may be heavy. Wind breakage is more common (Rudolph and Laidly 1990).

Jack pine is an early to mid-successional species on burns and other exposed sandy sites. In the absence of fire or other catastrophes, jack pine tends to give way to more-tolerant hardwood species - black spruce, white spruce, white birch *(Betula papyrifera)*, and balsam fir - except on the poorest, driest sites, where it may persist as a climax species (Rudolph and Laidly 1990). On better sites, it may succeed into a spruce-fir climax (Rudolph and Laidly 1990).

Competition

Jack pine is a shade-intolerant species that requires full sunlight at all stages of its life cycle to achieve optimum growth. However, the best initial germination and early survival occur on microsites with partial shading (Sims et al. 1990), which guards against excessive heat and drought, and thus reduces seedling losses. After establishment, jack pine requires full sunlight for survival. Table 1 compares the shade tolerance of jack pine with that of its common associates.

Table 1. Relative light requirements for jack pine as compared to other boreal mixedwood species

Species	Light Requirement Rating* (1=least, 5=greatest)
White birch	5.0
Jack pine	5.0
Trembling aspen	4.2
Black spruce	3.5
Balsam poplar	3.5
White spruce	2.3
Balsam fir	2.0

(Adapted from Bakuzis and Hansen 1959)

years after germination, it can usually outgrow most of its competitors, except on better sites. Jack pine does not develop well under a cover of aspen, white birch, or other broad-leaved species. A light, uniform cover of aspen or brush, transmitting 80% of full sunlight, can be maintained for 1 to 2 years after planting and may reduce mortality during drought years. However, jack pine should be released from practically all overhead competition within a year after planting (Benzie 1977). It will most likely require release from poplar, birch, and cherry competition on loamy tills and from graminoid, raspberry, and poplar competition on silty or clayey sites (Galloway 1986).

Competition from grasses has resulted in severe mortality of jack pine. Sedge *(Carex* spp.*)* competition can be severe enough to prevent natural establishment of jack pine on poor sandy sites. Beaked hazel *(Corylus cornuta)* is a major competitor of young jack pine; it may alter the chemical composition of the litter layer and may significantly affect nutrient cycling.

Damaging Agents

More than 58 species of insects affect jack pine. Approximately half of these cause significant damage or reduce-tree growth. Five of these insect pests - jack pine budworm, Swaine jack pine sawfly, sawyer beetles, eastern pine shoot borer, and white pine weevil - are considered serious management problems (Sims et al. 1990). Jack pine budworm *(Choristoneura pinus),* which causes deformed or multiple leaders, dieback, and mortality, primarily affects open stands that are more than 40 years old and have heavy mate cone crops. Swaine jack pine sawfly *(Neodiprion swainer)* causes severe defoliation of the trees and may result in a reduction in height growth in trees that are growing on poor, shallow soil sites. Sawyer beetles *(Monochamus* spp.) feed on the bark and twigs of mature and immature jack pine that are growing in proximity to harvested areas or fire-damaged trees. Eastern pine shoot borer *(Eucosma gloriola)* damages the leaders' seedlings, primarily in plantations. White pine weevil *(Pissodes strobi)* attacks and kills the young leaders of jack pine trees, affecting tree form, primarily in poorly stocked plantations.

Jack pine is relatively resistant to damage by most diseases (Sims et al. 1990). The principal diseases that affect jack pine are Scleroderris *canker (Ascocalyx abietina),* which can cause mortality in trees with poor vigour; sweetfern blister rust *(Cronartium comptoniae),* which results in large, resinous cankers that can kill seedlings through girdling; western gall rust

(Endocronartium harknessii), which causes round stem galls and may cause mortality of seedlings; shoestring root rot *(Armillaria ostoyae)*, which frequently results in mortality of jack pine seedlings and juvenile stands; needle cast *(Davisomycella ampla)*, which kills all foliage except the current year's needles, resulting in reduced growth; and heart rot *(Phellinus pini)*, which is common in jack pine stands.

Snowshoe hares *(Lepus americanus)* are responsible for nipping and girdling of young seedlings that have been planted under aspen canopies or close to weeds or brush tall enough to furnish cover for the hares. Damage can occur in almost 100% of the trees in a plantation (Little 1984).

Wildlife Considerations

Jack pine stands provide food and shelter to many game species, including deer *(Odocoileus virginianus)* and snowshoe hare (Rudolph 1983). Jack pine seedlings are highly preferred winter food for snowshoe hares, which prefer jack pine over red pine *(Pinus resinosa)*, black spruce, or white spruce (Bergeron and Tardif 1988).

Deer browse on jack pine, but jack pine is generally considered to be moderately preferred by deer (Benzie 1977). Young stands can be heavily browsed by deer if the populations of the latter are high (Bell 1991). Dense stands offer some wind protection and winter shelter, but other conifer species provide better shelter. Older stands of jack pine tend to be more open than those of other conifer species and to have abundant understory plants and herbaceous vegetation, providing a better food supply for deer (Benzie 1977).

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1995 • NUMBER 12

An Introduction to the Autecology Notes

by David H. Weingartner[1] and G. Blake MacDonald[2]

> ***The Boreal Mixedwood Forest is defined as forest sites that could support stands of the five predominant tree species***

The Boreal Mixedwood Forest is defined as forest sites that could support stands of the five predominant tree species (MacDonald and Weingartner 1995). The predominant tree species may not all occur simultaneously in a stand, but over extended periods all are present in a number of successional stages. The boreal mixedwood landscape consists of dominant-tree canopies and layers of lesser vegetation; many species of wildlife also play important roles in the functioning of these communities. Proper management of the Boreal Mixedwood Forest, as an ecosystem, requires that the interactions in space and time among all flora and fauna, and their influence on the shared environment, be considered when promoting the appropriate species combinations through management prescriptions.

The notes in this section provide summaries of the autecology for some of the more important species found in the Boreal Mixedwood Forest. Inclusion of autecology notes for all species found within the Boreal Mixedwood Forest is not the intent of the Boreal Mixedwood Notes series and is beyond the resources available. However, the *Boreal Mixedwood Management Philosophy* (Weingartner and MacDonald 1995) specifies that each person working in this Forest has a responsibility to increase his or her knowledge and understanding of this ecosystem by actively seeking out relevant information, and then to apply this knowledge for the long-term maintenance of the ecosystem and its biodiversity.

Practitioners require a thorough understanding of autecology to ensure that the appropriate species mixtures are promoted at each successional stage. It is suggested that the autecology notes be studied and viewed in the broader contexts of synecology and ecosystem dynamics. The autecological facts presented define the species' niches and are the basic building blocks considered in ecosystem management. A synecological

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perspective is necessary to properly fulfil our mandate of resource management. The challenge for those involved in managing the Boreal Mixedwood Forest is to merge this information with their experience and understanding to achieve the desired ecosystem goals.

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General Autecology of Shrub Species in Boreal Mixedwood Stands

by Robert W. Arnup[1] and Kimberly C. Taylor[2]

> *The diversity and abundance of the shrub understory in mixedwood ecosites corresponds to a gradient of soil texture and moisture regime...*

Introduction

Shrub layers are important components of the species and structural diversity in boreal mixedwood stands. Relative to other boreal forest types, boreal mixedwood stands contain a high diversity of shrub species. They often contain several layers of shrubs of different heights. In more open stands, shrubs may be arranged as a more-or-less continuous canopy, or in clumps and patches associated with canopy gaps. Abundant shrub understory affects stand development by competing with crop trees for nutrients, water, and light. For example, the shading they provide lowers soil temperature, which will reduce the sprouting capacity of aspen. Shrubs in boreal mixedwood stands provide summer escape cover and year-round food sources for many wildlife species.

This note provides information about the environmental requirements, ecosite relationships, life cycles, reproductive strategies, phenology, vegetative reproductive capacity, reproduction by seed, and responses to disturbance for shrub species commonly found in Ontario's boreal mixedwood stands. Considerations for developing vegetation management strategies and silvicultural applications are presented.

Environmental Requirements of Shrub Species

All plant species have specific requirements for moisture, nutrients, light, and heat. These basic needs determine the relative abundance of a shrub species on a particular set of site conditions and its competitiveness on different sites. Soil conditions determine the moisture and nutrients available to the plant community occupying a particular site. The light regime in a stand depends on the species composition of the canopy and the density of trees in both the overstory and understory, while the amount of heat is affected by the seasonal light regime and by site factors such as slope and aspect. For example, mountain maple (*Acer spicatum*) prefers relatively high moisture but is very shade tolerant and survives under dense overstory. Beaked hazel (*Corylus cornuta* ssp. *cornuta*) has lower nutrient and moisture requirements than mountain maple but prefers more light. Bush honeysuckle (*Diervilla lonicera*) tolerates low moisture and nutrients, and therefore tends to be more abundant on coarser soils, but also has

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relatively high light requirements and is more abundant in stands with an open canopy. Serviceberries (*Amelanchier* spp.) have relatively high requirements for nutrients, light, and heat and tend to be most abundant on the richest, warmest sites (Bakusis and Hansen 1959).

Ecosite relationships

An adequate supply of mineral nutrients is essential for plant growth. Fine loamy and clayey soils provide more nutrients than sandy or coarse loamy soils due to their higher cation exchange capacity and the mineralogy of the fine parent materials. Soil moisture, more than any other factor, controls plant species distribution in the landscape. Fine soils tend to be moister due to their lower infiltration rates, higher water storage capacities, and the generally lower topographic positions in which they are deposited.

The diversity and abundance of the shrub understory in mixedwood ecosites corresponds to a gradient of soil texture and moisture regime. Table 1 illustrates differences in the relative abundance and composition of the shrub communities in boreal mixedwoods in northeastern and northwestern Ontario. Generally, from left to right in the table, relative soil nutrient and moisture levels increase and shrub diversity increase accordingly. Some shrub species are common to most soil types (e.g., mountain maple and beaked hazel), others are associated with the nutrient-poor and drier coarse loamy soils (e.g., blueberries – *Vaccinium* spp. and bush honeysuckle), and some are associated with the richer and generally moister fine loamy and clayey soils (e.g., speckled alder – *Alnus incana* ssp. *rugosa* and red-osier dogwood – *Cornus stolonifera*).

Light and heat

Intensity, duration, and quality of light determine plant vigour and regulate various aspects of species life history. In low light conditions, most plants become suppressed and produce few seeds. Conversely, in full light, species grow more rapidly, produce fuller foliage and more abundant seed crops (Haeussler and Coates 1986).

Shrubs are classed as tall or low but the relative development of shrub layers depends on the amount of light transmitted through higher canopy layers.

Table 1. *Presence and relative abundance (1=lowest, 16=highest) of shrub species on boreal mixedwood ecosites in Ontario (numbers refer to ecosite designations provided in Racey et al. 1996 (northwest) and Taylor et al. 2000 (northeast)).*

	Northwest Ecosites									Northeast Ecosites							
Species	**19**	**21**	**23**	**27**	**28**	**29**	**30**	**32**	**33**	**3**	**6c**	**7c**	**6m**	**7m**	**6f**	**7f**	**10**
Acer spicatum	1	1	1	1	1	1	6	2	2	1	-	1	-	1	-	1	2
Alnus incana ssp. *rugosa*	-	-	-	-	-	-	-	4	4	4	-	-	1	-	1	-	1
Amelanchier spp.	-	-	-	-	-	-	1	-	-	6	5	-	3	6	8	8	16
Cornus stolonifera	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	7
Corylus cornuta ssp. *cornuta*	2	2	2	2	2	2	7	3	3	2	2	2	-	2	-	2	3
Diervilla lonicera	3	3	-	3	3	6	-	1	-	5	1	3	2	3	2	3	5
Ledum groenlandicum	-	-	-	-	-	-	-	6	-	-	-	-	-	-	-	-	9
Lonicera spp.	4	4	-	4	-	7	4	-	-	-	6	4	5	7	7	5	12
Prunus spp.	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	8
Ribes spp.	-	-	-	-	-	5	5	-	8	-	-	-	9	5	4	4	6
Rosa acicularis ssp. *sayi*	-	-	-	-	-	-	-	5	5	-	7	-	7	-	9	11	14
Rubus idaeus ssp. *melanolasius*	-	-	-	-	-	-	3	-	7	-	-	-	4	-	5	7	4
Salix spp.	-	-	-	-	-	-	-	-	-	8	4	-	-	-	-	-	11
Sorbus spp.	5	-	3	-	-	8	-	-	1	7	8	6	8	8	10	10	15
Vaccinium spp.	-	-	-	-	-	-	-	-	-	3	-	5	6	4	3	9	10
Viburnum edule	-	-	-	-	-	4	-	-	6	-	3	-	-	-	6	6	13

Dense, pure aspen canopies transmit more light than pure coniferous canopies, while mixed stands tend to transmit the most light due to the nature of the tree crowns. The amount of light available to the shrub layers changes throughout the life of a stand. High light levels are present until the canopy closes. The lowest light levels occur immediately after canopy closure. In mixedwood stands, light levels gradually increase as the stand matures and the canopy opens, from approximately 30 to 120 years (Lieffers 1995). Canopy openings develop through self-thinning, pathogens, and windthrow. Light levels tend to be higher in older stands, of which many support dense, multi-layered shrub communities.

The light regime in mixedwood stands also changes with the season. The amount of light available to the shrub layers is lowest in summer (often near or below the photosynthetic light compensation point for some species), highest during the deciduous leaf-off period in the spring, and intermediate in the fall (Constabel and Lieffers 1996). This provides opportunities for understory shrubs to use different photosynthetic strategies. Most tall shrubs, such as mountain maple and beaked hazel, are summer green and adapted to low light conditions; their photosynthetic capacity peaks in the summer months. In contrast, low evergreen shrubs, such as blueberries or Labrador tea (*Ledum groenlandicum*), are adapted to low temperatures and take advantage of the extra light available in spring and fall by photosynthesizing in these seasons (Lieffers 1995). The greatest potential for dense communities of understory shrubs exists in open, older stands. The degree of shrub development will affect the establishment and growth of conifers in the understory, which will be very slow until the trees begin to grow through the shrub canopy.

Temperature affects plant growth by altering the rates of photosynthesis and respiration. The amount of heat increases with the light levels in the stand, and varies with the season, the degree of canopy closure, and the stand development stage. At a regional level, total available heat units generally decrease with increasing latitude. This affects the species composition of mixedwood stands. Locally, the warmest sites occur at higher topographic positions and on south-facing slopes. These microclimates have the potential to support the most diverse and abundant shrub communities, which is an important consideration in predicting the likely response of a shrub community to silvicultural activities. Both soil and air temperatures are important. For instance, soil temperature affects the suckering ability of shrubs that use this adaptation.

Reproductive Strategies

Shrubs in boreal mixedwood communities reproduce through root collar sprouting, suckering, and seed dispersal by wind, mammals, and birds. Some of these varying reproductive strategies are adaptations to natural disturbances, such as fire. Many species rely on different forms of reproduction at different times in their life cycle or adapt to existing environmental conditions.

Table 2 summarizes the rooting zone, primary mode of vegetative reproduction, seed dispersal mechanisms, and seed banking ability for selected shrub species that are common in boreal mixedwood stands. For additional information about these species, refer to Bell (1991) and Arnup *et al.* (1995).

Vegetative reproduction and response to disturbance

Phenology refers to the development of a plant through different stages over the course of the growing season; for example, stages of root growth, bud break, flowering, leaf flush and expansion, stem growth, cessation of growth, seed or fruit maturation, leaf senescence, and leaf drop. Changes in the physiological and morphological condition of a shrub species, including moisture content, carbohydrate reserves, and the maturity of reproductive structures, occurs at different stages of development. A plant's phenological condition at the time of disturbance affects its capacity to sprout or sucker and its ability to regenerate from seed or fruit (Haeussler and Coates 1986).

As a plant begins to grow in the spring, its stored carbohydrate reserves are mobilized. By late spring or early summer, during the period of most active growth, these reserves are at their lowest levels. Following maturity, carbohydrate reserves are again accumulated in preparation for the next growing season. Plants that reproduce by sprouting or suckering are most sensitive to disturbance during the period of active growth (late spring and early

Table 2. *Autecological characteristics of selected shrub species common in boreal mixedwood stands.*

Species	Common name	Rooting zone	Primary mode of vegetative reproduction	Seed dispersal	Seed banking?
Acer spicatum	mountain maple	organic	root collar sprouts	wind	
Alnus incana ssp. *rugosa*	speckled alder	mineral/organic	root collar sprouts	wind, water	
Amelanchier spp.	serviceberries	mineral/organic	root collar sprouts	wildlife	yes
Cornus stolonifera	red-osier dogwood	mineral	stolons	wildlife	yes
Corylus cornuta ssp. *cornuta*	beaked hazel	organic	root suckers	wildlife	
Diervilla lonicera	bush honeysuckle	mineral	rhizomes	wildlife	
Ledum groenlandicum	Labrador tea	organic	stolons	wind	
Lonicera spp.	honeysuckles	mineral/organic	lower stem sprouts	wildlife	
Prunus spp.	cherries	mineral	root suckers	wildlife	yes
Ribes spp.	currants	mineral	stolons	wildlife	yes
Rosa acicularis ssp. *sayi*	prickly wild rose	mineral	rhizomes	wildlife	yes
Rubus idaeus ssp. *melanolasius*	wild red raspberry	mineral	rhizomes	wildlife	yes
Salix spp.	willows	organic/mineral	root collar sprouts	wind, water	
Sorbus spp.	mountain ashes	mineral/organic	(root collar sprouts*)	wildlife	yes
Vaccinium spp.	blueberries	mineral/organic	rhizomes	wildlife	
Viburnum spp.	squashberry / highbush cranberry	mineral	root collar sprouts	wildlife	yes

(*) Known to reproduce by sprouting, but main mode of reproduction is seeding.

summer) when carbohydrate levels stored in roots and protected stem tissue are lowest. Plants are least sensitive to disturbance during dormant periods (usually from late summer to early spring, depending on the species), and usually recover quickly from abundant stored carbohydrates and dormant, protected buds. Generally, the capacity of a species to respond to disturbance increases with age but declines as the plant becomes overmature and begins to lose vigour. Vigorous, healthy plants are likely to recover more quickly.

Reproduction by seed and response to disturbance

In the boreal mixedwood forest, seed maturity and dispersal for shrub species generally occurs from mid-summer to early fall, depending on the species. The post-disturbance response of plant species that regenerate by seeding depends on whether seeds are immature or mature, destroyed by the disturbance or stimulated to germinate by the post-disturbance environment, or dispersed onto freshly created, receptive seedbeds (Haeussler 1991). All of this is affected by the time of year at which the disturbance occurs.

Large amounts of banked seed often exist in the litter layers of boreal mixedwood stands. The response of seed banking species to disturbance depends on the relative number and depth at which stored seeds are buried in the upper soil horizons. As litter depth (which is partly a function of stand age) increases, the amount of banked seed also generally increases.

Response to Disturbance

Succession is the gradual replacement of one vegetation community by another over time. In the disturbance-driven boreal forest, possible post-disturbance successional pathways vary depending on site conditions, pre-disturbance species composition and condition, and disturbance intensity and frequency (Alexander and Euler 1981). Post-disturbance species abundance is related to differences in site disturbance history, initial distribution of species, species resistance to disturbances, and spatial variations in disturbance intensity (Halpern 1989).

Vegetation that is established on the site prior to disturbance often has reproductive structures that will help it survive. For example, while severe fires tend to destroy vegetative reproductive structures and banked seeds by removing litter layers and transmitting heat into the mineral soil, moderate fires tend to favour the reestablishment of woody shrubs that reproduce by suckering, sprouting, or seed banking. Post-fire environmental conditions (increased temperature, light, and nutrients) are ideal for the rapid reestablishment and growth of many shrub species.

Fire tends to affect relative abundance and dominance of understory shrubs, rather than change species composition. However, repeated fires can deplete on-site sources of regeneration (e.g., buried seeds, rhizomes, and sprouts) as well as the carbohydrate reserves of surviving plants over time. Shafi and Yarranton (1973) described three stages in early post-fire succession in Ontario's Clay Belt forests:

- 0-1 year post-fire: initial heterogeneity, characterized by the rapid growth of invading species (mainly herbaceous seed plants like fireweed, grasses and sedges, pioneer mosses, and liverworts)
- 1-4 years post-fire: early phase during which understory herbs and shrubs that were previously present on the site reestablish and increase in abundance
- 4-11 years post-fire: late phase during which the tree canopy begins to close, the understory species become shaded and decrease in abundance, and the community stabilizes.

Shrubs in mixedwood stands respond vigorously to increases in light and temperature. As mixedwood stands age, openings in the canopy caused by tree mortality will rapidly fill with shrubs and hardwood tree species, mainly through suckering of existing understory. This often has the effect of reducing or excluding conifer regeneration, unless the openings are large. These shrub/hardwood patches result in increased vertical and horizontal structure in mixedwood stands and enhance wildlife habitat and biodiversity characteristics. Although the effects of large-scale windthrow events on shrub communities in boreal mixedwood stands are not well documented, it is likely that shrub populations will also be enhanced by such occurrences.

The relative resistance of boreal shrub species to forest floor disturbances, such as forest fires or harvesting or site preparation operations, depends on the nature of their root systems. Species that develop shallow root systems in surface organic layers, with fibrous roots, stolons, or rhizomes above or in close proximity to the mineral soil surface are sensitive to disturbance and some will not subsequently regenerate. Resistant species develop root systems in both the surface organic layers and upper mineral soil, usually with fibrous roots and rhizomes growing within 5 cm of the mineral soil surface. Highly resistant species develop deep root systems, with rhizomes growing more than 5 cm below the mineral soil surface or with deep tap roots capable of regenerating by means of adventitious buds (McLean 1969).

Chambers (1993) synthesized existing information and expert opinion on the vegetation communities that developed following various natural and artificial disturbances to predict successional pathways by site types in northeastern Ontario. This first approximation is useful for developing successional models and vegetation management prescriptions.

Management Applications

Silvicultural options for managing shrub communities on boreal mixedwood sites can provide conditions suitable for a range of forest products and enhance species that provide wildlife habitat. In boreal mixedwood stands, competing shrub species generally need to be controlled to promote successful conifer establishment. The purpose of vegetation management is not to eliminate all competing plants but rather to temporarily direct more of the site's resources towards fulfilling the management objective. Vegetation control can be achieved using ground or aerial herbicide applications. Or partial-cutting strategies can be applied that maintain sufficient overstory canopy cover to help reduce the abundance of understory shrubs. In mixedwood stands with more conifer cover, prescribed burns under moderate to high indices may help to achieve duff removal objectives, control sprouting and suckering shrubs, and remove part of the seed bank to encourage conifer establishment.

Clearcutting generally provides the conditions suitable for the reestablishment of sprouting and suckering shrub species and hardwoods, although severe soil disturbance can reduce regeneration capacity. Since suckering is dependant on soil temperature, sites with heavy grass competition and thick duff layers may have fewer suckering species. Prescribed burning under light indices will usually stimulate suckering and germination from the seed bank and can be used to enhance wildlife habitat. Prescribed burns increase browse quality for animals by supplying young, more palatable hardwood sprouts that grow within an animal's reach. Plant species used by wildlife, especially seed-eating birds, regenerate well following prescribed burning (Haeusseler 1991).

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Autecology of Lesser Plants and Fungi in Boreal Mixedwood Stands

by Robert W. Arnup[1] and Kimberly C. Taylor[2]

> *Mixedwoods support high diversity and abundance of herbaceous species relative to other boreal forest types...*

Introduction

The lesser plant layers (herbs, ferns and allies, graminoids (grasses and sedges), mosses, liverworts, lichens, and fungi) are important components of the species and structural diversity of boreal mixedwood stands. They compete with crop trees for nutrients, water, and light during the establishment period, but also are a food source for wildlife species, especially small mammals and forest birds.

Mixedwoods support high diversity and abundance of herbaceous species relative to other boreal forest types, but relatively low abundance of mosses, liverworts and lichens. Boreal mixedwood stands do support a high diversity of fungi, particularly mycorrhizal species, because of the wide variety of microsites and substrates that occur in these stands. Fungi are key decomposers of the litter layer and are important for nutrient cycling. Mycorrhizal fungi develop symbiotic relationships with tree species, enhancing nutrient uptake, and possibly resulting in synergistic interactions between certain tree species.

This note provides some very general information about the environmental requirements, ecosite relationships, phenology, and responses to disturbance of lesser plant and fungi species that are common in Ontario's boreal mixedwoods. Considerations for developing vegetation management strategies and silvicultural applications are presented.

Environmental Requirements of Lesser Plants

All plant species have specific environmental requirements for moisture, nutrients, light, and heat. These basic needs determine the relative abundance of a plant species on a particular site as well as its competitiveness on different sites. Soil conditions determine the moisture and nutrients available to the plant community occupying a particular site. The light regime in a stand depends on the species composition of the canopy and the density of trees in both the overstory and understory. Local temperatures are affected by seasonal light regimes and site factors such as slope and aspect.

Many fern species tolerate low light and temperature but require relatively high moisture and nutrient levels. An exception is bracken fern (*Pteridium aquilinum var. latiusculum)*, which prefers area with full light and warm temperatures, but needs little

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Ontario

moisture and nutrients, thus has an affinity for the coarser and dryer soils and stands with an open canopy.

In boreal mixedwood stands, light transmission varies considerably but exhibits a definite seasonal pattern. Light levels are highest in the spring and fall when the deciduous plants are without leaves. Light transmission to the forest floor tends to be very low in the summer regardless of canopy condition, because mixedwood stands with an open canopy tend to support high shrub populations (Constabel and Lieffers 1996).

Graminoids require high light levels for optimum growth and seed production, and also need relatively high moisture and nutrient levels. Since most boreal mixedwood stands have low light at the forest floor during the summer, the abundance of graminoids in established boreal mixedwood stands is generally low (Constabel and Lieffers 1996). Some grasses, such as Canada blue-joint (*Calamagrostis canadensis*), appear to respond to changes in light intensity with changes in stomatal conductance, a strategy for moisture conservation in open areas that makes the species unable to take advantage of sunflecks in otherwise deep shade (Lieffers 1995). Graminoids respond vigorously to most disturbances and can be a severe competition problem for crop trees during the establishment phase, especially on rich, moist sites.

Herbs in boreal mixedwood stands use a variety of strategies to take advantage of seasonal light conditions. Many herbs are summer green; that is, they grow during the main spring/summer periods and are persistently visible. These herbs tend to be tall to take advantage of as much light as possible, have photosystems that operate at high efficiency in during early to mid-summer, and are more responsive to changes in temperature and light regime, e.g., wild sarsaparilla (*Aralia nudicaulis*). Others lesser plants, such as low, biennial, or evergreen herbs, e.g., goldthread (*Coptis trifolia*), and semi-shrubs, e.g., twinflower (*Linnaea borealis ssp. longiflora*), are able to photosynthesize in the colder temperatures in spring and fall making the most of the higher light levels during these seasons (Landhäusser *et al.* 1997).

Ecosite relationships: herbs, ferns and allies, and graminoids

Differences in the species composition and relative abundance of the herbaceous communities for ecosites in northwestern and northeastern Ontario are illustrated in Table 1 (adapted from Racey *et al.* 1996, Taylor *et al.* 2000).

The diversity and abundance of the herbaceous plants varies based on soil texture and moisture regime. Generally, in Table 1, going from left to right within each region's ecosites, soil nutrient and moisture levels are increasing and herb diversity increases accordingly. Many of the herb species are common to all ecosites, but most species of ferns, fern allies, and graminoids are most abundant on the finer-textured, moist soils, with some exceptions (e.g., bracken fern as described above).

Ecosite relationships: mosses, liverworts, lichens, and fungi

Most moss and liverwort species prefer moist conditions. They reproduce vegetatively by spores, by fragmentation of plants into small parts that grow into new plants, or by specialized reproductive structures called propagula. At certain points in their life cycle they also reproduce sexually. During the sexual reproduction process, male germ cells travel to the female germ cells located in specialized structures on female plants, usually through films of water, which is one reason these species are more abundant on moist sites, although some mosses are adapted to dry conditions. These species, especially feathermosses, generally tolerate low levels of nutrients, light, and heat. They are also associated with the more acid forest floor conditions common in conifer-dominated forests. Although more-or-less continuous carpets of feathermosses do occur in boreal mixedwood stands, these species are generally not abundant in these stands; although diversity can be high, especially in older stands with more structure. Low moss and liverwort abundance in boreal mixedwood stands is likely due to the generally dry, nutrient-rich forest floor conditions. Their establishment may also be inhibited by shading and deciduous litterfall from hardwoods and woody shrubs.

The most common species (occurring in more than 40% of stands) in boreal mixedwoods include

Table 1. *Presence and relative abundance (ranked in each ecosite from 1=highest to 19=lowest) of herbaceous species (herbs, grasses and sedges, ferns and fern allies) on boreal ecosites in Ontario.*

	Northwest Region Ecosites[1]									Northeast Region Ecosites							
Species	**19**	**21**	**23**	**27**	**28**	**29**	**30**	**32**	**33**	**3**	**6c**	**7c**	**6m**	**7m**	**6f**	**7f**	**10**
Actaea spp.	11	-[2]	-	-	11	-	-	-	-	-	-	-	-	-	-	-	-
Anemone quinquefolia var. *quinquefolia*	-	-	-	-	-	6	-	-	-	-	12	13	17	-	17	14	19
Aralia nudicaulis	2	3	3	3	4	3	1	1	1	5	3	3	1	3	2	2	5
Aster macrophyllus	1	1	1	1	1	1	4	6	-	8	2	1	2	1	1	1	1
Clintonia borealis	7	6	6	6	7	8	-	3	4	4	7	6	5	5	6	3	8
Coptis trifolia	-	-	-	-	-	-	-	4	-	-	11	-	14	12	12	11	14
Cornus canadensis	10	9	9	9	10	11	-	8	8	3	1	7	4	7	3	4	3
Fragaria virginiana ssp. *virginiana*	-	-	-	-	-	2	5	-	-	-	-	-	12	-	13	-	15
Galium triflorum	6	5	5	5	6	7	9	-	13	-	-	14	11	15	16	15	16
Maianthemum canadense	9	8	8	8	9	10	3	7	7	7	4	9	7	9	11	13	13
Mertensia paniculata	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	10
Mitella nuda	3	-	-	-	2	12	10	5	6	-	-	-	9	-	8	5	7
Petasites frigidus var. *palmatus*	-	-	-	-	-	-	-	-	11	-	9	-	13	14	9	10	11
Pteridium aquilinum var. *latiusculum*	-	-	-	-	-	-	-	-	-	1	-	2	-	2	-	-	-
Streptopus roseus	4	2	2	2	3	4	6	2	3	-	13	10	16	11	18	12	18
Trientalis borealis ssp. *borealis*	8	7	7	7	8	9	-	-	5	10	10	12	18	13	15	16	17
Viola renifolia	5	4	4	4	5	5	-	-	-	-	8	11	10	10	10	9	12
Equisetum spp.	-	-	-	-	-	-	2	-	12	-	-	-	15	-	14	-	9
Ferns	-	-	-	-	-	-	8	-	10	9	-	8	8	4	7	6	4
Lycopodium spp.	-	-	-	-	-	-	-	-	-	6	5	4	6	6	4	8	6
Graminoids	-	-	-	-	-	-	7	-	9	5	6	5	3	8	5	7	2

1. For ecosite descriptions see Racey *et al.* 1996 and Taylor *et al.* 2000

2. "–" indicates species does not occur in that ecosite

feathermoss - *Pleurozium schreberi*), plume moss (*Ptilium crista-castrensis*), stair-step moss (*Hylocomium splendens*), and shaggy moss (*Rhytidiadelphus triquetrus*). Aside from feathermoss, broom moss (*Dicranum* spp.) and *Bracythecium* spp. are also commonly found in boreal mixedwood stands. On moist sites, generally those with fine-textured soils, tree moss (*Climacium dendroides*), hair-cap moss (*Polytrichum* spp.), fern moss (*Thuidium* spp.), peat mosses (*Sphagnum* spp.), and *Drepanocladus* spp. also occur (Racey *et al.* 1996, Taylor *et al.* 2000). Many moss species have very specific microsite requirements. For example, pylaisiella moss (*Pylaisiella polyantha*), a small arboreal species, grows almost exclusively on the bark of aspen and balsam poplar trees.

Lichens are less common in boreal mixedwoods than in conifer-dominated forests. Lichens are well adapted to low levels of moisture, nutrients, and heat but they require high light levels (Bakusis and Hansen 1959), which is one of the reasons they are not abundant in boreal mixedwood stands. When they do occur, it is generally on sites with coarser soils and in stands with more open canopies. Reindeer lichen (*Cladina rangiferina*) is the most common species recorded in boreal mixedwood ecosites in Ontario (Racey *et al.* 1996, Taylor *et al.* 2000).

Crites and Dale (1998) studied the diversity and abundance of bryophytes, lichens, and fungi in relation to woody substrate and successional stages in aspen mixedwood boreal forests. They found that species composition differed between three age classes: young (23-26 years), mature (51-63 years), and old (122-146 years) based on the type and amount of coarse woody debris. In young stands, there was a pulse of coarse woody debris input from pre-existing logs and snags following disturbance. In mature stands, this input of downed woody debris from the disturbance continued to decay and was increased by fallen snags, plus some new material from self-thinning processes. In old stands, there was a more continuous input of coarse woody debris in all size classes as the stand began to break up, greatly increasing the structural diversity. Thus, older stands had the greatest species diversity, mainly the result of more species of liverworts and fungi. Young and mature stands had similar richness, but all three age classes supported different species composition. Non-vascular plant species' affinities are related to differences between coarse woody debris in early, middle, and late stages of decay; the decay type influences nutrient and organic matter dynamics, and moisture status, providing a range of microsites to which different species are adapted. The older stands contain coarse woody debris with more diversity in size classes and more volume in advanced decay stages. Time also influences abundance, with some species that were present in all age classes increasing in older stands. Non-vascular species populations are also affected by the vascular plant community, which influences microclimate and nutrient regime at the microsite level.

Mixedwoods support a variety of fungal species. Of particular interest to forest managers are mycorrhizal species and crop tree pathogens. Trees and other forest plants often grow in association with ectomycorrhizal fungi. These fungi differ physiologically in their ability to transport water, break down organic nutrients, absorb mineral nutrients, and provide protection from pathogens at different stages in the host plant's life cycle. They also provide forest plants the ability to establish and grow on a wider range of soil microenvironments. Different plant species may be connected by several common types of mycorrhizal fungi, resulting in synergistic benefits, such as nutrient exchange, for both species (Peterson *et al.* 1997).

Due to the diversity of tree species, shrubs, and lesser plants in boreal mixedwood stands, a variety of forest pathogens are present. Miller (1996) reviewed common pathogens of aspen, while Whitney (1978, 1988) reviewed conifer pathogens. Whitney (1978) showed that pathogen infection rates are related to both soil texture and moisture regime, with some agents preferring coarse soil and others fine soil; infection rates generally increase with higher moisture levels. However, trees on better-drained sites with lower moisture levels have more extensive root rot than those of the same age on less well drained sites (Whitney 1976, 1978).

Response to Disturbance

Forest herbs can be classed into three broad groups based on their survival strategies and responses to disturbance (Lieffers 1995):

- Understory avoiders – are poorly adapted to grow underneath the shaded forest canopy; grow best in open conditions present immediately after disturbance. These species often invade sites following disturbance by means of water or windborne seed, for example fireweed (*Epilobium angustifolium*), or seeds dispersed by mammals and birds. Other early successional species, such as Bicknell's geranium (*Geranium bicknellii*), use seed-banking strategies
- Understory obligates – are adapted to the cooler, lower light, and higher humidity conditions under the forest canopy. These include most of the common forest herbs associated with mixedwoods, such as wild sarsaparilla and naked mitrewort (*Mitella nuda*)
- Understory tolerators – grow best in the open conditions of early succession but are able to persist, usually at low levels, in the understory of mixedwood stands

Some species combine these strategies to maximize their chance of survival. Many graminoids, such as Canada blue-joint, have seed banking strategies, are able to survive at low levels in the understory, and will invade canopy gaps in mixedwood stands.

Many forest herbs have deep taproots, corms or bulbs, rhizomes or stolons that store food and permit rapid response to favourable changes in environmental conditions. These structures are often located deep in the organic matter or mineral soil, which is likely an adaptation to survive fire. Examples include wild sarsaparilla and bluebead lily (*Clintonia borealis*).

Halpern (1989) studied vegetation responses in boreal mixedwood stands up to 20 years old following fire and logging disturbances. He found that the timing of establishment, and the timing and magnitude of peak species abundance was related to mode of reproduction, phenology, and temporal and spatial variations in disturbance. Post-disturbance species abundance was related to differences in the disturbance history of sites, the initial distribution of species, their resistance to disturbances, and spatial variation in disturbance intensity.

Early successional species included invading species (e.g., fugitive annuals), which reproduce by large quantities of windborne seed and are poor competitors, usually disappearing one or two years after the disturbance. Other successional species included persistent annuals and perennial windborne species (e.g., fireweed), which invade and expand rapidly for up to three or four years post-disturbance, then decline, and biennials and short-lived perennials, e.g., Compositae (asters and goldenrods), which expand more slowly and persist longer. Residual species began to reestablish and expand after the first year following disturbance. These included existing species temporarily released by disturbance (subordinate herbs), and pre-existing dominant herbs, which increase following disturbance. Some pre-existing herbs experience little or no change in abundance following disturbance.

Management Applications

Silvicultural management of herbs and other lesser plant communities on boreal mixedwood sites can provide conditions suitable for producing a range of forest products and, at the same time, maintain or enhance species that provide wildlife habitat. With the exception of graminoids, herbs rarely provide significant competition for light resources when crop trees are establishing in boreal mixedwood stands. In fact, the partial cover provided by these species is beneficial to white spruce in that it imparts some frost protection. However, lesser plants may compete with crop trees for nutrients and moisture, requiring some degree of vegetation control. This control can be achieved using ground or aerial herbicide applications. Some (e.g., Lieffers 1995) advocate the use of partial cutting strategies as a biocontrol strategy for competing species but sufficient overstory canopy cover and shading must be maintained to minimize the abundance of understory plants.

The post-disturbance survival of plant species with underground vegetative reproductive organs, such as rootstocks or rhizomes, is affected by the nature and degree of the disturbance, the depth of the rooting material in the soil, and the ability of the belowground organs to survive physical damage. Only intense fires that burn into the surface soil layers will kill these species. Mechanical site preparation is less effective than other strategies in controlling these species, but may provide an option in certain circumstances.

Prescribed burning under light indices will usually stimulate germination from the seed bank and thus is considered a silvicultural option that enhances wildlife habitat. Prescribed burn areas often support plant species used by wildlife, especially seed-eating birds (Haeussler 1991).

Examples of natural disturbance emulation techniques to promote non-vascular plant populations include leaving patches and snags, and retaining downed coarse woody debris. Since older stands contain the greatest diversity of non-vascular species, some older mixedwood stands should be maintained on the landscape through time using appropriate harvest scheduling strategies.

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The Nature and Properties of Soils Supporting Boreal Mixedwood Forests

by Gordon J. Kayahara*

> *Most BMW sites occur where moisture conditions are fresh to very moist and nutrient conditions are medium to rich...*

Introduction

Boreal mixedwood (BMW) forests in Ontario occur on sites where the climatic, topographic and edaphic conditions and biological legacy favour the establishment and growth of healthy and productive mixedwood stands, typically dominated by trembling aspen (*Populus tremuloides* Michx.) or white birch (*Betula papyrifera* Marsh.) in early successional stages, black spruce (*Picea mariana* (Mill.) B.S.P.) or white spruce (*Picea glauca* (Moench) Voss) in mid-successional stages, and balsam fir (*Abies balsamea* (L.) Mill.) in late successional stages (MacDonald and Weingartner 1995). Most BMW sites occur where moisture conditions are fresh to very moist and nutrient conditions are medium to rich. Correlated with these moisture and nutrient conditions are soils that are well aerated and relatively warm (MacDonald and Weingartner 1995, Arnup 1998).

This note focuses on describing and characterizing the soils supporting BMW forests and defining the terminology of soil nutrient and moisture regimes. The note adds context and detail to the description of BMW sites provided by MacDonald and Weingartner (1995) and to the relationship of BMW sites to Ontario's Forest Ecosystem Classification (Arnup 1998). The intent is to provide field practitioners with a basic theoretical soils framework within which to fit their field observations. The combination of practical field experience and theoretical knowledge base is intended to help field practitioners get a "better feel" for forest ecosystems.

General Description of BMW Sites

Soil moisture regime (SMR) is the average amount of soil water annually available for evaoptranspiration by vascular plants over several years. It is determined mostly by the soil's water holding capacity and climate. The water holding capacity of a soil depends on soil attributes that affect drainage characteristics (Table 1), and the actual water available for plants (SMR) depends on both the water holding capacity of the soil and climate attributes such as precipitation, hours of sun, temperature, and spring snowpack. In Ontario, soil moisture regime definitions are based on the available water in the soil, while in British Columbia definitions are based on annual water balance (Table 2).

Soil nutrient regime (SNR) is defined as the amount of essential soil nutrients that are available to vascular plants over a period of several years. Five general SNR classes represent the nutritional status of a soil,

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Table 1. *Available soil water storage capacity descriptions and characteristics (adapted from Meidinger and Pojar 1991).*

Available soil water storage capacity	Description	Soil and Slope Properties			
		Depth to impermeable layer	Soil texture	Slope position	Slope gradient
Extremely low	very rapidly drained; water removed extremely rapidly in relation to supply; precipitation is the primary water source	very shallow (<0.5 m)	very coarse (gravelly-sandy), abundant coarse fragments	ridge crests, shedding	very steep
Very low	rapidly drained; water removed rapidly in relation to supply; precipitation is the primary water source	shallow (<1 m)	coarse to moderately coarse (loamy sand-sandy loam), moderate coarse fragments	upper slopes, shedding	steep
Low	rapid to well drained; water removed rapidly in relation to supply; precipitation is the primary water source				moderate
Moderate	well to moderately well drained; water removed slowly in relation to supply; precipitation is the primary water source	moderately deep (1-2 m)	moderate to fine (loam-silty loam), few coarse fragments	middle slopes, shedding= receiving, rolling to level	
High	moderately well to imperfectly drained; water removed slowly enough to keep the soil wet for a significant part of the growing season; precipitation is a water source but some temporary seepage may occur	variable, depending on seepage	variable, depending on seepage	lower slopes, receiving	slight
Seepage	poor to very poorly drained; water removed slowly enough to keep the soil wet for most of the growing season; permanent seepage and mottling present				flat
Water table	very poorly drained; water removed slowly enough to keep the water table at or near the surface for most of the year; gleyed mineral or organic soils; permanent seepage from the surface to 30 cm depth.			depressions, receiving	

ranging from very poor to very rich depending on soil attributes that reflect nutrient storage, turnover, and availability (Table 3) (Jones et al. 1983). However, it is very difficult to capture the nutrient status of 6 macronutrients (N, P, K, Ca, Mg, S) and 12 micronutrients (Bo, Fe, Mn, Cu, Zn, Mo, Cl, Co, V, Na, Si, Ni), as well as pH, along one axis. Research in British Columbia suggests that this axis reflects primarily a nitrogen availability gradient (Klinka et al. 1994, Wang and Klinka 1996, Chen et al. 1998). In general, nitrogen availability limits growth in more forests in more regions than any other nutrient (Fisher and Binkley 2000). Where other nutrients (e.g., P) are limiting or excessive (e.g., ultramafic parent materials), an additional descriptor needs to be added to the SNR categories.

The edatopic grid, shown in MacDonald and Weingartner (1995), is used here as the focal point for understanding the soils of BMW sites (Table 4). The edatopic grid reduces the variety of soil conditions into two broad axes, soil moisture and soil nutrients, nested within a regional climate. Although this grid represents a simplified model of the myriad of interacting factors in a complex web, it does provide an easily understood framework and captures the essence of what silviculturalists need to be able to conceptualize for general site conditions. Details and nuances can then be added to the edatopic grid framework as required. For example, although soil aeration can generally be viewed as correlated with soil moisture (i.e., the wetter the soils, the poorer the aeration), telluric water is an exception. This exception, therefore, needs to be added to the moisture and nutrient gradient for wet moisture regimes. Other sites with unique environmental properties, such as those with

Table 2. Identification and definition of soil moisture regimes used in Ontario (Hills 1952) and British Columbia (Meidinger and Pojar 1991).

Class	Soil Moisture Regime Characteristic Hills (1952) Ontario	Meidinger and Pojar (1991) British Columbia
		Rooting-zone groundwater absent during the growing season • Water deficit occurs (soil-stored reserve water is used up and drought begins if current precipitation is insufficient for plant needs)
excessively dry	Aerated zone with periodic effective capillary water	thus actual evapotranspiration (AET) < potential evapotranspiration (PET) a) Deficit > 5 months
very dry	Aerated zone with periodic effective capillary water	≤
moderately dry	Aerated zone with periodic effective capillary water	b) Deficit > 3 months but ≤5 months
slightly dry	Aerated zone with periodic effective capillary water	c) Deficit > 1.5 months but≤ 3 months
		d) Deficit > 0 months but 1.5 months
fresh	Continuously effective capillary water	• No water deficit occurs thus AET = PET
moist	effective capillary water seasonally saturated	a) Utilization (and recharge) occurs (current need for water exceeds supply and soil-stored water is used)
		b) No utilization (current need for water does not exceed supply; temporary groundwater table > 60 cm deep may be present) **Rooting-zone ground water present during the growing season**≤
very moist	zone of continuous saturation	• No water deficit occurs (water su≤pply exceeds demand) but AET PET
wet		≤ a) Groundwater table > 30 cm but 60 cm deep
very wet		b) Groundwater table > 0 but 30 cm deep

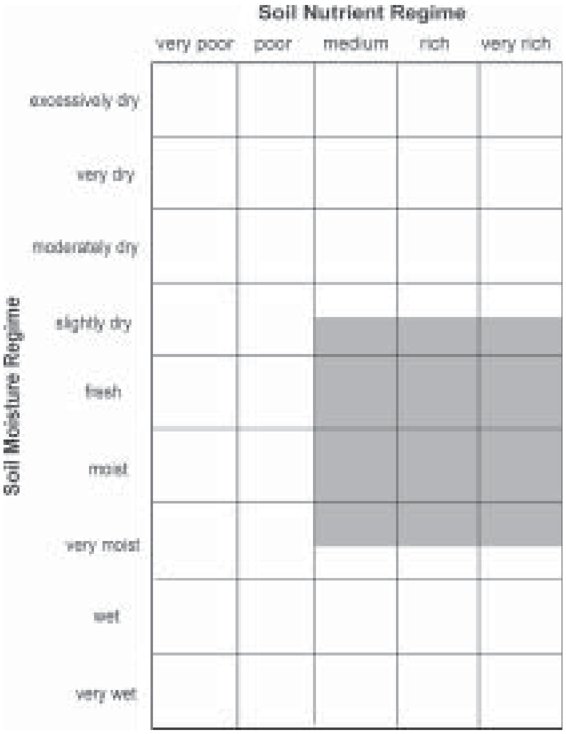
c) Groundwater table at or above the ground surface

Table 3. Definition and soil characteristics for common nutrient regimes (from Jones et al. 1983).

<table>
<tr><th>SOIL NUTRIENT REGIME</th><th>A
VERY POOR</th><th>B
POOR</th><th>C
MEDIUM</th><th>D
RICH</th><th>E
VERY RICH</th></tr>
<tr><td>DEFINITION</td><td><i>Very poor nutritional status, very small supply of available nutrients</i></td><td><i>poor nutritional status, low supply of available nutrients</i></td><td><i>medium nutritional status, medium supply of available nutrients</i></td><td><i>rich nutritional status, plentiful of available nutrients</i></td><td><i>Very rich nutritional status, abundant supply of available nutrients</i></td></tr>
<tr><td>BEDROCK SOURCE</td><td colspan="5"></td></tr>
<tr><td><i>Igneous</i></td><td colspan="5"><i>→ granite ↔ granodiorite ↔ diorite ↔ gabbro ↔ peridotite ←</i></td></tr>
<tr><td><i>Volcanic</i></td><td colspan="5"><i>→ rhyolite ↔ dacite ↔ andesite ↔ basalt ←</i></td></tr>
<tr><td><i>Metamorphic</i></td><td colspan="5"><i>→ quartzite ↔ quartz gneiss ↔ garnet schist ↔ biotite schist ↔ slate phylite</i></td></tr>
<tr><td><i>Sedimentary</i></td><td colspan="5"><i>→quartz sandstone ↔ conglomerate ↔ graywacke ↔ argillite ↔shale↔dolomite↔limestone</i></td></tr>
<tr><td>TEXTURE</td><td colspan="5"><i>→ very coarse ↔ coarse ↔ medium ↔ fine ↔ very fine ←</i>
<i>→ (sandy) ↔ (loamy - - - - - - - - - - - - - - - - - silty) ↔ (clayey) ←</i></td></tr>
<tr><td>CATION EXCHANGE CAPACITY</td><td colspan="5"><i>→ low ↔ moderate ↔ high ←</i></td></tr>
<tr><td>ORGANIC MATTER CONTENT</td><td colspan="5"><i>→ low ↔ moderate ↔ high ←</i></td></tr>
<tr><td>HUMUS FORM</td><td colspan="5"><i>→ acid mors ↔ intermediate mors and moders ↔ moders and mulls ←</i></td></tr>
</table>

* *The presence of nutrient-rich seepage waters may compensate for other factors and improve nutrient status (usually by 1 class).*

***Table 4.** The edatopic grid (Meidinger and Pojar 1991) with the shaded region indicating the primary range for occurrence of boreal mixedwood sites (MacDonald and Weingartner 1995).*



Soil Moisture Regime	very poor	poor	medium	rich	very rich
excessively dry					
very dry					
moderately dry					
slightly dry			▨	▨	▨
fresh			▨	▨	▨
moist			▨	▨	▨
very moist			▨	▨	▨
wet					
very wet					

strongly fluctuating water tables or floodplains, also require additional descriptors (Meidinger and Pojar 1991).

In addition to nutrients and moisture, soil temperature and aeration affect the vegetation community on a site. Soil temperature is a balance between heat gains and losses. Solar radiation is the principal source of heat, and losses are due to radiation, conduction, and convection. Soil temperature greatly affects the physical, biological, and chemical processes occurring in soils (Paul and Clark 1996). Both soil specific heat (the amount of heat necessary to raise the temperature of the soil) and soil conductance (how well heat can move down through the soil) are influenced somewhat by texture, and especially soil water content and organic matter content. Water has high specific heat (requires lots of energy to raise its temperature) and high conductance (transmits the heat well), thus wet soils are slower to change their temperature (Fisher and Binkley 2000). Poorly drained soils in temperate regions that are wet in the spring have temperatures 3 to 6° C lower than comparable well-drained soils (Brady and Weil 1999). The soil temperature framework is not as well developed as the edatopic grid for moisture and nutrients. However, a correlation exists between soil moisture and nutrients and soil temperature. Generally, rich soil nutrient regimes are associated with warm soil temperatures and warm soil temperatures are associated with fresh and moist soil moisture regimes.

Soil air is important primarily as a source of oxygen for tree roots and other aerobic organisms. Oxygen is used by plant roots and soil microorganisms, and carbon dioxide is released in root respiration and by aerobic decomposition of organic matter. Gaseous exchange between the soil and the atmosphere above it takes place primarily through diffusion. The term poor aeration refers to a condition in which the availability of oxygen in the soil is insufficient for growth, and occurs where compaction cuts off or water slows down gas exchange.

Poor aeration typically impedes plant growth when 80% of the pore space is filled with water. Under these conditions, the water-filled pores have little space to store oxygen and the water blocks the pathway for gas exchange with the atmosphere and oxygen diffusion to the root surface can occur. However, if the soil water is moving (telluric), it may have a reasonably high oxygen content brought in by mass flow of water (Tisdale et al. 1993, Brady and Weil 1999, Fisher and Binkley 2000).

Gleying and mottling are the primary indicators of permanent or periodic anaerobic conditions. Under an anaerobic environment, the stability of Fe and Mn tends to occur in reduced forms, thus the gray-blue colour (Bohn et al. 1985). Mottling occurs where there are periodic water fluctuations causing changes between anaerobic and aerobic condition. For example, in clay soils even when a water table is lowered periodically, the lower hydraulic conductivity of clay holds the water in the clay matrix, maintaining anaerobic conditions. Any open portions, such as root channels, drain becoming aerobic and Fe is oxidized producing reddish-coloured mottles.

The soil aeration framework is not as well developed as the edatopic grid framework, although there is a correlation between soil moisture and nutrients and soil aeration. Generally, well aerated soils are dry to moist. However, under telluric (moving water) high water table conditions, dissolved oxygen can act as a source of aeration.

Biological and Chemical Processes in BMW Soils

Soils are predominantly a mixture of various compositions of coarse rock fragments and sand-silt-clay matrix, containing living and dead organic matter with varying amounts of gases and liquids within the matrix. Soils provide the medium in which plants grow, supplying water, nutrients, oxygen for root respiration, and physical support. As such, soils, along with climatic factors, determine a site's productive potential and the vegetation it supports. In addition, soil is a dynamic system that provides habitat for many organisms with essential roles in nutrient cycling, the development and maintenance of soil structure, and the development of organic layers (Fisher and Binkley 2000, Brady and Weil 1999, Coleman and Crossley 1996). To maintain the productive capacity of a site, soil features and processes must be considered when developing forest management strategies and silvicultural prescriptions.

The following is a description of selected soil and site characteristics that affect and/or reflect a site's moisture, nutrient, temperature, and aeration. These characteristics include: parent materials (mineralogy and mode of placement); soil physical properties of texture, coarse fragment content, structure, bulk density and depth; slope position and gradient; humus form and organic matter content. Boreal mixedwood sites are identified by the subset of these characteristics that combine to form fresh to moist moisture regimes, medium to very rich nutrient regimes, moderate soil temperatures, and good soil aeration.

Parent materials. Parent materials consist of consolidated or unconsolidated mineral materials that have undergone some degree of physical or chemical weathering. The soil mineralogy (Table 3) affects the nutrient regime directly through differences in weathering of elements, and indirectly through influence on soil texture. The influence of mineralogy diminishes with weathering over very long periods but is still in effect in the recently glaciated soils (approximately 10,000 years ago) of boreal Ontario. The mode of placement in the current location (Table 5) indirectly influences the nutrient regime of a site through its influence on soil texture and coarse fragment content.

Rock types such as granite, quartzite, rhyolite, quartz, and sandstone are considered acidic because of the felsic mineral composition with high concentrations of SiO_2 and lower concentrations of other minerals containing nutrient elements (e.g., Ca, K, Na, Mg, Mn). Further, these rock types are more resistant to weathering since they are made up of minerals that have a 3-dimensional framework crystal structure, e.g., quartz and feldspar. Rock types associated with soils of boreal mixedwood sites tend to be considered intermediate, basic, and carbonaceous (Table 3). As the rock types go from intermediate to basic, the mafic mineral composition increases, with lower concentration of SiO_2 and higher concentrations of other minerals containing macro- and micronutrient elements. Resistance to weathering decreases since the mineral composition along this gradient goes from minerals with sheet structure (e.g., mica) to chain structure (e.g., amphibole, pyroxene) to isolated tetrahedra (e.g., olivine). The carbonaceous rock types (e.g., limestone and dolomite) are alkaline, contain very low concentrations of SiO_2, high Ca, Mg, and other variable constituents containing nutrient elements, and are very susceptible to weathering to silts and clays (compiled from Loughnan 1969, Fisher and Binkley 2000, Dietrich and Skinner 1979).

Mode of placement influences soil texture and coarse fragment content (Table 5). Aeolian soils are likely to have finer textures than those deposited by running water. Outwash sands laid down by flowing water from melting glaciers are made up of sediments, with sands and gravels sorted by flowing water. Glacial till soils formed by the grinding action of advancing glaciers are heterogeneous (unstratified) mixtures of debris that vary from boulders to clay. Lacustrine deposits formed in glacial lakes range from coarse deltaic materials and beach deposits near the shore to the larger areas of fine silts and clays deposited from the deeper, stiller waters of the centre of a glacial lake. Soils of boreal mixedwood sites tend to originate from fine-textured glacial tills with lower amounts of coarse fragments, fine sand and silt fluvial deposits, and lacustrine silt and clay deposits. However, in coarse soils seepage can alter the moisture and nutrient regimes to be suitable

Table 5. Classification of parent material by mode of placement in current location for ice-contact and proglacial materials. (Adapted from Chorley et al 1984, Summerfield 1991, Hambrey 1994, Brady and Weil 1999).

Parent material origin Transported and deposited by:	Descriptor	General form	Genetic term	Resulting soil coarse fragment content and texture
Formed in place from rock	Residual			dependent on mineralogy, e.g., silt from limestone; coarse sand from granite
Water				
Rivers	Fluvial		Sandur	sand and gravel
Oceans	Marine	spread	raised mud flat	silt and clay
		terraces, ridges	raised beach	sand and gravel
		terrace	raised delta	clay, sand and gravel
Lakes	Lacustrine	spread	lake plain	silt and clay
		terraces, ridges	beach	sand and gravel
		terrace	kame delta	clay, sand and gravel
Ice				
Subglacial meltwater flow	Fluvial	ridge	esker	sand and gravel
		mound	kame and kame complex	
		spread with depression	kettled sandur	
Direct deposit	Glacial till		e.g., ground moraine, end moraine	poor sorting, from boulders to a fine clayey matrix
Wind	Eolian		e.g., sand dunes; barchans	sand

for boreal mixedwood stands (compiled from Chorley et al 1984, Summerfield 1991, Hambrey 1994, Brady and Weil 1999, Fisher and Binkley 2000).

Glacial deposits are not single events, however. Not only the type of deposit but the timing and sequence of deposits becomes important in influencing a soil's nutrient and moisture status. Changes in texture throughout a soil profile due to different timing of depositional events tend to slow water movement, whether the change is from coarse to fine (the fine horizon has lower saturated conductivity thus the water moves downward more slowly) or from fine to coarse (water cannot leave the fine layer and enter the coarse layer except near full saturation) (Fisher and Binkley 2000). For example, a 50 cm layer of fine sands over coarse sands or cobble exhibits what is known as a "flower pot effect" (Ken Armson, pers. comm.[1]). Because of the greater negative water potential of the fine sand compared to the underlying coarse material, the water tends to be held in the fine sands resulting in moister soil conditions compared to a soil profile composed of fine sands alone. Once the soil becomes totally saturated, the water will drain from the fine sand into the underlying coarse material preventing water-logged conditions. The reverse texture gradient, a 30-cm clay-silt layer over compacted clay can alter the moisture/aeration relationship to provide a very productive boreal mixedwood site (Kayahara, pers. observ.).

Soil physical properties: Texture, coarse fragment content, structure, bulk density, and depth. Soil physical properties determine soil nutrient and moisture holding capacity and oxygen availability (aeration). Soil texture describes the size of the soil particles. Mineral soils are usually grouped into various combinations of three broad texture classes: sand (very fine 0.05-0.10 mm; fine 0.10-0.25 mm, medium 0.25-0.5 mm; coarse 0.5-1.0; very coarse 1.0-2.0 mm), silt (0.002-0.05 mm), and clay (<0.002 mm). The most important differences in soil texture relate to the surface areas of particles of different sizes. Medium sand (diameter 0.25-0.50 mm) has a specific surface area of 0.013 m^2/g, while clay particles have a surface area in the range of 10

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[1] Forest Consultant, Toronto, ON

m^2/g. This difference in surface area affects water potential, aeration, weathering rates, organic matter binding, cation exchange capacity, and overall biotic activity (Fisher and Binkley 2000). In general, the greater the specific surface area the greater:

- The soil water holding capacity. Clay soils have a high proportion of capillary (small-diameter) pores, thus have high moisture holding capacity, slow infiltration of water, and a potential to waterlog. Fine-textured soils have higher water retention capacity than sands, and can store larger amounts of water following storm events. But the large negative water potential of clays also means they hold water strongly during periods of drought. By contrast, sandy soils with a large proportion of non-capillary (large-diameter) pores generally are well aerated, have rapid infiltration, and low moisture-holding capacity.
- The soil nutrient retention capacity. Cation exchange capacity and, to a limited degree, anion exchange capacity, occur on the surfaces of the finer clay fractions. Such colloidal clays, along with organic matter, are the sites within the soil where ions of essential mineral elements such as Ca, K, and S, are held and protected from excessive loss by percolating rain. Subsequently, these elements can be taken up by plant roots.
- The rate of release of plant nutrients from weatherable minerals. For example, where silt is composed of weatherable minerals, the smaller particles allow weathering to proceed rapidly enough to release significant amounts of nutrients.
- The propensity for soil particles to stick together forming structure. (See below)
- The greater the height of the capillary fringe. The upper surface of the zone of saturation in a soil is called the groundwater table. Extending upward from the water table is a zone of moist soil known as the capillary fringe resulting from the height of capillary rise. In fine-textured soils, this zone of moisture may approach a height of one m or more, but in sandy soils it seldom exceeds 25 to 30 cm. Trees may be able to obtain moisture from the capillary fringe, depending on water table depth during the growing season (Brady and Weil 1999; Fisher and Binkley 2000).

Soils associated with boreal mixedwood sites tend to have high silt and clay content. Seepage can alter the moisture and nutrient regimes of coarse soils to be suitable for boreal mixedwood stands. As mentioned above, the sequence of deposition events can alter soil nutrient/moisture potential beyond that what the texture indicates.

Coarse fragments are rock fragments greater than 2 mm in diameter. These coarse-textured materials contribute very little directly to plant nutrition except by reducing the volume of soil and in effect, diluting the nutrient holding capacity of the soil, as well as changing the rate of soil warming in spring (Fisher and Binkley 2000).. Coarse fragments may increase penetration of air and water because differences in expansion and contraction between stones and soil produce channels and macropores. Boreal mixedwood soils tend not to have large volumes of coarse fragments.

Bulk density is the dry mass of soil particles (<2 mm) of a given volume of intact soil in g/cm^3. Loose, porous soils have low bulk densities while compacted soils have higher values. Organic matter has very low bulk density thus soils high in organic matter tend to have lower bulk densities. As a rule, the higher the bulk density, the more compacted the soil, the more poorly defined the structure, and the less pore space available.

Soil structure refers to the aggregation of individual mineral particles and organic matter into larger, coarser units called aggregates. Common descriptors are massive, platy, blocky, and granular. This aggregation modifies the influence of texture, generally reduces bulk density, and increases pore volume, thus increasing water movement and aeration. Aggregate formation is initiated when microflora and roots produce fibrils, filaments, and polysaccharides that combine with clays to form organo-mineral complexes. Soil structure is created when physical forces of drying, shrink-swell, freeze-thaw, root growth, faunal movement (especially the activity of larger fauna such as millipedes), and compaction mold the soil into aggregates. The formation and maintenance of a high degree of aggregation in silt and clay soils is important since relatively large structural aggregates provides for low bulk density and high proportion of macropores for high productivity soils (compiled from Tisdale et al. 1993, Paul and Clark 1996, Brady and

Weil 1999, Fisher and Binkley 2000).

Soil depth reflects the growing space volume for tree roots above some restricting layer. This space determines the volume of soil available as a nutrient pool and the amount of water that can be held. Thus, shallow soils reduce total nutrients and, depending on slope position, can either reduce available moisture (water shedding upper slopes) or increase moisture to excess levels (water receiving depressions). Boreal mixedwood sites have soils that are generally moderately deep or deeper.

Slope position and gradient. Topography or landscape context can influence both soil moisture and nutrient regimes, although caution about generalizations is advised. In a simplified version, downslope movement of water within the soil layers, variously termed throughflow, interflow and lateral flow, is the important factor. Vertical flow within the soil usually dominates in coarse-textured soils. If the soils are fine-textured silts and clays, resistance to vertical flow occurs and downslope subsurface throughflow is initiated. In fine-textured soils, fissures, cracks and channels largely replace textural voids as the main avenues for flow. Ridgetop soils may be excessively well drained. Mid-slope sites receive water and dissolved nutrients from upslope but also lose some water and nutrients downslope. Lower slope positions may receive more water and nutrients than leach away (seepage), and in some cases become saturated and flooded. Maximum water flow occurs at the base of slopes, in hollows along the slope profile, and in areas of thin or less permeable soils. Thus upper slopes tend to be drier and lower slopes moister and richer due to water inflow and the concomitant element migration. Boreal mixedwood sites generally occur on mid- to lower slope positions (Gerrard 1981, Birkeland 1984, Fisher and Binkley 2000).

Humus form and organic matter content. The term soil organic matter includes (1) the living biomass in soils; (2) dead root and other recognizable plant tissues, the L and F layer of the humus form layer, and (3) a large amorphous and colloidal mixture of complex organic substances no longer identifiable as tissues, the H layer of humus forms, and the soil humus incorporated into mineral soil horizons (Brady and Weil 1999). For convenience, organic matter is divided into the portion at the soil surface, the humus form, and the portion incorporated into mineral soil horizons.

Humus forms are the group of organic and organic-enriched mineral horizons at the soil surface that are formed from biologically mediated decomposition of organic materials. Humus forms provide habitat for decomposer organisms, are the interface for nutrient cycling (the macronutrients in particular), and are one of the determinants of rooting zone temperature, aeration, moisture, and nutrition (Tate 1987; Green et al. 1993). Dead recognizable plant tissues accumulate on the forest floor forming the L-litter layer where the material is decomposed by a variety of organisms (F-fragmented layer) and where some of the nutrients are released for uptake by flora and fauna and others are decomposed into a recalcitrant amorphous material named humus (humus layer). Different types of soil organic matter on the forest floor have different nutrient cycling rates due to the differing composition of the decomposer communities, the soil animals and microbes. The mor humus tends to be dominated by small mites, enchytraeid worms, and springtails (Collembola) that are associated with a thriving fungal community. Since decomposition by fungi is relatively slow, these humus forms have a deep partially decomposed F layer, are acidic, and have low nutrient cycling rates. They are usually matted together with fungal hyphae or compacted or both, and appear as a layer of unincorporated organic matter distinct from the mineral soil, reflecting the lack of activity from a decomposing faunal community. A mull humus tends to be dominated by a soil animal population rich in larger invertebrates such as earthworms, slugs, and millipedes associated with a more bacterial, microbial community. Since decomposition associated with bacterial communities is relatively rapid, these humus forms have a rich Ah layer of forested soil consisting of mixed organic and mineral material, near neutral pH, and rapid decomposition rates. A mull blends into the upper mineral layers without an abrupt change in soil characteristics reflecting the high activity of the decomposing faunal community (Killham 1994). A moder humus forms a class that is a gradation between the mor and mull with characteristics of each and moderate decomposition rates. Boreal mixedwood sites are generally associated with moder humus forms.

The type of humus form is linked to the soil's inherent nutrient richness in a feedback loop. Nutrient-rich soils tend to be associated with moder and mull humus forms which in turn have rapid decomposition and nutrient turnover. Certainly the humus form can be used as an indicator of a site's nutrient status. In addition, organic layers have low thermal conductivity (gain and lose heat slowly), with lower maximum summer temperatures and higher minimum winter temperatures. Organic matter has low conductance and impedes the movement of thermal energy (insulates) (Fisher and Binkley 2000).

Within the actual mineral soil matrix is various amounts of organic matter, primarily the amorphous humus. The soluble fulvic acid fraction of the H layer moves through the soil with water and is deposited within the mineral fraction. This organic matter has significant direct and indirect influences on soil properties (Stevenson 1994, Brady and Weil 1999, Fisher and Binkley 2000):

- Humus is resistant to decay thus protecting associated essential nutrients against rapid mineralization and loss from the soil.
- The specific surface area of humus colloids is very high and the cation exchange capacity exceeds that of clays.
- Soil water retention is improved since humus within mineral soil increases the permeability of the soil to water as a result of increased porosity and also absorbs several times its own mass in water.
- Humus plays a role in aggregate formation and stability of soil structures.

Soils associated with boreal mixedwood sites generally are dark, indicating that large amounts of organic matter have been incorporated the mineral soil matrix.

Field Identification of Boreal Mixedwood Sites

The above features can be combined to identify fresh to moist and medium to rich sites. Thus, boreal mixedwood sites generally have the following features, although factors may compensate to form ecologically equivalent sites (i.e., same moisture and nutrient conditions) but with different characteristics (e.g., a loam soil on a mid-slope position may have similar nutrient and moisture conditions to a sandy soil on a water-receiving lower slope position):

- Soil texture ranges from fine sand to clay, with most productive sites dominated by silts. Where the soil is fine sand, the fine material generally overlies a coarse sand or gravel. Where the soils are clay, at least the upper 10-30 cm must be of a silt-clay mix of lower bulk density than massive clay.
- Soil depth is general moderate to deep.
- Humus form is a moder.
- Occurs on land forms of fine-textured tills, lacustrine, and glaciofluvial materials on mid- to lower slope positions.

Along with soil and site properties, the understory flora can also be used to identify boreal mixedwood sites, particularly if there are combinations of

Table 6. *Key indicator plant species for facilitating the identification of the soil moisture regime (SMR) and soil nutrient regime (SNR) associated with boreal mixedwood sites (adapted from Ringius and Sims 1977).*

Species	Common name	SMR	SNR
Shrubs			
Corylus conrnuta	**Beaked hazel**	**Fresh**	**Rich**
Ribes lacustre	**Bristly black currant**	**Moist-Fresh**	**Rich**
Rubus pubescens	**Dwarf raspberry**	**Wet-Fresh**	**Rich**
Herbs			
Actaea rubra	**Red baneberry**	**Fresh**	**Rich**
Aralia nudicaulis	**Sarsaparilla**	**Moist-Fresh**	**Medium-Rich**
Circaea alpina	**Smaller enchanter's nightshade**	**Moist**	**Rich**
Galium triflorum	**Fragrant bedstraw**	**Moist-Fresh**	**Rich**
Mitella nuda	**Naked miterwort**	**Moist-Fresh**	**Medium-Rich**
Moneses uniflora	**One-flowered wintergreen**		
Ferns and Allies			
Athyrium filix-femina	**Lady fern**	**Wet-Fresh**	**Rich**
Dryopteris carthusiana	**Spunulose shield fern**	**Moist-Fresh**	**Medium**
Gymnocarpium dryopteris	**Oak fern**	**Moist-Fresh**	**Rich**
Lycopodium lucidulum	**Shining clubmoss**	**Moist-Fresh**	**Rich**

indicator plant species that generally are found on medium to rich, moist to fresh sites (Table 6).

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boreal mixedwood Notes

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Ecology and Management of Microclimate in Boreal Mixedwoods

by L.M. McKinnon* and G.J. Kayahara*

> *Boreal mixedwood management practices can be used to create microclimatic conditions that differentially favour or discourage the establishment, survival, and growth of individual tree species...*

Introduction

Microclimate refers to the small-scale climate directly above and below the ground surface, within the zone of plant growth (Ryans and Sutherland 2001). Microclimatic factors potentially important to the establishment, survival, growth, and form of plants include light availability; air, soil, and ground surface temperatures; and atmospheric and soil moisture. In general, earlier successional, shade intolerant tree species require higher light levels and higher temperatures for optimum performance than later successional, more shade tolerant tree species (Burns and Honkala 1990). Among conifers, earlier successional species tend to have lower soil moisture requirements and be less sensitive to atmospheric moisture deficits than later successional species. In contrast, moisture requirements tend to be relatively high among early successional hardwoods.

Boreal mixedwood management practices are selected to help direct tree species composition and stand structure into a desired future stand condition. One potentially effective way of accomplishing this is to vary overstory tree canopy cover (harvesting intensity) so as to create microclimatic conditions that differentially favour or discourage the establishment, survival, or growth of individual tree species. The intent is to mimic what occurs during natural stand development on boreal mixedwood sites, where changes in canopy cover, and hence microclimate, are associated with distinct changes in tree species composition and resulting stand structure (Chen and Popadiouk 2002).

The objectives of this note are to (i) review the relationship between microclimate and canopy cover; (ii) identify how microclimate and tree species composition change during natural stand development on boreal mixedwood sites; and (iii) identify microclimate-related opportunities and challenges relevant to boreal mixedwood management. We focus on the influence of overstory tree canopy cover on microclimate, which is important in boreal mixedwood management because of the associated tree species mixtures and use of partial harvesting. Other issues, such as the influence of site preparation on microclimate, apply more generally to the management of all site and stand types; for a review of the effects of site

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preparation on seedling microclimate, the reader is referred to Wagner and Colombo (2001).

The relationship between microclimate and canopy cover

Variation in overstory tree canopy cover greatly influences the microclimate of regenerating trees. Momentarily ignoring the effects of competition from vegetation, increasing tree canopy cover (or decreasing distance from the centre of an opening towards tree canopy cover) results in the following modifications to seedling microclimate on any given site relative to open areas receiving 100% of full sunlight (Groot and Carlson 1996; Marsden et al. 1996; Tanner et al. 1996; Carlson and Groot 1997; Groot et al. 1997; Man and Lieffers 1997, 1999; Groot 1999; Coopersmith et al. 2000; MacDonald 2000; MacDonald and Thompson 2003):

- increasingly lower light levels
- lower frequency and severity of frost events and other low or high air temperature extremes (higher minima, lower maxima)
- decreased soil temperature
- increased relative humidity and decreased vapour pressure deficit
- improved retention of surface moisture (although absolute soil moisture availability may be lower due, at least in part, to greater canopy interception of precipitation).

Where present, overtopping understory vegetation may also modify seedling microclimate by further reducing light levels, air and soil temperatures, and vapour pressure deficits below levels found under the influence of an overstory tree canopy (e.g., Groot 1999). In general for any given site, the cover of understory vegetation, and thus its effects on microclimate, will be positively related to the amount of light transmitted through the overstory tree canopy (e.g., Lieffers and Stadt 1994; Constabel and Lieffers 1996; Groot et al. 1997). Thus, understory vegetation cover will generally be lowest when overstory tree cover is highest, and vice versa. Sudden removal of the overstory will temporarily destabilize the relationship between light and vegetation cover (resulting in disproportionately low vegetation cover relative to light availability) but, given sufficient time (full site occupancy can be attained within 1-2 years), vegetation will respond to the disturbance and accompanying increase in light, and vegetation cover will again be positively related to overstory light transmission (e.g., Lieffers and Stadt 1994; Groot et al. 1997). These trends in microclimate with canopy tree and understory vegetation cover will be qualitatively similar on all sites, although specific conditions may differ depending on factors such as climate and site quality.

Microclimate and natural stand development

Understanding how microclimate and tree species composition change during natural stand development provides the foundation for identifying related management opportunities and challenges. At the stand level, this information can be used to create microclimatic conditions that may help to direct tree species composition and stand structure into a desired future stand condition and to avoid those conditions that do not. At the landscape level, stands can be created and managed in different successional stages (and for different tree species compositions) to create a mixedwood mosaic (MacDonald 1995) that simultaneously meets multiple forest management objectives, including timber production, visual aesthetics, water quality and fisheries, wildlife habitat, and general structural, spatial, and biological diversity. Trends in microclimate and tree species composition during natural stand development are discussed below. Stand development stages follow Chen and Popadiouk (2002).

The stand initiation stage begins following a major disturbance that removes most or all mature trees on a site. In the absence of vegetation, the microclimate at this stage can be described as an “open-area” microclimate, characterized by abundant light, air temperature extremes (including high daily maximum temperatures, low daily minimum temperatures, and potential frost risk), potentially high wind speeds, and relatively high evaporative demand (e.g., Groot and Carlson 1996; Tanner et al. 1996; Carlson and Groot 1997; Groot et al. 1997; Groot 1999). Soil temperatures are likely to be warmer than those in the intact forest, although the difference may be less pronounced wherever a thick forest floor remains after disturbance. Early successional shade intolerant species such as trembling aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*), white birch (*Betula papyrifera*), jack pine (*Pinus banksiana*), and tamarack (*Larix laricina*) are favoured under these conditions.

With the development of vegetation during the stand initiation stage, the "open area" microclimate of the disturbed area is rapidly altered. Initially, microclimatic conditions that are potentially unfavourable to some tree species may be ameliorated as vegetation colonizes the site. For example, vegetation may lower vapour pressure deficits, buffer air temperature extremes, and provide protection from frost or wind (e.g,. Groot et al. 1997). Conversely, where vegetation development becomes substantial, it may compete with tree species for light, soil moisture, and nutrients, and may shade the soil surface sufficiently to reduce soil temperature (Carlson and Groot 1997; Groot et al. 1997; Groot 1999; Staples et al. 1999). Because of more rapid initial height growth rates, shade intolerant tree species (particularly poplar and birch of sucker and sprout origin) are less likely to be overtopped by lesser vegetation than slower-growing more shade tolerant conifers such as white spruce (*Picea glauca*), black spruce (*Picea mariana*), balsam fir (*Abies balsamea*), and white cedar (*Thuja occidentalis*). Early dominance gained by shade intolerant tree species during the stand initiation stage is generally carried over to later stand development stages.

The stem exclusion stage of stand development begins once the developing tree canopy has fully closed. Usually, the canopy comprises shade intolerant pioneer species (typically aspen or birch, but in some cases also balsam poplar, jack pine, or tamarack). The microclimate beneath the main tree canopy is characterized by relatively low light levels, few air temperature extremes, low potential frost risk, relatively low soil temperatures, low wind speeds, and low evaporative demand (Groot and Carlson 1996; Carlson and Groot 1997; Groot 1999). Later successional, more shade tolerant species are favoured beneath the canopy in large part due to light limitations for shade intolerant species. However, this may not be the case early in the stem exclusion stage, when light levels can sometimes be low enough to severely compromise survival of even the most shade tolerant species (e.g., as low as 4% of full sunlight has been measured beneath juvenile aspen canopies; Pinno et al. 2001). Light levels tend to increase towards the end of the stem exclusion stage after some self-thinning of the overstory has taken place. This has been explicitly shown for aspen (Pinno et al. 2001; see also Lieffers and Stadt 1994) and probably also applies to birch.

Table 1 shows the approximate amount of light available beneath closed aspen and birch canopies during the latter part of the stem exclusion to early canopy transition stages. In Ontario, light levels beneath mature closed aspen canopies (6-23% of full sunlight) tend to be insufficient to marginal for long-term survival of understory shade tolerant conifers (approx. >25% of full sunlight is required; after Greene et al. 2002). Light levels will be even lower where understory conifers are further shaded by understory vegetation, especially on the more productive sites[1] (e.g., Groot et al. 1997; Groot 1999). Even though vegetative competition should be at a minimum during the stem exclusion stage (Lieffers and Stadt 1994; Groot et al. 1997), light attenuation by overstory and understory vegetation combined may sometimes result in light levels as low as 2-6% of full light at or near the forest floor (Constabel and Lieffers 1996; Messier et al. 1998; Groot 1999; Aubin et al. 2000). In such cases, light constraints and a general lack of suitable seedbeds will render tree establishment and survival difficult.

Comparable information is lacking on light conditions beneath mature closed canopies of white birch. However, data from Quebec and British Columbia suggest that light levels may range from 10–19% of full sunlight, either similar to or lower than those observed under aspen (Table 1).

Both canopy transition and gap dynamics stages of stand development are characterized by the presence of canopy gaps that form as a result of the death of individual trees or groups of trees due to age-related mortality and/or non-stand replacing disturbances (e.g., insects, diseases, or small-scale windthrow) (Chen and Popadiouk 2002). Microclimate within these forest gaps may vary greatly depending on their size, shape, and orientation, the height and species composition of neighbouring or overtopping

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[1] Light availability at or near the forest floor is likely to be lower on moister, more fertile sites than on drier, less fertile sites because total community leaf area (overstory + understory) increases with increasing edaphic quality (site water balance and soil nutrition) as well as with increasing climatic favourbility (Grier and Running 1977; Waring et al. 1978; see also Gholz et al. 1979).

Table 1. Light levels beneath closed (intact) canopies of aspen and birch during the late stem exclusion stage to early canopy transition stage of stand development. Unless otherwise indicated, light measurements were taken below the main tree canopy but above any understory vegetation. Stands are all ≥ 35 years old.

Canopy type	Range of light availability, % of full sunlight	References
Trembling aspen overstory	**6–23%, Ontario**	**Carlson and Groot 1997; Groot et al. 1997; Groot 1999; MacDonald and Thompson 2003** [a]
	8–13%, Quebec	**Messier et al. 1998**
	18-32%, prairie provinces	**Lieffers and Stadt 1994; Chen et al. 1997; see also Stewart et al. 2000** [b]
	14-28%, British Columbia	**Tanner et al. 1996; Comeau 2001**
White birch overstory	**Ontario data not available**	**Ontario data not available**
	12–19%, Quebec	**Messier et al. 1998**
	10–18%, British Columbia	**Comeau et al. 1998**

a. In MacDonald and Thompson (2003), it was not completely clear that light levels were unaffected by understory vegetation. However, light levels were measured at 1-m height and any effect of understory vegetation would have been relatively small. If this data point is disregarded (6% of full sunlight), the reported range for Ontario becomes 18-23% full sunlight.

b. In Stewart et al. (2000), light levels under mature aspen in Alberta were 19–34% of full light, but stand age was not specified.

trees, and the amount and composition of vegetation within the gap. Generalizations on microclimate during the canopy transition and gap dynamics stages are therefore not possible for natural stands, other than to indicate that light and other microclimatic conditions will fall in the intermediate range and be variable. Light levels are moderate, and air and soil temperatures, wind speeds, and vapour pressure deficits are intermediate between those typically encountered under the open conditions characteristic of the stand initiation stage and the closed canopy conditions characteristic of the stem exclusion stage (e.g., see canopy cover effects in Groot et al. 1997). Therefore, relative to open areas, partial canopy cover can reduce the frequency and severity of night frosts (Groot and Carlson 1996; Man and Lieffers 1999). Surface moisture also tends to be better conserved under partial canopy cover than in open areas, although the absolute amount of soil moisture may be less (e.g., Groot et al. 1997).

Although microclimate may vary greatly with gap size during the canopy transition and gap dynamics stages of stand development, there is a general trend for most gaps to be relatively small through the canopy transition stage, with larger gaps becoming more common once stands reach the old growth, gap dynamics stage (Kneeshaw and Bergeron 1998). In general, shade tolerant species tend to be favoured by lower light levels and other conditions in smaller gaps, while shade intolerant species are favoured by higher light levels and other conditions in large gaps (Coates and Burton 1997). However, substrate limitations and vegetative competition may potentially preclude successful tree seedling establishment even when gap sizes are otherwise favourable. For example, large gaps otherwise favourable for aspen may be dominated by shrubs if these gaps formed gradually as a result of eastern spruce budworm (balsam fir trees attacked by budworm remain standing for some time following death) (Kneeshaw and Bergeron 1998).

Managing for microclimate in boreal mixedwoods

How to manage for microclimate

It is generally not necessary to manage for individual microclimatic factors other than light, perhaps with the exception of soil temperature and moisture where site preparation may be necessary to ensure management objectives are met (e.g., Man and Lieffers 1999). This is because most microclimatic factors are directly related to light, and under field conditions measures of light availability actually represent integrative indices of canopy influence, i.e., light and all factors that vary with light (Horn 1971). Furthermore, light is a good candidate for the management of microclimate because it can be measured or estimated (e.g., as percent cover), it is sensitive to small changes in canopy cover (it varies more than other factors such as soil temperature), and any changes in it generally result in marked changes in the performance of both tree species and other vegetation. Indeed, light is recognized as a particularly critical factor driving forest succession (e.g., Kobe 1996).

Where tree establishment, survival, and growth are of interest, it may be useful to manage light (and thus other aspects of microclimate) first on the basis of overstory light transmission and second on the basis of any further reduction in the light available to regenerating trees caused by overtopping vegetation. This is because light attenuation by vegetation cover will be in addition to that from overstory tree canopy cover, and regenerating trees respond to the total reduction in light from both sources (e.g., see Groot et al. 1996, 1997; Groot 1999). Boreal mixedwood sites in Ontario have the potential to support vigorous shrub and herb communities, particularly during early stand development.

Management opportunities and challenges

Given that microclimate varies with canopy cover, it is possible to manage the overstory tree canopy so as to create forest openings (canopy gaps) suited to addressing specific silvicultural objectives. Most commonly, these are:

1) to ameliorate environmental conditions that are otherwise deemed potentially limiting to good tree performance, especially on frost-prone (e.g., Groot and Carlson 1996; Man and Lieffers 1999), hot, or dry sites (Childs and Flint 1987);
2) to manipulate environmental conditions to limit competition from more aggressive and undesired tree species (e.g., aspen, wherever it will form a higher than desired proportion of a stand) and/or some species of lesser vegetation (e.g., Lieffers and Stadt 1994; Groot et al. 1997; Groot 1999; Zasada et al. 2001), thereby reducing costs associated with site preparation and other methods of vegetation management; and
3) to create light conditions conducive to "acceptable" (optimal or suboptimal) survival and growth of desirable tree species (targeted light conditions will vary depending, for example, on whether the objective is maximizing tree growth or enhancing retention levels for habitat or biodiversity concerns).

Specific management opportunities and challenges related to these objectives are discussed below. In all cases, where target light levels are a function of the overstory tree canopy, vegetation control will be applied as required to maintain these conditions at seedling or sapling height. Objectives 1 and 2 generally apply only where conifer regeneration is being promoted. In contrast, objective 3 applies more universally to all boreal tree species targeted to form a future stand condition.

Objective 1: Ameliorating harsh microclimatic conditions

Tree species are particularly prone to environmental stress during their juvenile stage, especially immediately after planting (Burdett 1990; Margolis and Brand 1990). From the perspective of boreal mixedwood management, most problems have been encountered with shade tolerant white spruce, which is particularly susceptible both to frost damage (Groot and Carlson 1996; Man and Lieffers 1999) and to high vapour pressure deficits (for a review, see Grossnickle 2000), as frequently encountered in clearcuts. Tree species selection and the use of genetically superior stock could be used to circumvent these problems in some cases (e.g., on frost prone sites either do not select white spruce for reforestation or choose white spruce stock with high frost resistance). However, another viable option is to leave some residual tree canopy cover to ameliorate harsh environmental conditions (Childs and Flint 1987; Groot and Carlson 1996; Marsden et al. 1996; Man and Lieffers 1999; Kneeshaw et al. 2002). Residual overstory trees can either be retained or removed following successful tree seedling establishment (or release of advance regeneration).

To achieve frost protection:

- Light levels may need to be reduced to 50-75% of full sunlight for the residual overstory canopy to provide adequate frost protection of susceptible tree seedlings (Groot and Carlson 1996, Man and Lieffers 1999).

To ameliorate high vapour pressure deficits:

- The amount of shading required to provide regeneration of susceptible tree species with sufficient physiological relief from high vapour pressure deficits under field conditions is less clear, but it appears to be similar to the 50-75% of full sunlight required for frost protection (Marsden et al. 1996, Groot et al. 1997, Man and Lieffers 1999).

Objective 2: Limiting competition

When attempting to promote conifers, a second objective when managing microclimate is to limit competition from more aggressive and undesired tree species (typically aspen) and/or some species of lesser vegetation (e.g., Lieffers and Stadt 1994, Groot et al. 1997, Groot 1999, Zasada et al. 2001), thereby reducing costs associated with site preparation and other methods of vegetation management. The potential exists to use a partial overstory tree canopy to control competition because many major competitors are light demanding, and vegetation cover decreases with increasing overstory tree canopy cover or decreasing overstory light transmission (e.g., Lieffers and Stadt 1994, Groot et al. 1997). Residual overstory trees used for suppressing competition can either be retained or removed following tree seedling establishment.

To limit undesired competition:

- Light levels may need to be reduced to 40-60% of full sunlight to reduce aspen suckering to 50% of what would develop in a clearcut (Groot et al. 1997, MacDonald 2000) and to 25% of full sunlight to reduce suckering to 10% of what would develop in a clearcut (Groot et al. 1997)[2]. However, the latter partial canopy removal treatment may still initially leave >10,000 aspen stems × ha^{-1}. Given this, it is likely that many levels of partial harvesting will need to be augmented with a cleaning treatment even when a mixture of conifers and hardwoods is the goal[3].

With regard to subsequent growth of aspen suckers under the influence of partial shade, data from Ontario show a moderate reduction in aspen height growth at 38% of full sunlight compared to full sunlight (MacDonald and Thompson 2003). In contrast, work in British Colombia suggests that near optimal aspen height (but not diameter) growth can be maintained until light levels fall below about 20% of full sunlight (Wright et al. 1998). Regardless, aspen is unlikely to survive for prolonged periods when suppressed (Kobe and Coates 1997)[4].

- Light levels may need to be reduced to 40–50% of full light to successfully suppress light-demanding vegetation such as Canada blue-joint grass (*Calamagrostis canadensis*) and fireweed (*Epilobium angustifolium*), at least in drier climates or on drier sites (Lieffers and Stadt 1994).

In contrast, the feasibility of using partial overstory shade to successfully suppress more shade tolerant vegetation such as beaked hazel (*Corylus cornuta)* and mountain maple (*Acer spicatum*) on fresh to moist fertile sites in Ontario is questionable (Groot et al. 1996, 1997; Groot 1999; MacDonald and Thompson 2003). On many boreal mixedwood sites, it is likely that effective silvicultural options for partial harvesting will require management of both the overstory tree canopy and understory vegetation.

Where the objective is to promote conifers and there are concerns that competition may reduce conifer establishment and/or growth following overstory harvest, it may be advantageous to:

- artificially establish a new cohort of shade tolerant conifers prior to overstory harvest (i.e., create advance regeneration when vegetation competition is at a minimum) by underplanting or using understory scarification in a mast seed year (Stewart et al. 2000), and/or
- where a two-stage harvesting method[5] or conventional shelterwood silvicultural system is used, remove residual overstory trees only when

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[2] The configuration of forest openings can also be important (Groot et al. 1997).

[3] The efficacy of this latter treatment has been somewhat unclear (MacDonald and Thompson 2003). Care must be exercised to achieve uniform and adequate (ground) application of herbicides in partially cut aspen stands.

[4] Likewise, in the experiment described by Groot et al. (1997) for northern Ontario, almost all aspen that had regenerated in small circular openings one-half (ca. 25% full sunlight) to one tree height (ca. 50% full sunlight) in diameter subsequently died within 10 years (A. Groot, pers. comm.). This suggests that aspen may not form a significant stand component where overstory light transmission is less than 50%.

[5] In the two-stage harvesting system, a mature overstory comprising shade intolerant trees (typically aspen) is removed in the first harvesting entry, thereby releasing a well developed understory layer of shade tolerant conifers (typically spruce) that is harvested in a second entry (e.g., see Welham et al. 2002).

Table 2. Approximate maximum heights of some selected species of vegetation that compete with conifers in boreal Ontario (OMNR 2003) [a].

Species	Maximum height (m)
Acer spicatum **(mountain maple)**	3
Alnus crispa **(green alder)**	3
Alnus incana **ssp.** ***rugosa*** **(speckled alder)**	4
Calamagrostis canadensis **(blue-joint grass)**	1-2
Corylus cornuta **(beaked hazel)**	3
Diervilla lonicera **(bush honeysuckle)**	1
Epilobium angustifolium **(fireweed)**	2
Prunus pensylvanica **(pin cherry)**	5
Rubus idaeus var. strigosus **(wild raspberry)**	2

a. Actual (observed) heights may vary with soil type (e.g., Shropshire et al. 2001).

shade tolerant understory conifer regeneration has reached a height that exceeds, or nearly exceeds, the maximum anticipated height that competing vegetation will attain following overstory removal. These "free-to-grow" heights for conifers will depend on the maximum expected height of dominant lesser vegetation under full sunlight (Table 2). Likewise, to be able to withstand post-harvest competition from aspen suckers, it is recommended that conifers be 2.5-3.4 m tall (Johnson 1986, Yang 1989, MacDonald and Thompson 2003).

Objective 3: Maintaining acceptable survival and growth

The third and most common objective when managing microclimate is to create or maintain target light levels that will meet regeneration standards for desirable tree species. Regardless of the silviculture treatment used, the foremost regeneration objective is usually to ensure that a suitable number of trees survive to form the future stand, whether these individuals exist as advance growth prior to harvest or become newly established post-harvest through natural, assisted natural, or artificial (planting or direct seeding) means. Beyond minimum survival, minimum acceptable growth rates are targeted. These can be either optimal or suboptimal for a species depending, for example, on whether the objective is maximizing tree growth, establishing advance growth prior to harvest, or enhancing retention to meet habitat or biodiversity objectives.

Light levels for minimum acceptable survival

Minimum height growth rates thought to allow for survival and the eventual response of saplings to release are shown in Table 3 for some boreal conifers, based on a plant height of ≥1 m (Ruel et al. 2000). Although some evidence indicates that balsam fir, black spruce, and white spruce may all maintain their respective minimum height growth rates at >10% of full sunlight (cf. >40-45% of full sunlight for shade intolerant jack pine) (Ruel et al. 2000), a more conservative estimate of 25% of full sunlight has been suggested. For example, to successfully plant white spruce under aspen, recommended minimum light levels at seedling height are >25% of full sunlight, given the assumption that the overstory aspen will be removed within 10-20 years (Greene et al. 2002). This minimum light level is probably suitable for balsam fir, black spruce, and white cedar, but is unlikely to be sufficient for ensuring survival and the eventual response to release of more shade intolerant jack pine and tamarack. Prescriptions for regenerating shade intolerant conifers do not generally involve partial canopy removal methods that result in dense overstory shading.

In natural aspen-dominated stands, light levels are not generally reported to approach levels suitable for underplanting (ca. >25% of full sunlight; after Greene et al. 2002) until towards the end of the self-thinning (stem exclusion) stage, which may occur at stand ages of approximately 20 years in Alberta

Table 3. Minimum height growth rates for survival of boreal conifers at a base height of ≥1 m (after Ruel et al. 2000). Species attaining these height growth rates may survive and be capable of responding favourably to release. White spruce, black spruce, and balsam fir may require on the order of 10–25% of full sunlight to achieve these height growth rates, while jack pine may require at least 40–50% of full sunlight.

Species	Relative shade tolerance[a]	Minimum height growth rate (cm · year^{-1})
Abies balsamea **(balsam fir)**	**Very tolerant**	**10–15**[b]
Larix laricina **(tamarack)**	**Very intolerant**	**undefined at present**
Picea glauca **(white spruce)**	**Tolerant**	**10**
Picea mariana **(black spruce)**	**Tolerant**	**5–10**
Pinus banksiana **(jack pine)**	**Very intolerant**	**20–30**
Pinus resinosa **(red pine)**	**Intolerant**	**undefined at present**
Pinus strobus **(white pine)**	**Intermediately tolerant**	**undefined at present**
Thuja occidentalis **(eastern white cedar)**	**Tolerant to very tolerant**	**undefined at present**

a. Shade tolerance categories follow Baker (1949).
b. The minimum height growth rate for balsam fir is probably lower in northern Ontario (A. Groot, CFS pers. comm.).

(Pinno et al. 2001) and 30 years in British Columbia (DeLong 1997). No similar documentation exists of the generalized age that aspen stands in Ontario may become suitable for underplanting, given the same criteria of >25% of full sunlight. However, there are indications that, at a comparable stage of stand development, light levels under aspen stands in northern Ontario tend to be insufficient to marginal for underplanting (Table 1; mean 6-23% of full sunlight). Furthermore, for stands where overstory light transmission is suitable, vegetation control would still likely be required to create or maintain these light conditions at planting height (light levels presented in Table 1 are those above understory vegetation). It is uncertain whether light levels under mature closed canopies of birch in Ontario are suitable for underplanting (Table 1).

As an alternative to targeting light levels required for conifer establishment and survival through natural stand development (e.g., postponing underplanting until light conditions become suitable), appropriate overstory conditions could be artificially created by thinning (tending) or a partial harvest of the overstory tree canopy. Again, vegetation control would likely be required to maintain sufficient light conditions at planting height (Groot 1999).

Light levels for minimum acceptable growth

Standards for *minimum acceptable growth* of regenerating trees will vary with the management objectives for any given stand. Where maximum timber production is the primary objective, silviculture systems are generally prescribed that result in no or minimum loss of tree growth. In this case, the minimum acceptable growth rate is that which is considered *optimal or near-optimal* for the crop tree species. Either an open-area environment is maintained or any temporary residual tree canopy cover is removed before tree growth is negatively influenced by the overstory component (standard yield curves for open-grown trees generally apply; Thrower and Associates 1995). In boreal Ontario, clearcut and conventional shelterwood silvicultural systems may fall within this category[6].

In clearcut systems, residual canopy trees (if any) are likely to have little overall influence on the microclimate of regenerating trees, assuming that tree seedlings are not purposely planted in close proximity to residual stems (Jull and Stevenson 2001). This is the case in Ontario because of the low density of residual trees typically left behind after clearcut harvesting (ca. 25 stems·ha^{-1})[7] and the relatively short average tree height in the boreal

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[6] Silvicultural systems follow Smith et al. (1997). In this case, the irregular shelterwood is analogous to the “retention system” described by Mitchell and Beese (2002).

region of the province. For example, the sheltering effect of mature aspen stands extends up to about one dominant tree height in length into an opening (Groot et al. 1997, Kneeshaw and Bergeron 1998), which in northern Ontario may only be approximately 20 m. Beyond this, light and other environmental factors rapidly approach those of open areas.

Residual canopy trees may also have little or no negative effects on the growth of regenerating trees within seed tree (modified clearcut) and conventional shelterwood cuts, so long as residual tree cover is not too dense and is removed before the growth of regenerating trees is compromised. Even on harsh sites, any beneficial (ameliorating) effects of canopy cover decrease with time as tree regeneration becomes larger because environmental stress is to some extent size- and condition-dependent (greater for smaller establishing plants than for larger established plants) and because light requirements for tree growth may increase with increasing plant size (Givnish 1988). Conventional shelterwoods used as nurse tree systems are generally intended to provide only temporary protection from frost, desiccation, and/or hardwood or vegetative competition, and are removed once regenerating trees become well established. Where they have commercial value, seed trees are also frequently removed following seedling establishment.

Where the primary forest management objective is other than timber production (e.g., wildlife habitat or visual aesthetics), enhanced residual retention levels may be applied that result in reduced growth of regenerating trees due to the long-term retention (persistent shading) of canopy trees. In this case, growth losses are generally accepted *a priori* as a cost of maintaining other forest values. Accordingly, the goal with respect to tree regeneration then becomes one of ensuring that trees survive and exhibit a minimum acceptable *suboptimal* level of growth (thus, application of standard yield curves is likely not appropriate; Thrower and Associates Ltd. 1995). Irregular shelterwoods (shelterwoods with enhanced retention) and selection silvicultural systems fall within this category. Because these silviculture systems can accommodate a range of canopy retention, the amount of overstory retained, and therefore light levels, can be varied to achieve different levels of "acceptable growth".

Where some loss of growth of regenerating trees is anticipated, the loss may be approximated based on the light-growth relationship of the species of interest. Equations describing the relationship between light availability (% of full sunlight) and the height growth of boreal tree species are shown in Table 4. Ontario data are sparse so caution is advised in applying these equations because these relationships may potentially vary with (i) plant size (e.g., Duchesneau et al. 2001, Claveau et al. 2002); (ii) climate (Wright et al. 1998); (iii) site quality (see Canham et al. 1996); (iv) slope, aspect, and other aspects of landscape structure or local topography (Chen et al. 1999); and (v) species composition of the overstory (e.g., for the same relative light level measured in summer, annual light transmission will be greater through deciduous than coniferous canopies). Genetic differences among families may also play a role. In general, however, minimum acceptable height growth rates are expected to be higher for shade intolerant species because these species are likely to exhibit much poorer survival than more shade tolerant species at any given low growth rate (Kobe et al. 1995, Kobe and Coates 1997).

Summary

Three main objectives when managing for microclimate are (i) ameliorating harsh microclimatic conditions (particularly frost and high vapour pressure deficits); (ii) controlling competing vegetation; and (iii) creating light levels conducive to the acceptable survival and growth of regenerating tree species. These objectives can all be achieved by varying overstory tree canopy cover to attain specific light conditions and using vegetation management as required to maintain target light conditions at seedling height. It is possible to use light to manage for other microclimatic factors because most microclimatic factors vary with light (light represents an integrated index of canopy influence).

Target light levels required to achieve these objectives were identified as:

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[7] Natural disturbance pattern emulation (NDPE) guidelines in Ontario require that a minimum average of 25 well-spaced stems ha^{-1} remain after clearcutting, and as few as six of these stems must be living (Ontario Ministry of Natural Resources 2001).

Table 4. *Sample equations used to describe the relationship between light availability and the height growth of boreal tree species. In all cases, light availability (L, % full sunlight) is measured at plant height and is a function only of overstory tree canopies, not understory vegetation. Unless otherwise indicated, HI refers to annual height increment (cm×year^{-1}). Diameter and/or biomass responses are also reported within many of these same studies.*

Species	Climate and location	Light-height growth relationship	Reference
Abies balsamea (balsam fir)	Boreal, Quebec	[a] $RHG=0.05\ ln(L)-0.04$ (saplings)	Duchesneau et al. 2001
Betula papyrifera (white birch)	Moist temperate, British Columbia	$log_{10}(HI)=1.853*L/(1.853/0.456+L)$ (saplings)	Wright et al. 1998
Larix laricina (tamarack)	*Light-growth equations are not available, but some evidence from controlled studies suggests that 45% full sunlight is sufficient for maximum height growth at 5 years (**Logan 1966**)* [b].		
Picea mariana (black spruce)	Plains Boreal, British Columbia	$log_{10}(HI)=1.583*L/(1.583/0.247+L)$(saplings)	Wright et al. 1998
Picea glauca (white spruce)	Boreal, Alberta	$HI=-1.39+0.658*L$ (valid to 40% L only)(saplings)	Lieffers and Stadt 1994
	Intermontane Boreal, British Columbia	$log_{10}(HI)=1.824*L/(1.824/0.152+L)$(saplings)	Wright et al. 1998
	Plains Boreal, British Columbia	$log_{10}(HI)=1.678*L/(1.678/0.154+L)$(saplings)	Wright et al. 1998
	Boreal, Ontario	$HI=19.26-0.601*L+0.016*L^{2}-0.000108*L^{3}$ (planted seedlings)	Groot 1999
Pinus banksiana (jack pine)	*Light-growth equations are not available, but some evidence from controlled studies suggests that full sunlight is sufficient for maximum height growth at 5 years (**Logan 1966**)* [c].		
Pinus resinosa (red pine)	*Light-growth equations are not available, but some evidence from controlled studies suggests that full sunlight is sufficient for maximum height growth at 6 years (**Logan 1966**)* [c].		
Pinus strobus (eastern white pine)	Great Lakes-St. Lawrence, Quebec	Annual height increment (HI): relationship not significant Total height (H, cm): $ln(H)=0.26*\ ln(L)+4.48$ (saplings)	Messier et al. 1999
Populus balsamifera (balsam poplar)	Not available		
Populus tremuloides (trembling aspen)	Moist temperate, British Columbia	$log_{10}(HI)=1.959*L/(1.959/0.532+L)$ (saplings)	Wright et al. 1998
Thuja occidentalis (eastern white cedar)	*Light-growth equations are not available, but some evidence from controlled studies suggests that 45% of full sunlight is sufficient for maximum height growth at 9 years (**Logan 1969**)* [b].		

a. RHG (relative height growth) was defined here as the ratio of current annual leader increment to total plant height.

b. Height growth at 45% and 100% of full sunlight was similar and greater than that at 25% of full sunlight. It is possible that height growth may have peaked somewhat below 45% of full sunlight because the author did not test light levels between 25% and 45% of full sunlight.

c. The author concluded that full sunlight was required for maximum height growth, but he did not test light levels between 45% and 100%. Thus, height growth could potentially have peaked somewhere in between.

- reducing light availability to 50-75% of full sunlight to provide adequate frost protection of susceptible tree seedlings (particularly white spruce)
- reducing light availability to 50–75% of full sunlight may also be sufficient to provide adequate physiological relief from high vapour pressure deficits, although this is less well characterized
- reducing light availability to 40-60% of full sunlight to reduce aspen suckering to 50% of that occurring in a clearcut, or to 25% of full sunlight to reduce suckering to 10% of what would develop in a clearcut
- reducing light availability to 40–50% of full sunlight to successfully suppress light-demanding, non-crop species such as *Calamagrostis canadensis* and *Epilobium angustifolium*, in drier climates or on drier sites (in contrast, the feasibility of using overstory canopy shade to successfully suppress more shade tolerant vegetation on fresh to moist fertile sites in Ontario is questionable)
- maintaining, creating, or targeting (e.g., for underplanting) light levels of >25% of full sun to ensure the survival and response to release of understory shade tolerant conifers
- ensuring above minimum light levels required for survival, which involves targeting species-specific light levels >>25% of full light, based on predetermined acceptable growth rates

Where maximizing tree growth is the primary concern, clearcut systems are used to provide immediate open-area environments (approx. full sunlight; standard yield curves apply). Otherwise, a conventional shelterwood may be used to provide temporary microclimate amelioration or vegetation control. In the latter case, residual overstory is removed once tree seedlings become established, thereby also creating an open-area environment for maximizing tree growth (standard yield curves may apply).

Conversely, irregular shelterwood systems (shelterwoods with enhanced retention) or selection silvicultural systems are used where long-term retention of residual canopy trees is required to protect or enhance non-timber values such as wildlife habitat and visual aesthetics. In this case, trees regenerating under persistent canopy shade (<<100% sunlight) are expected to exhibit suboptimal growth (standard yield curves for open-grown trees do not apply). Growth rates under partial shade can be approximated from species-specific light-growth relationships, but data specific to Ontario are sparse and the aforementioned precautions apply.

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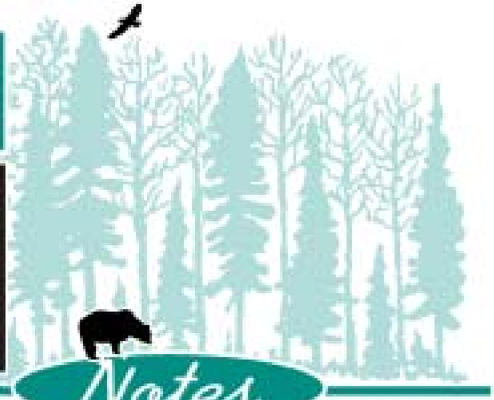

ECOSYSTEMS

Elemental Storage and Cycling in Boreal Mixedwoods

by Dave M. Morris*

> *The development and implementation of more intensive silvicultural options, even within an adaptive management framework, raises concerns about stand nutrition and long-term site productivity...*

Introduction

The boreal mixedwood forest comprises over half of Ontario's productive forest landbase (McClain 1981, Scarratt 1992, Wedeles *et al*. 1995) and contributes substantially to Ontario's annual wood supply (estimated at 24-25 million m^3 – Bell *et al*. 2000). Although the global demand for wood products continues to increase, Ontario's wood supply has been decreasing due to an unbalanced distribution (Thornton 2000). Recent estimates also indicate that an additional net loss of approximately 4 to 5% of the future wood supply has occurred as a result of Ontario's Living Legacy land use strategy (*i.e.*, protection has been extended to an additional 2.4 million ha as provincial parks, conservation areas, and forest reserves) (OMNR 1999). These withdrawals place even greater demands on Ontario's shrinking productive landbase. Meanwhile, societal pressure is being applied to demonstrate to the international community that Ontario's forest products are being produced under a sustainable forest management regime.

To deal with these wood supply issues, some have advocated better commercial utilization of the previously underutilized boreal mixedwood forest (*e.g.*, MacDonald 1995). For example, the species composition, age structure, and successional relationships of boreal mixedwood stands may present opportunities to implement modified harvest methods (*e.g.*, two-stage harvesting – Kenney and Towill 1999; specialized thinnings – MacDonald and Cormier 1998). More recently, interest in implementing intensive forest management (IFM) has increased in Ontario, including both intensive and elite silvicultural options (Bell *et al*. 2000). The application of these options would likely be directed, in part, to productive mixedwood sites. The latter are areas with climatic, topographic, and edaphic conditions that favour the production of closed canopies dominated by trembling aspen (*Populus tremuloides* Michx.) or white birch (*Betula papyrifera* Marsh.) in early successional stages, black spruce (*Picea mariana* (Mill.) B.S.P.) or white spruce (*Picea glauca* (Moench) Voss) in mid-successional stages and balsam fir (*Abies balsamea* (L.) Mill.) in late successional stages

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(MacDonald and Weingartner 1995). Although these sites are considered to be relatively resilient using current harvesting methods (*e.g.*, full-tree logging) and rotation lengths (60+ years), the development and implementation of more intensive silvicultural options, even within an adaptive management framework, raises concerns about stand nutrition and long-term site productivity (Archibald *et al*. 1997). The objectives of this note, therefore, are (1) to briefly introduce the patterns and processes involved in nutrient cycling in boreal mixedwoods, (2) to illustrate their importance to the management of boreal mixedwoods, and (3) to outline the possible implications of these potential silvicultural alternatives from a stand nutrition and productivity standpoint.

Elemental Stores

A good starting point for understanding nutrient dynamics in boreal mixedwoods is to characterize the nutrient forms, storage, and distribution (abiotic and biotic components) for typical boreal mixedwood ecosystems. Boreal mixedwood sites have been characterized as having well to imperfectly drained, fresh to moderately moist, fertile soils situated along mid-slope positions (Arnup 1998). Most of these soils/sites support highly productive and diverse forest communities

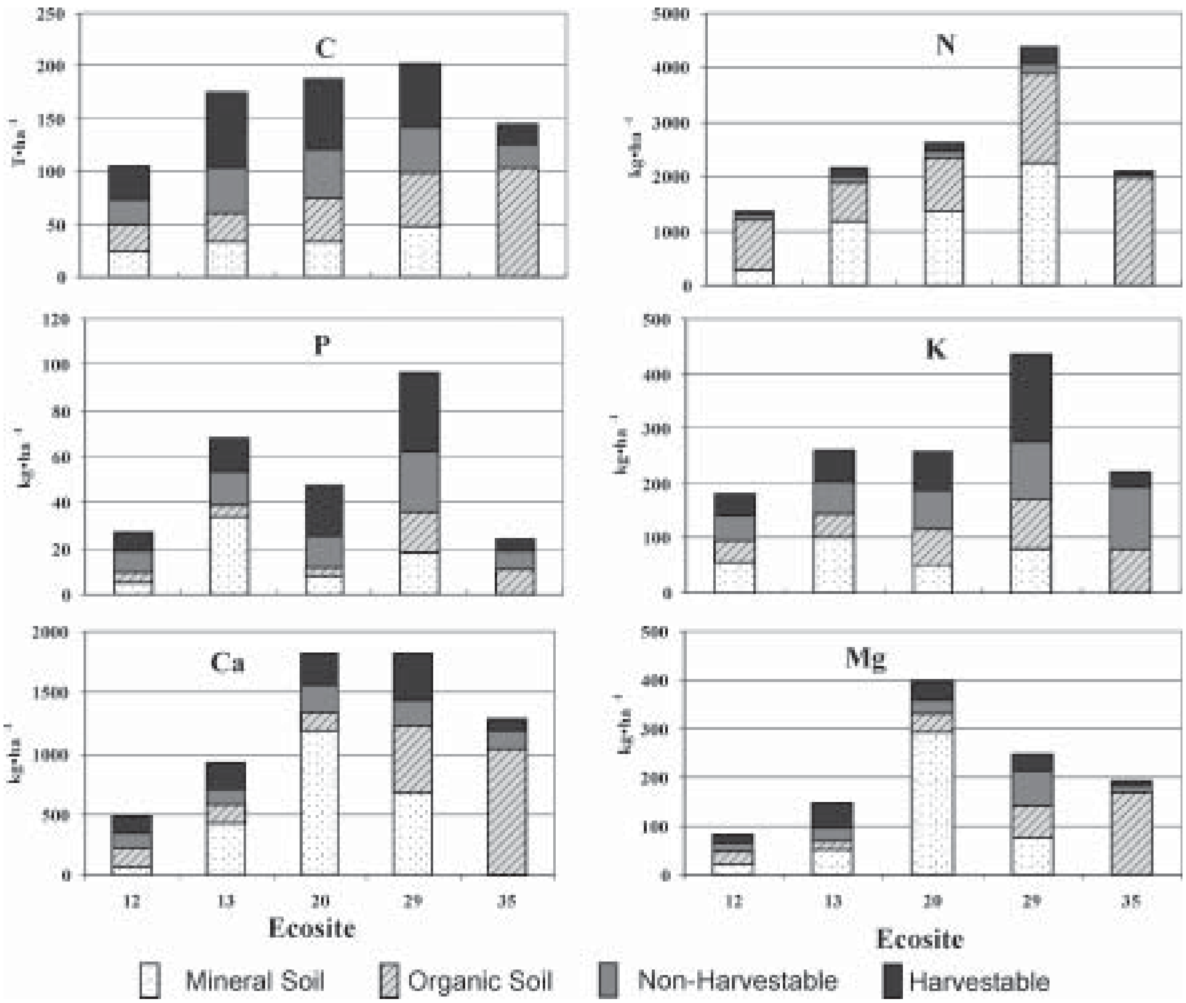

Figure 1. Comparison of carbon and macronutrient stores for a range of boreal ecosites in northwestern Ontario (data summaries modified from Gordon 1981, 1983; Pastor and Bockheim 1984; Haung and Schoenau 1996; Duckert and Morris 2001; and Duckert et al. 2001). Northwestern ecosite designations are: ES12: very shallow, coarse loamy - jack pine / black spruce; ES13: dry-mod. fresh sandy - jack pine; ES20: fresh coarse loamy - black spruce / jack pine; ES29: fresh fine loamy - hardwood-fir-spruce mixedwood; ES35: poor swamp, organic soil - black spruce (Racey et al. *1996).*

(MacDonald and Weingartner 1995). Not unexpectedly, total site macronutrient (carbon (C), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg)) stores tend to be larger on mixedwoods (e.g. ES29 ecosites) than those reported for other site types[2] (Figure 1). For example, elemental stores for conifer-dominated (jack pine (*Pinus banksiana* Lamb.) - black spruce mixtures) forests growing on shallow tills in northwestern Ontario (ES12 ecosites) have been estimated at: N - 1300, P - 30, K - 170, Ca - 480, Mg - 80 kg · ha^{-1} (Duckert *et al.* 2001).

In some cases (*i.e.*, N, Ca), these elemental stores are as little as one quarter of the reserves present on boreal mixedwood sites. However, due to the combination of diverse site conditions occupied by boreal mixedwood forests (*i.e.*, 11 soil types could be expected to support boreal mixedwood stands across northern Ontario – McCarthy *et al.* 1994, Racey *et al.* 1996) and varied stand histories (*e.g.*, disturbance frequency and intensity), a considerable range in nutrient stores is likely to exist.

Nutrient Cycling Processes

Although boreal mixedwood sites contain large reserves of macronutrients, only small amounts are available for plant uptake at any given time. It is through a dynamic and complex system of biogeochemical cycling that the soil matrix and the nutrients held therein are replenished and, through decomposition processes, made available to support forest productivity. Each element essential for plant growth has a unique chemistry in both plants and soil, a particular relationship to lithology and atmospheric inputs, and its own rate and magnitude of cycling through vegetation (Attiwill and Adams 1993). Figure 2 illustrates macronutrient pool sizes and transfer rates among ecosystem compartments in a stylized boreal mixedwood forest.

Based on results of past biogeochemical cycling studies from a number of forested ecosystems (Carlisle *et al.* 1966, Reiners 1972, Eaton *et al.* 1973), elements that are primarily in ionic form in the cell sap (*e.g.*, K, Mg) are generally cycled rapidly between the "living organic matter" and the "available soil nutrient pool". On the other hand, elements found predominately in non-

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[2] ES20, though not considered a mixedwood ecosite in the true sense of the definition, could be considered on the nutritional edge of becoming a mixedwood site.

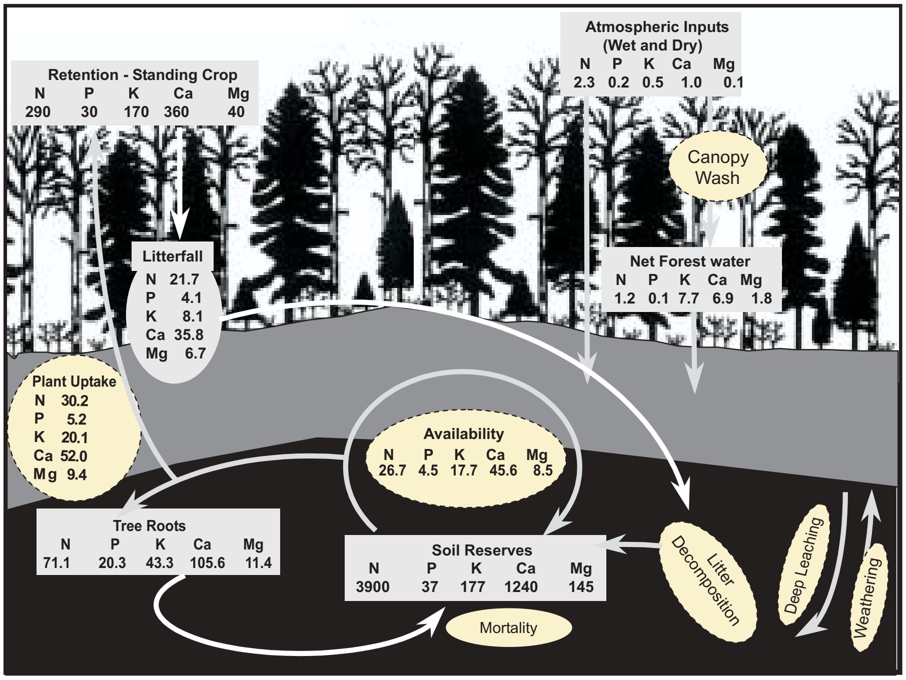

Figure 2. A stylized nutrient cycling diagram for a typical boreal mixedwood (50% hardwood – aspen, birch; 50% conifer - spruce, fir) growing on modal conditions (modified from Gordon 1981, 1983). Nutrient pool sizes are expressed in kg • ha^{-1}, whereas transfer rates (fluxes) are in kg · ha^{-1} · yr^{-1}.

ionic forms as constituents within plant tissues or storage molecules (*e.g.*, N, P, Ca) are cycled more slowly and commonly require decomposers to complete the cycle (Gordon *et al.* 2001).

A major portion of nutrients taken up into the aboveground components of trees is returned to the forest floor annually. Nutrient losses from plants can result from several different processes, including (1) defoliation by herbivores, (2) leaching of plant tissues by rainwater, (3) discarding of dead plant tissues (litterfall), and (4) whole-tree mortality. Although large pulses of herbivory can occur (*e.g.*, spruce budworm outbreaks), this typically involves substantially less nutrient transfer than that associated with the other pathways. Generally, the movement of nutrients through canopy wash and litterfall represent the most important pathways in the return phase of the nutrient cycle.

For any given boreal mixedwood stand, incoming precipitation delivers a dilute nutrient solution to the forest canopy. During its movement through the canopy and over plant structures, this precipitation also would be expected to pick up elements from the vegetation. Precipitation that passes through the canopy and falls directly to the forest floor is called **throughfall**. The portion of precipitation that reaches the ground by running down the branches to the bole and is, in turn, deposited at the base of the tree is called **stemflow** (Figure 3).

Throughfall typically represents a large pathway for mobile ions such as K and Mg (Foster and Gessel 1972, Fahey *et al.* 1988, Morris 2000). Although stemflow can provide highly concentrated deposits of elements to the base of individual trees, its overall deposition rates (per hectare) are generally only a fraction of those of throughfall (Mayer and Ulrich 1972, Morris 2000).

A proportion of a mature forest's total biomass pool (commonly referred as standing crop) is removed annually through the death of plant parts, and subsequently transferred to the soil and the detritus food web (Meentemeyer *et al.* 1982). The transfer of this organic material from the aboveground biomass pool to the forest floor is called **litterfall**. Along with depositing up to 2 tonnes · ha^{-1} · yr^{-1} of dry matter onto the forest floor, litterfall returns for the five macronutrients in a mature, mixedwood forest would also be substantial. For example, Gordon (1981, 1983)

Figure 3. A typical stemflow sampler on a black spruce stem (A) and stemflow collection being measured with a graduated cylinder (B).

reported litterfall returns of: N - 21.7, P - 4.1, K - 8.1, Ca - 35.8, and Mg - 6.7 kg · ha^{-1} · yr^{-1}, respectively (Figure 2). Thus, this process represents a major pathway through which surface soils, continuously depleted by nutrient uptake and leaching, are replenished (Morrison 1991). A common characteristic of a mature mixedwood stand is the surface accumulation of organic matter, referred to as humus. In most cases, this organic pool is an important source of nutrients for plants (Persson and Wiren 1995, Rauland-Rasmussen and Vejre 1995) and plays a role in maintaining long-term site fertility (Morris 2000, Prescott *et al.* 2000). Decomposition rates of this organic pool are highly variable, depending on both internal (*e.g.*, litter quality) and external (*e.g.*, soil temperature and moisture) factors.

Based on the assumption that the total accumulation of organic matter and nutrients in the forest floor of a mature forest represents a stable pool (deposition = decomposition), mean residence time (MRT) for organic matter or nutrients can be estimated by dividing the total pool size by the annual input (Vogt *et al.* 1986). The reciprocal of MRT, commonly expressed as a percentage, provides an estimate of the proportion of the pool “turning over” in a given year. This fraction represents the pool of nutrients available for microbial immobilization, plant uptake, or deep leaching. In boreal mixedwoods, residence times (N – 30 yrs; P – 4 yrs; K – 5 yrs; Ca – 9 yrs; Mg – 7 yrs) tend to be shorter and turnover rates (N - 3%; P - 25%; K - 20%; Ca - 11%; Mg - 14%) higher than for most other boreal ecosites, particularly those dominated by conifers (Gordon 1983). For example, N availability could be expected to be as high as 40 kg · ha^{-1} · yr^{-1}. In contrast, N availability in a similar-aged, upland, black spruce-dominated forest was estimated at only 14 kg · ha^{-1} · yr^{-1}, and in lowland black spruce forests (wet, peaty-phase soils) was estimated at just under 7 kg · ha^{-1} · yr^{-1} or one-sixth that of the boreal mixedwood site (Morris 2000).

Successional Relationships

The processes involved in the transfer and turnover of nutrients described above are complex and highly variable. For example, mechanisms of nutrient dynamics in forest systems may vary among nutrient elements (noted above), with stand age (Gholz *et al.* 1985, DiStefano and Gholz 1989), tree species composition (Vitousek and Reiners 1975, Pastor and Bockheim 1984), intrinsic properties of the site, and environmental conditions (Côté *et al.* 2000, Prescott *et al.* 2000). In particular, several studies have documented changes in soil nutrient availability along temporal (*i.e.*, time since stand-replacing disturbance) and successional (*i.e.*, species compositional changes over time) gradients in the boreal forest. These studies have shown declines in nutrient availability, especially N (Brais *et al.* 1995), decreases in nutrient concentration in litterfall (Gosz 1981), decreases in soil respiration, reductions of available macro- and micronutrients (Paré *et al.* 1993), increases in C:N ratios (Côté *et al.* 2000), and increases in forest floor biomass (Brais *et al.* 1995), accompanied by a change in forest humus form (*i.e.*, from mull to more acidic mor humus), resulting in lower soil temperature: a negative feedback loop with respect to nutrient turnover and availability, due almost exclusively to stand compositional changes.

MacDonald and Weingartner (1995) identified five defining boreal mixedwood tree species – trembling aspen, white birch, black spruce, white spruce and balsam fir – but pointed out that stand composition and species dominance at any point in time may include only a subset of these defining species. As illustrated in Figure 4 and detailed in Arnup (1998), the most common successional pathway/sequence for a typical boreal mixedwood site includes (A) an early successional stage dominated by intolerant hardwoods (*e.g.*, trembling aspen, white birch), (B) a transitional stage where mid-tolerant conifers (*e.g.*, black and white spruce) become established beneath the diffuse hardwood canopy, (C) a maturing stage where the mid-tolerant conifers begin to dominate the overstory, and (D) a late successional stage dominated by tolerant conifers (*e.g.*, balsam fir). More recent dendrochronological studies (Paré and Bergeron 1995, Galipeau *et al.* 1997, Kneeshaw and Bergeron 1998) have suggested a modification to the standard mixedwood model that includes a

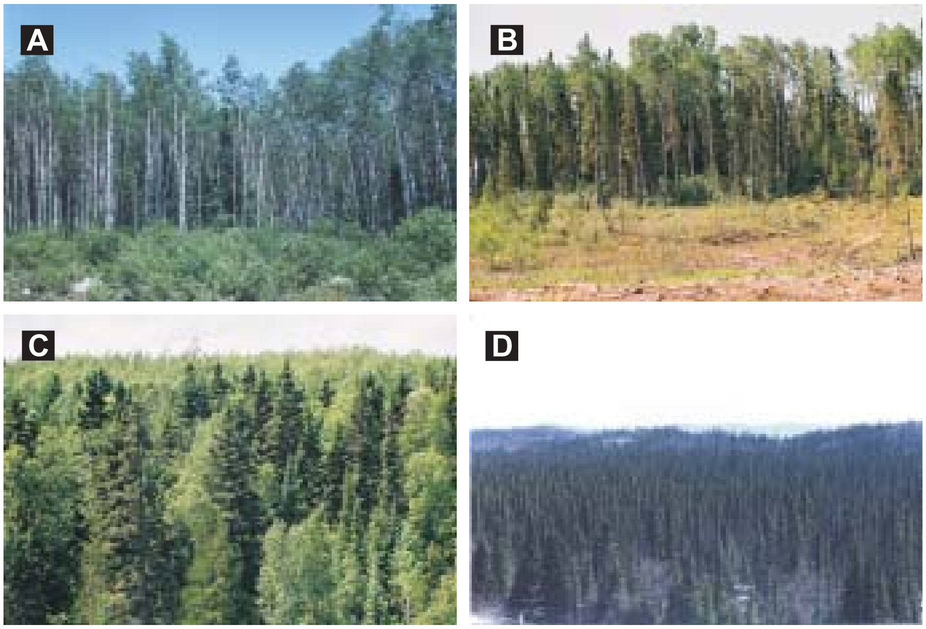

Figure 4. The boreal mixedwood seral stages: (a) early stage dominated by intolerant hardwoods, (b) transitional stage with mid-tolerant conifer underneath diffuse hardwood canopy, (c) mature stage with mid-tolerant conifers emerging through hardwood canopy gaps, and (d) mid-tolerant and tolerant conifers dominating the forest stand.

second cohort of aspen and an extended mixedwood phase of slow conifer recruitment (gap-phase dynamics).

When considering these shifts in species composition (deciduous to conifer), a nutrition aspect relevant to boreal mixedwoods is that nutrient cycling tends to be accelerated by the presence of a deciduous component (Tappeiner and Alm 1975, Assman 1977, Perry 1978). The early successional species (*e.g.*, trembling aspen) that regenerate on boreal mixedwood sites after disturbances, such as stand-replacing wildfire or clearcut harvesting, tend to act as nutrient pumps (deep-rooted, maximal uptake, luxury consumption—Boring *et al*. 1981, Paré *et al*. 1993) and provide large amounts of nutrient-rich leaf litter. In addition, the high pH of this litter raises forest floor and upper mineral soil pH, which in turn increases cycling efficiencies (*e.g.*, reduced residency times, higher mineralization rates, larger pool of available nutrients – Paré and Bergeron 1996, Ste-Marie and Paré 1999). On the other hand, the presence of conifers tends to promote slower nutrient turnover rates due to higher lignin and other polyphenolic compounds (Vitousek 1977, Pastor *et al*. 1987), and lower nutrient contents in their leaf litter (Côté and Fyles 1994). The chemical constituents of forest water fluxes (*i.e.*, throughfall and stemflow) also reflect these differences, as rainwater passes through deciduous or conifer canopies. For example, Morris (2000) reported stemflow pH for trembling aspen at 6.1, compared to 3.7 and 3.8 for jack pine and black spruce, respectively.

From a forest nutrition (*i.e.*, nutrient availability) perspective, the anticipated decline in soil fertility associated with the development of a conifer-dominated, late-successional forest may be compensated for by the positive influence of an extended period of hardwood dominance/co-dominance (Pastor *et al*. 1987, Rothe and Binkley 2001), as commonly occurs in mixed stands. For example, birch species have long been recognized for their soil ameliorating effects, which include the capacity to reduce soil acidity and increase Ca availability (Miller 1984). Therefore, any silvicultural prescription that maintains a hardwood component on a site, while ensuring adequate conifer regeneration and growth, should help to maintain high nutrient cycling rates, and, ultimately, maximize forest productivity in later successional stages.

Management Implications

When considering forest sustainability from the perspective of nutrient storage, cycling, and long-term productivity, a critical question would be: *Is* *the quantity of nutrients removed during clearcut harvesting operations on boreal mixedwood sites of concern*? There is little question that a stand-replacing disturbance (natural or anthropogenic) in a mature forest ecosystem changes ecosystem structure and function for a significant period. However, all ecosystems tend to recover towards their pre-disturbance condition through succession, a pervasive process that provides ecosystems with inherent stability (Kimmins 1974). Regardless of the type of ecosystem or seral stage, if the external stress (*e.g.*, harvest removals) is not too great and if the frequency of disturbance (*e.g.*, rotation length) is low relative to the rate of recovery, the system would be expected, eventually, to return to its pre-disturbance condition eventually. In terms of the biogeochemical cycle, the length of the recovery period is a function of (1) the degree of site nutrient depletion accompanying harvesting (Timmer *et al*. 1983, Mahendrappa *et al*. 1987), (2) the rate of replacement of these nutrient losses (Wells and Jorgensen 1979), and (3) the rate of vegetative recruitment and establishment (Van Cleve and Noonan 1975, Hughes and Fahey 1994).

Nutrient Replacement Times: Full-tree vs. Tree Length Harvesting

In their simplest form, nutrient replacement times can be estimated by dividing the amount of a given nutrient removed during harvesting (harvestable material - logging slash) by annual system inputs. This model assumes 100% retention of nutrient inputs through precipitation (wet and dry deposition), or, at a minimum, that weathering inputs equal exports through leaching. Although simplistic, these replacement times provide an early indication of nutrients that may become limiting for future stands.

Table 1 summarizes the calculated replacement times across a range of ecosites and compares harvest removals and replacement times for full-tree and tree-length logging. In this modelling exercise, a considerable range (19 to 170 years) in nutrient replacement times was generated for the ES29 (fresh, fine loamy: hardwood-fir-spruce mixedwood) simulations depending on the nutrient being considered and logging method selected. Although boreal mixedwood sites have large total site reserves (Figure 1), the amount allocated to harvestable material also tends to be greater than that for conifer-dominated ecosites. As a result, calculated nutrient replacement times for boreal mixedwoods tend to be larger than for the other ecosites included in Table 1 (for all elements except Mg). These differences become more apparent when comparing replacement times generated with the full-tree logging option.

Nutrient replacement times associated with a result, Ca, K, and P returns over an 80-year rotation would not be equivalent to the harvest-related removals, generating deficits and draw downs in soil nutrient reserves over the long term. Replacement times for cations, particularly Ca, tend to be high for boreal mixedwood sites, irrespective of logging method. These extended replacement times are largely a function of the large amounts of these elements stored in the bole (stemwood and bark), particularly in aspen (Paré *et al*. 1993). This, in turn, suggests that alternatives to clearcutting might be more beneficial in terms of conserving nutrient capital than increasing slash retention.

Nutrient inputs *via* precipitation vary considerably across ecodistrict and ecoregional boundaries, primarily the result of differences in precipitation patterns and industrial influences. For example, total N inputs in northwestern Ontario are rather low (2 kg · ha^{-1} · yr^{-1} – Morris 2000), but increase to 7 kg · ha^{-1} · yr^{-1} as you move easterly across Ontario (Foster and Morrison 1976), and have been reported at 14 kg · ha^{-1} · yr^{-1} in northwestern Quebec (Jacques and Boulet 1990). These substantial shifts in inputs would affect calculated replacement times for specific locations or stands.

Soil Nutrient Pool Dynamics Through Time

A major limitation to the replacement time approach is that there is no recognition of the changes in supply (*i.e.*, turnover and nutrient availability) and demand (*i.e.*, plant uptake) for nutrients during stand development. Figure 5 provides a representation of the changes in

Table 1. Post-harvest site reserves, biogeochemical inputs, and nutrient replacement times for both full-tree and tree-length harvesting options for a range of boreal ecosites.

		Elemental Pools (kg•ha^{-1})				
		N	P	K	Ca	Mg
Atmospheric inputs (kg•ha^{-1}•yr^{-1})		5.2	0.2	1.6	3.0	0.5
Ecosite 12	**Soil Reserves**	**1208.50**	**9.50**	**95.20**	**221.20**	**48.50**
Full-tree	Harvest	84.60	8.18	40.76	127.77	19.81
	Residual/Slash	79.78	9.71	45.05	127.44	15.30
	Replacement Time (Years)	**16.3**	**40.9**	**25.5**	**42.6**	**39.6**
Tree-length	Harvest	36.64	3.22	20.43	80.90	11.44
	Residual/Slash	127.74	14.67	65.37	174.23	23.67
	Replacement Time (Years)	**7.0**	**16.1**	**12.8**	**27.0**	**22.9**
Ecosite 13	**Soil Reserves**	**1875.00**	**38.9**	**145.70**	**583.70**	**69.80**
Full-tree	Harvest	164.30	14.74	59.15	218.64	51.97
	Residual/Slash	120.80	14.68	55.29	122.72	26.22
	Replacement Time (Years)	**31.6**	**73.7**	**37.0**	**72.9**	**103.9**
Tree-length	Harvest	78.77	6.05	31.69	144.11	30.87
	Residual/Slash	206.33	23.38	82.75	197.25	47.32
	Replacement Time (Years)	**16.1**	**30.2**	**19.8**	**48.0**	**61.7**
Ecosite 20	**Soil Reserves**	**2353.00**	**11.9**	**116.00**	**1331.10**	**329.90**
Full-tree	Harvest	154.00	14.18	71.38	268.16	37.82
	Residual/Slash	126.71	14.97	70.96	224.19	27.61
	Replacement Time (Years)	**29.6**	**70.9**	**44.6**	**89.4**	**75.6**
Tree-length	Harvest	74.32	6.11	39.93	180.69	22.50
	Residual/Slash	206.39	23.03	102.4	311.67	42.91
	Replacement Time (Years)	**14.3**	**30.6**	**25.0**	**60.2**	**45.0**
Ecosite 29	**Soil Reserves**	**3899.00**	**36.00**	**172.00**	**1226.00**	**143.00**
Full-tree	Harvest	301.33	34.04	159.45	383.21	36.46
	Residual/Slash	169.57	26.26	102.96	209.38	69.73
	Replacement Time (Years)	**57.9**	**170.2**	**99.7**	**127.7**	**72.9**
Tree-length	Harvest	98.94	11.62	68.80	211.15	18.28
	Residual/Slash	371.96	48.68	193.61	381.43	87.91
	Replacement Time (Years)	**19.00**	**58.1**	**43.0**	**70.4**	**36.6**
Ecosite 35	**Soil Reserves**	**1970.35**	**10.66**	**78.23**	**1031.4**	**170.4**
Full-tree	Harvest	52.10	5.07	27.68	99.75	9.60
	Residual/Slash	78.13	8.67	45.42	152.68	13.75
	Replacement Time (Years)	**10.0**	**25.3**	**17.3**	**33.2**	**19.2**
Tree-length	Harvest	22.31	1.98	13.99	63.21	5.24
	Residual/Slash	107.92	11.76	59.10	189.22	18.21
	Replacement Time (Years)	**4.3**	**9.9**	**8.7**	**21.1**	**10.5**

Note: Atmospheric inputs used in the replacement time calculations represent mean values based on studies conducted across northern Ontario (Foster and Morrison 1976, Gordon 1983, Morrison 1991, Morris 2000).

nutrient capital, supply, and plant uptake from stand initiation to steady state for a typical boreal mixedwood after a clearcut harvest. Immediately following the harvest, the soil nutrient pool increases as a result of added logging slash, stumps, and root material. This pool, however, is quickly reduced to below pre-harvest levels as a result of faster humus layer decomposition. For example, Morris and Duckert (2001) reported nutrient pools dropping to as little as half their original size within 3 years of a full-tree logging operation. The released nutrients are added to the available nutrient pool (*i.e.*, pool increases after harvest), but a high potential for off-site leaching also exists at this stage of stand development since nutrient demand (*i.e.*, plant uptake) is reduced to near zero after a clearcut harvest. Gordon (1983) stated that post-harvest deep leaching could greatly extend replacement times depending on the time it takes to revegetate the site. It would follow that the rapid recovery of vegetation after harvesting is an important factor in regulating nutrient cycling processes as it restores the evapotranspiration stream, moderates soil temperature, and reduces nitrate production / availability (Richardson and Lund 1975, Currie *et al*. 1999). For most boreal mixedwood sites, a brief reorganization phase (5-10 years) occurs as trembling aspen, shrubs, and herbaceous cover quickly reclaim the site after disturbance. Once vegetation becomes re-established on the site, the amount of nutrients taken up (captured) by plants increases to or above available levels (*i.e.*, nutrient availability becomes limiting). Following crown closure, leaching losses become minimal, crown pruning and self-thinning occur, litterfall rates become maximal, and the soil nutrient pool begins to rebuild toward pre-disturbance levels. As the stand continues to self-thin, nutrient demand decreases and eventually stabilizes at a level equivalent to supply (steady state).

Since the period of maximal nutrient demand coincides with when soil nutrient pools are at their minimum, and, sites may not be able to supply adequate nutrients to maximize early growth. Therefore, it is imperative that silvicultural systems are designed to: (1) enhance/maintain soil nutrient pools at or near pre-disturbance levels, and (2) encourage rapid re-colonization of the site by plants, thereby reducing the leaching potential of mobile elements (*e.g.*, K, NO_3 - N). These types of systems will help to conserve site nutrient capital and maximize the site's growth potential.

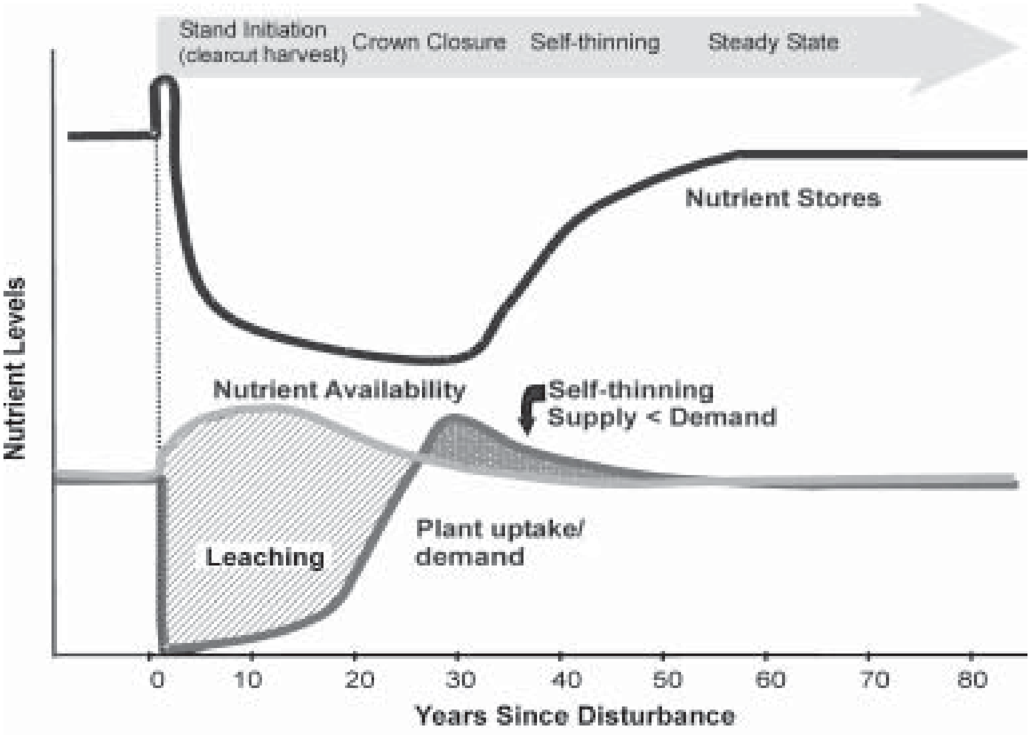

Figure 5. Changes in nutrient capital, availability, and demand over time after a clearcut harvest operation of a typical boreal mixedwood site.

Other Site/Soil Factors to Consider

Nutrient loss and retention after clearcut harvesting of boreal mixedwoods is an important consideration for maintaining forest sustainability. Other concerns exist as well. Although mixedwood sites, by their nature, tend to be relatively fertile and resilient, the soil types commonly associated with mixedwood stands can be susceptible to rutting and soil compaction (Archibald *et al*. 1997). In particular, the finer-textured soils (*i.e.*, silty, fine loamy-clayey) tend to be most susceptible particularly when the soils are wet. Changing soil structure may increase bulk density and reduce soil porosity. These altered physical properties could, in turn, affect water infiltration, hydraulic conductivity and lateral flow, root penetration and development, gas exchange between roots and the soil, and plant germination potential (Archibald *et al*. 1997). These same authors provide a set of best management practices to minimize rutting and soil compaction for these susceptible soil conditions. Moving from a one-entry (clearcut) to a two-pass or multi-entry silvicultural system (Figure 6), requires careful consideration of skid trail layout (repeat use) and operational timing (avoidance of sensitive conditions) to minimize or avoid site damage.

Summary

The cycling of elements in a stand is an integrating process that brings together most other functions of a forest system (Cole and Rapp 1981). As a result, information on soil nutrient dynamics is not only necessary to make good land use decisions in forestry, but also is a prerequisite for developing new silvicultural approaches when managing boreal mixedwoods to best emulate natural stand development, dynamics, and productivity.

Boreal mixedwood sites represent some of the most fertile and resilient sites across the boreal region, supporting highly productive and diverse forest communities. Even with large soil nutrient reserves and relatively efficient nutrient cycles, losses in productivity that could represent long-term sustainability concerns may result from clearcut, full-tree harvest operations. Since the presence of a deciduous component within a given stand matrix may improve soil productivity *via* increased nutrient cycling, any silvicultural treatment package (*e.g.*, logging method - variable canopy retention, multiple-entry systems) that can increase logging slash retention or extend the residency time of deciduous species (*i.e.*, trembling aspen, white birch), while providing for adequate conifer regeneration and growth, should help to conserve soil nutrient reserves, increase nutrient cycling efficiency, and maintain forest productivity.

Future Needs

The current research challenge is to develop and test, in an adaptive management framework, these

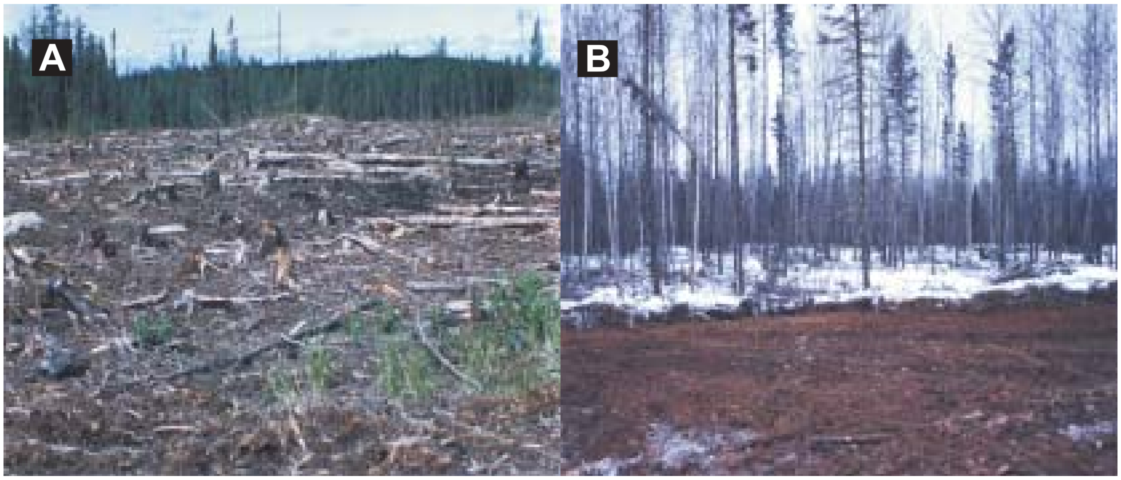

Figure 6. The results of (a) a typical clearcut, full-tree harvest operation and (b) partial harvest (60% of merchantable volume removed) using a long-boom, single-grip harvester.

alternative silvicultural treatments, as well as evaluate the potential impacts of a suite of intensive forest management options on the health and productivity of Ontario's boreal mixedwoods. As a component of this evaluation, there is a growing need to incorporate process-based models that can accurately simulate the complexities of boreal mixedwood structure, nutrition, and productivity over the long term. For example, Welham *et al.* (2002) recently used the ecosystem-level model FORECAST to simulate and compare future forest conditions after a clearcut *versus* a two-pass harvesting system in boreal mixedwoods. Although a variety of process-based models currently exist, there is a need for regional validation and model refinements, as well as an effective way to incorporate these tools into a forest management planning framework.

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LANDSCAPE

Boreal Mixedwood Management and Prescribed Fire

by R. Wiltshire and D.J. Archibald

> ***Boreal mixedwood forests are dependent upon periodic fire to maintain their health, productivity, and faunal and floral diversity.***

Introduction

The boreal mixedwood (BMW) is an important component of the boreal forest, comprising over half of Ontario's productive forest landbase (McClain 1981; Scarratt 1991; Towill and Wiltshire in prep.). MacDonald and Weingartner (1995) define a BMW forest as an area with climatic, topographic and soil conditions that favour the production of closed canopies dominated by trembling aspen (*Populus tremuloides* Michx.) or white birch (*Betula papyrifera* Marsh.) in early successional stages, black spruce (*Picea mariana* (Mill) B.S.P.) or white spruce (*Picea glauca* (Moench) Voss) in mid-successional stages and balsam fir (*Abies balsamea* (L.) Mill.) in late successional stages. At any given time throughout their development, other associated tree species may be present in the canopy.

These mixedwood forests are dependent upon periodic fire to maintain their health, productivity, and faunal and floral diversity (Alexander and Euler 1981; Heinselman 1978). Modern fire suppression strategies have acted as a disturbance to forest ecosystems (Heinselman 1973; Suffling 1990; Baker 1994) by significantly reducing the frequency and extent of fires in the boreal forest. The use of prescribed fire as a silviculture tool reintroduces fire as a natural component into the ecosystem (Weber and Taylor 1992; Heinselman 1971). Prescribed fire under the right conditions can also be a cost-effective technique to meet specific vegetation management goals (Armson 1985).

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Cette publication technique n'est disponible qu'en anglais.

This technical note reviews the ecological role of fire in BMW forests. It provides resource managers with background information necessary to apply prescribed fire in these forest types.

Ecological Role of Fire in Boreal Mixedwood Forests

Fire is a fundamental component of the Canadian forested landscape (Rowe and Scotter 1973; Heinselman 1978; Weber and Taylor 1992). Kelsall *et al.* (1977) defined the BMW forests as fire-dependent ecosystems that would lose their character, vigour, and faunal and floral diversity in the absence of fire. If fire was completely excluded from the landscape, Day and Harvey (1981) suggest that the BMW forest would shift towards later successional species such as balsam fir, white spruce, mountain maple (*Acer spicatum* Lam.) and beaked hazel (*Corylus cornuta* Marsh.). The influence of wildfire is complex, highly variable and depends on fire regime and weather conditions (Scotter 1974: Wright and Heinselman 1973; Rowe and Scotter 1973; Alexander and Euler 1981). Elements of fire regime include fire type (ground, surface or crown), fire severity and intensity, fire frequency and size (Heinselman 1978).

At the landscape level, fire cycle (or natural fire rotation) is probably the most important aspect of fire regime. This term is defined as the average number of years required to burn an area equivalent to the whole forest (Heinselman 1971; Van Wagner 1978). During a rotation period, some areas within the area under consideration will burn more than once and others not at all. Fire cycle is determined by physical and biological conditions of the forest and its location with respect to climatological conditions (Alexander and Euler 1981). Modern fire suppression strategies have increased the length of natural fire cycles and resulted in a greater proportion of forest in the older age classes (Woods and Day 1977; Alexander and Euler 1981; Cayford and McRae 1983; Peterson and Peterson 1992; Ward and Tithecott 1993).

A number of studies have looked at fire cycles in boreal forests and boreal Great Lakes–St. Lawrence transition forests (Swain 1973; Woods and Day 1977; Van Wagner 1978). In general, natural fire cycles in northern Ontario range from 50 to 120 years, depending on the topography, fuel, elevation and climate (Johnson 1992). Forest types and their associated flammability have an important influence on the role fire plays on a landscape level. It is widely known that conifers stands are more flammable than hardwoods mainly due to form and available fine fuels (Johnson 1992). Since the BMW forest includes a wide range of cover types on predominantly fresh-to-moist rich sites, these forest types burn less frequently than drier upland conifer-dominated site. However, BMW forests will readily burn in spring before the green-up of understory vegetation, or during periods of extreme drought.

Fire initiates primary plant succession, controls species composition and age structure of forest stands, and produces the mosaic vegetation patterns related to faunal succession (Heinselman 1971; Wright and Heinselman 1973). Natural selection processes within boreal species have favoured development of fire-adaptive traits that ensure the perpetuation of these species (Rowe and Scotter 1973). Within the boreal forest there are fire-sensitive species and fire-resistant species, both of which have adapted to natural fire regimes (Rowe 1983). Two examples of plant adaptive traits are cone serotiny in jack pine and black spruce, and vegetative reproduction from suckers or root-collar sprouts in trembling aspen and white birch. Conversely, fire-sensitive species such as balsam fir and white spruce are best adapted to areas with longer fire cycles.

Wildfires on BMW sites tend to maintain a high proportion of white birch and trembling aspen as they reproduce prolifically by vegetative means. In addition, improved seedbed conditions, combined with an abundance of wind disseminated seeds from surrounding areas, allow for a rapid ingress of birch and trembling aspen seedlings. On black spruce dominated mixedwood sites, the combination of a constant seed supply and the reduction of both competing vegetation and organic matter depth ensures black spruce regeneration. When young mixedwood stands are burned there is almost always a succession to hardwoods on the site (MacLean 1960). Major species shifts are rare and occur when there is a low density of species present on site or if a site is dominated by fire-sensitive, late-successional species. (Haeussler 1991).

In the boreal forest, forest floor organic matter accumulates due to slow decomposition rates associated with low temperatures (Scotter 1974; Alexander and Euler 1981; McRae 1986). Terms such as “nutrient-lockup” or “frozen assets” have been used to describe this condition (Kayll 1968; Scotter 1974). Fire acts as a rapid mineralization agent, responsible for releasing nutrients and making them available for plant uptake. In addition to the deposition of a nutrient-rich ash layer on the forest floor, fire creates other related conditions that are favourable for plant growth and development:

- Higher temperatures due to canopy removal and the blackened soil surface.
- Decreases in soil acidity due to release of cations in the ash layer.
- Post-fire increases in microbial populations.

These effects of fire are all inter-related and contribute to increases in nutrient availability during early stand development (MacLean *et al.* 1983; DeBano 1990). Generally, there is an increase in available soil nitrogen, calcium, phosphorus and potassium after burning (Ahlgren and Ahlgren 1960; Kayll 1968; Scotter 1974; Viro 1974; Smith and James 1977; Weber and Taylor 1992). Favourable conditions for plant growth created by fire are known to exist for many years depending on post-fire climatic conditions and site characteristics. Armson (1969) found higher pH values on burned sites and they persisted for approximately ten years.

There are a number of fire/disease and fire/insect interactions in the BMW forest, but the association of fire with spruce budworm (*Choristoneura fumiferana* (Clem.)) is the most significant (Stocks 1987; Haggith 1988). When an area becomes extensively damaged by budworm, high fuel concentrations increase the probability of large fires. Natural fire also plays a role in limiting the extent of late-successional forest types, limiting budworm population growth. Fire suppression has disrupted the natural balance between these two natural disturbance agents. A study by Stocks (1987) indicates that forest fire potential in budworm killed balsam fir stands is significantly higher for five to eight years following stand mortality.

Prescribed Fire in Boreal Mixedwood Forests

Prescribed burning is defined as "The knowledgeable application of fire to a specific land area to accomplish predetermined forest management or other land management objectives" (Merrill and Alexander 1987). It has been used in North America since 1925 for silvicultural purposes (Armson 1985; Van Wagner 1993), although the controlled use of fire by aboriginal people to clear brush for hunting and agriculture before this time is documented (Russell 1983; Pyne 1994).

On mixedwood sites, there are many advantages to using prescribed fire over mechanical site preparation treatments. In general, fire will result in increased soil nutritional status, provide better control of competing vegetation, result in plant community types most similar to natural wildfire, and eliminate balsam fir advance growth (McRae 1985a; Arnup 1989). Prescribed fire has also proven to be a cost-effective treatment relative to other methods (Alexander and Euler 1981; Isherwood and MacQuarrie 1985; Brown and DeByle 1989; Weber and Taylor 1992).

The main application of prescribed fire in Ontario's BMW forests is to prepare sites for conifer seeding or planting, or to stimulate hardwood regeneration. These objectives include burning for slash and duff reduction to stimulate hardwood suckering, creating receptive seedbed or plantable spots, and controlling competing vegetation during early stand development. A knowledge of specific vegetation objectives for the site, combined with an understanding of plant species autecology, enables the resource manager to develop site-specific silvicultural prescriptions. Guidelines have been developed for the mixedwood fuel slash complex to predict fuel consumption and estimate fire behaviour (McRae 1980; 1985b).

Management Objectives

Prescribed fire in BMW forests can be used for:

a) promoting vegetative reproduction of trembling aspen
b) controlling competing vegetation for planting or seeding conifer species
c) encouraging natural regeneration of red and white pine
d) stand conversion of budwormed killed balsam fir

A description of each of these applications follows.

Trembling Aspen and White Birch Regeneration

Prescribed burning for trembling aspen regeneration after harvest requires a light to moderate severity burn to stimulate suckering. These burns consume litter, fine woody debris and shrubs, and reduce duff depth by up to 40 percent. This type of burn stimulates suckering through increased light levels from removal of ground vegetation and the increased temperatures associated with the blackened surface (Peterson and Peterson 1992). Horton and Hopkins (1963) reported that a light fire that only partially removes surface litter and ground vegetation may be insufficient to promote good suckering, as optimal soil heating will not occur. Weber (1991) compared suckering potential in 20 year-old trembling aspen ecosystems under different treatments. He found that the amount of suckering was a function of burn intensity. If the stand was killed outright (moderate intensity) it exhibited the greatest amount of suckering; if trees were only girdled (low intensity) suckering density was diminished. It is important to note that the trees in this study were small in diameter and susceptible to damage.

Light to moderate severity burns require lower fuel moisture code values of the Canadian Forest Fire Weather Index (FWI) System (Anon. 1987). Prescriptions that use lower indices will increase the burning windows and decrease fire control efforts for fire managers. Burning as soon as possible after harvest will take advantage of lower shrub and herb biomass to allow adequate fire behaviour. Burning in early spring, when the nutrient reserves are still in the roots, will result in higher densities and greater vigour of trembling aspen suckers. Most poplar suckers appear within the first two years after burning, then self thinning quickly commences (Peterson and Peterson 1992).

White birch reproduces vegetatively from lower stem and root collar sprouts, with sprouting vigour greatest in trees less than 60 years of age. Although a light to moderate severity burn will stimulate vigourous clumps of sprouts in saplings and young trees, most regeneration of birch after logging and fire will be from seed. White birch is a prolific seed producer, and the light seeds will travel for considerable distances over snow. A moderate to high severity fire that consumes most of the organic matter provides good seedbed for white birch (Perala and Alm 1990).

Conifer Regeneration

If a management objective requires a significant proportion of jack pine, white spruce, or black spruce in the future mixedwood stand, prescribed fire after harvest is an attractive site preparation alternative. In the boreal forest, where sites are generally very productive and warrant intensive management, planting of conifer species is a common practice (Chrosciewicz 1978; McRae 1996a).

Prescribed fire is used to reduce both logging slash and organic matter depth to create suitable planting microsites, and to control vegetative competition for early plantation establishment and growth.

Additional benefits of prescribed fire include increased nutrient availability, and the elimination of balsam fir. Arnup (1989) compared individual tree growth response of ten year old black spruce for both mechanical and prescribed burning site preparation treatments. He found no significant difference in growth between the two treatments, although there were higher volumes per hectare on the burn sites due to higher survival rates. He also found that planting on prescribed burned sites were more uniformly spaced, there was less vegetative competition, and balsam fir advance growth was eliminated. In a similar study McRae (1985a) did not find any significant differences in early plantation growth on mixedwood sites in the Clay Belt, and recommended forest managers choose the site preparation treatment that is most cost effective. In a study on BMW sites in northwestern Ontario that looked at differences between prescribed fire and mechanical site preparation, prescribed burning was clearly the superior treatment option. The burned sites had significantly greater individual tree height, diameter, and volume growth over the mechanical treatments (Towill pers. comm.).

When burning BMW sites for conifer regeneration it is recommended that deep, late summer burns are used. Thin burned duff reduces vegetative reproduction of hardwoods and shrubs, and decreases the seed bank of competitive species in the organic matter while creating suitable plantable spots. Burning earlier in the season to take advantage of reduced vegetation biomass will widen the burning window, perhaps reducing the need for chemical pre-treatment to cure fuels (Archibald *et al.* 1994).

Red and White Pine Regeneration

In northwestern Ontario, most white pine and red pine are found growing in mixedwood conditions (Bowling and Niznowski 1996). It is known that these species are fire-resistant and that natural wildfire plays a role in their perpetuation and maintenance. Prescribed fire has a role in maintaining the red and white pine component in these mixedwood types. A low intensity understory fire prior to harvest can create receptive seedbed and reduce vegetative competition for natural regeneration of these species (McRae *et al.* 1994).

Species Conversion of Budworm Killed Balsam Fir Stands

Many BMW sites in Ontario have succeeded to a heavy balsam fir component, due in part to very effective fire suppression over the past half century. These areas have subsequently been infested with spruce budworm and represent an extreme fire hazard. To bring these areas back into production, prescribed fire (usually after salvage harvest and tramping operations) is used to effectively reduce heavy surface fuel loadings before planting (McRae 1986).

Forest Ecosystem Classification Systems and Prescribed Fire

Forest Ecosystem Classification (FEC) systems have been developed for the boreal forest (McCarthy *et al.* 1994; Racey *et al.* 1996). These systems describe various forest types based on soil and vegetation associations and provide a framework for forest managers to aggregate and combine potential forest management applications and interpretations. In the BMW, FEC systems can be useful in identifying potential forest floor duff types (L, F and H layers) and the amount and type of post-harvest fire resistant fuels which will impact fire behaviour and effects. Some tools have been developed in conjunction with FEC that can assist with prescribed burn planning in BMW forests (Wearn *et al.* 1982; Stocks *et al.* 1990; McCarthy *et al.* 1994; McRae 1996b).

Summary

Prescribed fire has a role as a silviculture tool in the management of Ontario's BMW forests. Prescribed fire may have certain ecological and silvicultural advantages over mechanical or chemical site preparation on some sites, but forest managers must consider all associated costs and benefits in meeting their management objectives. Recent technological advances and greater understanding of prescribed fire applications and effects will enable prescribed fire to continue as a silvicultural option for forest managers.

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Ontario's Boreal Mixedwood Natural Disturbance Regimes: Implications for Managed Forests

by Janette C. Desharnais[1], William D. (Bill) Towill[2], and R.O. Wiltshire[3]

> *The nature and frequency of disturbances, pre-disturbance stand composition, and the time elapsed since the last major disturbance all influence forest development...*

Introduction

One approach to protecting ecological integrity and ensuring the sustainability of Ontario's forests and natural resources is to adopt an *ecosystem management philosophy* (Bradshaw *et al*. 1994, Haila *et al*. 1994, Galindo-Leal and Bunnell 1995, Armstrong 1999, Spence and Volney 1999, McRae *et al*. 2001). Indeed Ontario's Crown Forest Sustainability Act (Statutes of Ontario 1995) requires that a *sustainable approach* for management of the province's natural resources be adopted to ensure that the social, economic and environmental values accruing from Ontario's forests are available today and for future generations, and that biodiversity and long-term forest health and productivity are protected.

Emulation of natural disturbance patterns has been proposed as one template for ecosystem management, given that natural disturbance regimes play a role in controlling landscape composition and ecological function by influencing species composition and stand development. The natural disturbance paradigm assumes that if we emulate natural disturbances, including rates of change, we will be able to maintain a variety of patch sizes and species compositions that are characteristic of a *natural landscape*.

The purpose of note is to promote awareness and understanding of natural disturbance regimes that operate within the eastern Canadian boreal mixedwood forests. Practitioners are encouraged to consider the forests for which they are the stewards and to reflect upon how disturbance regimes have influenced current forest and stand conditions including their compositional and structural attributes and their growth and productivity. Variations in local site conditions interact with disturbance regimes to affect stand development and how these differences manifest themselves at both larger (landscape) and smaller (within stand) spatial scales. We hope that readers will creatively reflect upon how silviculture activities and interventions can be used in the *managed* forest to create stands and

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landscapes with compositional and structural attributes similar to those resulting from natural disturbance regimes. The premise is that if the effects of forest management activities closely resemble those of natural disturbances, native species habitat and associated ecological processes will persist, helping to ensure that biodiversity is maintained (Parminter and Daigle 1997).

Natural Disturbance Events

Natural disturbances create landscape and stand patterns. Variables associated with natural disturbances, such as type, frequency, size, and intensity affect each ecosystem differently, thus creating a mosaic of landscape patterns with different attributes (i.e., relative abundance of stand development stages, habitats, and connective or edge components). At broad scales, disturbances affect landscape composition, patch size, stand age, and distribution of specific forest types. At finer scales, disturbances influence individual stems or groups of stems, shaping the species composition and structural characteristics of individual stands (Simard 1997).

Disturbance events occur at different intensities. Two broad categories of intensity referred to throughout this note are the notion of stand-replacing and non-stand-replacing (or 'gap' type) disturbances. Stand-replacing disturbance events are intense, often act over large areas, and can significantly change the composition and structure of a stand and groups of stands, or forested landscape, in a very short time. These events tend to return stands to the initiation stage, and create significant levels of variability and heterogeneity on the ground (Andison 2001), even when even-aged stands are created (FSC undated). The most common example of a stand-replacing natural disturbance event is a wildfire, but catastrophic wind damage is another possible agent.

Non-stand-replacing disturbance events result in the creation of canopy gaps, and can contribute to ecosystem fitness and resilience by eliminating less fit and overmature trees in both the understory and main canopy layers. A single tree or a group of trees may be involved, as is the case with windthrow or a low-intensity understory fire.

Disturbance Agents

Natural disturbance agents can be categorized as abiotic (e.g., fire, wind, drought, erosion, flooding, snow/ice) or biotic (e.g., insects, diseases). The primary natural disturbance agents operating on the boreal landscape are a mixture of both biotic and abiotic agents: fire, wind, drought, insects and disease. Anthropogenic disturbances include timber harvesting and other silvicultural activities (Ward and Tithecott 1993, Scarratt 1996, Lautenschlager 1997).

The integrated effects of the abiotic and biotic disturbance agents operating at one or more hierarchically integrated spatial scales give character and definition to the natural disturbance regime operating within a forest. Most tree, plant and animal species and communities in northern ecosystems have evolved and developed adaptations to survive, and in some cases even thrive following large-scale disturbances such as forest fires and insect outbreaks, as evidenced by their occurrence, abundance, and diversity following disturbance events (Bendell 1974, Larsen 1980, Kimmins 1987, Kuusela 1990). For an individual stand, current species composition and future successional pathways are influenced by more than just local site conditions. The nature and frequency of disturbances, pre-disturbance stand composition, and the time elapsed since the last major disturbance all influence forest development (Scarratt 1996).

Fire

In Ontario's boreal forest, fire and spruce budworm infestations are the two inter-related natural disturbance agents with the greatest effects on forest dynamics (Johnson 1992, Englemark *et al.* 1993, Payette 1992, Weber and Flannigan 1997). Ontario's boreal mixedwood forest is a fire-dependant ecosystem acquiring its character, vigour, and faunal and floral diversity from the fire regime (Alexander and Euler 1981).

Fires vary in size and intensity. In boreal Ontario, stand-replacing crown fires are common, causing high tree mortality and stand replacement (Thompson 2000). Non-stand-replacing surface fires also occur (Bergeron *et al.* 2002), creating small openings in the forest by killing young, shade-tolerant trees and shrubs, but few mature trees. Few details are available about fire cycles and return intervals in forest conditions other than boreal.

It is known that the natural fire cycle varies across Ontario's boreal forest region. Turner and Romme (1994) and McRae *et al.* (2001) summarize the fire cycle for the boreal forest as approximately 20 to 500 years, while others offer a more conservative estimate of 20 to 300 years (Johnson *et al.* 1999, Dansereau and Bergeron 1993, Gauthier *et al.* 1996, Ward and Tithecott 1993, Van Wagner 1978, Heinselman 1981, Cogbill 1985, Bergeron and Harvey 1997). Some stands may burn more than once during a fire cycle, further affecting patch mosaic development. Fire return intervals are shorter in the northwest and north central parts of the province than in the northeast because of differences in precipitation gradients and forest cover conditions (Thompson 2000).

Human activities and climatic variations also influence forest fire dynamics (Lefort *et al.* 2003); for example, a reduction in burned area has been observed in many regions of Canada (Suffling *et al.* 1988, Masters 1990, Bergeron 1991, Johnson and Larsen 1991, Johnson and Wowchuk 1993).

Although small fires that burn less than 100 ha are most frequent, it is the largest fires that contribute to large-scale changes in landscape composition and structure (Heinselman 1973, Johnson 1992, Flannigan 1993). Fires tend to be smaller in deciduous and mixed stands regardless of fire weather indices. Based upon an analysis of historic fire records for Ontario in which all fires greater than 200 hectares were recorded, the mixedwood portions of Ontario's boreal forest region generally had an abundance of smaller fires (Perera *et al.* 1998), while larger fires that were fewer in number characterized the coniferous region (Bergeron *et al.* 2000, Thompson 2000). Coniferous fuel types exhibit higher rates of fire spread than mixedwood and deciduous fuel types under similar weather and topography (Van Wagner 1983, Forestry Canada Fire Danger Group 1992, Kafka 1997, Weir and Johnson 1998). Also, conifer forests usually give rise to higher intensity fires and more frequent fires than hardwood-dominated forests (Flannigan 1993).

Changes in landscape structure following fire disturbance depend on fire intensity, season, soil moisture, and availability of a seed supply. In the absence of fire, forest structure and composition are closely linked to other disturbances, especially outbreaks of spruce budworm (*Choristoneura fumiferana* Clem.) and windthrow, both of which are common in eastern Canadian boreal forests. Advanced regeneration on many logged sites favours the continued presence and increased abundance of balsam fir (*Abies balsamea* (L.) Mill.) that historically would have been reduced by wildfires. Advanced balsam fir regeneration can compete with more commercially desirable conifers, such as white (*Picea glauca* (Moench) Voss) and black spruce (*Picea mariana* (Mill.) BSP). Balsam fir also provides a preferred source of food and habitat for spruce budworm, allowing the budworm to maintain endemic populations that can initiate another infestation as soon as the trees reach maturity (McRae *et al.* 2001). Balsam fir-dominated forests are more prone to spruce budworm outbreaks and windthrow as they age (Ruel 1995), yet the probability of burning is independent of stand age (Johnson 1992).

Wind

In the absence of fire, wind is an important agent of succession in the boreal forest (Carleton and Maycock 1978, Johnson 1992, Kneeshaw and Bergeron 1998). However, because of relatively deeper roots, trees in boreal mixedwoods are less prone to blowdown than those for example in lowland black spruce stands growing on organic soils (Chen and Popadiouk 2002). Windthrow potential may be influenced by many inter-related factors including tree and stand attributes (tree height, stem taper, root development, age and condition, species, stand density, and edge effects), site condition (soil moisture, soil depth, depth to a root restricting layer, and topography), and local wind characteristics. At the stand level, mixed species stands with a proportionate mixture of wind-prone and wind-resistant species as well as a contour of irregular edges are most stable (Navratil 1995).

Wind damage (uprooting and stem snapping) can be either a stand-replacing or non-stand-replacing disturbance. However, although the former is associated with stand replacement (destruction of the tree canopy), some stand structure usually remains. The latter type of wind damage, generally associated with smaller-scale wind events, results in single- or multiple-tree canopy gaps.

Drought

Drought can also affect boreal mixedwood sites. While drought stress directly affects forest vegetation, of more concern are its interactions with secondary disturbance agents, such as insects and disease organisms, that kill drought-stressed and weakened trees. Similarly, drought can add to the stress caused by insect defoliation, resulting in mortality.

Drought may benefit populations of some major insect pests. For example, Sanders *et al.* (1978), Lucuik (1984), and Mattson and Haack (1987) suggest that the warmer and drier conditions of drought increase reproduction and survival of the spruce budworm. Drought conditions also stimulate flowering in jack pine, which increases the survival of jack pine budworm (*Choristoneura pinus*) (Nealis and Lomic 1994).

Snow and Ice

Snow and ice also operate as disturbance agents in Ontario's boreal forest. Damage from these agents includes crown or stem breakage, stem bending, and uprooting of trees. However, as with wind, the extent of damage from these agents depends on tree and stand attributes, site condition, and local meteorological conditions. Damage can be either stand replacing or non-stand replacing.

Relatively few studies have investigated the effects of meteorological factors such as snow and ice as disturbance agents in boreal mixedwood stands. Gill (1974) looked at the effects of a major snowstorm that hit boreal mixedwood stands in northern Alberta. He observed that:

- damage was patchy, and generally occurred where there was an abrupt change of forest cover type
- deciduous species were damaged more frequently and to a greater extent than conifers (in part due to the upswept branches that form a greater cross-sectional area when pushed down)
- mature and over-mature trees were more subject to damage in uneven-aged stands
- stem breakage height increased with increasing stand density and distance from a clearing
- stem breakage height was not associated with trunk rots or other structurally weakening factors
- trees less than 8 cm dbh suffered minimal stem breakage although chronic bending was prevalent in many locations
- damaged trees generally had a higher 'tree form or slenderness coefficient' (ratio of the total height of the tree to its dbh) than undamaged trees

No published studies were found on the influence of ice damage on succession in boreal mixedwood stands.

Insects

Insect outbreaks are ubiquitous in the boreal forest (Blais 1983, Morin 1994). In fact, as a disturbance agent, insects have twice the impact of fire (Hall and Moody 1994). In Canada, average annual volume losses to the spruce budworm alone total approximately 75% of the loss to fire (Hall and Moody 1994). Their cyclical outbreaks typically result in continuous damage over several years. Along with tree mortality, insects also affect the forest landscape pattern indirectly by rendering trees susceptible to disease, windthrow, extreme cold, drought, or fire (Thompson 2000). The spruce budworm, jack pine budworm and forest tent caterpillar (*Malacosoma disstria)* are most likely to affect the defining boreal mixedwood species.

Spruce budworm is considered the most important biotic disturbance agent in Ontario's boreal forest (Prebble 1975c, Howse 1981, Howse 1995). Outbreaks of the pest have recurred in 8- (Howse 1981) to 70-year intervals (Blais 1983*)*, and defoliate and kill trees over large areas for periods of 2 to 4 years (Howse 1981), 8 years (Prebble 1975c), and even up to 10 to 15 years (Blais 1983). Although spruce budworm infestations in eastern Canada occur in white spruce or white spruce-dominated stands, the most extensive and destructive outbreaks have occurred in balsam fir-spruce stands, especially those with significant proportions of older balsam fir (Prebble 1975c, MacLean and Ostaff 1989, Bergeron *et al.* 1995). Hardwood-conifer mixtures are less vulnerable, both at the stand and the landscape level, to outbreaks of spruce budworm (Prebble 1975c, Bergeron *et al.* 1995) than conifer-dominated stands. This is the result of several factors including the ability of mixed stands to host a greater abundance of spruce budworm parasitic enemies (Cappuccino *et al.* 1998).

Fire suppression, coupled with the afforestation of abandoned agriculture land and the dominance by fir and white spruce arising from old field succession on abandoned agricultural land, are thought to have increased the importance of insect pests such as eastern spruce budworm, red pine cone beetle (*Conophthorus resinosae*), and white pine cone beetle (*C. coniperda*) (Miller 1978, Blais 1985, Wade *et al.* 1989). The occurrence and extent of spruce budworm outbreaks appear to have increased (Blais 1983, Blais 1985, Morin *et al.* 1993) in part due to the increase in time elapsed since the last fire (longer fire cycle) (Bergeron and Dubuc 1989).

Although there are a number of fire/disease and fire/insect interactions in the boreal mixedwood forest, the association of fire with spruce budworm is paramount. Stocks (1987) notes that stands with high levels of budworm-caused mortality (or that resulting from other pathogens) are pre-disposed to fire. In fact, Prebble (1975c) claims that several of the more massive forest fires in eastern Canada can be attributed to the presence of budworm-killed trees across large contiguous portions of the forest.

Jack pine is the principal host species of the jack-pine budworm, but other species of pine and spruce are attacked as well (Howse 1995), especially when they occur in stands with jack pine (Prebble 1975b). Although jack pine budworm is a close relative of the aforementioned spruce budworm, its effect on forested landscapes isn't as severe (Prebble 1975b). Outbreaks occur at approximately 10-year intervals and may last 2 to 4 years (Howse 1986, Volney and McCullough 1994). Large-scale outbreaks have occurred in northwestern Ontario and smaller infestations have been detected in the southern and eastern parts of the province. The jack pine budworm can cause pockets of mortality following repeat defoliation (Prebble 1975b, Howse 1995), but usually reduces tree growth and kills understory trees (Gross 1992, Hopkin and Howse 1995).

The forest tent caterpillar, which feeds primarily on aspen in the boreal forest, is a significant biotic disturbance agent. Outbreaks regularly occur in 10- to 11-year cycles (Prebble 1975a, Howse 1995, Roland 1999), usually for relatively brief but dramatic periods (2 to 4 years or longer), wherein the zone of active defoliation can increase from hundreds to millions of hectares in 2 to 3 years. Forest tent caterpillar feeding generally causes low levels of localized tree mortality, although the risk of mortality does increase with repeated defoliations (Hildahl and Reeks 1960). Forest tent caterpillar recently caused widespread mortality of aspen in northeastern Ontario following close to 8 years of repeated defoliation during drought conditions (Keizer and Melbourne 2002). Also, branch and tree mortality tends to occur more frequently on nutrient poor, xeric to dry sites, especially if trees are exposed to another stress like drought after defoliation (Prebble 1975a).

Diseases

Although diseases in the boreal forest do not operate with the same intensity and at the same spatial scales as fire or insects, they shape the character of the forested landscape by causing mortality of susceptible stems (e.g., trees weakened by spruce budworm attacks; Basham 1981) and creating canopy gaps. Fungal stem decay and root rot diseases, such as Armillaria *(Armillaria spp.)* and Tomentosus *(Inonotus tomentosus)*, primarily affect older conifer and hardwood stands on a site-specific basis and are a component of the biological legacy of a site; i.e., generally exist on the site prior to the establishment of the current stand. Many fungi that cause rot cannot penetrate intact, healthy bark or sapwood; they usually enter via dead broken tops, dead branches and stubs, trunk wounds, or the root system (i.e., root- or butt-rotting fungi) (Basham 1981).

Unlike areas where there have been large fires, massive blowdowns, or spruce budworm epidemics, dead and wind-felled trees caused by root rot are usually scattered and in various stages of deterioration. Another defining characteristic of disease-related disturbance, at least in the case of root rot, is that the losses are continuous rather than periodic (Whitney 1981). For more information on these and other tree diseases in boreal mixedwood forests, refer to Greifenhagen (2003) and McLaughlin (2003).

The Emulation Silviculture Concept

The concept of using natural disturbance templates for ecosystem management has received much attention. At the landscape level, natural disturbance emulation includes maintaining structure, composition and pattern within the limits of modelled stochastic variability, reflecting our understanding of the historic forest condition and the natural disturbance regime (Mladenoff *et al.* 1993, Landres *et al.* 1999). At the stand level, ecosystem management implies the use of silvicultural systems inspired by natural dynamics that maintain the structural and biotic attributes or legacies of natural stands (Seymour and Hunter 1992, Franklin 1993).

Hunter (1993) identifies three ways in which timber harvesting practices can emulate natural disturbance at the landscape scale:

- The *frequency of harvest* can be matched to the frequency of natural disturbance,
- The *total area*, *size* and *distribution of harvest blocks* can be matched to the total area, size and distribution of openings created by natural disturbance, and;
- The *amount of residual organic material left on site* after harvest can be matched to that which would be left after a natural disturbance.

The development of silvicultural strategies that are based on the emulation of natural stand dynamics involves several steps. Firstly, natural disturbance regimes must be well-understood (Attiwill 1994). While identifying disturbance agents is not difficult, identifying disturbance regimes (intensity, frequency, etc.) can be because disturbance regimes vary with regional climate and biophysical conditions and over time. Secondly, reconstruction of historical disturbance patterns can be helpful. This is best done in areas relatively unaffected by anthropogenic disturbances, such as the northern boreal forest. A variety of sources, including inventory, fire, and insect infestation historical maps and qualitative information can be useful in this regard. The next step consists of developing or adapting silvicultural interventions and treatments to create stand conditions characteristic of those resulting from natural disturbance dynamics. The final step prior to implementation should involve simulation modelling to determine whether the proposed portfolio of silvicultural activities and their scheduling through successive planning periods will contribute to the desired future forest condition over the medium- to long-term. The silvicultural approach should aim to preserve the key ecosystem processes and landscape patterns (MacDonald 1995).

Most efforts to create a natural disturbance template for forest management have focused on emulating stand-replacing fire (Armstrong *et al.* 1999, Armstrong 1999, OMNR 2001, Bergeron *et al.* 2002). Armstrong (1999) suggests that this is because fire is the most important and visible natural agent of change in the boreal forest.

As discussed above, many researchers have tried to calculate the fire return interval in various areas of the boreal mixedwood forest. These numbers are important to forest resource managers as they attempt to emulate the frequency of natural disturbances in forest stands using harvesting and silvicultural activities. In Ontario, the natural disturbance rate is not used to determine harvest rate. Rather, it is used primarily to model and assess landscape patterns arising from proposed harvest activities. Alternatives include variable rotation management strategies (Stelfox 1995) or using models that constrain forest structure to fall within acceptable bounds of modelled variation in landscape composition (cover type and age class) (see Cumming *et al.* 1994). Moving from sustained yield to natural disturbance models of forest management can have tremendous implications for the timber supply potential of an area, and choosing the natural disturbance rate appropriate for a forest is both difficult and risky (Armstrong *et al.* 1999).

Emulating stand-replacing disturbance

Telfer (1974), Dolgaard *et al.* (1976), and Euler (1977) assert that certain forest and vegetation management practices can duplicate fire effects and in some cases create habitat suitable for wildlife. For example, McRae *et al.* (2001) has suggested that both logging and fire generally increase species diversity immediately following disturbance until the stem exclusion stage and the onset of crown closure. Also, the retention of both living and dead-standing stems or groups of stems during harvest activities will contribute to the conservation of habitat structure in the regenerating stand. At the landscape level, the distribution of stands by size class, their spatial relationships to each other, and the area and types of stands selected for harvest may be managed to emulate the patterns left by wildfire (Armstrong 1999).

Stand-replacing fires result in abrupt changes in the pattern of forest patches across the forest landscape and clearcut harvesting produces similar changes in the forest mosaic (Li 2000). Both fire and clearcutting also affect soil moisture and temperature relationships, climate near the ground, and the interception and retention of moisture from precipitation. During intense wildfires, losses of biomass and nitrogen to combustion can be comparable in magnitude to what would be removed by harvesting comparable stands (McRae *et al.* 2001).

There are, however, many differences between wildfires and clearcuts (Harvey *et al.* 1995, Gordon

Table 1. *A comparison of the effects of clearcuts and wildfires at various scales.*

Issue	Result from stand-replacing fires	Result from clearcut harvesting
Large patches and peninsulas of unburned trees (affects the distribution, abundance and movement of wildlife) [1]	More [1,2]	Less [3,4], but application of NDPE Guide (OMNR 2001) should help remedy this
Permanent roads (remove natural habitat, alter drainage and stream dynamics, cause erosion, introduce edge effects, fragmentation and corridor for non-native species) [5,6,7,8,9]	Not generally associated with fire suppression activities	Important part of silvicultural activities Could cause long-term negative effects for species dependant on certain structure and ecosystem processes for reproduction and survival [10,11, 12,13]
Effects of change in structure and ecosystem processes on wildlife and other biota	Biotic organisms have multiple adaptations developed over long periods	Generally, cyclical rotation of similarly composed stands [14]
Stand succession	Some stands return to start of succession cycle through fire activity, while others continue through natural successional transitions	Differences in spatial patterns of canopy disturbance, forest floor disturbance, species composition, biomass and nutrient accumulation, and nutrient availability [18]
Structure and function of ecosystems [15,16,17]	Differences in spatial patterns of canopy disturbance, forest floor disturbance, species composition, biomass and nutrient accumulation, and nutrient availability [18]	
Shape of disturbed areas [19]	Elliptical shape with irregular edges	Not generally in an elliptical shape – usually straight line boundaries with a uniform edge; application of NDPE Guide (OMNR 2001) may help remedy this
Tree and vegetation removal/ retention [20]	Leaves standing dead trees and some live trees, and removes understory vegetation	Removes large trees but retains understory vegetation [21]
Stand-age distribution, especially in older age classes	Retained in many regions	Generally not retained [22]
Number of snags and amount of coarse wood left on site [22,23,24,25,26,2]	Considerable	Generally full-tree and tree-length harvesting leaves few standing trees and not much large debris, but application of NDPE Guide (OMNR 2001) will change this
Post-disturbance vegetation	Abundant conifers except balsam fir [27,28], which is temporarily eliminated from burned sites [34,30]	Abundant hardwoods [29,30,28,31,24,33]; balsam fir may constitute much of the advanced regeneration [2]
Retention of calcium, phosphorus, potassium and magnesium contained in tree biomass [35,36,37,2]	Conserved in situ	May be removed from the site
Soil compaction	N/A	Issue linked to heavy equipment on skidding lanes [38], especially on sensitive sites
Soil profile disruption	Much of the litter and forest floor may be consumed during wildfire, yet underlying profiles remain intact [2]	Limited forest floor disturbance due to churning by harvesting machinery [39,40,41,42,43]

[1] Kafka et al. 2001; [2] McRae et al. 2001; [3] Bergeron 1991; [4] MacDonald 1995; [5] Forman 1995; [6] McGurk and Fong 1995; [7] Evink et al. 1996; [8] Haskell 2000; [9] Jones et al. 2000; [10] Hobson and Schieck 1999; [11] Imbeau et al. 1999;; [12] Drapeau et al. 2000; [13] Voigt et al. 2000; [14] Harvey et al. 1995; [15] Gluck and Rempel 1996; [16] Johnston 1996; [17] Bergeron et al. 1999; [18] Johnston and Elliott 1996; [19] Alexander 1985; [20] DesGranges and Rondeau 1993; [21] Thompson 1993; [22] Harmon et al. 1986; [23] Covington and Sackett 1992; [24] Freedman et al. 1994; [57] Freedman et al. 1996; [26] Fleming and Freedman 1998; [27] Furyaev et al. 1983; [28] Carleton and MacLellan 1994; [29] Van Wagner and Methven 1978; [30] Payette 1992; [31] MacDonald 1996; [32] Davidson et al. 1988; [33] Heinselman 1996; [34] Carleton and Maycock 1978; [35] Freedman 1981; [36] Freedman et al. 1986; [37] Chrosciewicz 1990; [38] OMNR 2001; [39]Greacan and Sands 1980; [40] Froelich and McNabb 1984; [41] Waring and Schlesinger 1985; [42] Freedman 1995; [43] Kimmins 1997

1996, Lautenschlager *et al.* 1997, Thompson 2000, McRae *et al.* 2001) (Table 1). One of the most obvious is that fire is a chemical process, while harvesting is a physical and mechanical process (OMNR 2001). In Ontario, emphasis is on the emulation of patterns resulting from natural disturbance regimes.

Emulating gap-type disturbance

In trying to emulate gap-type stand disturbances, the aim should be to maintain substantial canopy cover, a mixed-age distribution of overstory trees, and sufficient regeneration in the understory to contribute to a new cohort of more shade-tolerant individuals within the stand. On boreal mixedwood sites, balsam fir tends to be the most important species in canopy gaps, due to its relatively high shade tolerance, high rate of seed production, and ability to germinate and survive on undisturbed organic material (Fowells 1965, Carleton and Maycock 1978, Kneeshaw and Bergeron 1998). If balsam fir has not successfully regenerated under competition, some large gaps may remain open and become dominated by dense shrubs for a long period (Ghent *et al.* 1957, Kneeshaw and Bergeron 1996). Kneeshaw and Bergeron (1998) found that most gaps in boreal forests dominated by old balsam fir were less than 100 m^2, while in younger forests most gaps were less than 50 m^2. However, gaps greater than 3,000 m^2 were also reported.

Given that spruce budworm outbreaks produce varying gap sizes (as well as variable overstory mortality; Blais 1983), Forbes (1997) suggests emulating the effect of such a disturbance by creating a variety of gap sizes via selection cuts in conifer-dominated and conifer-conifer mixtures. Bergeron *et al.* (1998) suggest applying careful logging with protection of advanced regeneration and the soil. However, although the effects of careful logging may mirror those resulting from a spruce budworm outbreak, this silvicultural practice does not necessarily generate the vertical structure (i.e., residual trees) and abundance of snags characteristic of post-budworm infestated stands.

The Forest Management Guide for Natural Disturbance Pattern Emulation (NDPE Guide; OMNR 2001) provides limited direction on maintaining the mostly uneven-aged state of boreal mixedwood forests. These stand characteristics can be achieved through the retention of advanced growth and natural age class structures and partial harvest methods such as HARP (Harvesting with Advance Regeneration Protection), CLAAG (Careful Logging Around Advanced Growth), and other methods of harvesting with understory protection.

Emulation silviculture at the landscape level

Special consideration is required to ensure that natural disturbance attributes are emulated not only at the stand-level, but also at the landscape level. To maintain a specific structure or composition of over-mature stands in managed forests and to favour transitions from one stand type to another, Bergeron and Harvey (1997) suggest silvicultural practices and scheduling that may maintain species and ecosystem diversity with minimal effects on allowable cut (Figure 1). Consistent with this intent, the first cohort, originating from fire, is replaced by clearcutting and planting or seeding, the second cohort by partial cutting that emulates natural succession, and the third cohort by selection cutting that mimics the natural gap dynamics of old growth stands. This way, a range of stand-replacing and non-stand-replacing disturbance is emulated on a forest. The proportion of stands treated by each of these silvicultural practices will vary in relation to the natural disturbance cycles and the maximum harvest age for the species and cover types (Bergeron *et al.* 1999, Bergeron *et al.* 2002). Since in nature not all stands develop to a mature or old-growth stage before being burned and returning to an early successional stage, not all stands will pass through the three cohorts.

Modelling as a tool for emulation silviculture

Silvicultural emulation of natural disturbances requires computer-based decision support tools to assist planners in applying principles of natural disturbance to operational aspects of sustainable forest management (Rempel 1999). Modelling is a useful management tool that incorporates important elements of historic variability, including site history, natural disturbance regimes and successional processes. The value of biological legacies should also be a component of these models. Fire process models can also be used to simulate fires over large landscapes and long temporal scales to help understand fire dynamics (Li *et al.* 1996, 1997, Li 2000).

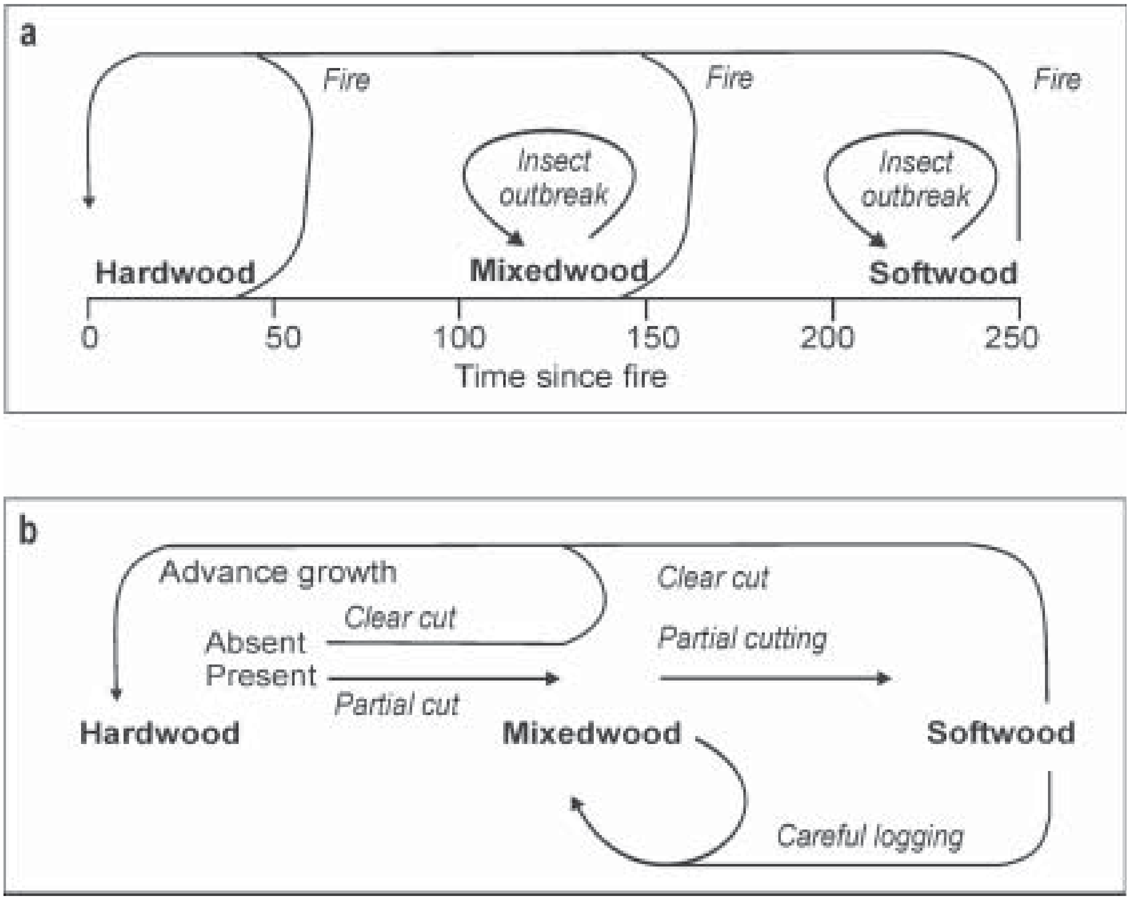

Figure 1. *Models presenting (a) natural dynamics and (b) a proposed silvicultural strategy for mixedwood sites in the Lake Duparquet Research and Teaching Forest (from Bergeron and Harvey 1998).*

Discussion

As emulation silviculture is a relatively new field of study, there is a need to assess the empirical evidence supporting its application. Given our limited understanding of natural disturbance regimes and their variability across stands and landscapes, we should proceed with caution, using the concept as a guide or framework rather than as a conclusive solution (Landres *et al.* 1999).

More study is needed to determine how our understanding of the occurrence of natural disturbances can guide the spatial distribution of forestry interventions and how these might differ for boreal mixedwoods relative to pure species stands. Criteria should be drawn from our understanding of natural disturbances as well as from objectives aimed at conservation and valuing the economic potential of non-wood resources (Welsh and Venier 1996). Elements such as biodiversity conservation, and the importance of maintaining sufficiently extensive residual forested areas to maintain interior wildlife species should also be taken into consideration (Hunter 1987, Rolstad 1991).

In practice, emulation silviculture will always be a compromise between what is economically feasible and what is socially acceptable. However, no matter which natural disturbance emulation practices are selected, a careful experimental approach will be required to evaluate the effects of complex disturbance patterns and their similarity at the microsite, stand, and landscape level when applied across a landscape gradient.

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Notes

Boreal Mixedwood Site, Vegetation and Soil Types in Northeastern Ontario

by R. Arnup[1]

The northeast ecological land classification system provides a framework for accumulating and applying knowledge about mixedwood forests gained from management experience and research. The "language of site" inherent in the NE-ELC aids communication between managers. The site, soil and vegetation types provide a means of recognizing and describing

Introduction

To develop effective management options for mixedwoods, it is important to identify the specific site, soil and vegetation conditions that characterize an area. This can be accomplished by applying the ecological land classification system for northeastern Ontario (NE-ELC) as described in McCarthy *et al.* (1994). The NE-ELC provides a framework for accumulating and applying knowledge about mixedwood forests gained from management experience and research. The "language of site" inherent in the NE-ELC system aids communication between resource managers.

The NE-ELC system has three components: site, vegetation and soil types. The different types occur at different scales in the landscape. Site types are the broadest elements and may comprise several different soil and vegetation types. While site types are well-suited for mapping and for silvicultural decision-making, the more detailed information contained in the soil and vegetation types may be useful for certain research and management purposes, such as understanding forest succession or characterizing biological diversity. The site, soil and vegetation types provide a means of recognizing and describing different boreal mixedwood forest conditions.

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Ontario

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Boreal mixedwood sites are areas with climatic, topographic and soil conditions that favour the production of: i) closed canopies dominated by trembling aspen or white birch in early successional stages, ii) black spruce or white spruce in mid-successional stages, and iii) balsam fir in late successional stages. These sites typically occur on well-drained, fertile soils on mid-slope positions, and exclude wetlands, dry sandy soils and shallow soils over bedrock. Mixedwood stands must contain a component of one or more of the five defining tree species (trembling aspen, white birch, black spruce, white spruce and balsam fir). A variety of associated species can be present as well, provided that the basal area of any one species is not greater than 80% (MacDonald and Weingartner 1995).

This note will identify and describe the NE-ELC site, vegetation and soil types that occur in boreal mixedwood forests in northeastern Ontario. Relationships between the vegetation and soil features will be discussed in the context of boreal mixedwoods. Further descriptions of the use and characteristics of the NE-ELC system components can be found in McCarthy *et al.* (1994).

Site Types

The NE-ELC site types (ST) identify management-oriented groupings of vegetation on specific ranges of soil conditions. There are seven STs that comprise mixedwood forests. Figure 1 highlights the edaphic conditions corresponding to boreal mixedwood sites (well-drained, fertile soils on mid-slope positions) on the NE-ELC site type diagram (adapted from McCarthy *et al.* 1994). The diagram plots average values for each site type on axes of soil moisture regime and herb species richness. Moisture regime is related to topographic position and hydrologic factors, while species richness is related to site capability, which is influenced by soil nutrient availability, microclimate and stand history.

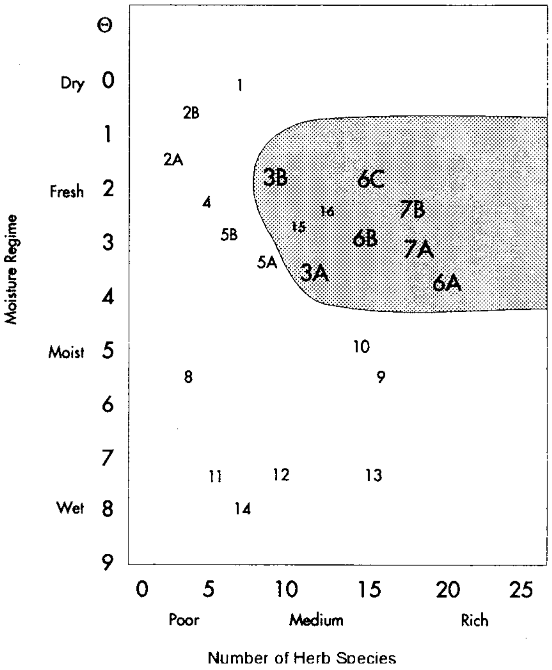


Figure 1. Boreal mixedwood site types in northeastern Ontario.

STs were defined on the basis of differences in the understorey vegetation, although they were often associated with distinctive overstorey types. The "3," "6," and "7" series STs have similar understorey vegetation, but occur on different soil conditions as indicated by the "A," "B," and "C" annotations. Table 1 summarizes the occurrence of some common trees and woody shrub species associated with these site types. Some of the variance in the occurrence and abundance of understorey vegetation can be related to the site's soil texture, nutrient status, moisture regime and canopy composition.

In STs 3a and 3b, the richness of the herb layer is poor to medium, with the fewest number of species, on average, of all mixedwood STs. This may be due to the better-drained, less nutrient-rich, coarse-textured soils on which they occur. Abundant herb species include large-leaved

Table 1. Occurrence[a] of some common tree and shrub species in boreal mixedwood site types in northeastern Ontario.

Species	**Site type[b]** **3a**	**3b**	**6a**	**6b**	**6c**	**7a**	**7b**
Trees							
Abies balsamea	2	1	1	4	1	1	1
Betula papyrifera	0	2	1	2	3	1	2
Picea mariana	3	3	5	3	2	1	1
Picea glauca	1	2	1	3	3	2	3
Pinus banksiana	5	6	2	5	3	1	1
Pinus resinosa	0	1	0	0	1	0	0
Pinus strobus	0	0	0	1	1	0	0
Populus balsamifera	1	0	3	2	0	2	1
Populus tremuloides	6	6	6	6	7	8	8
Thuja occidentalis	0	0	0	0	1	0	1
Woody shrubs							
Acer spicatum	2	3	2	3	8	7	8
Alnus incana	2	0	5	3	0	4	2
Amelanchier spp.	6	6	8	8	6	5	4
Corylus cornuta	2	3	3	5	8	6	7
Diervilla lonicera	8	9	6	7	8	6	8
Ledum groenlandicum	5	3	1	1	0	0	0
Lonicera spp.	0	2	6	6	7	9	6
Prunus virginiana	0	0	0	1	1	3	4
Ribes spp.	0	0	7	6	3	8	6
Rosa acicularis	3	3	10	6	4	7	4
Rubus idaeus	1	1	3	2	3	4	4
Sorbus spp.	5	5	6	8	5	6	4
Vaccinium angustifolium	8	9	3	6	6	2	2
Viburnum spp.	2	1	5	4	2	8	3

[a] Numbers in the table represent the percentage of sample plots in which the species occurred (e.g., 10 = 100% of samples, 9 = 90%).

[b] Site type names: 3a = Mixedwood - medium soil; 3b = Mixedwood - coarse soil; 6a = Mixedwood - fine soil; 6b = Conifer mixedwood - medium soil; 6c = Hardwood mixedwood - coarse soil; 7a = Hardwood - fine soil; 7b = Hardwood - medium soil.

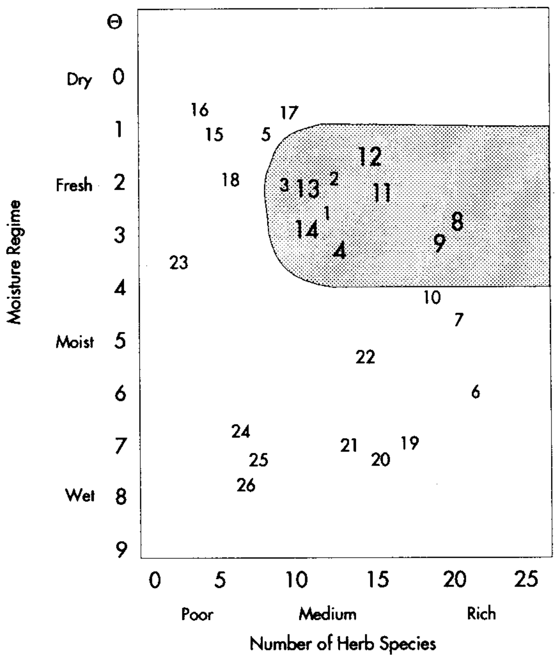
aster (*Aster macrophyllus*), bluebead lily (*Clintonia borealis*) and wild lily-of-the-valley (*Maianthemum canadense*), which also occur on most other mixedwood STs. Bush honeysuckle (*Diervilla lonicera*) is an abundant shrub species. Ericaceous shrubs (e.g., Labrador-tea, *Ledum groenlandicum*; sheep laurel, *Kalmia angustifolium*; and blueberry, *Vaccinium* spp.) are more abundant in these STs than in other mixedwood types.

In the ST 6 series, the abundance of herbs and shrubs is generally intermediate between ST 3 and the richer ST 7s. The herb layer composition is generally medium to rich on silty soils, loams and sandy loams (ST 6b), and on coarse loamy soils (ST 6c); and herb-rich on fine soils (ST 6a). On the rich, fine soils (ST 6a), conifer-dominated stands occur, which creates more acidic soil conditions, encouraging the development of feathermosses, reducing nutrient exchange and tempering vegetational development. On the poorer, coarse soils (ST 6c), deciduous litterfall from the hardwood–dominated stands enhances soil nutrient status.

The ST 7 series comprises hardwood-dominated stands (usually trembling aspen) on loams, sandy loams and silty soils (ST 7b) or fine loamy to clayey soils (ST 7a). These are the most species-rich of mixedwood STs due to the fine, rich soil textures, with their enhanced moisture-retaining properties, and the nutrient-rich litterfall from deciduous species. Both the herb and shrub layers have many species, which generally occur in greater abundance than in either ST 3 or 6. The rich-soil herb species common on these STs include fragrant bedstraw (*Galium triflorum*), naked mitrewort (*Mitella nuda*), rose twisted-stalk (*Streptopus roseus*) and sarsaparilla (*Aralia nudicaulis*). Ferns can be abundant on moist sites. Shrubs that are characteristically abundant on these STs include squashberry (*Viburnum* spp.), gooseberry (*Ribes* spp.), honeysuckle (*Lonicera* spp.) and mountain maple (*Acer spicatum*).

Vegetation Types

The NE-ELC vegetation types identify mature-forest plant communities, based on specific ranges of species composition and abundance. Due to successional processes, different vegetation types can occupy a boreal mixedwood site at different times, depending on disturbance history and landscape factors such as seed sources. Figure 2 highlights the vegetation types that are most commonly asso-



Mixedwood vegetation types are indicated in large type.

Figure 2. Boreal mixedwood vegetation types in northeastern Ontario.

ciated with boreal mixedwood sites. Table 2 illustrates compositional differences between the vegetation types by comparing the frequency of occurrence of some common tree and woody shrub species.

Table 2. Occurrence[a] of some common tree and shrub species in boreal mixedwood vegetation types in northeastern Ontario.

	Vegetation type[b]						
Species	**V4**	**V8**	**V9**	**V11**	**V12**	**V13**	**V14**
Trees							
Abies balsamea	3	1	3	1	1	1	3
Betula papyrifera	8	0	2	1	2	1	4
Picea mariana	0	1	2	2	2	1	6
Picea glauca	0	4	0	0	1	3	6
Pinus banksiana	3	3	0	1	4	5	4
Pinus strobus	10	0	0	0	0	0	0
Populus balsamifera	0	4	2	0	0	0	0
Populus tremuloides	5	8	8	10	8	7	3
Thuja occidentalis	0	0	0	1	0	0	0
Woody shrubs							
Acer spicatum	0	5	3	1	1	0	2
Alnus incana	5	7	5	4	7	6	5
Amelanchier spp.	8	4	7	10	9	3	5
Corylus cornuta	5	7	6	9	9	8	6
Diervilla lonicera	0	1	0	0	0	2	2
Ledum groenlandicum	5	9	9	7	6	2	2
Lonicera spp.	0	2	3	2	1	0	1
Prunus virginiana	3	9	9	3	2	1	1
Ribes spp.	0	9	5	3	5	3	2
Rosa acicularis	0	4	4	3	3	1	1
Rubus idaeus	10	7	8	2	4	7	5
Sorbus spp.	5	3	2	2	8	8	8
Vaccinium angustifolium	0	7	6	3	2	2	0
Viburnum spp.	0	1	9	2	9	6	10

[a] Numbers in the table represent the percentage of sample plots in which the species occurred, e.g., 10 = 100% of samples, 9 = 90%, etc.

[b] Vegetation type names: V4 = White pine mixedwood; V8 = Trembling aspen - black spruce; V9 = Trembling aspen - balsam fir - mountain maple; V11 = Trembling aspen - mountain maple - beaked hazel; V12 = Trembling aspen mixedwood; V13 = Trembling aspen black spruce - blueberry; V14 = White spruce - white birch - feathermoss.

Soil Types

The NE-ELC soil type identifies groups of forest soils based on texture, depth, moisture regime, calcareousness and forest humus form. Figure 3 highlights the soil types corresponding to boreal mixedwood site conditions (well-drained, fertile soils on mid-slope positions). Characteristics of the NE-ELC soil types that are most commonly associated with boreal mixedwood sites are listed in Table 3.

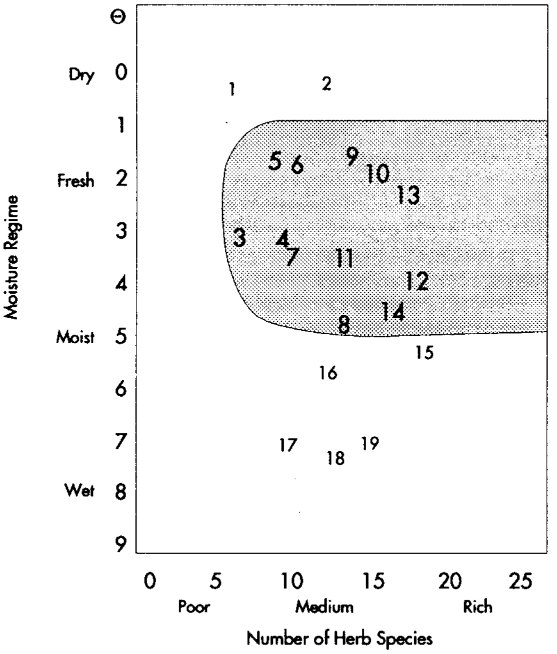


Figure 3. Boreal mixedwood soil types in northeastern Ontario.

Boreal mixedwood sites comprise the fresh to moist, nutrient-rich soils with fine loamy to clayey soil textures; and the fresh to moist, moderately rich soils with coarse loamy to silty soil textures. Soil profile development on these soil conditions is characteristic of the gray luvisol group or the dystric brunisol group respectively. Podzolic profiles, which occur mainly on sandy, acidic, nutrient-poor soils, are rarely found in the mixedwood forest.

Forest humus development varies greatly within mixedwood stands, depending on overstorey and understorey composition, degree of canopy closure, and microclimatic conditions. In general, conifer–dominated stands tend to develop an abundance of feathermosses on the forest floor, which break down slowly and usually form poorly-humified mats over the mineral soil (fibrimor). Shading and litterfall in stands with abundant deciduous species limits the development of the moss layer, resulting in a mat of leaf litter which becomes well-humified (humimor). The richest and warmest stands support the greatest populations of soil macrofauna, which mix and incorporate the humus layers with the uppermost layer of mineral soil (moders and mulls). Soil moisture regime also affects forest humus development in mixedwoods. Thick and well-humified humus profiles occur most commonly on moist sites.

Management Application

The site type describes landscape segments at a scale corresponding to the ecosite level of the ELC hierarchy. Site types can be mapped at scales ranging from approximately 1:50 000 to 1: 10 000. Vegetation and soil types correspond to the eco-element level of the ELC hierarchy, and cannot be mapped at inventory scales. Thus, a landscape segment comprised of a single site type may encompass more than one vegetation and/or soil types (Table 4).

Table 3. Soil types associated with boreal mixedwood sites in northeastern Ontario.

Soil Type	Moisture Regime	Free Carbonates Present	Texture class[a]	Usual mode(s) of deposition
S3	Fresh to moist	No	Sandy	Glaciofluvial
S4	Fresh to moist	Yes	Sandy	Glaciofluvial
S5	Dry to fresh	No	Coarse Loamy	Morainal (till), glaciofluvial
S6	Dry to fresh	Yes	Coarse Loamy	Morainal (till), glaciofluvial
S7	Fresh to moist	No	Coarse Loamy	Morainal (till), glaciofluvial
S8	Fresh to moist	Yes	Coarse Loamy	Morainal (till), glaciofluvial
S9	Dry to fresh	No	Medium Loamy to Silty	Morainal (till); shallow water lacustrine
S10	Dry to fresh	Yes	Medium Loamy to Silty	Morainal (till); shallow water lacustrine
S11	Fresh to moist	No	Medium Loamy to Silty	Morainal (till); shallow water lacustrine
S12	Fresh to moist	Yes	Medium Loamy to Silty	Morainal (till); shallow water lacustrine
S13	Fresh	Yes	Fine Loamy to Clayey	Deep water lacustrine, clay till
S14	Moist	Yes	Fine Loamy to Clayey	Deep water lacustrine, clay till

[a] Texture classes: Sandy = sand and loamy sand; Coarse Loamy = very fine sand, loamy very fine sand, silty sand; Medium Loamy = loam and sandy loam; Silty = silt and silt loam; Fine Loamy = sandy clay loam, clay loam, and silty clay loam; Clayey = sandy clay, silty clay, and clay.

Table 4. List of the vegetation and soil types associated with the NE-ELC site types that meet the defining criteria for boreal mixedwood stands and sites*.

Site type	Vegetation type	Soil type[a]
3a	13^5 14^2	9^2 11^4 12^2
3b	13^5 14^2	$[1\& 2]^4$ 5^2 7^2
6a	7^2 8^3 $(9,13)^2$	13^6 14^4
6b	8^3 12^3 13^3	9^3 10^2 12^4
6c	12^5 $(5, 7, 8, 13)^2$	$[1\&2]^4$ $(5,6)^2$ 7^2
7a	9^5 10^1 $(11, 12, 14)^2$	13^7 14^3
7b	9^3 11^3 $(8, 10, 12, 13)^3$	9^3 10^2 11^3

Superscripts refer to the frequency of occurrence of the soil or vegetation type in the sample (e.g., 9^3 indicates that this vegetation or soil type occurred in 30% of samples for the associated ST).

* The soil types listed in square brackets are dry, sandy soils, which do not meet the criteria for boreal mixedwood sites.

Forest management prescriptions are planned for and applied at the scale of the site type. However, recognizing the spatial distribution of different vegetation types within an area characterized by a single site type will provide information on structural, compositional and successional differences that may assist in refining management prescriptions (e.g. determining species-specific habitat potential or developing site-specific vegetation management prescriptions).

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Notes

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Ecological Framework for the Management of Boreal Mixedwood Sites: Relationships to Ecosite, Vegetation, and Soil Types in Northwestern Ontario

by W.D. Towill[*], L.M. McKinnon[**], and R.O. Wiltshire[***]

> *The complexity inherent in the ecology and dynamics of tree species mixtures constitutes one of the greatest management challenges...*

Introduction

Boreal mixedwood sites occur on well-drained, fertile soils on mid-slope positions across Ontario at latitudes associated with boreal climatic conditions (McClain 1981). These sites are characterized by varying combinations of climatic, topographic, and soil-site conditions that favour the establishment and growth of healthy and productive boreal mixedwood stands (MacDonald and Weingartner 1995). Boreal mixedwood stands are tree communities occurring on boreal mixedwood sites in which no single species comprises over 80% of the basal area. These forests tend to be dominated by one or more of five defining boreal tree species throughout the different stages of stand development. Trembling aspen (*Populus tremuloides* Michx.) and white birch (*Betula papyrifera* Marsh.) tend to dominate in early successional stages, black spruce (*Picea mariana* (Mill) B.S.P.) or white spruce (*Picea glauca* (Moench) Voss) in mid-successional stages, and balsam fir (*Abies balsamea* (L.) Mill.) in late successional stages. Other associated tree species may also occur (MacDonald and Weingartner 1995).

The complexity inherent in the ecology and dynamics of tree species mixtures constitutes one of the greatest management challenges (Smith *et al*. 1997) for two reasons. First, these well-drained, fertile sites have particularly high competition potential (e.g., Groot *et al*. 1997), because total community leaf area (biomass carrying capacity) correlates positively with site quality (rooting volume, moisture, nutrients and depth), as well as with those climatic conditions that favour the establishment, survival, and growth of a diversity of plant species (Grier and Running 1977; Waring *et al*. 1978; see also Gholz *et al*. 1976). Secondly, the high productivity of boreal mixedwood sites also means that these sites can potentially support a high compositional and structural diversity of trees and other plants (Chen and Popadiouk 2002, Popadiouk *et al*. 2003).

Given that forest recruitment, establishment, survival, and subsequent growth and development can differ with climate, as well as landform, soil, and the particular mixture of trees and other vegetation present, some method of stratifying sites based on these factors is essential for effective forest management (Smith *et al*. 1997). The "language of site classification and description" aids communi-cation among resource managers. For example, knowledge of how site factors influence and alter stand dynamics prior to

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and following disturbances and management interventions can help managers anticipate yield and requirements for site preparation, regeneration, and tending.

The purpose of this note is to outline the ecological framework used for the management of boreal mixedwood sites in Ontario, and to describe the linkages between this framework and Ontario's Ecological Land Classification (ELC) (ELCWG, in prep) and the Forest Ecosystem Classification (FEC) system for northwestern Ontario (Sims *et al*. 1997). Individual boreal mixedwood eco-sites (ES), soil (S) types, and vegetation (V) types for northwestern Ontario are identified and described.

The Ecological Framework for Managing Boreal Mixedwood Sites in Ontario

Climate, landform, soil, and species composition are all drivers of variability in forest ecosystems (Bailey 1996, Smith *et al*. 1997), and hence also the successional trajectories observed on boreal mixedwood sites (Chen and Popadiouk 2002, Popadiouk *et al*. 2003). Ecological variability is controlled at the highest level by climate, and at successively lower levels by landform, soil, and associated differences in species composition (Bailey 1996, Smith *et al*. 1997). Accordingly, the first version of recommendations for the management of boreal mixedwood sites in Ontario have been based on this hierarchy of factors (OMNR 2003). The three main hierarchical divisions of the ecological framework for the management of these sites are, in descending order:

- eco-region (representing differences in climate and landform)
- broad soil group (representing differences in soil)
- stand composition type (representing differences in current and/or desired future tree species composition)

Unlike eco-region, which is assessed at a regional scale, the latter two factors are assessed at the scale of landform/slope position or as descriptors of individual sites or stands. Broad soil group appears at a higher level in the hierarchy than vegetation because it is a more stable ecosystem feature (vegetation changes much more rapidly as a result of disturbance and succession) (Bailey 1996). Together, eco-region and broad soil group define a consistent set of environmental conditions that provide an estimate of "site potential". Site potential encompasses potential site productivity, and defines other related opportunities and constraints for management of the site (e.g., selection of a site preparation method). Stand composition type defines biological legacies that may influence the compositional and structural development of the stand following disturbance. These biological legacies determine management opportunities and constraints related to activities such as renewal.

Eco-region

Eco-regions are ecological land units defined by climate and landform originally described by Hills (1961). Boreal eco-regions in the Northwest Region of Ontario include 3S, 3W, 4S, and 4W. These are generally drier than eco-regions in the more easterly boreal portions of the province (OMNR 2003).

Broad Soil Group

Although all boreal mixedwood sites are considered relatively productive, some variation in productivity does exist (Pierpoint 1981). In northwestern Ontario, the most nutrient-rich and productive boreal mixedwood sites are located on deep, fresh to moist, fine to very fine loamy to clayey soils. Moderately productive boreal mixedwood sites are located on deep to moderately deep, fresh to very fresh coarse, loamy soils. Less productive boreal mixedwood site conditions include deep to moderately deep, moist to very moist soils and peaty phase mineral soils. To help account for such differences, boreal mixedwood sites have been classified into four broad soil groups, which were limited to those with soil moisture regimes ranging from 2-5 (OMNR 2003):

- coarse soils (sandy to coarse loamy)
- medium soils (medium loamy to silty)
- fine soils (fine loamy to clayey)
- moist mineral soils (all textures)

In the order listed, these soil groups roughly represent a moisture gradient from dry/fresh to moist, while the nutrient gradient is somewhat more complex, varying with depth, texture and parental material (see OMNR 2003 for a more detailed description of these broad soil groups).

Stand Composition Type

Boreal mixedwood sites can support both pure species stands and boreal mixedwood stands (boreal mixedwood sites only have to have the *potential* to support boreal mixedwood stands; Pierpoint 1981, MacDonald and Weingartner 1995). Nine current stand composition types that can occur on boreal mixedwood sites have been defined in the boreal mixedwood silviculture guide for Ontario (Table 1). Stand composition types other than those listed in Table 1 are also possible on boreal mixedwood sites (e.g., stands with larger components of tree species other than the five defining boreal mixedwood tree species). However, these additional stand types are not covered by the current version of the boreal mixedwood silviculture guide (OMNR 2003).

Relationships Among the Ecological Framework, the Ecological Land Classification, and Northwest Region Forest Ecosystem Classification

Given that the ELC and FEC systems and interpretive tools are used for forest management planning in Ontario (OMNR 2004, ELCWG, in prep;), it is important to understand the linkages between these classifications and the ecological framework described above. These systems provide a systematic and robust framework for accumulating and applying knowledge about mixedwood forests gained from management experience, research and regulatory guides and guidelines. The eco-regions used in the ecological framework are identical to those defined by the ELC. In contrast, the broad soil groups and stand composition types used to represent soil and species composition are not ecological classification units recognized by the ELC or FEC. Instead they describe a non-taxonomic aggregation of eco-sites (site types) and eco-elements (V-types and S-types) for specific boreal mixedwood management purposes.

Strong linkages exist between these FEC classification units and the broad soil groups and stand composition types described above, as

Table 1. *Nine stand composition types that can occur on boreal mixedwood sites. The stand types shown represent those eligible to be managed under Ontario's boreal mixedwood silviculture guide (OMNR 2003). Eligible current stand conditions are restricted to those where tree species other than the five defining boreal mixedwood species comprise <20% of the basal area. Stand composition type is assigned based on current stand conditions that are run through the table in the order listed. Adapted from OMNR (2003).*

Criterion	Stand Composition Type (Current Stand Condition)	Stand Composition (Percent Basal Area)
If a single species exceeds 80%, defined as **pure species stands**	Aspen-pure	Pt (trembling aspen) > 80%
	Birch-pure	Bw (white birch) > 80%
	Softwood-pure (single species)	Sw (white spruce)> 80% or Sb (black spruce) > 80% or Bf (balsam fir) > 80%
If no single species exceeds 80%, defined as **boreal mixedwood stands**	*Hardwood-dominated* Aspen-dominated	80% ≥ Pt > 50% and all conifers ≤20%
	Birch-dominated	80% ≥ Bw > 50% and all conifers ≤20%
	Hardwood-softwood mixes Aspen-leading	(Pt + Bw) ≥ all conifers and Pt > Bw
	Birch-leading	(Pt + Bw) ≥ all conifers and Pt < Bw
	Softwood-leading	50% > (Pt + Bw) > 20% and all conifers > all hardwoods
	Softwood-dominated Softwood-dominated	(Sw + Sb + Bf) > 50% and all hardwoods ≤20% and Sw ≤80% and Sb ≤80% and Bf ≤80%

overviewed in Table 2. Broad soil groups are simply groupings of existing FEC soil (S)-types (S-types were grouped for management purposes). Both stand composition types and FEC vegetation (V)-types describe overstory tree composition, but the latter does so with more precision than the former. In contrast to FEC V-types, stand composition types do not include information about understory species composition, which may also be useful for management purposes.

The remainder of this note details the specific eco-sites, S-types, and V-types that represent boreal mixedwood site and stand conditions in northwestern Ontario. Successional relationships among northwest eco-sites are described in another note in this series (Towill *et al.* 2004).

Boreal Mixedwood Eco-sites (Site Types)

An eco-site, or site type, is a mappable ecological land unit that integrates the abiotic components (soil depth, texture, moisture regime, nutrient regime) and biotic components (plant community composition and structure) of a site (Racey *et al.* 1996). Physical features such as soil depth and texture, moisture regime, and general humus form are generally maintained throughout the length of the forest rotation, and many such attributes persist following disturbance. Biological components may change more rapidly. However, eco-sites are considered relatively stable from the time of canopy closure until a stand-replacing disturbance (e.g., wildfire or harvest) occurs or succession causes a significant shift in overstory composition (Racey *et al.* 1996). Thus, because eco-sites are relatively stable and mappable land units (at inventory scales), they are used in Ontario to describe the productive forest landbase, to define forest units for forest management modelling purposes, and in other forest management planning applications. Twenty-eight forested eco-sites have been described in northwestern Ontario (Racey *et al.* 1996), 12 of which are considered boreal mixedwood eco-sites based on MacDonald and Weingartner's (1995) definition and are addressed in Version 1 of the boreal mixedwood silviculture guide (OMNR 2003). Five other eco-sites may also be considered boreal mixedwood sites using Pierpoint's (1981) evaluation of boreal mixedwood moisture and nutrient regimes. These eco-sites are included in this note.

By convention, eco-site numbering follows a continuum of increasing moisture availability (relatively drier to wetter), increasing nutrient status (relatively poorer to richer), and varying vegetative cover (Racey *et al.* 1996). Note that the average or modal condition for each of the Northwest boreal mixedwood eco-sites falls within the most productive area of the edaphic grid (Figure 1). Overstory, vegetation, and soil characteristics are described in Tables 3 and 4 for boreal mixedwood eco-sites comprising primarily hardwoods and conifers, respectively.

Individual boreal mixedwood eco-sites can transcend more than one broad soil group and stand composition type (refer to Table 2). This is because eco-sites, which are used primarily at landscape levels for planning, are broader elements in the ELC taxonomy and represent a coarser scale of resolution than what may be required for the management of specific individual boreal mixedwood sites. In fact, the entire range of conditions defining individual eco-sites may

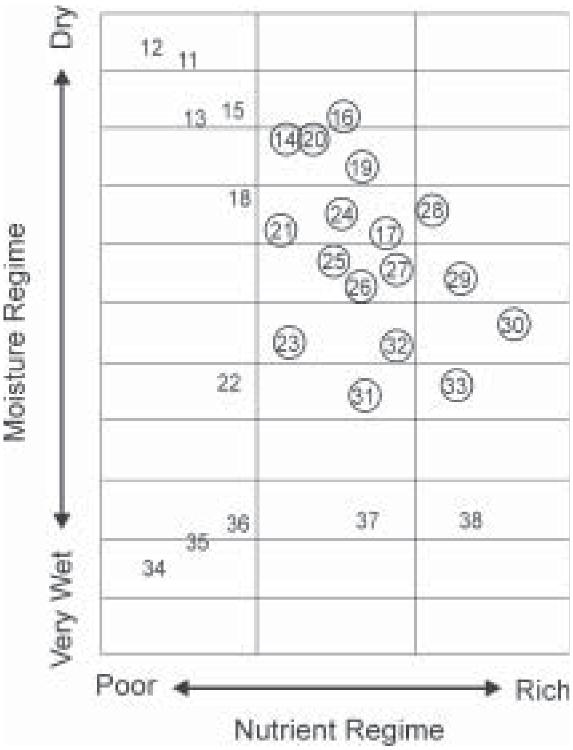

Figure 1. *Edaphic grid showing the location of Northwest eco-sites along gradients of soil moisture and nutrients. Adapted from Racey* et al. *(1996). [Circles denote boreal mixedwood eco-sites].*

Table 2. Overview of relationships among broad soil groups, stand composition types (as defined in Table 1), eco-sites (ES) (described in Tables 3-4), soil (S) types, and vegetation (V) types for boreal mixedwood sites in northwestern Ontario.

Stand Composition Type (current stand condition)	Broad Soil Group (and associated soil types)			
	Coarse (S1, S2, S3, SS5, SS6)	Medium (S4, S5, SS7)	Fine (S6, SS7)	Moist mineral (S7, S8, S9, S10, S11, SS7, SS8)
Aspen-pure or aspen-dominated	ES19 S2, S3 V5, V8	ES28 S4, SS7 V5, V8	ES29 S6, SS7 V5, V8 ES30 S6 V1, V2	ES23 S7, S8, SS8 V5, V8 ES33 S9, S10, S11, SS8 V5, V8
Birch-pure or birch-dominated	ES19 S2, S3 V4			
Aspen-leading	ES16 S2, SS5 V6, V8, V9, V10 ES19 S2, S3 V6, V8, V9, V10	ES28 S4, SS7 V6, V8, V9, V10	ES29 S6, SS7 V6, V7, V8, V9 ES30 S6 V1, V2	ES23 S7, S8, SS8 V6, V7, V8, V9 ES33 S9, S10, S11, SS8 V5, V6, V7, V8
Birch-leading	ES19 S2, S3, SS6 V4			
Fir / spruce-leading	ES21 S3, SS6 V14, V15, V16, V19	ES27 S4, S5, SS7 V14, V15, V16, V19	ES26 S6, SS7 V19, V20, V31 ES27 S6, SS7 V14, V15, V16	ES32 S9, S10, SS8 V14, V15, V16, V19
Pure fir or spruce or fir / spruce-dominated	ES21 S3, SS6 V24, V25	ES27 S4, S5, SS7 V24, V25	ES27 S6, SS7 V24, V25	ES32 S9, S10, SS8 V24 ES31 S9, S10, SS7, SS8 V31
Jack pine / spruce - leading	ES14 S1, S2, SS5 V10, V18, V20, V33	ES25 S4, SS7 V10, V20		
Jack pine / spruce - dominated	ES20 S2, S3, SS5, SS6 V28, V29, V30, V31 V32, V33	ES 25 S4, SS7 V31, V32		
Red and white pine	ES24 S2, S3, SS5, SS6 V26, V27	ES24 S4, SS6 V12, V13		
Cedar-leading and dominated	ES 17 S3 V14	ES 17 S4 V21	ES 17 S6, SS7 V21	ES17 S9, S10 V21

Table 3. Description of hardwood-dominated or hardwood-leading boreal mixedwood eco-sites in northwestern Ontario. In all cases, the hardwood component exceeds 50% of the canopy. Adapted from Racey et al. *(1996).*

Eco-site Type	Eco-site Name	Dominant Species	Occasional/Other Species	Soil	Comments
ES16	Hardwood-Fir-Spruce Mixedwood: Sandy Soil	*Populus tremuloides* *Betula papyrifera* *Abies balsamea*	*Picea glauca* *Picea mariana* *Pinus banksiana*	· dry to moderately fresh · rapidly to well drained · coarse to fine sandy	· from relatively pure trembling aspen or white birch to a range of hardwood-dominated mixedwoods · conifer overstory composition typically quite variable · typically shrub- and herb-rich · boreal mixedwood S-types include S2 and SS5 · boreal mixedwood V-types include V6, V8, V9, and V10
ES19	Hardwood-Fir–SpruceMixedwood: Fresh, Sandy–Coarse Loamy Soil	*Populus tremuloides* *Betula papyrifera* *Abies balsamea*	*Picea glauca* *Picea mariana*	· fresh · well drained · coarse loamy to fine sandy	· white birch mixedwood · overstory conifer component typically quite variable · understory composition variable shrub- and herb-rich · boreal mixedwood S-types include S2, S3, and SS6 · boreal mixedwood V-types include V4, V5, V6, V8, V9, and V10
ES23	Hardwood-Fir–SpruceMixedwood: Moist, Sandy–Coarse Loamy Soil	*Populus tremuloides* *Betula papyrifera* *Abies balsamea*	*Picea glauca* *Picea mariana* *Pinus banksiana*	· moist · sandy to coarse loamy	· trembling aspen mixedwood · moderately shrub- and herb-rich · typically occurs on lower slopes in rolling terrain · boreal mixedwood S-types include S7, S8, and SS8 · boreal mixedwood V-types include V5, V6, V7, V8, and V9
ES28	Hardwood-Fir–SpruceMixedwood: Fresh, Silty Soil	*Populus tremuloides* *Betula papyrifera*	*Abies balsamea* *Picea mariana* *Pinus banksiana* *Picea glauca*	· fresh · well to moderately well drained · silt or silt loam	· trembling aspen mixedwood · extremely variable and productive eco-site · shrub- and herb-rich · boreal mixedwood S-types include S4 and SS7 · boreal mixedwood V-types include V5, V6, V8, V9, and V10
ES29	Hardwood–Fir–Spruce Mixedwood: Fresh, Fine Loamy–Clayey Soil	*Populus tremuloides* *Abies balsamea* *Picea glauca* *Picea mariana*	*Betula papyrifera* *Pinus banksiana*	· fresh · moderately well to well drained · fine loamy-clayey	· plant species composition varies slightly from ES28 as a result of occurring on finer textured parent material · shrub- and herb-rich · boreal mixedwood S-types include S6 and SS7 · boreal mixedwood V-types include V5, V6, V7, V8, and V9
ES30	Black Ash Hardwood: Fresh, Silty–Clayey Soil	*Fraxinus nigra*	*Populus tremuloides* *Betula papyrifera* *Populus balsamifera* *Thuja occidentalis*	· fresh to moist · well to imperfectly drained · silty to clayey	· balsam poplar mixedwood · characteristically found in subdued topography and depressions · often associated with fine-textured soils and small intermittent watercourses · boreal mixedwood S-types include S6 · boreal mixedwood V-types include V1 and V2
ES33	Hardwood–Fir–Spruce Mixedwood: Moist, Silty–Clayey Soil	*Populus tremuloides* *Betula papyrifera* *Abies balsamea* *Picea glauca*	*Picea mariana* *Populus balsamifera*	· moist · imperfectly to poorly drained · silty to clayey	· topography typically subdued and low · moderately shrub- and herb-rich · boreal mixedwood S-types include S9, S10, S11, and SS8 · boreal mixedwood V-types include V5, V6, V7, and V8

Table 4. *Description of conifer-dominated or conifer-leading boreal mixedwood eco-sites in northwestern Ontario. In all cases the coniferous component exceeds 50% of the canopy. Adapted from Racey* et al. *(1996).*

Eco-site Type	Eco-site Name	Dominant Species	Occasional/Other Species	Soil	Comments
ES14	Pine-Spruce Mixedwood: Sandy Soil	*Pinus banksiana* *Picea mariana*	*Betula papyrifera* *Populus tremuloides*	· moderately dry to moderately fresh · rapidly to well drained · coarse to fine sandy	· landform types variable from sand plains to rolling morainal deposits · understory variable but usually abundant herbs and shrubs · ground cover consists of feathermoss, conifer and broad-leaved litter · boreal mixedwood S-types include S1, S2, SS5 · boreal mixedwood V-types include V10,V18, V20, and V33
ES17	White Cedar: Fresh-Moist, Coarse-Fine Loamy Soil	*Thuja occidentalis*	*Abies balsamea* *Betula papyrifera* *Picea glauca* *Populus tremuloides*	· variable; occurs on a wide variety of soil textures and moisture conditions	· eco-site extremely variable · shrub layer variable, usually dominated by *Acer spicatum*, balsam fir, and white cedar · shrubs dense where concentration of hardwoods is high or canopy is thin · often viewed as post gap-phase stage of mixedwood continuum · boreal mixedwood S-types include S3, S4, S6, SS7, S9 and S10 · boreal mixedwood V-types include V21 often associated with V14, V24
ES20	Spruce-Pine / Feathermoss: Fresh, Sandy-Coarse Loamy Soil	*Picea mariana* *Pinus banksiana*	*Populus tremuloides* *Betula papyrifera* *Abies balsamea*	· dry to fresh · rapidly to well drained · fine to coarse sandy or coarse loamy	· overstory ranges from almost pure pine or spruce to various mixtures · hardwood species occur with limited cover · usually shrub- and herb-poor, cut may be locally rich where silt content in higher · boreal mixedwood S-types include S2, S3, SS5 and SS6 · boreal mixedwood V-types include V28, V29, V30, V31, V32 and V33
ES21	Fir–Spruce Mixedwood: Fresh, Coarse Loamy Soil	*Abies balsamea* *Picea glauca* *Picea mariana*	*Populus tremuloides* *Betula papyrifera*	· fresh · well drained · coarse loamy	· extremely variable and dynamic eco-site in terms of forest cover · typically shrub- and herb-poor with abundant feathermoss · *Acer spicatum* may be locally abundant · spruce budworm drives many aspects of stand dynamics · boreal mixedwood S-types include S3 and SS6 · boreal mixedwood V-types include V14, V15, V16, V19, V24, and V25
ES24	Red Pine-White Pine: Fresh, Fine Loamy Soil	*Pinus resinosa* *Pinus strobus* *Betula papyrifera*	*Abies balsamea* *Picea mariana*	· fresh · well drained · fine loamy	· shrub- and herb-rich, including *Acer spicatum*, *Corylus cornuta*, and *Aster macrophyllus* · boreal mixedwood S-types include S4, SS7 · boreal mixedwood V-types include V12 and V13 on fresh coarse loamy soils and V26/V27 on dry to fresh coarse sandy soils
ES25	Pine-Spruce / Feathermoss: Fresh, Silty Soil	*Pinus banksiana* *Picea mariana*	*Populus tremuloides* *Betula papyrifera* *Abies balsamea*	· fresh · well to moderately well drained · silt to silt loam	· relatively homogenous eco-sitetypically shrub- and herb-poor in younger fire origin stands, but may vary to shrub- and herb-rich with increased silt content or reduction in crown closure (for occasional relatively pure jack pine stands) · boreal mixedwood S-types include S4 and SS7 · boreal mixedwood V-types include V31 and V32
ES26	Spruce-Pine / Feathermoss: Fresh, Fine Loamy–Clayey Soil	*Picea mariana* *Pinus banksiana*	*Populus tremuloides* *Betula papyrifera* *Abies balsamea*	· fresh · well to moderately well drained · fine loamy–clayey	· relatively complex eco-site · typically shrub- and herb-poor · boreal mixedwood S-types include S6 and SS7 · boreal mixedwood V-types include V19, V20, and V31

Table 4. *Continued*

Eco-site Type	Eco-site Name	Dominant Species	Occasional/Other Species	Soil	Comments
ES27	Fir–Spruce Mixedwood: Fresh, Silty–Fine Loamy Soil	*Abies balsamea* *Picea mariana* *Picea glauca*	*Populus tremuloides* *Betula papyrifera*	· fresh · well to moderately well drained · silty to fine loamy	· vegetation cover relatively uniform · typically shrub- and herb-poor · boreal mixedwood S-types include S4, S5, S6, and SS7 · boreal mixedwood V-types include V14, V15, V16, V19, V24, and V25
ES31	Spruce-Pine / Feathermoss: Moist, Silty–Clayey Soil	*Picea mariana* *Pinus banksiana*	*Populus tremuloides* *Betula papyrifera* *Populus balsamifera* *Picea glauca* *Abies balsamea*	· moist · silty to clayey	· moister soil conditions contribute to a more diverse overstory · relatively uniform eco-site · typically shrub- and herb-poor · boreal mixedwood S-types include S9, S10, SS7, and SS8 · boreal mixedwood V-types include V31
ES32	Fir–Spruce Mixedwood: Moist, Silty–Clayey Soil	*Abies balsamea* *Picea glauca* *Populus tremuloides* *Picea mariana*	*Betula papyrifera* *Pinus banksiana* *Populus balsamifera*	·moist ·silty to clayey	· overstory composition variable · moderately shrub- and herb-rich · boreal mixedwood S-types include S9, S10, and SS8 · boreal mixedwood V-types include V14, V15, V16, V19, and V24

not always be representative of boreal mixedwood site and stand conditions. Because of this, the specific S- and V- types that represent boreal mixedwood conditions within individual eco-sites are also included (see Table 2) because of their use in understanding succession and characterizing structural and compositional differences between forest conditions. These are described briefly below.

Boreal Mixedwood Eco-elements (Soil and Vegetation Types)

Eco-elements are classification units consisting of S- and V- types, which are descriptors of site quality and of mature-forest plant communities, based on specific ranges of species compositions and abundance, respectively. Eco-element descriptions are more precise than eco-site descriptions, and are generally applied at the stand level (unlike eco-sites, eco-elements cannot be mapped at inventory scales). Thus, more than one S- or V-type can be associated with any given eco-site. Due to successional processes, different V-types can occupy a boreal mixedwood site at different times, depending upon disturbance history and other factors affecting the growth and recruitment of species onto a site. It is not usually possible to accurately predict an S-type from a given V-type, or vice versa (Sims *et al*. 1997).

Soil Types

A soil type is a classification unit for soil determined by a few critical parameters such as depth to bedrock, soil moisture regime, soil parent material texture, and organic layer qualities (Sims *et al*. 1997). In the northwestern Ontario FEC system, S-types with at least 100 cm of mineral or organic substrate are defined as 'deep soils' (D). Very shallow to moderately deep soil types having less than 100 cm of mineral or organic substrate are defined as 'shallow soils' (SS) (Sims *et al*. 1997).

S-types can be used to represent site productivity, to predict the occurrence of various plant species, and to identify the most likely competitive species. Table 5 shows the comparative frequency with which several common tree and woody shrub species occur on the S-types associated with boreal mixedwood eco-sites in northwestern Ontario (Buse and Bell 1992). Predictive relationships are evident between soil types and the potential for non-tree vegetation.

Table 5. *Frequency of occurrence of common tree and woody shrub species in boreal mixedwood soil (S) types of northwestern Ontario. Frequency is presented on a relative scale (0 - 4):* ***0****, absent;* ***1****, 1-25% frequency;* ***2****, 26-50% frequency;* ***3****, 51-75% frequency; and* ***4****, 76-100% frequency. Adapted from Buse and Bell (1992).*

Common Species	Soil (S) Types														
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	SS5	SS6	SS7	SS8
	Deep mineral											Shallow to moderately deep			
	Xeric to dry	Dry to very fresh		Moderately to very moist							Wet	Dry to very fresh			Moist
Trees															
Abies balsamea	3	3	4	4	4	4	3	3	4	4	3	3	3	4	3
Betula papyrifera	2	2	2	2	2	2	2	2	2	1	1	3	3	2	2
Picea glauca	2	2	2	2	2	2	2	1	2	2	1	1	2	1	1
Picea mariana	3	3	3	3	3	3	4	3	3	3	4	3	3	3	4
Pinus banksiana	3	3	2	2	2	2	2	2	2	1	1	2	3	2	3
Pinus resinosa	1	1	1	1	1	1	0	1	1	0	0	1	1	1	1
Pinus strobus	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1
Populus balsamifera	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1
Populus tremuloides	2	2	2	2	2	2	2	2	2	2	1	3	2	2	2
Woody Shrubs															
Acer spicatum	2	2	3	2	2	3	2	2	2	2	1	1	2	2	3
Alnus incana ssp. *rugosa*	1	1	1	1	2	1	1	1	2	2	2	1	1	1	1
Alnus viridis ssp. *crispa*	2	2	2	2	2	1	1	1	1	1	1	2	2	2	2
Amelanchier spp.	2	2	2	3	3	3	2	2	2	3	2	3	2	2	2
Cornus stolonifera	1	1	1	2	2	2	1	1	1	2	1	1	1	1	1
Corylus cornuta	2	2	2	2	2	3	1	2	2	2	1	1	2	2	2
Ledum groenlandicum	1	2	2	2	1	1	3	3	2	1	4	2	1	1	2
Prunus pensylvanica	1	1	1	1	0	1	1	1	1	1	0	1	1	1	1
Prunus virginiana	1	1	1	1	2	2	1	1	1	1	1	1	1	1	1
Ribes spp.	1	1	2	2	3	3	1	2	3	3	2	1	1	1	1
Rosa acicularis	2	2	2	3	4	3	2	2	3	3	2	2	2	2	1
Rubus idaeus	1	1	1	1	2	1	1	1	2	2	1	1	1	1	1
Salix spp.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Vaccinium angustifolium	3	3	2	2	2	2	3	2	2	2	3	2	3	2	3
Vaccinium myrtilloides	3	3	3	3	2	2	3	3	3	2	3	3	3	3	3
Viburnum edule	1	1	1	2	2	2	1	1	2	2	1	0	1	1	1

Table 6. *Frequency of occurrence of common tree and woody shrub species in boreal mixedwood vegetation (V) types of northwestern Ontario. Frequency is presented on a relative scale (0 - 4):* ***0****, absent;* ***1****, 1-25% frequency;* ***2****, 26-50% frequency;* ***3****, 51-75% frequency; and* ***4****, 76-100% frequency. Adapted from Buse and Bell (1992).*

Common Species	Vegetation (V) Type													
	1	2	4	5	6	7	8	9	10	12	13	14	15	16
	Misc. Hardwoods		Birch	Aspen-pure, dominated or leading						White or red pine leading mix		Balsam fir - white spruce leading mix		
Trees														
Abies balsamea	4	4	4	3	4	4	4	4	4	4	4	4	4	4
Betula papyrifera	3	2	3	3	2	2	2	2	2	2	3	2	2	3
Picea glauca	2	3	2	1	2	2	3	4	2	2	1	2	4	4
Picea mariana	2	1	3	2	1	2	3	2	4	1	2	2	2	3
Pinus banksiana	1	0	2	1	1	1	2	2	3	1	2	1	1	2
Pinus resinosa	0	0	0	1	0	0	0	0	1	2	4	1	0	0
Pinus strobus	0	0	0	0	0	1	1	1	0	4	2	1	1	0
Populus balsamifera	3	1	1	1	1	1	1	1	1	0	1	1	1	1
Populus tremuloides	2	1	1	3	4	3	3	3	3	3	2	3	2	2
Woody Shrubs														
Acer spicatum	3	4	3	3	4	3	4	3	1	4	3	4	3	3
Alnus incana ssp. *rugosa*	3	3	1	1	1	2	1	2	1	1	0	1	1	1
Alnus viridis ssp. *crispa*	1	0	2	2	1	1	1	2	3	2	2	1	1	1
Amelanchier spp.	3	2	3	3	2	2	3	3	3	3	2	2	3	2
Cornus stolonifera	3	3	1	2	1	2	1	1	1	1	1	2	2	1
Corylus cornuta	2	2	2	4	3	3	4	4	2	4	3	3	3	2
Ledum groenlandicum	1	1	1	1	1	1	1	1	2	1	1	1	1	1
Prunus pensylvanica	1	0	1	1	1	1	1	1	1	1	1	0	0	0
Prunus virginiana	2	3	1	2	1	2	1	2	1	1	1	1	1	1
Ribes spp.	4	4	2	2	2	3	2	2	2	1	1	2	3	2
Rosa acicularis	4	1	1	3	2	3	3	3	2	2	0	2	3	2
Rubus idaeus	3	2	1	2	1	1	1	2	1	1	1	1	2	1
Salix spp.	1	1	1	1	1	1	1	1	1	1	1	0	1	1
Vaccinium angustifolium	1	1	3	2	1	1	2	2	3	1	3	2	2	2
Vaccinium myrtilloides	1	1	3	2	1	2	2	2	3	2	3	2	1	3
Viburnum edule	3	2	1	2	2	2	2	2	2	0	0	2	2	2

Table 6. *Continued*

Common Species	Vegetation (V) Type														
	17	18	19	20	21	24	25	26	27	28	29	30	31	32	33
	Misc. Hardwoods		Birch	Aspen-pure, dominated or leading						White or red pine leading mix		Balsam fir - white spruce leading mix			
Trees															
Abies balsamea	4	3	4	2	4	4	4	4	4	3	2	2	4	2	2
Betula papyrifera	3	3	2	3	2	2	2	2	3	3	2	2	2	1	1
Picea glauca	2	1	1	1	3	4	4	2	1	1	1	1	2	1	1
Picea mariana	3	4	4	4	1	2	3	1	3	2	3	4	4	4	4
Pinus banksiana	4	4	2	3	0	1	2	1	2	4	4	4	4	4	2
Pinus resinosa	1	1	0	0	0	0	1	2	4	0	0	0	0	0	1
Pinus strobus	1	1	0	1	1	0	0	4	1	1	0	0	0	0	1
Populus balsamifera	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1
Populus tremuloides	3	2	3	1	2	2	1	2	2	2	1	1	2	1	1
Woody Shrubs															
Acer spicatum	2	1	2	1	4	3	2	3	2	1	1	1	1	1	1
Alnus incana ssp. *rugosa*	1	1	2	1	1	2	1	0	0	0	0	0	1	1	1
Alnus viridis ssp. *crispa*	3	2	2	2	0	1	1	1	2	2	2	1	2	2	1
Amelanchier spp.	3	2	3	3	2	4	3	3	2	4	2	2	2	2	2
Cornus stolonifera	1	1	1	1	2	2	1	1	1	1	1	1	1	1	1
Corylus cornuta	3	0	1	1	2	3	2	3	2	3	1	1	2	1	1
Ledum groenlandicum	1	2	3	3	1	1	1	0	1	1	2	2	2	3	3
Prunus pensylvanica	1	1	1	0	0	0	1	0	1	1	1	1	1	1	0
Prunus virginiana	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1
Ribes spp.	2	1	2	0	3	3	1	1	1	1	1	1	1	1	1
Rosa acicularis	3	2	3	1	2	3	3	2	2	2	2	1	3	2	2
Rubus idaeus	1	1	1	1	1	2	1	2	1	2	1	1	1	1	1
Salix spp.	1	1	1	1	0	1	1	1	1	1	2	1	1	1	1
Vaccinium angustifolium	3	3	3	3	1	1	2	2	3	3	3	4	3	3	3
Vaccinium myrtilloides	2	4	3	3	1	2	2	2	4	4	4	4	4	4	3
Viburnum edule	1	1	2	0	1	1	2	0	0	1	0	0	1	1	1

Vegetation Types

A vegetation type is a classification unit representing mature forest plant communities derived from an analyses of the relative presence and abundance of all species. In the northwestern Ontario FEC system, a forest stand is allocated using a decision tree to one of 40 possible V-types based on general overstory composition and, where necessary, also to the presence/absence or general abundance of a few key understorey plants (Sims *et al*. 1997). Like S-types, V-types can be used to predict the occurrence of various plant species and to identify the most important competitive species. Table 6 compares the frequency of occurrence of several common tree and woody shrub species on the V-types commonly associated with boreal mixedwood eco-sites in northwestern Ontario (Buse and Bell 1992). Predictive relationships are evident between V-types and the potential for non-tree vegetation. This information may help managers anticipate site preparation and tending requirements.

Additional information on boreal mixedwood eco-sites, S-types, and V-types can be found in other Ontario Ministry of Natural Resources publications (Racey *et al*. 1996, OMNR 1997, Sims *et al*. 1997, OMNR 2003).

Summary

The use of an ecological framework to classify site and stand conditions can facilitate forest management. The ecological framework used for the management of boreal mixedwood sites in Ontario consists of a hierarchy of four principal ecological drivers. These are climate and landform (together represented by eco-region), soil (represented by broad soil group), and species composition (represented by stand composition type). This ecological framework is strongly linked to Ontario's ecological land classification framework and the forest ecosystem classification system for northwestern Ontario in that it can be cross-referenced to specific eco-regions, eco-sites, and soil and vegetation types. Interpretations of eco-site, soil and vegetation types provides information used at a landscape level for forest management planning and improving management decisions, and for predicting succession and yield at the stand level.

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Successional Trends by Site Types in Boreal Mixedwood Forests in Northwestern Ontario

by R. Arnup[1]

> ***Differences in the vegetation between site-types (STs) occurring on similar soils may represent either age-related successional phases or alternate successional pathways initiated by different disturbance history.***

Introduction

Resource managers are often required to predict the likely effects of natural disturbances or management prescriptions on mixedwood stands. Most stand-level management prescriptions endeavour to alter the vegetative successional path by creating conditions that favor the establishment and growth of desired species (e.g., crop trees). At a broader level, strategies may be employed to create patterns of mixedwood stands across landscapes (e.g., for promoting wildlife habitat). An understanding of successional processes will aid in the development of management strategies and prescriptions for boreal mixedwoods. This technical note describes the development of vegetation over time on different boreal mixedwood site types following natural and artificial disturbances.

In northeastern Ontario, the eco-element level (approximately, stand-level) in the Provincial Ecological Land Classification hierarchy is represented by Site Types (STs). STs are mappable, management-oriented groupings of vegetation on specific ranges of soil conditions (McCarthy et al. 1994). STs are numbered according to similar vegetation communities, based on the understorey, and lettered by similar soil conditions. For example, ST 3b and ST 6b occur on similar soil types but have different understoreys. In some cases, differences in the vegetation between STs

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occurring on similar soils may represent either age-related successional phases, or alternate successional pathways initiated by different disturbance history (e.g., fire severity or frequency). Natural and managed successional trends in northeastern Ontario STs were reviewed in part by Chambers (1993).

ST 3a (Mixedwood - Medium Soil) and ST 3b (Mixedwood - Coarse Soil)

Natural Succession

In early stages after fire, trembling aspen and jack pine establish quickly as pioneer species. Black spruce may establish at the same time but is outgrown. White birch may become established, typically at low density.

As the canopy closes, feathermosses increase and gradually dominate the forest floor. Black spruce continue to establish in the understorey and becomes the dominant element in the middle canopy.

Hardwood species decline as they reach their natural rotation age, permitting the black spruce in the middle canopy to progress into the main canopy. Balsam fir and white spruce become established in canopy openings.

A variety of herbs, seeding and sprouting shrubs are present throughout stand development. These STs have the least rich understoreys of the mixedwood types.

Effects of Management

Aspen, sprouting woody shrubs, pin cherry, raspberry and herbs tend to increase after mechanical site preparation, but their development is slow, due to the relatively poor soil nutrient status on coarse soils. Light to moderate prescribed burns stimulate the development of grasses, blueberries, and sheep laurel.

ST 6a (Mixedwood - Fine Soil); ST 6b (Conifer Mixedwood - Coarse Soil); and ST 6c (Hardwood Mixedwood - Coarse Soil)

Natural Succession

A number of species of varying growth rates make up the main canopy of these site types. Trembling aspen, black spruce, jack pine, and white birch are the main species established immediately after fire. On the rich, fine soils in ST 6a, aspen is likely able to out-compete jack pine, since mature stands have lower levels of this species than STs 6b and 6c. On the coarser soils associated with ST 6b, it is likely that more jack pine survive the initial period of competition. Aspen is most abundant in ST 6c, which may originate from light fires that favor aspen establishment over conifers.

Aspen (and jack pine if present) outgrow the black spruce, which forms a middle canopy layer. As the canopy closes, feathermosses increase in abundance on the forest floor. A moderately rich understorey of herbs and shrubs develops. White spruce and balsam fir begin to invade the understorey. Recruitment of black spruce continues.

As the aspen declines, the middle layer of conifers begins to grow rapidly into the main canopy. White spruce and balsam fir take advantage of canopy openings to grow into the middle canopy. Thick mats of feathermosses on the forest floor tie up nutrients, which may reduce the rate of invasion and growth of woody shrubs and herbs in middle stages.

In later stages, balsam fir and white spruce grow into the main canopy and eventually become dominant stand components. As the stand opens up through mortality and windthrow, woody shrubs increase in abundance in the understorey, taking advantage of canopy openings. Low levels of white birch and aspen persist through suckering and sprouting. Average balsam fir levels are highest in ST 6b, which may represent an older phase of ST 3b on medium soils.

Effects of Management

Aspen, sprouting woody shrubs, pin cherry, raspberry and herbs increase after mechanical site preparation. Their development is generally intermediate, especially on sites where the feathermoss remains relatively undisturbed. Light prescribed burns will stimulate the growth of sprouting shrubs. Stands In later successional stages often require tramping of residual vegetation followed by high severity burns for competition control.

ST 7a (Hardwood - Fine Soil) and ST 7b (Hardwood - Medium Soil)

Pioneering poplar species establish, grow rapidly and dominate the main canopy. Since aspen is the dominant component of mature stands, these site types may originate from light fires that produce conditions less favourable for the establishment of coniferous tree species. Various grasses and sedges establish during the early stages of succession.

Following canopy closure, white spruce and black spruce invade the understorey and gradually grow into a middle canopy. A rich and abundant understorey of various herbs and shrubs develops, along with small amounts of white spruce and black spruce regeneration. A variety of feathermosses and other upland mosses (the latter developing with the shade from the developing coniferous canopy) invade the understorey. They generally remain at low levels due to the rich understorey and litterfall from the deciduous trees.

As the aspen declines, balsam fir establishes in the lower layers and gradually dominates the understorey. Black spruce and white spruce, followed by balsam fir, grow into the main canopy, leading to a more mixed stand composition.

Frequent surface fires may maintain the hardwood component in these stands. In the absence of fire, later successional stages probably move towards a condition similar to ST 6a or 6b.

Effects of management

Aspen, sprouting woody shrubs, pin cherry, raspberry and herbs increase in abundance (density) and relative dominance on a site, after mechanical site preparation. Their development is rapid on these rich sites. Light prescribed burns will stimulate vigorous sprouting of aspen and woody shrubs. High severity burns in late summer, when food reserves of sprouting species are lowest, are recommended for competition control.

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STAND DYNAMICS

Basic Concepts of Succession in Boreal Mixedwood Forests in Northeastern Ontario

by R. Arnup[1]

Resource managers are often required to predict the effects of natural disturbances or management prescriptions on mixedwood stands. The present-day boreal mixedwood forest in Ontario is a successional mosaic of stratified mixed stand of disturbance origin.

Introduction

Succession is the change in vegetation composition, structure and diversity over time (Halpern 1989). The traditional concept of succession involves orderly, predictable replacement of vegetation communities. Pioneer communities of short-lived, intolerant species are replaced with longer-lived, more tolerant associations, until a self-replacing climax community occupies the site (Chambers 1993). In the boreal forest, few mixedwood stands progress to the climax forest stage since the natural disturbance cycle is relatively short, about 75 ± 50 years (Day and Harvey 1981).

Boreal mixedwood sites are defined as areas with climatic, topographic and soil conditions that favor the production of closed canopies dominated by trembling aspen or white birch in early successional stages, black spruce or white spruce in mid-successional stages, and balsam fir in late successional stages. To be considered a mixedwood, a stand must contain components of one or more of these five defining tree species, although other species can also be present (MacDonald and Weingartner 1995). The present-day boreal mixedwood forest in Ontario is a successional mosaic of stratified mixed stands of disturbance origin (Day and Harvey 1981).

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Resource managers are often required to predict the effects of natural disturbances or management prescriptions on mixedwood stands. Most stand-level management prescriptions alter the vegetative successional path by creating conditions that favor the establishment and growth of desired species (e.g., crop trees). At a broader level, strategies may be employed to create patterns of mixedwood stands across landscapes (e.g., for promoting wildlife habitat). An understanding of successional processes will aid in the development of management strategies and prescriptions for boreal mixedwood forests. This technical note will review current knowledge of the factors affecting succession in boreal mixedwoods.

Factors Influencing Vegetational Succession

Although boreal forests are not complex floristically, understanding vegetative succession is complex since many environmental factors and their interactions affect boreal ecology (Bonan and Shugart 1989). These factors include disturbance regime, pre-disturbance stand composition and availability of seed sources, climate, soil and site conditions, and interactions with wildlife.

Disturbance

Disturbance results from natural agents, such as fire, insects, disease and windthrow; or artificial treatments such as harvesting, site preparation or tending. The response of a plant species depends on its mode(s) of reproduction, and the timing and severity of disturbance. For example, species with buried seed, windborne seed, or which sprout or sucker readily can quickly re-establish on disturbed sites (Buse and Bell 1992).

Wildfire

Wildfire is the dominant natural agent affecting boreal landscapes in northern Ontario. It is the most important natural factor influencing vegetative succession in boreal mixedwood forests. Fire releases nutrients locked up in organic material, increases light availability by removing vegetation, increases soil temperatures by increasing infiltration and storage of solar radiation, and creates seedbeds (Alexander and Euler 1981).

Depending on the severity and timing of the fire, different species groups may be favoured. Boreal plant species use a variety of strategies to survive following fires, including:

- *sprouting:* the establishment of new shoots from dormant buds at the root collar or stem base (e.g., blueberry or Labrador-tea)

- *suckering:* the establishment of new shoots from underground buds located along the original plant's roots or rhizomes (e.g., trembling aspen or balsam poplar)

- *insulating bark:* protects the tree's living tissues from lethal flames (e.g., red and white pine)

- *seed banking:* the storage of seed in the organic or mineral soil which remain dormant but may germinate following fire (e.g., pin cherry and wild red raspberry)

- *wind and water dispersed seed:* seeds carried by wind or water that germinate well on burned sites (e.g., fireweed and white birch)

- *bird and mammal dispersed seed:* seeds carried by birds or mammals that germinate well on burned sites (e.g., mountain ash and choke cherry)

- *serotinous cones:* heat from fire melts the resin between cone scales and releases stored seed (e.g., jack pine and black spruce)

- *flowering and seed production:* the post-fire environment stimulates production of seeds (e.g., Canada blue-joint grass).

Light burns that remove little organic matter tend to stimulate suckering from underground plant parts. Light burns also stimulate the germination of buried seeds. Plants that reproduce vegetatively have a competitive advantage over species that rely on seeding in after fire because of stored food reserves. Therefore, low-intensity spring burns tend to increase the amount of hardwood trees and shrubs in mixedwood stands at the expense of conifers. Kiil (1970) found that low-intensity spring burns in old white spruce–trembling aspen stands resulted in rapid influx of dense herbaceous vegetation, and stimulated the suckering of alder, willows and aspen. Little conifer reproduction occurred.

Severe burning that removes significant organic matter will reduce or eliminate the ability of plants to reproduce vegetatively, and will destroy seeds banked in duff layers. Severe burns also tend to create more favourable seedbeds for germination and survival of conifers than light burns. In a study in Minnesota, Ahlgren (1959) found good conifer reproduction on areas where fire had reduced the organic layer to a depth of 2 to 5 cm. Where the burn was light, leaving 8 to 15 cm of organic matter, young seedling mortality was high and little or no reproduction was established.

The autecological characteristics of mixedwood tree species in relation to fire are well documented. The semi-serotinous and serotinous cones of black spruce and jack pine retain seeds for several years following a fire, so that an outside seed source is not needed. However, white spruce and balsam fir require an outside seed source from unburned areas. Trembling aspen regenerates mainly from root suckering following fire, although regeneration from wind-borne seed also occurs. White birch regenerates after fire by sprouts from buds at the stem base as well as from seeds carried onto the site by wind or wildlife, or banked in organic layers (Alexander and Euler 1981; Kelsall *et al.* 1977).

Insects and Disease

There are a number of insect pests that can cause injury to the tree species common to boreal mixedwoods, including the spruce budworm, forest tent caterpillar and birch skeletonizer. Injury to infested trees usually occurs in the new foliage produced each year. Most trees recover from light or moderate infestations. However, mortality and reduced growth can result from intense infestations over several years.

In boreal Ontario, balsam fir is the species most affected by spruce budworm and can be significantly reduced in mixedwood stands during severe infestations. During and after a spruce bud-worm outbreak in Minnesota, balsam fir composition of the overstorey was reduced by 50 percent over a 20-year period. Raspberry, hazel and mountain maple invaded the understorey, limiting balsam fir reproduction. The net effect of the infestation was to convert the stand to an earlier successional stage in which aspen and birch dominated the overstorey (Batzer and Popp 1985).

Except for root rot, stem rot and birch dieback, few diseases have a major impact on the boreal mixedwood forest. Root and stem rot weaken trees so that they become more susceptible to damage by wind, resulting in early mortality. The incidence of diseases increases in older stands, which is likely a factor in creating canopy openings (Gross 1985; Whitney 1988).

Temperature

Development of forest ecosystems, including growth rates, species composition and vegetative succession, has been affected by past and present climatic conditions (Jozsa and Powell 1987). Climatic variations affect the rate of vegetative succession in boreal mixedwoods. Low temperatures limit the distribution of plant species and vegetation types (Woodward 1990). Since temperature is mainly influenced by latitude in boreal Ontario, the relative abundance of certain plant communities changes from northern to southern extremes (e.g., tolerant hardwoods).

Wind

Wind is an important agent of seed dispersal. This form of regeneration applies mainly to species with light or winged seeds that are easily transported by wind (e.g., trembling aspen). The direction of the wind at the time of seed dispersal is important for distribution of seeds onto disturbed areas.

Windthrow favors the development of woody shrubs at the expense of tree regeneration. Older stands are more susceptible to windthrow because of increased incidence of disease, prevalence of canopy openings and mechanical instability of taller trees. In New Brunswick, loss of birch due to dieback in an overmature mixedwood stand led to increased windthrow of large conifer trees. The understorey was vigorously invaded by mountain maple. Coniferous regeneration was limited to intermittent patches of dense growth (Baskerville 1965).

The effects of a catastrophic windstorm on a mixedwood stand in Minnesota were noted by Sakai and Sulak (1985). The storm destroyed the overstorey aspen, causing a temporary increase in species richness and a shift in dominance from trees to shrubs. Trembling aspen, balsam fir and white birch decreased in density because of high mortality and low recruitment. The stand was still dominated by a dense shrub layer 41 years after the storm.

Light

The amount of light reaching the forest floor has an effect on the rate of succession of understorey vegetation. Forest canopy composition affects light quality and quantity in the forest understorey. In early successional stages, the abundance of understorey herbs and shrubs can change rapidly in response to changes in light regime. Once a reasonably closed canopy has developed, the herbaceous component of the forest understorey tends to stabilize (Ross *et al.* 1986), while shade-tolerant trees and shrubs increase in importance.

Soil Factors

In a study of understorey composition in mixed jack pine stands, Carleton (1982) found that soil factors accounted for 40 to 50% of the variance in the vegetation data. Soil moisture regime and nutrient regime are the most important gradients affecting the distribution of vegetation on boreal mixedwood sites. Some plant species require specific site conditions to establish and compete successfully, while others grow equally well on a wide range of site conditions. For example, black spruce occurs on almost all soil and site conditions, balsam poplar is most abundant on rich, moist sites, while nutrient-demanding species such as aspen, balsam fir and white spruce tend to grow best on fine-textured soil types. Stand-level elements of ecological land classification systems describe the distribution of vegetation communities on specific soil and site conditions.

Moisture and nutrient regimes integrate many site characteristics, such as position on slope, texture, soil depth and parent material of the soil. Local topographic features can affect vegetative succession in mixedwood sites by influencing the soil moisture regime and microclimate.

Wildlife

Different stand ages and successional stages of mixedwoods are important in providing habitat and cover for wildlife. Wildlife can also directly affect vegetative succession by selective browsing. Moose will selectively eliminate aspen, birch and balsam fir from young stands. In a study in Newfoundland, parts of a mixedwood stand were protected from browsing with enclosures. Heights of balsam fir in enclosures were significantly greater than outside enclosures (1.01 m versus 0.60 m) and mean annual growth rate was more than three times greater inside. White birch were significantly taller inside enclosures compared with outside although densities were similar (Thompson *et al.* 1992).

Snowshoe hares may thin out saplings of many of the common tree species in mixedwood stands. Beaver will frequently eliminate all aspen and birch within 100 to 200 metres of waterways (Heinselman 1981), and have been known to selectively forage on white spruce (Johnston and Naiman 1990).

Wildlife species play an important role in the dispersal of seeds onto disturbed sites. In Minnesota, beaked hazel populations in mixedwood stands were shown to be persistent, but experienced periodic shifts in density unrelated to canopy changes (Kurmis and Sucoff 1989). Such cyclic variations in plant species dominance in different stages of mixedwood development may be the result of long-term trends in seed dispersal or animal behaviour (Smith 1980).

Succession After Fire

A typical successional sequence following fire in a boreal mixedwood stand can be described as follows (cf. Day and Harvey 1981):

1. Annual and biennial herbaceous species establish quickly from seed and are abundant for one or two years after the fire but decline in abundance and importance thereafter (Abrams *et al.* 1985).

2. Pioneer tree species establish in varying proportions depending on site conditions. Rapidly-growing species, including trembling aspen, white birch and jack pine, quickly achieve a closed canopy, relegating the slower-growing black and white spruce to the middle and lower layers of the understorey. These fast-growing species dominate the canopy for the first 50 years following fire.

3. Over time (50 to 75 years following fire), the pioneering aspen and white birch

begin to decline in vigor. These species remain in the main canopy but begin to experience mortality and support less foliage. Black spruce and white spruce in the middle layer are released in response to the more open canopy. Shade-tolerant balsam fir seedlings and woody shrubs, including mountain maple and beaked hazel, have invaded the understorey.

4. 75 to 100 years after fire, the aspen and white birch continue to decline, and longer-lived black spruce, white spruce and jack pine become more dominant in the main canopy. Further canopy openings create conditions suitable for the growth of suppressed balsam fir and woody shrubs.

5. More than 100 years after the fire, most of the original aspen and white birch have declined, and the pioneer jack pine begins to decline in vigor. Black and white spruce dominate the main canopy, while balsam fir and hardwood shrubs dominate the middle and lower layers.

6. In the absence of fire, balsam fir will eventually grow into the main canopy, and abundant hardwood shrubs in the understorey will limit further tree reproduction, leading to open stands dominated by balsam fir with a few large remnant spruce and pine trees and scattered hardwoods that have survived by suckering. In the absence of disturbance this successional stage would likely persist for a prolonged time, with minor shifts in canopy composition. However, in the natural boreal fire cycle most stands will burn before this stage is reached.

Many variations on this general sequence are possible, depending on pre-fire stand conditions and fire severity. The tree species that are initially able to establish on a burned site (which depends on pre-fire composition, seed production cycles and seed sources) appear to be a major determinant of future stand development (Zoladeski and Maycock 1990).

The fire cycle also affects succession: short intervals between fires are favourable for deciduous trees and shrubs over conifers because deciduous species are able to sprout or sucker at an earlier age, whereas conifers take longer to produce abundant seed for germination. Longer intervals between fires promote conifers over deciduous species because of greater longevity and shade tolerance of conifers (Alexander and Euler 1981). The exclusion of fire from the boreal mixedwood forests tends to minimize the pioneer phase and maximize the later successional phases (Day and Harvey 1981).

Succession After Harvesting

The harvesting method and the amount of overstorey removal affects light availability, the extent of ground disturbance, and the abundance and vigor of remaining vegetation. Most studies of vegetative succession following harvesting on boreal mixedwood sites have focused on changes in tree species composition.

Clear-cutting in boreal mixedwood stands favors the early reproduction of trembling aspen and balsam fir over regeneration of pine and spruce (Yang and Fry 1981; Larsson *et al.* 1949), since aspen suckering is stimulated by increased soil temperatures. Balsam fir seed germinates readily on mixedwood cutovers and advance growth is released by cutting. In a study of regeneration on clearcut boreal mixedwood sites, Yang and Fry (1981) found that jack pine, and black and white spruce regenerated poorly on untreated mixedwood cutovers, likely due to lack of suitable seedbeds and seed source. Black spruce regeneration improved slightly on moist compared to dry and fresh cutover mixedwood sites. White birch regeneration levels after logging were consistent with pre-cut levels of white birch.

The relationships between pre- and post-logging understorey species composition depend on the amount of canopy removal and the amount of forest floor disturbance. Clear-cutting stimulates the suckering of hardwood shrubs and the germination of buried seeds. Competition from these species also reduces coniferous regeneration levels. Partial cutting (e.g., conifer removal) generally results in lower levels of sprouting and suckering of hardwood trees and shrubs due to increased shade. If the forest floor remains undisturbed following harvesting, post-cut understorey species composition usually resembles the composition of the understorey in the original stand. Careful logging techniques that retain a portion of the canopy and protect coniferous advance growth will likely result in a stand and understorey composition most similar to the original stand.

Effects of Site Preparation

The most important objective of site preparation is to create conditions suitable for the establishment and growth of desired species. Untreated clear-cuts on mixedwood sites tend to develop into stands dominated by trembling aspen and balsam fir, with lower proportions of spruce and pine than the original stands (Yang and Fry 1981). To increase levels of spruce or pine on mixedwood cutovers, site preparation followed by a regeneration treatment (seeding or planting) is required. Mechanical site preparation reduces the levels of balsam fir regeneration present in plantations (Morris *et al.* 1988). The use of mechanical scarification on mixedwoods also tends to increase suckering of aspen and hardwood shrubs on sites which had vigorous stands of these species before cutting (Morris *et al.* 1988). On mixedwood sites where a conifer component is desired, further treatment will be necessary to control competition.

Prescribed burning has great potential for the management of mixedwood succession since the timing and depth of burn can be controlled. Deep, late summer burns can be prescribed to reduce the suckering of hardwoods and the germination of buried seeds, and to create suitable seedbeds for conifer establishment. Conversely, light spring burns that remove little duff can be prescribed to stimulate hardwood regeneration or to increase shrub and herbaceous cover for habitat enhancement. Fire is also an important tool for controlling balsam fir.

In mixedwood stands, thinning aspen could assist in maintaining the vigor of the coniferous component. An increase in the coniferous component of mixedwood stands may result after aspen thinning, provided that a seed source is available (Haavisto *et al.* 1991).

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Successional Trends for Boreal Mixedwood Stand and Site Conditions in Northwestern Ontario

by W.D. Towill[1] , R. Wiltshire[2] and C.L. Palmer[1]

> *A thorough understanding of successional patterns and stand dynamics following is a prerequisite for the development of BMW management and silviculture strategies...*

Introduction

Succession in the boreal mixedwood forest is characterized by species replacement in the main canopy through time. Historically a limited understanding of boreal mixedwood (BMW) stand dynamics and ecological processes often contributed to a lack of silvicultural and regeneration success in Ontario's boreal mixedwoods (MacDonald 1995). Ontario's Crown Forest Sustainability Act (Statutes of Ontario 1995) requires that forest managers adopt an ecosystem management approach founded on the emulation of natural processes. A thorough understanding of successional patterns and stand dynamics following both natural disturbance and harvesting is a prerequisite for the development of BMW management and silviculture strategies that are compatible with this legislated direction.

Describing BMW stand and site conditions using ecological land classification tools and products, such as ecosite types, can assist in the development of ecologically appropriate management strategies.[3] Northwestern Ontario ecosites (ES-type) (Racey *et al.* 1996) and vegetation types (V-type) (Sims *et al.* 1997) provide information about the relationship between the broad mixedwood stand cover types, both softwood- and hardwood-dominated, and associated stand-level ecological condition. Ecosites are ecological classification units that can be mapped and are described, in part, by characteristic associations of V-type and soil type (S-type), which are based on common assemblages of both abiotic (soil depth, texture, moisture regime, hydrology and nutrient regime) and biotic (plant community structure and composition) conditions. The development, persistence, vigour, and eventual change in the characteristic plant associations that define BMW stand conditions are strongly related to species autecology, site productivity, and site conditions (as well as individual species ecological amplitude) (Bergeron and Dubuc 1989, Wang 2000, Larocque *et al.* 2000). Differential patterns of species

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[3] Ecosites may occur in more than one category due to differences in soil texture and moisture regime and related species abundance and diversity.

Ontario

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recruitment, survival, and growth and development are associated with differences in broad groupings of boreal mixedwood stand types and soil conditions.

This note provides an overview of natural BMW stand dynamics and presents successional trajectories for broad groupings of boreal mixedwood stand types and soil conditions commonly found in northwestern Ontario. Pierpoint (1981) first differentiated these broad soil groupings (described in Table 1) on the basis of associations between site (soil moisture and nutrient regime) and forest cover condition. The successional trajectories presented were developed by interpreting the literature on local BMW successional relationships and stand dynamic processes, and combining this with knowledge of the critical silvics of boreal species, and expert opinion. The primary source of information is Kenkel *et al.'s* (1998) work on vegetation dynamics in the boreal forests of northwestern Ontario.

Ecosites may occur in more than one category due to differences in soil texture and moisture regime and related species abundance and diversity.

Natural stand dynamics of boreal mixedwoods

Ontario's boreal mixedwood sites are defined on the basis of soil/site, stand and forest characteristics as well as stand dynamics.

"A boreal mixedwood site is *an area with climatic, topographic, and edaphic conditions that favour the production of closed canopies dominated by trembling aspen* (Populus tremuloides *Michx.*), *or white birch* (Betula papyrifera *Marsh.) in early successional stages, black spruce* (Picea mariana *(Mill.) BSP) or white spruce* (Picea glauca *(Moench) Voss) in mid-successional stages and balsam fir* (Abies balsamea *(L.) Mill.) in late successional stages."* (MacDonald and Weingartner 1995)

In Ontario, boreal mixedwood stands are defined as tree communities on boreal mixedwood sites in which no single defining boreal mixedwood species comprises 80% or more of the total basal area (MacDonald 1995). Associated boreal mixedwood tree species (e.g. jack pine (*Pinus banksiana* Lamb.), balsam poplar (*Populus balsamifera* L.)) may also be present. Boreal mixedwood stand dynamics refer to the changes in structure and composition that occur in a stand over time, both during and after a disturbance (Chen and Popadiouk 2002). Chen and Popadiouk (2002) have identified the four sequential stages of BMW stand development, distinguished on the basis of differences in stand structure, composition, and ecological processes. They are: stand initiation, stem exclusion, canopy transition, and gap dynamics.

Although traditional theory suggested that succession is unidirectional (Clements 1949), Rowe (1961) first recognized that multiple successional pathways are possible in the boreal forest. BMW stand development depends on a combination of stochastic factors, species life history traits, the type, severity, and timing of disturbance, pre-disturbance stand and site (edaphic) conditions, microclimate, vegetative

Table 1. *Three classes of boreal mixedwood stand and site conditions and inferred site productivity levels (Pierpoint 1981).*

Stand Condition	Site Conditions	Relative Site Productivity
A. Fresh upland mixedwoods/ hardwood mixedwoods	· Slightly dry, fresh, and moist soil moisture regimes · Clays and fine loams	Most productive
B. Dry to fresh upland mixedwoods/ pine-spruce, spruce-pine, white birch and poplar conifer mixedwoods	· Slightly drier soil moisture regimes · Loams to fine sands	Moderately productive
C. Conifer mixedwoods/balsam poplar hardwood mixedwoods	· Wet or shallow sites · Moist soils	Least productive

competition, and the influence of neighbouring stands (Rowe 1961, Chen and Popadiouk 2002, OMNR 2003). These factors may also interact to influence the abundance, diversity, and relative dominance of boreal mixedwood species on a particular mixedwood site. The autecology and ecological plasticity of a species and its adaptive capacity to survive, grow, and reproduce on a variety of sites within its natural range (ecological amplitude) influence how a species reacts to disturbance (Halliday 1950).

Since any one of a number of successional pathways is possible in any particular BMW stand, depending on the above factors, stand development does not necessarily pass sequentially through the four developmental stages. Chen and Popadiouk (2002) describe five successional models, as originally summarized by Frelich and Reich (1995a), to explain the possible successional pathways that can occur in BMWs: cyclic, convergent, divergent, parallel, and individualistic.

The successional trajectories presented in this note indicate the expected pathways when stands pass through the four sequential BMW stand development stages. The trends noted for specific BMW cover types in each of the three site productivity classes generally confirm Oliver and Larson's (1996) concept of stand development, where stands become more open in later successional stages. These trends also support MacDonald and Weingartner's (1995) conceptual model of boreal mixedwood stand development, where there is a compositional shift from pioneer to late successional species in the absence of stand-replacing disturbance. Similar trends have recently been confirmed in a study of BMW stand dynamics throughout Ontario (Popadiouk *et al.* 2003). These trends have also been observed in earlier studies of natural BMW succession in northwestern Ontario (Zoladeski and Maycock 1990), Minnesota (Frelich and Reich 1995 a, b), and Quebec (Bergeron and Dubuc 1989, Bergeron and Dansereau 1993, Bergeron 2000, DeGrandpré *et al.* 2000, Lesieur *et al.* 2002).

Boreal mixedwood successional trends in northwestern Ontario by stand condition and cover type

A. Fresh upland mixedwoods/ hardwood mixedwoods

- Occur on richest, most productive sites
- Typically occur on fresh to moist, fine-textured (fine loamy to clayey), well to imperfectly drained soils
- Soils are frequently calcareous
- Normally associated with post-glacial Lake Aggassiz (clay lake bottom)
- Characterized by medium to rich herb and tall shrub layer

Most common NWO-FEC (Sims et al. 1997) soil types associated with Class A – Fresh upland mixedwoods/hardwood mixedwood stands are:

Soil type	Soil description
S4	Fresh/silty-silty loamy
S5	Fresh/fine loamy
S6	Fresh/clayey
S9	Moist/silty-silty loamy
S10	Moist/fine loamy-clayey
SS7	Shallow-moderately deep/silty fine loamy

These fresh upland mixedwood stands include the softwood-dominated mixedwood cover types: fir-spruce, jack pine-black spruce, and the hardwood-dominated mixedwood cover types: balsam poplar-black ash (*Fraxinus nigra* Marsh.), and aspen-fir-spruce as described below.

1. Softwood-dominated (softwood > 50%) Mixedwood Cover Types

<u>Fir-spruce mixedwood</u>

Northwestern Ontario ecosites, soil types, and vegetation types associated with Class A – Fresh upland mixedwoods/hardwoods mixedwoods: Fir-spruce mixedwoods are summarized below:

Ecosites (soil type)	Vegetation types	Stand description
ES32 (S9, S10)	V14, V15, V16, V19	Dominated by balsam fir, white spruce, and black spruce and associated with trembling aspen and white birch (occasionally jack pine and balsam poplar).
ES (S4,S5,SS7)	V15, V16, V19	

Description

- Dominated by balsam fir, white spruce, and black spruce in the canopy with mixtures of trembling aspen and white birch and occasionally jack pine and balsam poplar.
- Conifers dominate most stands (ES32 conifer component exceeds 50%) with white and black spruce often forming a dense canopy.
- Balsam fir most frequently forms the sub-canopy and sapling layers although it can be part of the main canopy. This late successional conifer can occasionally form pure stands.
- White birch and white spruce may occur in the sub-canopy and sapling layers.
- Shrubs are generally moderately abundant. Ericaceous shrubs occur occasionally.
- The herb layer is usually rich and forms extensive cover. Feathermoss (*Pleurozium schreberi* Brid. Mitt.) constitutes much of the ground cover.

Successional pathways

- Overall successional trajectory is towards a more open, uneven-aged canopy of mixed species composition.
- Black spruce occurrence decreases as the forest ages, while balsam fir increases.
- The sub-canopy and tall shrub layer become increasingly important over time. Herb cover tends to decrease but moss cover increases.
- Balsam fir tends to break up earlier due to optimum growth during early stages of development.
- When rotations are extended, white spruce can form a super-canopy over the main canopy of black spruce and balsam fir.

Additional succession notes

Spruce budworm outbreak can influence succession in these forest cover types. Periodic infestations can eliminate 70 to 100% of balsam fir stems and up to 40% of white spruce stems, if defoliation lasts at least 5 years. Defoliated trees are susceptible to root rot and windthrow. Openings in the canopy created by windthrow allow the release of balsam fir and white spruce seedlings from the understory, with white spruce often dominating. These openings may also stimulate the growth of tall shrubs, which often suppresses further balsam fir regeneration.

Jack pine-black spruce mixedwood

Northwestern Ontario ecosites, soil types, and vegetation types associated with Class A – Fresh upland mixedwoods/hardwoods mixedwoods: Jack pine-black spruce mixedwoods are summarized below:

Ecosites (soil type)	Vegetation types	Stand description
ES25 (S4,SS7)	V31, V32	Dominated by jack pine and black spruce with scattered occurences of trembling aspen, white birch, and balsam poplar. Sphagnum can occur in wetter locations.
ES26 (S5, S6, SS7)	V20, V31, V32	
ES31 (S9, S10, SS7)	V31, V32	

Description

- Overstory dominated by mixed canopy of black spruce and jack pine. Black spruce can be prominent in the canopy, sub-canopy, and sapling layers. Jack pine seldom dominates below the canopy layer.
- Tree cover is typically dense.
- Trembling aspen, white birch, balsam fir, and white spruce may occur in the upper two canopies in older stands.
- Regeneration in the sub-canopy layers is mainly to black spruce but occasionally balsam fir, white birch, and trembling aspen also occur.
- White birch, trembling aspen, and/or white spruce are often present in the sapling layer.
- Total shrub cover is low, but ericaceous shrubs are ubiquitous and persist at low to moderate cover levels. Labrador tea (*Ledum groenlandicum* L.) is often present on moist sites at moderate to high cover levels.
- Herb cover is typically low and the forest floor is covered by feathermosses.
- Sphagnum (*Sphagnum* spp.) moss occurs in wetter locations.

Successional pathways

- Continued dominance by black spruce is the probable successional trajectory for this forest type.
- Over time, stand structure changes from dense, even-aged stands to more open, uneven-aged black spruce stands.
- Balsam fir cover increases on moister sites but these rarely form part of the canopy.
- Diversity of older stands may increase due to the higher frequency of white birch, trembling aspen, and balsam fir.
- Labrador tea cover increases but herbaceous species tends to decline with time.

Additional succession notes

After a significant disturbance event, jack pine recruitment equals that of black spruce but while it is restricted to the first few years after stand initiation, black spruce recruitment continues for at least 60 years. In the initial stages, recruitment levels are high but become more gradual and more akin to those following low-intensity surface fires over time. Even black spruce recruitment ceases once stand closure occurs.

Balsam fir canopy cover and occurrence tends to be higher on moister sites. Sphagnum moss is also more abundant on these sites.

2. Hardwood-dominated Mixedwood Cover Types

Balsam poplar-black ash hardwood

Northwestern Ontario ecosites, soil types, and vegetation types associated with Class A – Fresh upland mixedwoods/hardwoods mixedwoods: Hardwood-dominated mixedwoods Balsam poplar-black ash are summarized below:

Ecosites (soil type)	Vegetation types	Stand description
ES30 (S4, S5, S6, S10)	V1, V2	Dominated by black ash with occurrence of trembling aspen, white birch, balsam poplar, and white cedar (*Thuja occidentalis* L.). Feathermoss and graminoids dominate the ground cover.

Description

- Dominated by black ash, usually in pure stands. Balsam poplar and white birch can occur in the canopy. Trembling aspen and white cedar may also be present.
- Canopy gaps may encourage balsam poplar, white birch, trembling aspen, and eastern white cedar to form more of the stand.
- The sub-canopy and sapling layers are dominated by black ash but balsam fir and white spruce may be frequent in older stands.
- Dense growth of mountain maple (*Acer spicatum* Lam.) and speckled alder (*Alnus incana* (L.) Moench spp. *rugosa*) is common in the understory.
- Currant (*Ribes* spp.) species can occur but cover is usually less than that of mountain maple and speckled alder.
- Herb richness and total cover is generally high.
- Ground cover consists of broadleaf litter, graminoid litter, feathermoss and wood. Moss cover remains low to moderate throughout the life of these stands.

Successional pathways

- Canopies in older stands tend to open forming multi-tiered and uneven aged stands. Total tree cover declines after age 100.
- Black ash stands in seasonally flooded sites are self-regenerating through coppice and seedling growth. Black ash continues to dominate the canopy and sub-canopy of older stands.
- Sites subject to frequent flooding exhibit regeneration declines.
- If no catastrophic event occurs, over time the density and percent cover of white birch and balsam poplar decline and eastern white cedar and white spruce increase. In this scenario, balsam fir may also begin to figure more prominently.
- On sites that are less subject to flooding, succession may slowly lead to dominance by eastern white cedar, white spruce, and balsam fir.
- If present, the relatively short-lived and intolerant balsam poplar will be succeeded by eastern white cedar, white spruce, and black spruce on wetter sites.
- Over time on mesic sites, white birch and balsam fir are favoured over balsam poplar.

- Dense cover of mountain maple continues to exist in well into later successional stages.
- Ericaceous shrubs are absent from older stands.
- A rich herb layer continues to exist in older stands but total cover decreases with time.

Additional succession notes

Soils found here are typically nutrient rich, mildly acidic, organic-enriched, fine-textured silts to clay usually of lacustrine origin. They are on moist to wet sites with well to imperfect drainage.

Usually these forests represent a limited area on the landbase and occur in subdued topography, depressions, and intermittent watercourses.

This forest type can have a wide range of associated vegetation types, occasionally transitional species such as red maple (*Acer rubrum* L.) occurs in Site Regions 4S, 4W, and 5S.

An alternate successional pathway for this forest cover type may occur if the water table is greater than 2 m deep and soil pH is neutral to slightly basic. Similar to sites that are not as likely to flood, in this case succession will lead slowly to eastern white cedar, white spruce, and balsam fir. This may also occur if the flooding regime has been altered by anthropogenic disturbance.

Aspen-fir-spruce mixedwood

Northwestern Ontario ecosites, soil types, and vegetation types associated with Class A–Fresh upland mixedwoods/hardwoods mixedwoods: Trembling aspen-fir-spruce are summarized below:

Ecosites (soil type)	Vegetation types	Stand description
ES28 (S4, SS7)	V6, V7, V8, V9	Dominated by trembling aspen, and white birch with conifer mix of black spruce, jack pine, white spruce, and balsam fir (<49%); wetter sites may have balsam poplar present.
ES29 (S5, S6, SS7)	V6, V7, V8, V9	
ES33 (S9, S10)	V6, V7, V8, V9	

Description

- Trembling aspen mixedwood forest cover types represent what is typically thought of as mixedwood forest conditions. These forest cover types are dominated by trembling aspen and occasionally by white birch.
- A conifer mix of balsam fir, white spruce, and black spruce that may act as co-dominants but pure hardwood stands are possible. Occasionally jack pine may also exist in the canopy and balsam poplar may occur on moister sites.
- A two-tiered canopy of aspen in the upper layer and balsam fir in the lower layer often exists.
- Young stands often have canopies of pure aspen; less common are canopies of mixed trembling aspen with balsam fir, white spruce, and/or white birch.
- Trembling aspen and balsam fir regeneration is typical for most stands. White birch and black spruce can also be found in the regeneration layer.
- Tall shrubs dominate the shrub layer but ericaceous shrubs are uncommon. These types of sites are typically moderately shrub and herb-rich.
- Feathermosses are present on sites that have fresh, silty and fine loamy-clayey soils.

Successional pathways

- Without the influence of disturbance, the successional trajectory for these forest cover types is towards a more open, multi-tiered and uneven-aged canopy of mixed species.
- Canopy cover increases up to age 100.
- Canopy cover decreases once trembling aspen begins to decline and conifer growth is encouraged by the new openings.
- Balsam fir and white spruce are common canopy replacements, moving from the sub-canopy into the canopy layer.
- Black spruce may increase in canopy importance on more acidic sites, where it can constitute up to 15% of the dominant-codominant layer within 85 years.
- Along watercourses, beaver activity may encourage softwood dominance.
- Tall shrubs continue to dominate the shrub layer in older stands.
- Herb cover begins to decline once the canopy cover starts to decrease.
- Ground cover by feathermosses increases with time but they tend to remain a minor component of the understory.

B. Dry to fresh upland mixedwoods/ pine-spruce, spruce-pine, white birch and poplar conifer mixedwoods

- Occur on less rich sites.
- Occur on drier, coarser soils.
- Shrub-rich to low shrub layer present.
- Poorest nutrient cycling is probably associated with black spruce-dominated tree cover and feathermoss-dominated forest floor (Pierpoint 1981).

Most common NWO-FEC (Sims et al. 1997) soil types associated with Class B – Dry to fresh upland mixedwoods/pine-spruce, spruce-pine, white birch and poplar conifer mixedwoods are:

Soil type	Soil description
S3	Coarse loamy
S7	Moist sandy
S8	Moist coarse loamy
SS5	Shallow moderately deep sandy
SS6	Shallow moderately deep coarse loamy

These dry to fresh upland mixedwood stands include the softwood-dominated mixedwood cover types: fir-spruce, jack pine-black spruce, and the hardwood-dominated mixedwood cover type: white birch-poplar as described below.

1. Softwood-dominated (softwood > 50%) Mixedwood Cover Types

Fir-spruce mixedwood

Northwestern Ontario ecosites, soil types, and vegetation types associated with Class B – Dry to Fresh upland mixedwoods/pine spruce, spruce pine, white birch-poplar conifer mixedwoods: Fir-spruce mixedwoods are summarized below:

Ecosites (soil type)	Vegetation types	Stand description
ES21 (S3, SS6)	V14, V15, V16, V19, V24, V25	Dominated by balsam fir, white spruce and black spruce with mixtures of trembling aspen and white birch. Shrub and herb poor with abundant feathermoss.

Description

- Species importance differs for conifer-dominated mixedwoods on drier, coarser-textured substrates. Jack pine and trembling aspen tend to be more prominent on these sites, while white spruce is less prominent.
- Balsam fir is more common in the canopy and often forms associations with white and black spruce. Less commonly, balsam fir cover types are associated with white birch, jack pine, and/or trembling aspen.
- A strong hardwood component can be characteristic of some stands but the coniferous component still exceeds 50% of the canopy.
- Shrubs are generally low to moderate in abundance. Mountain maple is more prominent on these sites and may be abundant in localized areas.
- These sites generally support an extensive herb-rich layer.

Successional pathways

- These forest types are self-perpetuating and show little change in floristic composition and community structure over time.
- On fresh, coarse loamy soils, white birch may occur more commonly than on the richer, finer-textured sites.
- Jack pine may have a competitive advantage over some of the more nutrient-demanding conifers on these coarser-textured soils but its presence decreases in importance in older stands.
- Older stands tend to be dominated by balsam fir and white spruce.
- Black spruce cover declines as the stand matures.
- Lower canopy layers are dominated by balsam fir.
- Total shrub cover increases with time, although ericaceous shrubs occur less in older stands.
- Herb layer cover decreases with stand age but tends to remain diverse.
- Electrified cat-tail (*Rhytidiadelphus triquestris* (Hedw.) Kindb.) and Brachythecium (*Brachythecium curtum* (Lindb.) Limpr.) mosses tend to increase in cover in mature stands.

Jack pine-black spruce mixedwood

Northwestern Ontario ecosites, soil types, and vegetation types associated with Class B – Dry to Fresh upland mixedwoods/pine spruce, spruce pine, white birch and poplar conifer mixedwoods: Jack pine-black spruce conifer mix - spruce-pine-feathermoss-Ledum are summarized below:

Ecosites (soil type)	Vegetation types	Stand description
ES20 (S3, SS6, SS5)	V31, V32	Dominated by black spruce and jack pine with possible mixtures of trembling aspen, white birch, white spruce, and balsam fir. Ledum occurs on moist sites.
ES22 (S7, S8, SS8)	V19, V20	

Description

- Jack pine is more prominent on the drier boreal mixedwood sites and black spruce is less common in the canopy.
- White spruce and balsam fir may also be more frequently encountered in the lower canopy and sapling layer on these sites compared to the richer sites.
- Tall shrubs are more prominent.
- Moss cover is somewhat lower but lichens occur more frequently.
- Species richness, diversity, and evenness are low relative to the other ecosites.

Successsional pathways

- Successional pathways are similar to those on the richer, finer-textured soils.
- Increased dominance and continued recruitment of black spruce is expected.
- On these drier sites jack pine relicts are likely to occur in older stands.
- Hair step moss (*Hylocomium spendens* (Hedw.) Schimp.) increases with age on these sites.
- Lichen cover declines as the stands mature.

2. Hardwood-dominated Mixedwood Cover Types

White birch-poplar-dominated mixedwood

Northwestern Ontario ecosites, soil types, and vegetation types associated with Class B – Dry to Fresh upland mixedwoods/pine spruce, spruce pine, white birch and poplar conifer mixedwoods: White birch and poplar mixedwoods – hardwood-fir-spruce are summarized below:

Ecosites (soil type)	Vegetation types	Stand description
ES19 (S2, S3, SS6, SS5)	V4, V10, V11, V17	Dominated by trembling aspen, white birch, and balsam fir, with occasional occurrence of white spruce, black spruce, and jack pine.
ES23(S7, S8, SS8)	V5, V6, V7, V8, V9, V19	

Description

- White birch or trembling aspen often dominate the upper layer of this forest canopy.
- When white birch figures more prominently in the canopy than aspen, jack pine may also be present.
- Pure canopies of hardwood are possible but coniferous species such as white spruce, balsam fir, and black spruce are occasional co-dominants. The hardwood component always exceeds 50% cover.
- A mono-dominant stand of aspen is typically associated with a strong component of balsam fir in the understory.
- Balsam fir, white spruce, and white birch commonly occupy the sub-canopy.
- Other associated boreal mixedwood hardwoods may also be present.
- Generally total tree cover is high.
- The shrub layers have a strong balsam fir component but white birch and black spruce can be present.
- Shrub cover is moderate to high in coverage. Mountain maple and beaked hazel (*Corylus cornuta* Marsh.) often dominate this layer. In stands that are dominated by white birch, *mountain maple* is usually replaced by green alder (*Alnus viridis* (Villars) DC spp. *crispa*) in the shrub layer.
- The herb layer is floristically rich with high cover levels.
- Mosses play a minor role in ground cover.

Successional pathways

- A probable successional pathway for these stands is towards a more open, mixed canopy of white birch and balsam fir.

- Intolerant hardwoods tend to become less prominent as these forests age and 'fall out' of the canopy after 100 years.
- Conifers tend to replace the hardwoods, typically white spruce, black spruce, and balsam fir, resulting in an uneven-aged stand structure.
- In older stands, trembling aspen and jack pine (if present) decline in cover over time and are usually absent in older stands.
- On moister sites, relicts of trembling aspen can persist for up to 200 years.
- Associated with the white birch-balsam fir canopy, white and black spruce can be present in the lower sub-canopy layers.
- Total tree-cover increases up to age 120 due to increasing subcanopy cover.
- Light, surface fires help to maintain white birch in the sub-canopy
- In an extended rotation, white spruce can form a super-canopy.
- Gaps in the canopy may favour the regeneration of black spruce during stand break-up in white birch-dominated mixedwoods.
- Gaps in the canopy may favour the regeneration of balsam fir in the trembling aspen-dominated mixedwoods.
- Total shrub layer declines with time. Mountain maple decline is more obvious than that of hazel.
- Blueberries (*Vaccinium* spp.) increase in older stands.
- Although aspen suckering is common, sucker-origin trees rarely enter the canopy on these sites.

C. Softwood mixedwoods/balsam poplar hardwood mixedwoods

- Least productive of the boreal mixedwood sites.
- Found on peaty phase, seepage-enriched, very moist to somewhat wet sites and on shallower soils.
- Support vigorous shrub, herb, fern and moss layers and high species diversity.
- Often sphagnum-rich sites.

Most common NWO-FEC (Sims *et al*. 1997) soil types associated with Class C – Conifer mixedwoods/balsam poplar hardwood mixedwoods are:

Soil type	Soil description
S10	Moist /fine loamy-clayey
S11	Moist peaty phase
SS8	Shallow-moderately deep with presence mottles and gley
SS9	Shallow moderately deep organic peaty phase

These softwood mixedwood stands include the softwood-dominated mixedwood cover types: fir-spruce, jack pine-black spruce, and the hardwood-dominated mixedwood cover type: black ash-other hardwood as described below.

1. Softwood (softwood > 50%)-dominated Mixedwood Cover Types

<u>Fir-spruce mixedwood</u>

Northwestern Ontario ecosites, soil types, and vegetation types associated with Class C– Conifer mixedwoods/balsam poplar hardwood mixedwoods; Conifer-dominated fir-spruce mixedwood are summarized below:

Ecosites (soil type)	Vegetation types	Stand description
ES32 (SS8)	V14, V15	Dominated by balsam fir, white spruce, and black spruce, associated with trembling aspen and white birch, and occasionally jack pine and balsam poplar. Shallower soils.

Description

- High canopy cover by black spruce, white spruce, and trembling aspen. Balsam fir and jack pine are less abundant.
- White spruce may dominate the canopy in some stands.
- Balsam fir and black spruce are typically found in the subcanopy and sapling layers. White birch and white spruce may be encountered in the sapling layer.
- Tall shrub cover is somewhat lower than on deeper sites but honeysuckle (*Diervilla lonicera* Mill.) is more abundant.

- Ericaceous shrubs occur at low cover.
- Dwarf raspberry (*Rubus pubescens* Raf.*)* cover is low.
- Herb layer is similar to the deeper sites and feathermoss cover is high. Other mosses, such as Brachythecium, hair step, and cat-tail, occur far less frequently.

Successional pathways

- These stands are most likely succeeding towards an uneven-aged canopy of balsam fir, black spruce, and/or white birch.
- Black spruce is less prominent in the canopy as stands age on these sites, while balsam fir gains prominence as the canopy opens up.
- Balsam fir dominates the canopy, subcanopy, and regeneration layer of older stands.
- White birch rarely occurs above the lower subcanopy and sapling layers. White and black spruce may also be found in these layers.
- Over time, tall shrubs such as mountain maple, green alder, and mountain ash (*Sorbus* spp.) increase in frequency and cover as the stands ages. Honeysuckle cover decreases.
- Ericaceous shrubs such as blueberry and Labrador tea increase in cover as the stand ages but are not prominent.
- Feathermoss cover increases with time and dominates this strata of ground cover.

Jack pine-black spruce mixedwood

Northwestern Ontario ecosites, soil types, and vegetation types associated with Class C – Conifer mixedwoods/balsam poplar hardwood mixedwoods: Jack pine/black spruce conifer mix – spruce-pine feathermoss.

Ecosites (soil type)	Vegetation types	Stand description
ES31 (S11, SS8, SS9)	V31, V32	Dominated by black spruce and jack pine with scattered occurrence of trembling aspen, white birch, and balsam fir. Moist, silty-clayey, grading to peaty phase. Herb to shrub poor. Sphagnum occurs in wetter locations.

Description

- Black spruce is more prominent than jack pine on peaty phase sites.
- On the shallower sites, these stands generally have lower stocking.
- Larch (*Larix* spp.) may occur in some stands.
- Balsam fir and white birch are more commonly encountered in the lower sub-canopy.
- Labrador tea is prominent in the low shrub layer.
- The herb layer is similar to that on more productive sites. Mosses are fairly prominent especially Sphagnum and *Ptilium crista-castrensis.*
- Lichens are infrequent.

Successional pathways

- The replacement of jack pine by black spruce occurs more rapidly on shallower sites.
- Balsam fir becomes more important in the later stages of succession on these sites and some stands may develop into a mixed balsam fir-black spruce canopy.
- Jack pine and larch rarely persist in older stands.
- White birch may persist in the sub-canopy and regeneration is favoured due to the more open canopy and in areas of windthrow, but it never becomes dominant on these sites.
- Herb cover declines.
- Moss prominence changes with stand age. Feathermosses and *Ptilium crista-castrensis* decline slightly in cover, while hair step moss increases. Sphagum may also increase.

2. Hardwood-Dominated Mixedwood Cover Types

Black ash/other hardwood

Northwestern Ontario ecosites, soil types and vegetation types associated with Class C – Hardwood-dominated mixedwood: rich swamp/black ash (other hardwood) are summarized below:

Ecosites (soil type)	Vegetation types	Stand description
ES38 (S11, S10)	V1, V2	Dominated by black ash and/or white elm on organic-mineral forested wetland soil. Seasonably flooded. Often shrub-herb-graminoid rich. Well-decomposed peat or fine-textured mineral soil.

Description

- These are the richest of forested wetlands. They are replenished by deposition of mineral and organic material during periods of flooding.
- They are usually dominated by black ash and/or white elm on peaty phase to moist soils.
- Mixedwood stands containing balsam poplar in the overstory are also associated with these sites. Pure stands of black ash can occur.
- A variation of this forest type may be black ash as a minor component of the tree layer with trembling aspen becoming the dominant species.
- White birch and balsam poplar are occasional co-dominants.
- A variety of other occasional overstory species occur in these forest cover types on these site conditions depending on the ecoregion.
- White cedar, red ash, balsam fir, and trembling aspen are known to be associated with this mixedwood forest cover type.
- The understory is consistently herb and shrub rich and diverse in nature. Tall shrubs are frequent with moderate cover but ericaceous species are absent. Herb cover is moderate to high.
- Ground cover by *Carex*, *Galium*, and *Viola* is prominent in these stands.
- Moss cover is low but species richness is high. Lichens are infrequent on these types of sites but if they do occur they are not prominent.

Successional pathways

- Most of these stands are self-regenerating.
- The perpetuation of these forest types may be negatively affected if spring and early summer flooding frequency and duration increase.
- Recruitment of black ash is continuous.
- Black ash may be succeeded by white cedar in areas less prone to flooding.
- Balsam poplar forests become an all-aged structured stand that will continue to regenerate especially if there is well-oxygenated seepage.
- If trembling aspen attains a contiguous slope position it will integrate with the balsam poplar stand of this forest cover type and eventually out compete it.
- Tree species are long-lived on these sites but exhibit low growth as nutrients are tied up by the high moisture regime.

Summary

Successful BMW management requires a thorough understanding of stand dynamics and successional trends. This note provides an overview of natural BMW stand dynamics and speculates on how northwestern Ontario ecosites reflecting different levels of inherent site productivity may change through time and in response to disturbance.

Based on the current state of knowledge of BMW stand dynamics and post-harvest succession in northwestern Ontario, it is clear that further research is required to obtain a better understanding of all stand development stages following both natural disturbance and harvesting. Because BMW management includes the use of reproduction and harvest methods beyond conventional clearcutting, studies of post-harvest succession should follow all types of harvesting methods. The knowledge gained from such studies would enable the development of silvicultural prescriptions that take full advantage of the productive capacity of boreal mixedwoods.

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boreal mixedwood Notes

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Importance and Use of Mixedwood Sites and Forest Cover by White-tailed Deer *(Odocoileus virginianus)*

by H.R. Timmermann[1]

> ***White-tailed deer are widely distributed throughout Ontario. Seasonal habitat needs include food, water, and cover provided by a variety of mixedwood***

Introduction

White-tailed deer (*Odocoileus virginianus*) belong to the deer family *Cervidae* which includes moose (*Alces alces*), woodland caribou (*Rangifer tarandus caribou*) and several species of deer in North America. Whitetails tolerate a wide range of temperatures ("eurythermal") and their range extends from Canada to Venezuela; with thirty subspecies identified (Baker 1984, Bolen and Robinson 1995). In 1980 the continental population was estimated at around 12 million (National Shooting Sports Foundation N/D). In Ontario white-tails are widely distributed; in portions of the southern section of the Boreal Forest Region and throughout the Great Lakes–St. Lawrence Forest Region (Cumming and Walden 1970, Rowe 1972, Dobbyn 1994). Seasonal habitat needs include food, water and cover provided by a variety of mixedwood stands. Recently disturbed, high quality mixedwood habitats have the potential to produce high deer densities, especially in central and southern Ontario when predation pressure is low and winter climate is moderate.

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Species Description and Distribution

White-tailed deer are the smallest and most commonly seen member of the deer family in Ontario (Dobbyn 1994). Adult males or bucks in good Ontario habitat commonly weigh between 100 and 130 kg live weight and adult females or does average 55 to 80 kg (Smith and Verkruysse 1983). In poor habitat, or where competition for food is high, deer of both sexes weigh much less.

White-tailed deer range is closely linked to land-use practices such as the extensive logging that occurred earlier this century. This disturbance produced a second growth forest that provided abundant food and thus allowed populations to expand northward into portions of the boreal forest. (Peterson 1966, Cumming and Walden 1970). Deer in Ontario moved as far north in Ontario as Kirkland Lake, Sioux Lookout and Red Lake during extended periods of mild winters in the 1950s and 1980s (Euler 1979). Winter weather extremes, in concert with changing habitat conditions and mortality from hunting and predation, control herd size and distribution (Ontario Deer Technical Committee 1978). Deer in Ontario live at the northern limit of their continental range and are distributed in three main geographic areas (Figure 1). These areas include the southern agricultural zone south of the Canadian Shield, the mixed hardwood–conifer central zone on part of the Shield and the Northwestern mixedwood hardwood boreal influenced zone extending west and southward from the Nipi-gon River to the Manitoba border. Deer are considered "extralimital within the Boreal Forest, although some isolated populations do exist in northwestern and northern Ontario where soils, climate and land use favour deer habitat" (Voigt *et al.* 1992:6).

The number of deer a given parcel can support (biological carrying capacity) is a function of the quantity and quality of deer forage and/or the availability of good winter habitat (Ellingwood and Caturano 1988). The bulk of Ontario's deer are found in the Great–Lakes St. Lawrence forests and their province-wide population has increased from 100,000 in the early 1980s to 250,000 by 1988 (Euler trans: vol. 84, p 14124, Environmental Assessment Board 1994). In 1995 there were more than 350,000 deer in Ontario (OMNR 1995).

White-tailed deer are a valuable renewable natural resource and in 1993, 147,600 Ontario hunters spent more than $56.8 million on activities, supplies and services directly connected with the activity (Legg 1995).

Figure 1. Distribution of white-tailed deer in Ontario (from Smith and Verkruysse 1983).

Movement and Habitat Use

During spring, summer and early fall white-tails usually remain solitary or in small family groups; whereas in winter they frequently aggregate in winter “yards” or concentration areas (Smith and Verkruysse 1983). Most studies of northern white-tailed deer habitat have been occupied with evaluating both summer and winter ranges (Telfer 1970, Kohn and Mooty 1971, Wetzel *et al.* 1975, Kearney and Gilbert 1976, Stocker *et al.* 1977, Potvin and Huot 1983). In late fall–early winter, northern white-tails make directed movements up to 40 km from summer range to winter concentration areas with suitable conifer shelter, and disperse in spring (Rongstad and Tester 1969, Verme 1973, Drolet 1976, Nelson and Mech 1981). Movement to winter habitats is associated with an increase in snow depth and windchill (Verme and Ozoga 1971, Ozoga and Gysel 1972, Drolet 1976). Deer adapt to winter survival by reducing movement, energy consumption and metabolic rate (Mautz 1978, Karns 1980, Moen 1968, 1976, 1978).

Optimal winter habitat in northern deer range “is any area of moderate elevation having a moderate to high proportion (10–60%) of softwood or mixedwood forest 10–20 m high, with a patchy conifer crown closure of 50–80%, interspersed with small (<50 ha) stands of early successional deciduous or mixed species 1–10 m high with a conifer crown closure of less than 50%” (Darby

Table 1. Attributes of winter mixedwood habitat for white-tailed deer (adapted from Darby 1990: 46).

Habitat Characteristics	Uses	Reference Source*
1. Mixedwood and deciduous species 1–10 m high, crown closure < 50%, interspersed with conifer stands in regenerating cut overs (-50 ha in size).	- food - day bedding	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11
2. Confer dominated mixedwood (10–60% of areas, 55–100% of trees) ž11 m high, crown closure 60–80%, basal area 30–65% m^2/ha.	- escape cover - protection from deep snow and weather - night bedding	1, 3, 5, 6, 7, 12, 13, 14, 15, 17, 18, 19, 20
3. Small (<2 ha) patches or strips of preferred browse in conifer stands.	- food - isolation	3, 5, 6, 7, 10, 17, 19, 20, 21, 22
4. High degree of edge between stands.	- escape cover, food - day/night bedding - gestation	3, 5, 6, 7, 9, 10, 14, 21, 22, 23, 24

Note

* Numbers conform to numbered references as follows: 1 - Telfer (1970); 2 - Byelich *et al.* (1972); 3 - Huot (1974); 4 - Tefler (1974); 5 - Wetzel *et al.* (1975); 6 - Smith and Borczon (1977); 7 - Stocker and Gilbert (1977); 8 - Drolet (1978); 9 - Tomm *et al.* (1981); 10 - Armstrong *et al.* (1983); 11 - Sweeny *et al.* (1984); 12 - Davenport *et al.* (1953); 13 - Gill (Gill 1957a in Halls 1984); 14 - Drolet (1976); 15 - Kearney and Gilbert (1976); 16 - Moore and Boer (1977); 17 - Euler (1979); 18 - Euler and Thurston (1980); 19 - OMNR (1984); 20 - Weber *et al.* (1983); 21 - Gill (1957b); 22 - Hepburn (1968); 23 - Telfer (1978); 24 - Potvin and Huot (1983).

1990:44, Table 1). "Topography should include ridges with southerly aspects, soils should be fertile, and patchy openings within the softwood forest should have an abundance of preferred browse" (Table 3).

"Optimal summer habitat should be more diverse than winter with more interspersion of types. There should be moderate to high representation of early successional shrubs, intolerant and tolerant hardwoods and mixedwoods with stand height 1–10 m and conifer crown closure <30%" (Darby 1990:44, Table 2). "Some mature hardwoods and mixed-woods should be present with herbaceous openings < 2 ha in size comprising 3–15% of the area" (Table 2). Stocker and Gilbert (1977) suggested summer habitats be less than 1500 m from open shallow water, and ridges with southerly aspects should be available. Sandy soils provide better habitat interspersion and a higher proportion of intolerant hardwoods which are more beneficial for deer than tolerant species according to McCaffery and Creed (1969). They found openings to be more productive on fertile soils.

Table 2. Attributes of summer mixedwood habitat for white-tailed deer (adapted from Darby 1990: 47).

Habitat Characteristics	Uses	Reference Source[*]
1. Early successional mixedwoods, shrubs and tolerant/intolerant hardwoods (15–55% of area), 1–10 m high, conifer crown closure <30%, clearcuts -50 ha.	- food - escape cover - day bedding - parturition, weaning and breeding	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
2. Mature mixedwoods and hardwoods, 10–20 m high, conifer crown closure 30–50%.	- food - escape cover - lactation	2, 4, 5, 8, 14
3. Small herbaceous-rich openings (3–15% of area), (-4 ha), near conifer-dominated mixedwood.	- food, travel - night bedding - lactation, weaning	1, 2, 3, 6, 7, 10, 11, 14
4. High degree of edge between stands.	- food, escape cover - day/night bedding - travel, lactation - weaning	1, 11, 12, 13

Note

[*] Numbers conform to numbered references as follows: 1 - McCaffery and Creed (1969); 2 - Kohn and Mooty (1971); 3 - Byelich *et al.* (1972); 4 - Drolet (1976); 5 - Kearney and Gilbert (1976); 6 - Stocker and Gilbert (1977); 7 - Euler (1979); 8 - Drolet (1978); 9 - Bennett *et al.* (1980); 10 - OMNR (1984); 11 - McCaffery *et al.* (1981); 12 - Tomm *et al.* (1981); 13 - Sweeney *et al.* (1984); 14 - McCaffery *et al.* (1974).

Characteristics for optimal year-round habitat in northern range according to Euler (1979) should contain 5–15% herbaceous openings 0.2–2.0 ha in size, and 30–60% of the range should be early successional mixedwood forest, such as regenerating clearcuts -50 ha in size, with uncut buffer zones between cuts. In Northwestern Ontario, Darby (1990: 72) suggested a suitable mosaic of desirable habitat types (mixedwood: 10–30% summer; 10–60% winter or 10–30% year-round) "with a high degree of edge, or interface between types is necessary for an area to have potential as good white-tailed deer habitat." Other habitat types included in the year-round habitat mosaic included: water (0–15%); open wetlands (0–15%); coniferous forest (10–30%); deciduous forest (5–15%); unimproved pasture and developed agricultural (3–20%) and shrubs and early successional forest (15–55%)

Table 3. Some browse species preferred by white-tailed deer in northern mixedwood forests.

	Time Period and Reference*	
Species	**Spring–Summer**	**Autumn–Winter**
Acer spicatum	1, 3, 6	2, 3, 5, 7
Corylus cornuta	1, 3, 4	1, 2, 3
Populus tremuloides	1, 3, 4, 6	1, 2, 3, 5
Prunus spp.	1, 3, 4, 6	1, 3, 7
Amelanchier spp.	1, 3, 4	1, 2, 3
Betula papyrifera	1, 3, 4	1, 3, 5, 7
Salix spp.	1, 3, 4	1, 3, 5, 7
Cornus stolonifera	1, 3, 6	2, 3, 5, 7
Diervilla lonicera	1, 3, 6	
Alnus crispa		1, 3
Abies balsamea		3, 4, 5, 7
Thuja occidentalis		3, 4, 5, 7

Note

* Numbers conform to numbered references as follows: 1 - Mooty (1976) and Kohn and Mooty (1971); 2 - Wetzel *et al.* (1975); 3 - Rogers *et al.* (1981); 4 - Skinner and Telfer (1974); 5 - Smith and Verkruysee (1983); 6 - McCaffery *et al.* (1974); 7 - Hepburn (1968)

Use of Mixedwood as Cover

Cover plays a key role in determining energy costs, and provides access to food resources as well as seasonal thermal relief (Voigt 1992b, Peek *et al.* 1982). In winter, deer move to suitable cover, reduce movement and decrease their metabolism and body temperature (OMNR 1990, Silver *et al.* 1969, Moen 1978).

Cover provides refuge from harsh winter weather, including deep snow, escape from predators and bedding opportunities which help minimize energy expenditures (Ozoga and Gysel 1972, Nelson and Mech 1981, Halls 1984). Snow depth and duration dictates mixedwood cover choice as snow depths >50 cm retards movements (Severinghaus 1947, Edwards 1956). In severe deep snow winters open softwoods and dense upland mixed-woods with cedar, hemlock, balsam fir, pine (*Pinus* spp.) and spruce is preferred, especially in late winter (Telfer 1970, Drolet 1976, McNicol and Timmermann 1981, Voigt 1992b). Lowland cedar provides low snow depths and both food and cover (Smith and Borczon 1981, Halls 1984). Snow depth is lower in softwoods and mixedwoods than in more open hardwoods and clear-cuts (Verme 1965, Ozoga 1968). In addition both stand types provide escape cover and, with higher densities, increased vigilance for predators (Schmidt and Gilbert 1978, Halls 1984). In less severe winters more use is made of open mixedwoods and clear-cuts.

Thirty-eight vegetation types have been described in the Field Guide to the Forest Ecosystem Classification for Northwestern Ontario (Sims *et al.* 1989). In this portion of the province winter severity is considered the limiting factor. "V-types which have significant composition of white spruce or balsam fir (V14–V16, V24, V25), cedar (V21, V22), black spruce (V19) or white and red pine (V12, V13, V26, V27) are most likely to be selected for winter shelter in areas which support white-tailed deer populations" (Racey *et al.* 1989: 4–2).

Use of Mixedwood as Forage

White-tailed deer are ruminants that require large quantities of easily digested food in order to satisfy their metabolic requirements for maintenance, growth, and reproduction (Short 1986). Leaves, stems and buds of woody plants are considered to be the mainstay of deer diet, as they are available throughout the year (Halls 1973, 1978). Woody plant and herbaceous species phenology changes throughout the year, and this variation in plant growth form is accompanied by changes in nutrient composition and digestibility by deer. Forage quantity and quality dictates the ability of an area to support white-tailed deer, especially since deer are more tolerant of adverse winter weather when high quality food is available (Moen 1968, 1976, Klein 1970). During severe northern winters, deep snow can render high quality food unavailable, and lead to major mortality (Karns 1980, Potvin *et al.* 1981). Any evaluation of habitat or carrying capacity should consider snow cover, topography and protective cover (Telfer 1967, 1978, Moen 1968, Ozoga and Gysel 1972, Drolet 1976, Kucera 1976, Armstrong *et al.* 1983). When forage nutrient intake is less than maintenance requirements, deer compensate forage intake through fat and tissue protein catabolism (Mautz *et al.* 1976, Swick and Benevenga 1977, Karns 1980). This is an adaptive mechanism which occurs whether or not food resources are adequate. When occasional severe winters exceed these physiological limits, overwinter mortality occurs (Karns 1980, Nelson and Mech 1986).

Growing Season Diet

In early spring, metabolic rate increases, does are in their last months of pregnancy, and a high quality diet is essential for fawn survival and reproductive success (Verme 1969, Silver *et al.* 1969, Voigt 1992b). Deer require high quality food from spring through fall for growth, to rebuild their fat reserves and recover over-winter physiological losses. Hence northern deer range managers now place a higher emphasis on summer habitat and forest openings than they did in the past (McCaffery and Creed 1969, Rutske 1969, Byelich *et al.* 1972, Euler 1979, McCaffery *et al.* 1981). In summer months deer use energy for antler development or feeding of fawns and body growth, and consume up to 4 kg (dry weight) of green plant material daily (Voigt *et al.* 1992). During this period they select high protein, high energy and highly digestible foods. Upland deciduous and upland mixedwood areas are used intensively for food as well as a variety of other uses (Tables 1 and 3). Summer ranges are generally larger than winter ranges and in Ontario "summer dispersion areas can be seven to ten times larger than the winter concentration area" (Voigt 1992b).

Recently Racey *et al.* (1989: 4–2) used the Northwestern Ontario Forest Ecosystem Classification (Sims *et al.* 1989) to interpret deer habitat capability. They suggested important spring and summer foods, including grasses, deciduous leaves and various components of a herb rich understory were generally dominant in rich hardwood dominated V-types (V1–V9).

Dormant Season Diet

In winter, woody browse usually is the main food available and forms the bulk of the diet (Table 3). During this period, the average deer requires approximately 2.3 kg of good quality browse per day (Smith and Borczon 1977). Winter cover value is enhanced if abundant winter browse, such as mountain maple, trembling aspen, beaked hazel, red-osier dogwood or black ash (*Fraxinus nigra*), commonly found in mixedwoods, exists in adjacent areas (Racey *et al.* 1989). Woody browse is low in nutrient quality and digestibility, and deer lose weight on it even when available in unlimited quantities (Ullrey *et al.* 1964, Verme and Ullrey 1972, Grigal *et al.* 1979). During the latter part of winter, deer fat reserves can be depleted and deer become nutritionally stressed if the winter is severe enough (Verme 1969, Mautz 1978, Karns 1980). This is a normal event and only becomes critical if the winter begins earlier or lasts longer than usual.

Habitat Management

White-tailed deer, moose and endangered or threatened Ontario wildlife species are currently “provincially featured” and specific habitat attributes must be identified and delineated using developed guidelines (Ranta 1993). Habitat methodologies detail how to locate, describe and delineate specific deer habitat attributes identified in developed guidelines (Ranta 1993, Voigt 1992a,b, Buss *et al.* 1993). These guidelines are designed to provide food and cover in both summer and winter ranges. Mixedwood habitat that provides adequate coniferous shelter interspersed with sufficient winter food is the primary concern on winter range. The amount of conifers in mixedwood stands should allow deer to move throughout the yard or winter concentration area and provide shelter in bedding areas. “Deer yards should have a mix of understocked conifers or mixedwoods where browse is abundant and interspersion of heavily stocked and relatively pure conifer for movement to food areas, bedding, and refuge during winter storms” (Voigt 1992b:3). “In mixedwood stands where conifer content is low, it is desirable to retain all of the conifers and confine tree removal to the hardwood component” (Voigt 1992b:4). Diversity of forage is required and three or more suitable species (Table 3) should be available (Voigt 1992b). In aspen dominated mixedwoods, Euler (1979) and Timmermann (1991) suggested a rotational cutting plan should comprise 10–30% of the range, with food and shelter in close proximity to each other. Voigt (1992a) provides habitat management direction in the form of Ontario timber management guidelines for the provision of white-tailed deer habitat.

Mixedwood cutovers, because of their inherent productivity and abundant deciduous regeneration following disturbance, are often prime candidates for herbicide treatment (Krefting and Hansen 1969, Tanner *et al.* 1978). Herbicide application using 2,4 D, for example, can be beneficial by slowing natural succession and promoting resprouting of preferred deciduous vegetation in a height range available to deer.

Knowledge Gaps

Research is required on methods of accurately and economically determining changes in habitat carrying capacity as well as quantifying spatial patterns of cover and forage within and among seasons. In addition to habitat assessment, continued research is needed on methods of assessing herd population dynamics. A fully developed deer information system should be developed to integrate data collection, inventory and assessment, allowing managers to modify management prescriptions in response to new information (Voigt *et al.* 1992).

Summary

Mixedwood sites provide critical cover and forage components necessary to sustain white-tailed deer. Recently disturbed, high quality mixedwood habitats have the potential to produce higher deer densities, especially when predation pressure and winter severity is low to moderate. A literature review dealing with species description, recognized populations, seasonal habitat use, movements, use of cover, and forage and mixedwood habitat management considerations is provided.

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boreal mixedwood Notes

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Use of Mixedwood Sites and Forest Cover by Woodland Caribou (Rangifer tarandus caribou)

by H.R. Timmermann[1]

Mixedwood stands associated with riparian habitats provide green period (summer) forage in the form of herbs and deciduous shrubs but appear to play a minor role in overall habitat use. Management strategies in commercial forests should focus on providing a sustainable mosaic of caribou habitat that was traditionally maintained by wildfire, and discourage mixedwood regeneration.

Introduction

Woodland caribou (*Rangifer tarandus caribou*) in boreal forests of North America use mature and overmature open spruce (*Picea* spp.) and pine (*Pinus* spp.) stands with shallow or infertile soils extensively throughout the year especially during the non-green period. Mixedwood stands associated with riparian habitats provide green period (summer) forage in the form of herbs and deciduous shrubs but appear to play a minor role in overall habitat use. Sites that generally support caribou are considered poor habitat for moose (*Alces alces*) or white-tailed deer (*Odocoileus virginianus*). Predation by gray wolves (*Canis lupus*) and black bear (*Ursus americanus*) plays a major role in determining woodland caribou habitat use. Management strategies in commercial forests should focus on providing a sustainable mosaic of caribou habitat that was traditionally maintained by wildfire and discourage mixedwood regeneration.

Species Description

Caribou (*Rangifer tarandus*) are members of the deer family (*Cervidae*, Order Artiodactyla), which also include moose and white-tailed deer. Adult individuals average about 1.1 to 1.2 metres (3.5 to 4 feet)

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high at the shoulder, intermediate in size to moose and deer (Godwin 1990). Males are larger than females and adult bulls or stags weigh between 118 and 205 kg (260 to 450 lbs) while cows or does weigh 80 to 110 kg (175 to 240 lbs). Both sexes often have antlers, a characteristic unique to this species among members of the deer family. Woodland caribou breed for the first time at 2.5 years of age and rarely produce twins (Bergerud 1978; Fuller and Keith 1981; Darby *et al.* 1989). The species demonstrates fidelity to seasonal ranges for calving and rutting, is highly mobile and is vulnerable to hunting mortality, predation and habitat fragmentation (Rock 1992).

Five subspecies of caribou including the woodland type are recognized in North America (Bergerud 1978; Miller 1982). Differences in physical appearance among subspecies are given by Banfield (1961), Kelsall (1984), Geist (1989) and others. All have relatively long legs, large crescent-shaped hooves and a broad muzzle.

The forest-dwelling woodland caribou (*Rangifer tarandus caribou*) found in the boreal forests of Ontario and elsewhere have a dark pelage, are less gregarious and are more sedentary than other subspecies. Low density woodland caribou populations once inhabited all of Ontario south to Lake Nipissing (De Vos and Peterson 1951; Dobbyn 1994). Their decline in the mixedwood forests of the Great Lakes–St. Lawrence Forest Region was coincidental with increased numbers of moose and white-tailed deer. Both deer and moose densities are related to early forest succession (up to 20 years) following disturbance by fire, insect infestation, blowdown, or logging and an increase in hardwood/mixedwood habitat (McNicol and Timmermann 1981; Smith and Verkruysse 1983; Timmermann and McNicol 1988). In contrast woodland caribou are considered species of mature and overmature coniferous dominated forests, whereas their use of deciduous forest is low (Darby *et al.* 1989).

The current (early 1990s) estimated Ontario population of 15,000 animals is found largely north of approximately 50 degrees latitude (Darby *et al.* 1989; Dobbyn 1994:104) (Figure 1). Cumming and Beange (1993) estimated that only about 800 of these animals utilize the current commercial forest area. The balance reside in the Hudson’s Bay Lowlands (13,000), in parks (800) and in current timber reserves (400).

In 1984 the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designated the Western Woodland Caribou in the area west of James Bay (British Columbia, Alberta, Northwest Territories, Saskatchewan, Manitoba and Ontario) as “vulnerable” (Kelsall 1984). Vulnerable species are defined as “any indigenous species of fauna or flora that is particularly at risk because of low or declining numbers, occurrence at the fringe of its range or in restricted areas, or for some other reason, but is not a threatened species.”

Cumming (1992) reviewed woodland caribou characteristics for forest managers. This review addresses characteristics that would be of interest to woodland caribou managers.

Recognized Woodland Caribou Populations

Our knowledge of woodland caribou has been obtained from several populations studied throughout North America. Included are herds in central and west-central British Columbia (Edwards and Ritcey 1960; Rominger and Oldemeyer 1989; Seip 1992; Cichowski and Banner 1993), west-central and northeast Alberta (Fuller and Keith 1981; Edmonds and Bloomfield 1984; Edmonds 1988), southeast Manitoba (Stardom 1977; Shoesmith and Story 1977; Darby 1979; Darby and Pruitt 1984; Schaefer 1988; Schaefer and Pruitt 1991), northwestern Quebec and Labrador (Brown *et al.* 1986), and Newfoundland (Bergerud 1971, 1972, 1974b; Chubbs *et al.* 1993).

In Ontario, descriptive studies based on visual and limited radio collared observations include those for all of northern Ontario (Simkin 1965; Ahti and Hepburn 1967); the Slate Islands, Lake Superior (Cringan 1956; Butler and Bergerud 1978;

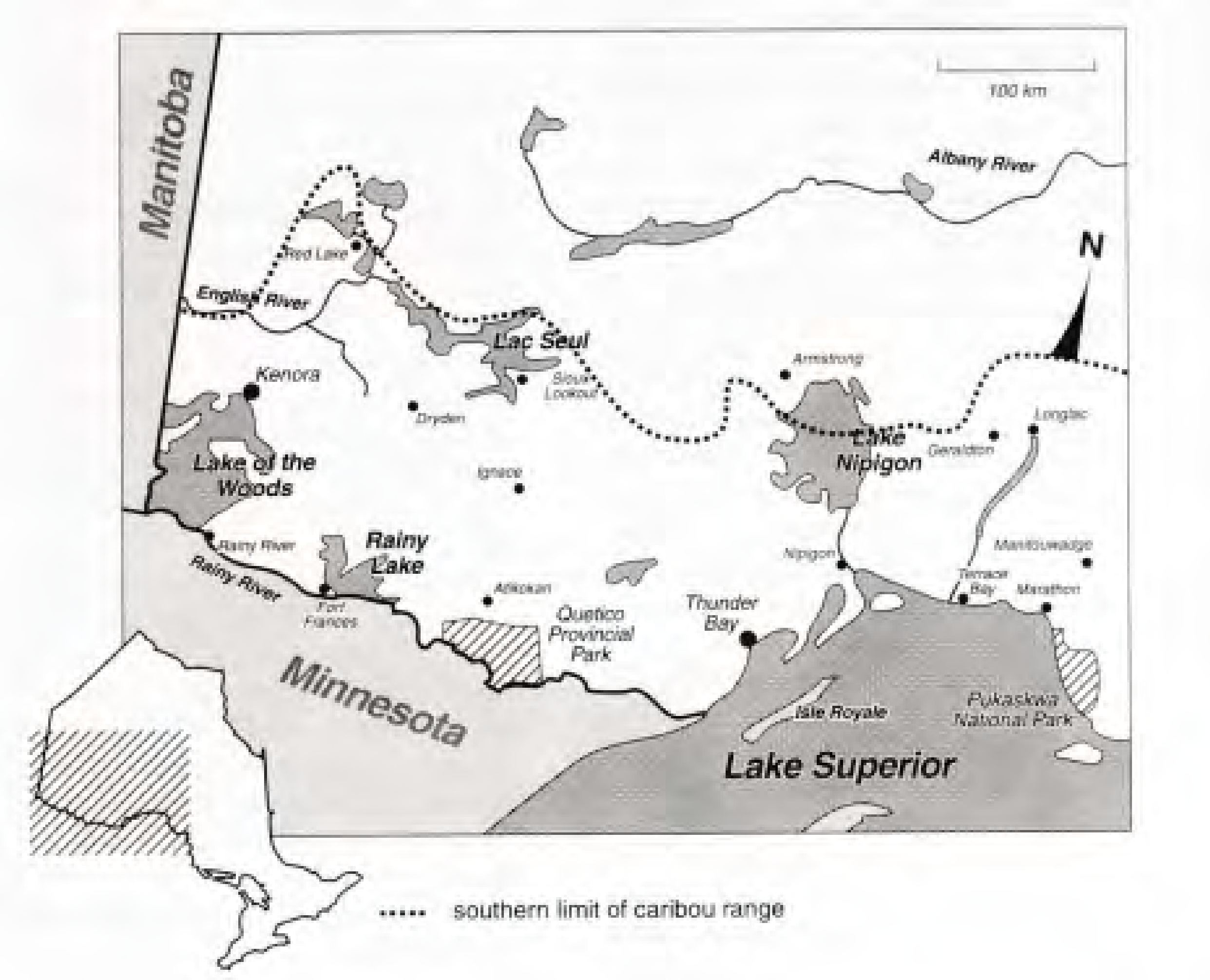

Figure 1. Location of southern limit of caribou range.

Euler *et al.* 1976); Pic Island, Lake Superior (Ferguson 1982); Pukaskwa National Park, Lake Superior (Bergerud 1985, 1989a) and Lake Nipigon-Armstrong (Cumming and Beange 1987, 1993; Bergerud 1989a; Bergerud *et al.* 1990). Data from these populations form the basis of this review.

Habitat Use and Movements

Woodland caribou select forested habitat extensively throughout the year, primarily to avoid predators and areas frequented by their alternate prey species moose and white-tailed deer, and secondarily to optimize food intake (Shoesmith and Storey 1977; Fuller and Keith 1981; Darby and Pruitt 1984; Brown *et al.* 1986; Bergerud and Page 1987; Bergerud *et al.* 1990). Caribou generally exist in areas of low plant productivity and diversity, and reduced availability of woody browse species (Cringan 1957; Racey *et al.* 1989). Range suitability is strongly governed by stand age, soil fertility and depth, and landform type including watershed configuration. Northwestern Ontario soil types common in woodland caribou winter range include the very shallow SS1 to SS3, moderately deep sands SS5, deep sands S1 and S2; with the organic types SS9, S11 and S12S in poorly drained locations (Racey *et al.* 1989:4–7; Morash and Racey 1990:19). Corresponding vegetation types frequently found in caribou winter range include upland V30, V29, V28, V32, V31, V20 and V18, and the lowland V34, V34, V38, V37, V36 and V23 (Sims *et al.* 1989; Morash and Racey 1990; Antoniak 1993). "Some very poor mixedwood stands, most likely keying to V18 and V20 could be comparable to the V30 type description" (Sims *et al.* 1989:63). The overstory of these jack pine (*Pinus banksiana*) and black spruce (*Picea mariana*) dominated mixedwoods may also contain trembling aspen, white birch, balsam fir and white spruce component. Antoniak (1993:43) studied nine woodland caribou wintering areas in northwestern Ontario and reported "there were no caribou found in mixed stands." Although detailed information is limited, these S and V types also appear to be the most heavily used during the rest of the year as well (Gollat pers. comm. 1996).

Seasonal habitat choice is governed by snow conditions, food availability, thermal regulation as well as predator abundance and distribution. Woodland caribou make extensive year round use of semi-open to open bogs where forage is abundant. In early winter they commonly forage in open and semi-open black spruce bogs (Darby and Pruitt 1984). When snow cover reaches 65 cm or crust hardness reaches 400 gm/cm^2 caribou will move into conifer stands of jack pine, black spruce, or mixed jack pine–black spruce stands (Stardom 1977; Fuller and Keith 1981; Darby and Pruitt 1984; Cumming and Beange 1987), although they can also utilize mixedwood stands (Euler *et al.* 1976). The preferred stands are generally open with an understory of evergreen shrubs, forbs and terrestrial lichens (*Cladonia* spp.), an absence of tall, woody shrubs and a relatively shallow snow cover (Darby and Pruitt 1984).

Average winter group size in Ontario varies from about four to ten animals (Simkin 1965; Cumming and Beange 1987; Bergerud 1989b). Herd winter range size occupied by forest-dwelling caribou varied from 32 km^2 to 164 km^2 in the Lake Nipigon area of Ontario (Cumming and Beange 1987), 253 km^2 at Reed Lake, Manitoba (Shoesmith and Story 1977) and 320 km^2 to 1470 km^2 in two areas of Alberta (Edmonds and Bloomfield 1984; Edmonds 1988). Winter ranges in the Birch Mountains of Alberta averaged 335 km^2 for bulls and 137 km^2 for cows (Fuller and Keith 1981). Faithfulness to winter areas varies as some groups return to the same areas year after year (Cumming and Beange 1989), while others appear to vary their choice between years (Harris 1990).

In early spring before breakup, caribou disperse and pregnant females move to their calving areas where concealment and predator avoidance opportunities are provided by the forest, topography and waterbodies (Bergerud and Page 1987). Woodland caribou reach their maximum dispersion in calving and summer habitat (Hatler 1986; Cumming and Beange 1987; Bergerud *et al.* 1990). Fidelity to calving sites and summer habitat (lake islands, shorelines, bogs or rugged topography) is strong and caribou will commonly return to these areas year after year (Simkin 1965; Shoesmith and Storey 1977; Darby and Pruitt 1984; Brown *et al.* 1986).

Woodland caribou are solitary during late spring and summer. It is at this time that they may utilize some limited mixedwood stands around open bogs, lakes and islands for calving, foraging and escape from predators. Green period food includes ground forbs, lichens, grasses, sedges (*Scirpus* spp. and *Carex* spp.) and a variety of deciduous buds and leaves (Bergerud 1972; Darby and Pruitt 1984). Summer ranges are usually smaller than the winter ranges. Herd range size occupied in spring and summer varied among five published studies (100 to 180 km^2 in spring according to Darby and Pruitt 1984; Shoesmith and Storey 1977 in Manitoba and 5.5 to 586 km^2 in summer according to the same authors as well as Fuller and Keith 1981, Edmonds and Bloomfield 1984; and Edmonds 1988) in Alberta.

The distance forest-dwelling woodland caribou will travel between seasonal habitats varies, and is probably related to habitat availability and supply. At Lake Nipigon, caribou move between 26 and 80 km (Cumming and Beange 1987) while at Aikins Lake Manitoba there is little or no seasonal movement (Darby and Pruitt 1984). In the Birch Mountains of Alberta they make seasonal movements of 12 to 71 km, but distances moved were less for cows than for bulls (Fuller and Keith 1981). Suitable summer and winter habitats in close proximity should facilitate caribou predator avoidance strategies during spring calving and wintering (Morash and Racey 1990). A recently (1995-96) initiated radio telemetry study in northwestern Ontario will provide more detailed information on seasonal habitat preferences and movements.

Cover, Space and Predation

The role and importance of cover to forest dwelling caribou is poorly understood. It is believed that in summer thermal cover provided by lowland black spruce with an understory of sphagnum and/or feathermoss likely provide cool sites harbouring relatively few insects (Rock 1992). In British Columbia, Johnson and Todd (1977) observed that woodland caribou approached highways with caution and took cover in nearby timber when encountered. In Newfoundland, Chubbs *et al.* (1993) reported female woodland caribou displaced by clear-cutting avoided open burns and hardwoods, and selected mature black-spruce forest. Prior to cutting they used habitats in proportion to their availability, however, wolves are absent on the island. Similarly the use of cutovers has rarely been observed and reported in Ontario. Cumming and Beange (1993) using radio telemetry, observed that "caribou reacted to cutting at Armstrong by continuing to use their wintering area but abandoning cut portions." Similarly they reported no winter use of cutovers by caribou based on tracks observed in the Springwater and O'Neil lake areas of Geraldton District. Historic records suggest that when caribou move from cut areas they cease to be recognizable as distinct herds and when they are forced from these areas they must move to alternative areas which may be less suitable and which may lead to increased mortality (Cumming 1996). Antoniak (1993) reported that caribou did not return to logged stands he examined, for up to 25 years after harvesting and not until 60 years in natural, fire-origin stands. However, he provided little quantified data to substantiate these statements.

Bergerud *et al.* (1990) and Bergerud (1993) believe cover as shelter from the elements is not nearly as important in habitat selection as space and predator densities and that spring migration and dispersion may be a common tactic to reduce predation risk especially for females and neonates. Disturbance of caribou habitat by wildfire and logging "reduces the available space for caribou, thereby increasing caribou densities elsewhere and forfeiting the advantage of space" (Bergerud 1989a:113). Caribou and moose densities in North America are low (0.06 to 0.10/km^2 for caribou and 0.20 to 0.50/km^2 for moose) where wolves (*Canis lupus*) are unexploited (Bergerud 1992). In contrast both caribou and moose commonly reach densities greater than 2/km^2 separately in the absence of wolves (Bergerud *et al.* 1983; Ferguson *et al.* 1988; Page 1989). When wolf densities are high (•6.5/1000 km^2) caribou cannot maintain their numbers in the absence of escape habitat according to Bergerud and Elliott (1986). Ballard (1994) concluded, based on a review of the literature, that black bear (*Ursus americanus*) predation on woodland caribou would likely be a secondary source of mortality after predation by wolves.

Forage

Woodland caribou foods can be divided into four seasons: spring, summer, autumn and winter (Bergerud 1972).

Spring Diet

In spring, rapidly growing green plants including sedges are among the first green foods eaten by Newfoundland caribou (Bergerud 1970,1972), followed by larch (*Larix laricina*) needles and leaves of alder (*Alnus* spp.) as they first appear. Sweet gale (*Myrica gale*) and false Solomon's seal (*Smilacina trifolia*) are also often taken as are a variety of evergreen shrubs prior to the appearance of deciduous growth. These include species such as sheep and pale laurel (*Kalma* spp.) cranberries (*Vaccinium* spp.), Labrador tea (*Ledum groenlandicum*), leatherleaf (*Chamaedaphne calyculata*), bog rosemary (*Andromeda glaucophylla*) black crowberry (*Empetrum nigrum*) and creeping snowberry (*Gaultheria hispidula*).

In Manitoba Darby and Pruitt (1984) reported that in early spring caribou fed on terrestrial lichens (*Cladonia* and *Parmelia* spp.) and on the tips of willow (*Salix* spp.) and alder twigs (*Alnus* spp.) on jackpine–rock ridges, south–facing slopes and lakeshores. Later in spring and early summer they fed on ground forbs, deciduous foliage and both arboreal and ground lichens, and used a greater diversity of habitat types.

In an Alberta study, Fuller and Keith (1981) documented heavy use of lowlands (black spruce muskegs, open muskegs and black spruce stands) during the entire year including the spring period. Aspen or aspen–conifer mixes were seldom used (two percent of all locations). Use of upland cover types in spring and summer was concomitant with increased abundance of vascular vegetation and varied from a 32 percent of all locations in April to 55 percent in August.

Simkin (1965) observed spring and summer feeding in the Irregular Lake area of northwestern Ontario. Lichens, especially ground lichens, were utilized much more in May and June than later in July (60 percent vs. 35 percent). Buds and twigs of white birch (*Betula papyrifera*), trembling aspen (*Populus tremuloides*) pin cherry (*Prunus pensylvanica*) and willow (*Salix* spp.) were browsed before green-up.

Summer Diet

In summer, caribou largely depend on deciduous leaves of shrubs and tree species (late June until early September). The species of *Salicaceae*, *Betulaceae*, *Rosaceae* and *Aceraceae* are heavily utilized as are *Viburnum* and *Nemopanthus* (Bergerud 1972, 1977, 1993). Preferred summer foods identified by Bergerud (1972: 915, Figure 1) in the rumina of 14 Newfoundland caribou included fungi (25 percent), terrestrial lichens (22 percent), deciduous shrubs (15 percent by volume), sedges (10 percent), forbs (eight percent), evergreen shrubs (eight percent by volume), aquatics (five percent), mosses (five percent) and arboreal lichens (two percent). Important deciduous shrubs in this study included birch (*Betula* spp.), blueberry (*Vaccinium* spp.) and Juneberry (*Amelanchier* spp.). Simkin (1965: 54, Table 14) found that as green-up progressed in northwestern Ontario, leaves of white birch, aspen, pin cherry, willow and juneberry in highland areas were used more frequently.

Autumn Diet

In Manitoba woodland caribou aggregated near semi-open and open bogs with the dormancy of ground forbs and leafy browse (Darby and Pruitt 1984). In late September as the rut begins, they feed on ground and arboreal lichens, sedges and a variety of bog ericoids (Labrador tea, leatherleaf, bog rosemary and sheep laurel) similar to those consumed in early spring. The authors reported the continued use of bogs until snow restricted travel in mid February. Cumming and Beange (1987) failed to find similar use in Ontario but data at that time of year were limited due to poor aircraft availability. Bergerud (1970, 1972) noted a striking change in diet at leaf fall in early October when animals began to consume large quantities of lichens and evergreen shrubs. Common seed plants in autumn rumina were bunchberry, sheep-laurel, bog-laurel, leatherleaf, Labrador tea, rhodora (*Rhododendron canadense*) and crowberry.

Winter Diet

Woodland caribou in North America generally migrate to their winter habitat after the first snowfall following breeding (Bergerud 1993). Access to winter forage may become limiting, especially in January and February when snow is often both soft and deep (Bergerud 1972). Woodland caribou, unlike deer and moose, make relatively little use of mixedwood stands in winter. As snow accumulates caribou feed increasingly on both terrestrial (*Cladina*, *Cetaria* and *Cladonia* spp.) and arboreal (*Usnea* and *Evernia* spp.) lichens on irregular upland jackpine and spruce rock ridges where snow cover is shallower and softer (Ahti and Hepburn 1967; Bergerud 1970, 1972, 1974b; Fuller and Keith 1981). Nearby frozen lakes are used for travel, escape habitat and sources of drinking overflow water in the form of slush. Food is obtained by "cratering," a digging pattern in the snow that facilitates access to ground lichens and associated species such as sweet gale, leatherleaf, Labrador tea and bog rosemary (Simkin 1965; Darby and Pruitt 1984).

Habitat Management

Woodland caribou are adapted to a fire-disturbed ecosystem (Schaefer and Pruitt 1991; Harris 1992) and have different habitat needs from deer and moose. Caribou range in Ontario has gradually receded northwards over the past 100 years for a variety of habitat related reasons (De Vos and Peterson 1951; Cringan 1957; Bergerud 1974a, 1974c; Darby *et al.* 1989), the best documented being cutting of winter habitat (Cumming and Beange 1993). Current efforts are aimed at developing management strategies to halt further range recession and manage seasonal habitats on a sound and sustained ecosystem basis (Racey *et al.* 1991).

Caribou habitats often include the "unproductive" lands of the commercial forest including bogs, fens and under-stocked jackpine and black spruce sites on thin infertile soils (Bergerud 1985). Caribou require large contiguous tracts of habitat to fulfil their life requisites (Rock 1992). Habitat management should focus on identifying the best late successional forest habitat and apporportioning age classes of timber to include currently used over-mature as well as younger forest succession stands for future habitat.

Ontario is in the process of developing a coordinated approach to managing woodland caribou (OMNR 1994a). Caribou will be designated by district managers as locally featured species for the purposes of Forest Management Planning. In areas north of the identified and approved caribou line (zone of continuous distribution, Figure 1) forest managers will consider both current and future caribou habitat needs. The “caribou habitat/forest mosaic” (Racey *et al.* 1991:112) is the basic approach currently suggested for all forest management units within caribou range. Ecosystem management designed to mimic the habitat disturbance pattern resulting from large naturally occurring fire will be the habitat management focus. Management guidelines for woodland caribou habitat (OMNR 1994b) assume logging can replace fire as a means of regenerating winter habitat and re-establish terrestrial lichens (*Cladina* spp.) in boreal forest cutovers (Harris 1992; Racey *et al.* 1996). Allocation of harvest areas are to be concentrated within what would become a large disturbance to provide future habitat blocks (+40 years), while cuts will not be allocated in large leave blocks of currently identified seasonal habitats (Timmermann 1993a, 1993b). Mixedwoods will be contained in large conifer-dominated mosaic blocks and contribute to providing space to minimize predation and limited growing season forage.

Specific guidelines for caribou management (e.g. calving site buffers, travel corridors, protection of wintering areas) are identified (OMNR 1994b). Critical/core caribou wintering areas or “virtual refuges” (Cumming 1996) are to be avoided in TMP allocations and road corridors. In addition Cumming (1996) suggests a three kilometre buffer should be considered around large or contiguous, clearly defined areas of wintering habitat (Cumming 1992; Cumming and Beange 1993). Caribou habitat management prescriptions will minimize edge habitat and develop patterns of cutting that do not favour moose as a means of controlling wolf numbers. Mixedwoods contained in large conifer-dominated mosaic blocks contribute to providing space and limited growing season forage.

Calving sites and associated summer habitat are key components of the overall habitat mosaic. A high priority is given to identifying calving areas, such as lakes with islands supporting mature or overmature coniferous or mixed wood forest, or open bogs and muskeg with dry hummocks or islands (OMNR 1994b; Broschart and Pastor 1993). All documented calving sites are to be identified by an area of concern (AOC) of 1000 m. Modified cutting prescriptions, if justified, may be applied at a distance of 400 to 1000 m from the shoreline and care needs to be taken to ensure that narrow no cut reserves do not become “traps” for caribou in areas easily searched by predators (Ferguson *et al.* 1988; Racey *et al.* 1991).

Timber management operations should be planned so that calving areas and winter habitat blocks are joined by travel corridors at least two kilometres wide consisting of any vegetation types greater than three metres in height. The integrity of the vegetation along these seasonal migration routes needs to be maintained through harvest scheduling.

Knowledge Gaps

Additional research is needed to describe and evaluate seasonal (non winter) vegetation types used by forest–dwelling woodland caribou. Home range size and yearly variability for specific herds using commercially viable forests remains poorly understood. In addition the interactions between woodland caribou, wolves, black bear and space need to be studied to give managers an appreciation of the likely consequences of various landscape management options. Finally an inventory effort is required to identify critical/core caribou seasonal (winter, and summer) habitats and their travel corridor linkages.

Summary

Published studies suggest that mixedwood stands associated with riparian habitats provide green period (summer) forage in the form of herbs and deciduous shrubs but play a minor role in overall woodland caribou habitat use. Most studies, however, have reported on winter use and it is hoped that current Ontario telemetry-based investigations will yield more detailed information especially on summer use. Mixedwoods contained in large conifer-dominated mosaic blocks contribute to providing space as well as limited growing season forage. Mixedwood management following logging disturbance in current caribou range should be discouraged to minimize an increase in local moose populations and a corresponding increase in predators. A literature review dealing with species description, recognized populations, seasonal habitat use, movements, use of cover, space and forage is provided.

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Importance and Use of Mixedwood Sites and Forest Cover by Moose *(Alces alces)*

by H.R. Timmermann[1]

> *Mixedwood sites provide critical seasonal cover and forage components necessary to sustain moose. Recently disturbed high quality mixedwood habitats have the potential to produce higher moose densities when predation and harvest is low.*

HABITAT

Introduction

Moose (*Alces alces* spp.) belong to the deer family (*Cervidae*) which also includes caribou (*Rangifer* spp.) and several species of deer in North America. In Ontario moose are widely distributed: in portions of the northern section of the Great Lakes–St. Lawrence Forest Region and throughout the Boreal Forest Region (Cumming 1972; Rowe 1972; Dobbyn 1994). Moose are a valuable renewable natural resource and consumptive use alone through sport hunting in northern Ontario added more than $57.2 million to Ontario’s economy in 1993 (Legg 1995).

Populations were estimated at 120,000 in 1993 (Bisset 1993) and provincial densities are generally between 0.2 and 0.4/km^2 over most of their range overlapping mixedwood forests (Jackson *et al.* 1991; Whitlaw *et al.* 1993). Their distribution during the last century has remained relatively stable with only a small reduction in the southernmost portion of their historic range. The reproductive potential of moose is adapted to maintain populations at low densities, allow a rapid expansion into areas following vegetative disturbance and a slow decline as forests mature (Cowan *et al.* 1950; Geist 1974). Recently disturbed, high quality mixedwood habitats have the potential to produce higher moose densities when predation pressure is low or in multi-ungulate systems, where white tailed deer (*Odocoileus virginianus*) are more vulnerable to predation by gray wolves (*Canis lupus*) (Crête 1987; Bergerud and Snider 1988).

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Ontario

Cette publication technique n'est disponible qu'en anglais.

Recognized Moose Populations

Our knowledge of moose energy requirements and habitat use has been obtained from several key studies throughout North America. Included are herds in Alaska (LeResche and Davis 1973; Gasaway and Coady 1974; Oldemeyer 1974; LeResche *et al.* 1974; Oldemeyer *et al.* 1977; Regelin *et al.* 1985; Risenhoover 1986; Oldemeyer and Regelin 1987; Schwartz *et al.* 1987; Hundertmark *et al.* 1990; Schwartz 1992), in British Columbia (Cowan *et al.* 1950; Ritcey and Verbeek 1969; Eastman and Ritcey 1987), in Alberta (Rolley and Keith 1980; Hauge and Keith 1981; Mytton and Keith 1981; Renecker and Hudson 1985,1986), in Saskachewan (Stewart *et al.* 1977), in Quebec (Des Meules 1964; Brassard *et al.* 1974; Poliquin *et al.* 1977; Crête and Jordan 1982; Crête 1988), in New Brunswick (Telfer 1968, 1970); in Minnesota (Berg 1971; Phillips *et al.* 1973; Peek *et al.* 1976; Miquelle and Jordan 1979; Irwin 1985) and on Isle Royale, Michigan (Krefting 1974a; Aho 1978; Risenhoover and Peterson 1986; Jordan 1987; Moen *et al.* 1990; Jordan *et al.* 1993).

Ontario has made a significant contribution to furthering knowledge of moose habitat. Studies include those of: movement (Goddard 1970; Addison *et al.* 1980; Dalton 1989), importance and use of mineral licks and aquatics (De Vos 1958; Cobus 1972; Chamberlin *et al.* 1977; Fraser 1980; Fraser *et al.* 1980, 1984; Fraser and Hristienko 1981; Timmermann and Racey 1989; Timmermann *et al.* 1990), use of winter food and cover (Hamilton and Drysdale 1975; McNicol and Gilbert 1978, 1980; McNicol *et al.* 1980; Hamilton *et al.* 1980; Welsch *et al.* 1980; Cumming 1980, 1987; Thompson and Vukelich 1981; Thompson *et al.* 1981; Todesco 1988), and moose habitat interpretation (Racey *et al.* 1989b; Jackson *et al.* 1991; McNicol and Baker 1993).

In addition several habitat review papers and models including those of Krefting (1974b), Peek (1974,1997), Telfer (1978, 1984), Belovsky (1981, 1984), Thompson and Euler (1984), Timmermann and McNicol (1988), Allen *et al.* (1987, 1988); Racey *et al.* (1989b), and Thompson and Stewart (1997) provide a summary overview of the subject. Data from these publications generally form the basis of this review.

Habitat Use and Movement

The word ‘moose’ is derived from the Algonquin Indian word meaning “twig eater” (Fraser *et al.* 1984). Indeed its winter diet consists entirely of twigs from a variety of deciduous shrubs, conifers and broad-leaved trees found in greatest abundance in mixedwood stands and recently disturbed areas. These foods, interspersed with stands of coniferous timber of various age classes, generally provide the necessary nutritional and cover requirements. The best moose habitats are mixed coniferous–deciduous seral stage forests (up to 30 years) following disturbance by fire, insect damage, blowdown or logging (Peterson 1953; Krefting 1974b; Peek *et al.* 1976; Kelsall *et al.* 1977; Davis and Franzmann 1979; Cumming 1980; Bangs and Bailey 1985; Thompson *et al.* 1995; Peek 1997). Good moose habitat provides both high quality food and cover supplied by early successional vegetation, interspersed with mature conifer and mixedwood areas. Each of three distinct seasonal habitats—summer, early winter and late winter—contributes to moose energy balance and/or their ability to avoid predators. Boreal mixedwood forests cover 18 percent (seven of 38 million hectares) of Ontario production forest (Towill 1989) and are key to sustaining high density moose populations (Figure 1).

“Moose, are not simply large ‘browsers’ but seasonally highly adaptable large concentrate (foliage) selectors relying on plant diversity in low, middle and higher strata of Northern habitats” (Hofmann and Nygren 1992:99). Habitat needs are summarized by Peterson (1955), Peek (1974), Telfer (1978), Coady (1982) and Timmermann and McNicol (1988). Moose require large quantities of forage (i.e. 18 kg in June for a yearling cow, to 51 kg in October for an adult bull) for maintenance and growth (Gasaway and Coady 1974). Several hundred plant species are known to be eaten by moose, but usually not more than 25 to 30 species are eaten in any one locality (Peterson 1955; Morrow 1976 - cited by Telfer 1978). Browse quality is as important as quantity for the maintenance of a healthy moose population and plant species diversity improves habitat quality (Oldemeyer *et al.* 1977; Miquelle and Jordan 1979).

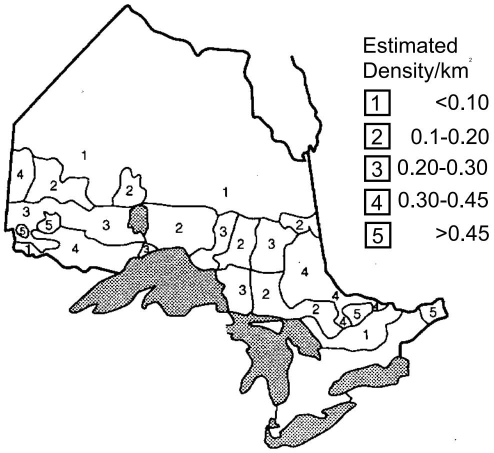

Figure 1. Estimated moose densities in Ontario since early 1990s (Whitlaw *et al.* 1993; Bisset 1993; Davies pers. comm; Morrison pers. com)

Range suitability is a function of stand age or structure, species composition, topography, soil productivity, as well as the spatial configuration and diversity of habitat conditions across the landscape (Racey *et al.* 1989b). Home range size is dictated by the minimum space necessary to provide adequate seasonal food and cover as well as the presence or absence of predators (Cederlund *et al.* 1987; Van Dyke *et al.* 1995). Nudds (1990) suggests several factors, including the interaction between deer, the brain worm parasite (*Parelaphostrongylus tenuis*), moose densities, snow condition and possibly wolf densities, all affect moose distribution. Adult eastern North American moose in contrast to Alaskian moose (*A.a. gigas*) do not migrate long distances from summer to winter range and generally occupy an area of 20 to 40 km^2 year -round (Crête 1988). Males occupy larger home ranges than females, especially during the annual fall rut, and young males may move long distances before establishing their own home range (Goddard 1970). In a northwestern Ontario mixedwood cutover study, annual range size for bulls was 91 to 168 km^2 and 31 to 45 km^2 for cows (Dalton 1989). “Home range size also varies seasonally: larger in summer when moose are more mobile and selective for forage than in winter when they are more sedentary and restricted in movement by snow” (Timmermann and

McNicol 1988: 242). Adult moose display strong home range fidelity by occupying similar overlapping areas between years and the adult cow is largely responsible for determining the home range of her progeny who tend to occupy home ranges adjacent to or overlapping their parent's home range (Gasaway *et al*. 1980; Lynch and Morgantini 1984; Cederlund *et al.* 1987).

Use of Mixedwood as Cover

Moose use vegetative cover to conceal themselves and for lateral protection from wind, as well as for overhead protection from precipitation and solar radiation. Three types of cover are recognized: security, winter and thermal cover (Timmermann and McNicol 1988).

Security cover is required prior to calving as pregnant cows seek secluded habitats and remain alone during parturition (Markgren 1969; Cederlund *et al.* 1987). Calving sites reflect the cow's desire for seclusion and often include mixedwood islands in water bodies, peninsulas, shorelands, or poorly drained areas near water where cows can better defend against predators (Peterson 1955, Markgren 1969; Le Resche *et al.* 1974; Bailey and Bangs 1980; Leptich and Gilbert 1986; Addison *et al.* 1990) as well as wooded elevations or small isolated patches of forest secluded from the surrounding terrain (Markgren 1969; Cederlund *et al.* 1987; Dalton pers. comm. 1987). It is believed that moose select secluded sites to minimize calf losses to predators such as black bear (*Ursus americanus*) (Stewart *et al.* 1985; Franzmann and Schwartz 1986) and wolves (Mech 1966; Peterson 1977). With autumn leaf abscission, the cover value of deciduous shrubs and trees decreases markedly, and mixedwood stand edges become more important in providing ready access to coniferous escape cover near forage (Timmermann 1991). In winter, cows with calves select sites away from other moose (Peek *et al.* 1974; Rounds 1978; Novak 1981). Based on several studies (Thompson and Vukelich 1981; Stephens and Peterson 1984) it is believed this social unit uses security cover often less than 60 m from conifer dominated mixedwood stands to help avoid predators. Finally, moose are more vulnerable to being shot by hunters when forest cover is removed by logging (Timmer-mann and Gollat 1982; McMillian *et al.* 1995). Eason (1985) suggested reducing clear cut size and leaving more uncut timber between cuts to provide security cover.

Winter cover use by moose follows a distinctive pattern related to forest stand composition (Telfer 1970; Van Ballenberghe and Peek 1971; Chamberlin 1972; Krefting 1974b; Peek *et al.* 1976; Welsh *et al.* 1980; Thompson and Vukelich 1981). Deep snow increases energy demands and limits access to forage in more open mixedwood stands (Coady 1974). Moose react by selecting shallower, less dense snow found in conifer dominated habitats (Kelsall and Prescott 1971; Peterson and Allen 1974). Snow depths in Alberta boreal mixedwoods studied by Rolley and Keith (1980), for example, were up to 70 percent greater than in nearby closed canopy forests. Snow depths exceeding 90 cm are considered critical, particularly in late winter when snow crusting and reduced fat reserves further limit moose movement (Des Meules 1964). In a Northern Ontario study, Hamilton *et al.* (1980) recorded 95 percent of all winter browsing by moose occurred in mixedwood cutovers within 80 m of uncut coniferous cover, when snow was crusted and deep. Boreal forest conifers that provide late winter cover include: jack pine (*Pinus banksiana*), black spruce (*Picea mariana*), balsam fir (*Abies balsamea*), white cedar (*Thuja occidentalis*) and white spruce (*Picea glauca*). White pine (*Pinus strobus*) and hemlock (*Tsuga canadensis*) provide winter cover in the Great Lakes–St. Lawrence forest region. In addition to providing winter shelter, Moen (1973) found conifers provide a more stable thermal balance by reducing wind velocities and subsequent heat loss during extreme cold. Winter cover quality increases as the proportion of conifers in mixedwood stands increase. Mixedwood stands composed of •60 percent coniferous species of sufficient height (>10.6 m) provide maximum thermal protection and lower snow depths according to Allen *et al.* (1987). McNicol and Gilbert (1980) reported moose activity within 16 boreal mixedwood cutovers examined in early winter was concentrated in areas supporting a scattered residual coniferous and deciduous component (basal areas equal, at approximately 2.5 m^2/ha). Payne *et al.* (1988) found twice the moose activity in partially cut mixedwood stands that retained a residual conifer and hardwood component and which provided a third more edge than adjacent more open cutovers. In addition evidence suggests moose select bedding sites close to immature coniferous cover on open mixedwood habitats to reduce wind chill by utilizing the softer and more compressible snow in the lee of these windbreaks (Des Meules 1965; McNicol and Gilbert 1978; McNicol and Timmermann 1981).

Thermal cover provided by mixedwoods are especially critical to minimize heat stress by reducing convective and radiant energy loss. Upper critical temperatures reported by Renecker and Hudson (1986) were 14 to 20ºC or more in summer and between -5 and 0ºC in winter. Peak feeding activity during hot summer periods occurs at night and at sunrise and sunset when air temperatures are cooler (Berg and Phillips 1970; Belovsky and Jordan 1978). Moose appear to help regulate their body temperature by seeking specific cover types such as dense moist lowland conifer and cooler dense lowland mixedwood stands near water for shade and by reducing their activity during hot weather (Timmermann and McNicol 1988). In addition McNicol and Gilbert (1978) found residual cover provides thermal advantages to moose when bedding in winter. These studies suggest adequate thermal cover to be an important year-round habitat requirement.

Use of Mixedwood for Forage

Fire, logging, insect outbreaks and plant diseases create seral shrub communities that provide extensive forage for moose, especially in mixed conifer-deciduous forests (Peek 1997). Density and frequency of mixedwood stands vary greatly between soil types and disturbance history and moose response may vary accordingly (Oldemeyer and Regelin 1987). Moose foods can be classified into growing season (mid-May to mid-September) or dormant season (mid-September to mid-May) forage. In addition three distinct seasonal habitat types have been identified: summer, early winter and late winter, each contributing to the energy balance and predator avoidance ability.

Growing Season Diet

In the spring moose increase their activity and shift to habitats which provide an abundance of high quality forage. The growing season or green period is defined as a time when leaf material is available to moose. It averaged about 130 to 140 days in the boreal east central mixedwood forests of Saskatchewan studied by Stewart *et al.* (1977). During spring, moose face their greatest nutritional demand and eat three to four times the quantity of a higher quality food than in winter (Renecker and Hudson 1985). Coady (1982) reported that over 200 percent more energy is produced from summer food than is required for maintenance. Surplus energy is invested in growth, cows with calves produce milk and raise young, bulls grow a new set of antlers and both sexes go through an entire body hair replacement and store protein and fat for winter (Edwards and Ritcey 1958; Klein 1962; Gasaway and Coady 1974; Belovsky and Jordan 1978). Energy intake during the growing season is considered critical to ensure moose will survive the long fall/winter dormant season of negative energy balance (Stewart *et al.* 1977).

During the growing season moose select a variety of stands ranging from pure deciduous to conifer-dominated mixedwoods with an abundance of shrub and herb-rich understory species (Racey *et al.* 1989a). About three quarters of a moose's diet (LeResche and Davis 1973; Belovsky and Jordan 1978) in summer consists of terrestrial plant material found in mixedwood stands, where moose strip the leaves from a variety of woody trees and shrubs (Table 1). The balance of a moose's summer diet consists of aquatic and herbaceous plants often found close to or in association with mixedwood stands. (De Vos 1958; Ritcey and Verbeek 1969; Cobus 1972; Belovsky and Jordan 1978; Fraser *et al.* 1980, 1984). In early summer, aquatic areas, mixed upland stands of mature balsam fir, and aspen-birch are extensively used, whereas by late summer more mature mixedwood stands appear to be preferred (Peek 1997). Several studies suggest different habitat use patterns by sex, with cows accompanied by calves using more closed canopy stands and bulls preferring both lowland and open upland habitats (Leptich and Gilbert 1989; MacCracken 1992).

In autumn, after leaf fall, moose often select remaining green digestible species such as red osier dogwood, willow and beaked hazel that have escaped frost. In some areas they feed heavily on aspen leaf litter which is more digestible and has a higher nutrient content than woody browse (Renecker and Hudson 1985; Timmermann and McNicol 1988). Peek *et al.* (1976) reported a preference for sparsely stocked stands during pre-rutting activities (7-21 September), a shift to lowland moist habitats during the rut followed by a movement to more open habitats with highest forage biomass after the rut.

Recently, Racey *et al.* (1989b) used the Northwestern Ontario Forest Ecosystem Classification (Sims *et al.* 1989) to interpret moose habitat capability. They predicted that prime summer and early winter habitats would occur on medium to rich sites, except the most wet or most dry sites. Seventeen mixedwood vegetative (V) types in northwestern Ontario were subjectively interpreted as providing summer feeding value and two V-types (V22, V23), thermoregulation attributes (Racey *et al.* 1989b: Figure 40 page 61).

Dormant Season Diet

Moose commonly lose weight during the dormant winter season (Gasaway and Coady 1974; Franzmann and Le Resche 1978), and movement declines as moose decrease their metabolism and body temperature (Coady 1974; Regelin *et al.* 1985; Schwartz *et al.* 1987). Nutrient levels for plants eaten by moose and their digestibility are significantly lower in winter than in summer (Belovsky 1981; Hjeljord *et al.* 1982; Timmermann 1991). Dormant season foods or 'woody browse' include the current year's growth of accessible (< 2.8 m) biomass of deciduous woody trees and shrubs, as well as the twigs and needles of balsam fir in mixedwood stands (Table 1). In winter moose typically prefer south facing upland mixedwood types which moderates daytime temperatures (Brassard *et al.* 1974; Prescott 1974; Telfer 1978; 1984; Thompson *et al.* 1995). High quality winter range consists of a mosaic of cover types that provide cover and high browse production. After mid-October (post rut) and into early winter, moose

Table 1. Common terrestrial browse species eaten by moose in boreal mixedwood forests.

Species		Growing Season	Dormant Season
trembling aspen	(*Populus tremuloides*)	1, 6, 7, 9, 10, 14	2, 3, 4, 5, 8, 9, 11, 12, 13, 15
white birch	(*Betula papyrifera*)	1, 6, 7, 9, 14	2, 3, 4, 5, 6, 8, 9, 11, 12, 13, 15
willow	(*Salix* spp.)	7, 9, 10, 14	2, 3, 4, 5, 8, 9, 10, 11, 12, 13, 15
mountain maple	(*Acer spicatum*)	1, 6, 7, 14	2, 3, 4, 5, 6, 8, 9, 11, 12, 13, 15
pin cherry	(*Prunus pensylvanica*)	1, 5, 7	2, 3, 4, 5, 6, 8, 9, 11, 12, 15
mountain ash	(*Sorbus americana*)	1, 6	2, 4, 5, 6, 8, 9, 11, 15
beaked hazel	(*Corylus cornuta*)	1, 6	2, 3, 4, 5, 6, 8, 9, 11, 12, 15
Juneberry	(*Amelanchier stolonifera*)	1, 14	2, 3, 4, 5, 8, 9, 11, 12, 15
red-osier dogwood	(*Cornus stolonifera*)	6	2, 4, 5, 6, 8, 9, 11, 13, 15
green alder	(*Alnus crispa*)	14	2, 3, 5, 8, 15
balsam poplar	(*Populus balsamifera*)	—	2, 5, 13, 15
balsam fir	(*Abies balsamea*)	—	2, 4, 5, 6, 8, 9, 11, 12, 13, 15

Source

1 - Krefting 1974a; 2 - Krefting 1974b; 3 - Hamilton and Drysdale 1975*; 4 - Joyal 1976; 5 - Peek *et al.* 1976; 6 - Belovsky and Jordan 1978; 7 - Joyal and Scherrer 1978; 8 - McNicol and Gilbert 1980*; 9 - NcNicol *et al.* 1980*; 10 - Mytton and Keith 1981; 11 - Thompson and Vukelich 1981*; 12 - Crête and Jordan 1982; 13 - Zach *et al.* 1982; 14 - Irwin 1985; 15 - Cumming 1987*

* Ontario Studies

feed heavily in high forage-producing, low overstory canopy mixedwood habitats until deep snow or cold temperatures restrict use (Peek *et al.* 1976).

Early winter moose range commonly consists of mature or overmature mixedwood stands of relatively low stocking (< 60 percent). Shrub production and browse availability is enhanced by the open canopy and immature conifers often provide protection from winds and concealment from predators (Jackson *et al.* 1991). Early successional cutovers or burns (five to 20 years) generally provide an abundant variety of browse, especially on mixedwood sites. In addition the provision of 'edge' can influence the quality of early winter habitat by allowing moose to utilize two or more mixedwood stand types for shelter and food, thus minimizing travel time and facilitating optimal foraging, bedding and ruminating activities (Hamilton *et al.* 1980; Allen *et al.* 1987). Fourteen mixedwood V-types in northwestern Ontario were subjectively interpreted as providing early winter habitat (Racey *et al.* 1989b: Figure 40, page 61).

In late winter moose movement becomes confined as snow depths approach 90 to 122 cm (Des Meules 1964; Telfer 1970; Coady 1974; Peek *et al.* 1976; Rolley and Keith 1980; Thompson and Vukelich 1981). "Midwinter activity reduction, reduced forage intake and greater use of heavier cover that ameliorates snow and weather influences are moose responses to existence in harsh winter environment" (Peek 1997:368). Conifer dominated mixedwood or conifer stands are typically used to minimize energy losses during this period because of their reduced snow depth and crust formation (Kelsall and Prescott 1971; Coady 1974; Todesco 1988). Movement within such stands is restricted to areas two to eight km^2 in size (Goddard 1970; Van Ballenberghe and Peek 1971), and habitat is best when stands provide abundant vertical and horizontal cover with good vertical distribution of branches. "Shelter and protection from deep snow are of prime importance but food or food-producing capacity nearby enhances the value of mixedwood habitat in winter as well as in summer" (Racey *et al.* 1989b:122, Table 1). Conifer stands with >70 percent stocking and trees >6 m in height help moderate snow conditions (Allen *et al.* 1987). Nine mixedwood V-types in northwestern Ontario were subjectively interpreted as providing late winter habitat (Racey *et al.* 1989b: Figure 40, page 61).

Habitat Management

Managing moose habitat requires consideration of seasonal habitat needs and the maintenance of aquatic feeding areas, mineral licks and calving sites within some defined space (Jackson *et al.* 1991). In an area of approximately 10,000 ha consider a vegetative mosaic pattern consisting of: 40 to 50 percent cutover <20 years old; five to 15 percent mature spruce–balsam fir >20 years old; 35 to 55 percent water and mature upland deciduous/mixedwood stands >20 years old including five to ten percent wetlands (Peek *et al.* 1976; Allen *et al.* 1987, 1988). Maintenance of such cover types over the long term should meet most moose habitat requirements. Jackson *et al.* (1991:48, Table 6) list eight tools available to managers in Ontario for determining or interpreting moose habitat value.

Ontario has developed and employed forest management guidelines for moose habitat since 1988 (OMNR 1988). Guideline objectives focus on vegetative management to maintain or increase moose populations and are applied locally when timber management plans are developed. Different guidelines apply to the two major forest regions of Ontario: Great Lakes–St. Lawrence and boreal. “Guidelines are intended to constrain timber harvest management by defining and delineating the spatial and temporal distribution and the shape, size and interspersion of cut and uncut stands to create a forest that contains the essential habitat elements necessary to sustain moose and other designated wildlife” (Thompson and Stewart 1997:391). Cut block sizes and configurations are regulated using operational guidelines to achieve the desired landscape patterns. For boreal forests, general guidelines suggest irregular cut blocks of 80 to 130 ha (mean size 100 ha), leaving uncut buffers between cuts, and residual stands within cuts to increase edge and yield good moose range (OMNR 1988). Mixedwood shelter patches of three to five hectares with at least 33 percent conifer and a basal area of 11 m^2/ha, 70 percent of which should be immature are recommended to be left to reduce the maximum distance between cut edges to 300 m. Shelter patches that are intended primarily for late winter use should contain a minimum 70 percent conifer stocking. In addition specific prescriptions are given for winter concentration areas (cuts - 400 m in width), and no cut reserves around mineral licks, calving sites and aquatic feeding areas.

Knowledge Gaps

In Ontario, current guidelines for the provision of moose habitat (OMNR 1988) are based on the best information available. These guidelines, however, need field testing to determine their effectiveness (Racey *et al.* 1989b; Environmental Assessment Board 1994:306). Thompson and Stewart (1997) believe that the most important question that needs research is whether habitat management programs have an effect at the population level on a management unit. They caution that investigators must control the many factors affecting moose populations, and to involve carefully formulated hypotheses that are adequately replicated. Managers need to understand how limiting factors, such as food and predation, interact with the spacial configuration of shelter and habitat components, and with abiotic factors such as weather. Can habitat management minimize or mitigate the negative influences of such limiting factors as predation? We need to determine the effects of current management practices including the influence of corridors, shelter patches, and stand conversion from natural mixed-wood to coniferous on moose population dynamics. More research is necessary on the long-term effects of glyphosate treatments on use of treated mixedwood areas by moose and deer (Environmental Assessment Board 1994:274).

Timmermann and McNicol (1988:242) identified several specific research needs including:

1) The characteristics and influence of good summer moose habitat, including the importance of aquatic feeding sites, summer cover, calving sites and mineral licks as well as moose utilization of terrestrial vegetation to meet their summer habitat needs.

2) The variation of carrying capacity on different boreal forest site types and forest conditions that enable moose to reach maximum carrying capacity.

3) The relationship between home range size, quality and reproductive success as well as factors affecting home range formulation and dispersal.

4) Social mechanisms operating within moose populations and how such mechanisms operate under various population densities and range conditions.

Summary

Mixedwood sites provide critical seasonal cover and forage components necessary to sustain moose. Recently disturbed, high quality mixedwood habitats have the potential to produce higher moose densities when predation pressure (including legal sport harvest) is low to moderate or in multi ungulate systems, where white-tailed deer are more vulnerable to predation by wolves. A literature review dealing with species description, recognized populations, seasonal habitat use, movements, use of cover, and forage and habitat management considerations is provided.

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boreal mixedwood Notes

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Habitat Requirements of Boreal Mixedwood Passerine Birds

by R.C. Weeber[1]

The autecology of many bird species is poorly understood or known only for limited parts of their range. Boreal populations of some species may respond to habitat disturbances differently from more southern populations. Forest planning should incorporate these uncertainties by implementing management strategies that develop a range of forest types, sizes, and age classes, while providing for species dependent on rare habitat types, elements, or sizes.

Introduction

The boreal mixedwood forests of northern Ontario serve as breeding habitat for over 85 species of passerine (or perching) birds (Welsh 1981), with a wide array of life history strategies. Both the presence and quality of breeding habitat are critical to the abundance, distribution, and reproductive success that lead to robust bird populations (Wiens 1989; Venier 1996). A basic understanding of avian habitat requirements is an essential first step toward forest management that maintains diverse and representative boreal bird communities.

This note provides forest managers with an overview of the species-specific habitat associations and requirements of the passerine birds breeding in Ontario’s boreal forests. The information is presented in a series of matrices designed to alert resource managers to some of the species likely to be affected by management activities, and to suggest whether these actvities may benefit or harm susceptible species. A companion boreal mixedwood note (Weeber 1999) reviews passerine responses to habitat changes by silviculture and spruce budworm (*Choristoneura fumiferana*) outbreaks and suggests management options and approaches.

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Birds included in the matrices (scientific names are provided in Appendix 1) breed in northern Ontario, above 47 degrees north latitude (i.e., north of Sault Ste. Marie and Sudbury) and below the northern limit of the boreal forests, exclusive of the Hudson Bay Lowlands region (James 1991). Species associated primarily with human-dominated areas are not included, but those dependent on other habitat types, some of which occur on mixedwood sites (e.g., shrubby field, pure aspen [*Populus tremuloides* Michx.] stand) (Macdonald and Weingartner 1995) or within a mixedwood forest matrix (e.g., bogs, riparian habitats), and may be affected by management activities in nearby mixedwood stands (e.g., through altered foraging habitats or predation pressures) are included. For each species, three general perspectives are presented: affinity for habitat types and successional stages, foraging requirements and behaviour, and nesting requirements.

Habitat matrices

Understanding which bird species are associated with specific forest types can help resource managers become aware of which birds are likely to be affected by changes to particular forest stands. Similarly, knowing species preferences for forest developmental stages will help them to know how each might respond to shifts in seral stages.

Species most sensitive to change are those that use only a narrow range of habitat types and stages, particularly if preferred forest types are uncommon or if a large block of habitat is required. Because these species may require special management efforts to conserve, the area sensitivity of each species is also provided. This classification, based on information from deciduous forest regions, is only a first approximation for the minimum area requirements of boreal birds. Some species that are usually thought to require large areas (e.g., Red-eyed Vireo, Ovenbird), can be quite common in relatively small patches sensitivity of other birds to patch size among habitat types may also differ (Welsh 1987).

Habitat type is defined by Forest Ecosystem Classification ecosite (Racey *et al.* 1996) or site type (McCarthy *et al.* 1994). Species u**se** of an ecosite type and stage is indicated by lowercase letters and PREFERENCE by uppercase letters in the habitat matrix. Associations were adapted from D'Eon and Watt (1994) for northeastern Ontario and from Racey (1996) for northwestern Ontario. Forest developmental stages, indicated by letters A(a) through E(e) in the matrix, correspond to those described by D'Eon and Watt (1994). The stages are:

A(a): Forest initiation - Most large, mature trees have been removed and/or killed. Vegetative cover is less than 0.5 m high and consists primarily of grasses, shrubs and seedlings of forest trees.

B(b): Regeneration - The forest floor has been revegetated and consists primarily of shrubs and tree saplings less than 3.0 m high.

C(c): Young - The area is dominated by forest tree species and the canopy is fully closed.

D (d): Mature - Overstory trees have reached full physiological development and are in full seed production; canopy closure remains complete, but mortality of individual trees has begun.

E(e): Old growth - Overstory trees are declining, snags and down logs are present, and irregular gaps occur in the canopy, allowing growth of understory trees.

Table 1. Northeastern Ontario habitat matrice for boreal mixedwood passerine birds organized by Ecosite (site) type (McCarthy et al. 1994) and forest development stages (D'Eon and Watt 1994).

Common Name	Area Sens.[1]	Ecosite Type															
		ST1	ST2	ST3	ST4	ST5	ST6	ST7	ST8	ST9	ST10	ST11	ST12	ST13	ST14	ST15	ST16
Alder Flycatcher	U								ab	ab	ab	ab	AB	AB	ab		
Eastern Kingbird	I	▥	**Open shrubby fields, riparian areas[2]**														
Eastern Phoebe	U	▥	**Open and riparian woods, often near cliffs or banks**														
Eastern Wood-Pewee	I			cde				cde								cDE	cDE
Great Crested Flycatcher	A										de					DE	DE
Least Flycatcher	A					de		DE	DE	de	DE	de	de	DE	DE	de	de
Olive-sided Flycatcher	U	de	de		de	DE			DE	de		DE	DE				
Yellow-bellied Flycatcher	?			cde	cde	cde	cde	cde	cDE	cde	cde	cDE	cDE	cde	cde		
Bank Swallow	?	▥	**River banks, bluffs, roadcuts**														
Tree Swallow	U	▥	**Beaver ponds, wet meadows, burns**														
American Crow	A	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde			cde		cde	cde
Blue Jay	I	b-e	b-e	bcDE	bcDE	bcDE	bcDE	bcDE	b-e	b-e	b-e	b-e	b-e	b-e	b-e	b-e	b-e
Common Raven	U	de	de	de	de	de	de	de	de	de				de			
Gray Jay	?	de	de	de	de	de	de	de	DE	de	de	DE	DE	de	DE	de	de
Black-capped Chickadee	I	b-e	b-e	b-e		b-e		bcDE	bcDE	b-e	bcDE	b-e		b-e	bcDE	b-e	b-e
Boreal Chickadee	?	de	de	de	de	DE	de	de	DE	de	de	de	DE	DE	DE		
Red-breasted Nuthatch	U	de	de	de	de	de	de	DE	de	DE	DE	de	de	de	de		
Brown Creeper	A	de	de	DE	de	de	DE	DE		DE	DE		de	DE		de	de
House Wren	I															ab	ab
Sedge Wren	?	▥	**Sedge meadows, marshes, bogs, fields**														Winter
Wren	U	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde
Golden-crowned Kinglet	U	de	de	de	DE	DE	DE	de	de	de	de	de	de	de	de		
Ruby-crowned Kinglet	?	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	CDE	CDE	CDE	cde		

Table 1. (continued)

Common Name	Area Sens.[1]	Ecosite Type															
		ST1	ST2	ST3	ST4	ST5	ST6	ST7	ST8	ST9	ST10	ST11	ST12	ST13	ST14	ST15	ST16
American Robin	I	a-e	a-e	a-e	a-e	a-e	a-e	a-e	a-e	a-e	a-e	a-e	a-e	a-e	a-e	a-e	a-e
Brown Thrasher	I							bc			bc					BC	BC
Eastern Bluebird	I	a	a	a	a	a	a	a	a	a	a			a		a	a
Gray Catbird	I			bc				bc			bc					BC	BC
Hermit Thrush	A	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde
Swainson's Thrush	U	cde	cde	cde	cde	cde	CDE	CDE	cde	cde	CDE	cde	cde	cde	cde	cde	cde
Veery	A				BCD	BCD		BCD	bcd	bcd	BCD			bcd	BCD	bcd	bcd
Cedar Waxwing	I	a-e	a-e	a-e		a-e	a-e	A-E	a-e	A-E	A-E	a-e		a-e	a-e	a-e	a-e
Philadelphia Vireo	?			BCD	bcd	bcd	BCD	BCD	bcd	BCD	BCD	bcd	bcd	bcd			
Red-eyed Vireo	A			bcd	bcd	bcd	BCD	BCD	bcd	bcd	BCD	bcd	bcd	bcd	bcd	bcd	bcd
Solitary Vireo	?	cde	cde		cde	cde	CDE	CDE	cde	CDE	cde	cde	cde	CDE	cde	cde	cde
American Redstart	A	cde	cde	CDe	cde	cde	cde	CDe	cde	cde	CDe	cde	cde	cde	cde	CDe	CDe
Black-&-white Warbler	A	cde	cde	cde	cde	cde	cde	CDE	cde	CDE	CDE	cde	cde	CDE	cde	CDE	CDE
Bay-breasted Warbler	?	cde	cde	cde	cde	cde	cDE	cDE	cde	cDE	cDE		cde	cde			
Blackburnian Warbler	U	de	de	de			de	de		de	de			de	de		
Black-throated Blue Warbler	A							cde		cde	cde			cde		CDE	CDE
Black-throated Green Warbler	A			CDE			cde	CDE		CDE	CDE		cde	CDE			
Canada Warbler	A				b-e			bCDE		bCDE	bCDE			b-e			
Cape May Warbler	?	de	de	de	de	de	de	DE	de	de	DE	de	de	de			
Connecticut Warbler	?				cde	cde			CDE	cde		CDE	cde	cde	A-E		
Common Yellowthroat	I				ABe	ABe		abe	ABe	abe	abe	ABe	abe		a-e		
Chestnut-sided Warbler	A			bc			bc	bc			BC					BC	BC
Magnolia Warbler	I			cde	cde	cde	CDE	CDE	cde	cde	cde	cde	cde	cde	cde		
Mourning Warbler	A	ab	ab	ab	ab	ab	AB	AB	ab	ab	AB	ab	ab	ab	ab	ab	ab

Table 1. (continued)

Common Name	Area Sens.[1]	ST1	ST2	ST3	ST4	ST5	ST6	ST7	ST8	ST9	ST10	ST11	ST12	ST13	ST14	ST15	ST16
		Ecosite Type															
Nashville Warbler	U	bcd	bcd	bcd	bcd	BCD	bcd	bcd	bcd	bcd	bcd	bcd	bcd	BCD	bcd	bcd	bcd
Northern Parula	A							cd			cd					CD	CD
Northern Waterthrush	A				cde	cde	cde	cde	cde	CDE	cde	cde	CDE	CDE	cde		
Orange-crowned Warbler	?			cde				cde			cde						
Ovenbird	A	cde	cde	cDe	cDe	cde	cde	cDe	cde	cde	cDe	cde	cde	cde	cde	cDe	cDe
Palm Warbler	?				ab	ab			ab			A-E	A-E		A-E		
Pine Warbler	I	cde	cde														
Tennessee Warbler	?	cde	cde	cde	cde	cde	CDE	cde	cde	cde	cde	cde	cde	cde	cde		
Wilson's Warbler	?			abc	abc	abc	abc	abc	abc	aBC	abc	abc	aBC	aBC	abc		
Yellow-rumped Warbler	U	cde	cde	cde	CDE	CDE	cde	cde	cde	cde	cde	cde	cde	cde	cde		
Yellow Warbler	U			ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab
Scarlet Tanager	A															cDE	cDE
Rose-breasted Grosbeak	A				b-e			b-e			b-e					B-E	B-E
Indigo Bunting	I															ab	ab
Chipping Sparrow	U	cde	cde	cde		cde	CDE	CDE	cde	cde	CDE	cde	cde	CDE	cde		
Clay-coloured Sparrow	?	**Thickets, shrubby fields**															
Dark-eyed Junco	?	a-e	a-e	a-e	ABcde	a-e	a-e	a-e	ABcde	a-e	a-e	ABcde	a-e	a-e	ABcde	a-e	a-e
Le Conte's Sparrow	?	**Wet meadows, bogs**															
Lincoln's Sparrow	?				abc	abc	abc		aBC	abc		aBC	abc	abc	A-E		
Savannah Sparrow	?	**Marshes, bogs, grasslands**															
Song Sparrow	I	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab
Swamp Sparrow	U	**Lake and marsh edges, riparian areas**															
Vesper Sparrow	?	**Grasslands, clearings**															
White-throated Sparrow	U	abe		abe	abe	abe	abe	abe	abe	abe	abe	abe	abe	abe	abe	abe	abe
Baltimore Oriole	I															de	de

Table 1. (continued)

Common Name	Area Sens.[1]	Ecosite Type															
		ST1	ST2	ST3	ST4	ST5	ST6	ST7	ST8	ST9	ST10	ST11	ST12	ST13	ST14	ST15	ST16
Brewer's Blackbird	?	▥	**Shrubby fields, burns**														
Brown-headed Cowbird	I	ab	ab	ab	ab	ab	ab	ab	ab	ab							
Common Grackle	I	▥	**Range of open forest and field habitats**														
Red-winged Blackbird	I	▥	**Marshes, occasionally near forest edges**														
Rusty Blackbird	?	▥	**Riparian areas, bogs**														
American Goldfinch	I	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a
Evening Grosbeak	?	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde
Pine Grosbeak	?	cde	cde	cde	CDE	CDE	CDE	cde	cde	cde	cde	cde	cde	CDE	cde		
Pine Siskin	?	de	de	DE		de	DE	de	de	de	de	DE		de	de		
Purple Finch	U					cde		CDE	cde	cde	CDE	cde	CDE	CDE			
Red Crossbill	?	de	de														
White-winged Crossbill	?	de	de	de	DE	DE	de	de	DE	DE		DE	DE	DE	de		

1. **Area sensitivity:** A = more likely to occur in large habitat units
U = unknown (Freemark and Collins 1992)
I = equally likely to occur in small and large habitat units
? = unknown (not covered by Freemark and Collins 1992)

2. **Hatching** = not included in D'Eon and Watt (1994), descriptions from Godfrey (1986), Ehrlich *et al.* (1988), and Birds of North America Series

Table 2. Northwestern Ontario habitat matrice for boreal; mixedwood passerine birds organized by ecosite (site) type (Racey *et al.* 1996) and forest development stages (D'Eon and Watt 1994).

Common Name	Area Sens.[1]	Ecosite Type																						
		ES11	ES12	ES13	ES14	ES15	ES16	ES17	ES18	ES19	ES20	ES21	ES22	ES23	ES24	ES25	ES26	ES27	ES28	ES29	ES30	ES31	ES32	ES33
Alder Flycatcher	U												ab									ab	ab	
Eastern Kingbird	I	▥	**Open shrubby fields, riparian areas[2]**																					
Eastern Phoebe	U	▥	**Open and riparian woods, often near cliffs or banks**																					
Eastern Wood-pewee	I						cde			cde				cde					cde	cde				cde
Great Crested Flycatcher	A						de							de					de	de	DE		de	de
Least Flycatcher	A						de			de				DE	de			de	de	de	de	DE	DE	DE
Olive-sided Flycatcher	U	de	de	de	de	de		de	de		de	de	de	de				de					de	de
Yellow-bellied Flycatcher	?						cde	cde	cde		cde	cde	cde	cde	cde	cde	cde	cde				cde	cde	de
Bank Swallow	?	▥	**River banks, bluffs, roadcuts**																					
Tree Swallow	U	▥	**Beaver ponds, wet meadows, burns**																					
American Crow	A	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde
Blue Jay	I	b-e	b-e	b-e	b-e	b-e	bcDE	b-e	b-e	bcDE	b-e	b-e	bcDE	b-e	b-e	b-e	bcDE	bcDE	b-e	b-e	b-e	b-e	b-e	b-e
Common Raven	U	de	de	de	de	de	de	de	de	de	de	de	de	de	de	de	de	de	de	de	de	de	de	
Gray Jay	?	de	de	de	de	de	de	de	de	de	de	de	de	de	de	de	DE	DE	de	de	de	DE	DE	de
Black-capped Chickadee	I	b-e	b-e	b-e	b-e	b-e	b-e	b-e	b-e	b-e	b-e	b-e	b-e	bcDE	b-e	b-e	b-e	b-e	b-e	b-e	b-e	bcDE	bcDE	bcDE
Boreal Chickadee	?	de	de	de	de	de	de	de	de	de	de	de	DE	de	de	de	DE	de	de	de	de	DE	de	de
Red-breasted Nuthatch	U	de	de	de	de	de	DE	de	de	DE	de	de	de	DE	de	de	de	de	DE	DE	de	de	de	DE
Brown Creeper	A	de	de	de	de	de	DE	de	de	DE	de	DE	de	DE	DE	de	de	dE	DE	DE	DE	de	DE	DE
House Wren	I																				ab			
Sedge Wren	?	▥	**Sedge meadows, marshes, bogs, fields**																					Winter
Wren	U	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde
Golden-crowned Kinglet	U	de	de	de	de	de	de	de	de	de	de	DE	de	de	de	DE	de	DE	DE	DE		de	de	de
Ruby-crowned Kinglet	?	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	CDE	cde	cde	cde	cde	cde	cde	cde	cde	CDE	cde	cde

Table 2. (continued)

Common Name	Area Sens.[1]	ES11	ES12	ES13	ES14	ES15	ES16	ES17	ES18	ES19	ES20	ES21	ES22	ES23	ES24	ES25	ES26	ES27	ES28	ES29	ES30	ES31	ES32	ES33
		Ecosite Type																						
American Robin	I	a-e	a-e	a-e	a-e	a-e	a-e	a-e	a-e	a-e	a-e	a-e	a-e	a-e	a-e	a-e	a-e	a-e	a-e	a-e	a-e	a-e	a-e	a-e
Brown Thrasher	I									bc				bc					bc	bc				bc
Eastern Bluebird	I	a	a	a	a	a	a	a	a	a	a	a			a	a	a	a	a	a	a			a
Gray Catbird	I									bc				bc					bc	bc			bc	bc
Hermit Thrush	A	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde
Swainson's Thrush	U	cde	cde	cde	cde	cde	CDE	cde	cde	CDE	cde	cde	cde	CDE	cde	cde	cde	cde	CDE	CDE	CDE	cde	cde	CDE
Veery	A						bcd	bcd	bcd	BCD		bcd		BCD	bcd			bcd	BCD	BCD	bcd		bcd	BCD
Cedar Waxwing	I	a-e	a-e				a-e	a-e	a-e	A-E		a-e		A-E	a-e			a-e	a-e	a-e	a-e		a-e	A-E
Philadelphia Vireo	?						bcd			bcd		bcd		BCD	bcd	bcd	bcd	bcd	BCD	BCD	bcd	bcd	bcd	BCD
Red-eyed Vireo	A	bcd		bcd	bcd	bcd	BCD	bcd	bcd	BCD	bcd	bcd	bcd	BCD	bcd	bcd	bcd	BCD	BCD	BCD	bcd	bcd	bcd	BCD
Solitary Vireo	?	cde	cde				cde	cde		cde		CDE		cde	cde	CDE	CDE	CDE	cde	cde		CDE	CDE	cde
American Redstart	A	cde	cde	cde	cde	cde	CDe	cde	cde	CDe	cde	cde	cde	CDe	CDe	cde	cde	cde	CDe	CDe	CDe	cde	cde	CDe
Black-&-white Warbler	A	cde	cde	cde	cde	cde	CDE	CDE	cde	CDE	cde	cde	cde	CDE	cde	cde	cde	cde	CDE	CDE	CDE	cde	cde	CDE
Bay-breasted Warbler	?	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	CDE	cde	cde		cde	cde	CDE	cde	cde		cde	CDE	cDE
Blackburnian Warbler	U	de		de	de	de	de	de		de	de	de	de	de			de	de	de	de		de	de	de
Black-throated Blue Warbler	A						cde			cde		cde		CDE				cde	CDE	CDE	CDE			cde
Black-throated Green Warbler	A						CDE			CDE		CDE		cde				CDE	cde	cde			CDE	CDE
Canada Warbler	A							b-e	b-e	cde		cde	B-E	bCDE				cde	b-e	b-e	bCDE	b-e	b-e	bCDE
Cape May Warbler	?	de	de	de	de	de	de	de	de	de	de	DE	de	DE	de	de	de	DE	de	de	de	de	DE	DE
Connecticut Warbler	?										ab		ab			ab	ab					ab		
Common Yellowthroat	I			ABe	ABe		abe	abe	abe	abe	ABe	abe	ABe			abe	abe					abe		
Chestnut-sided Warbler	A						bcd			bcd		bcd		bcd				bcd	bcd	bcd	bcd		BC	BCD
Magnolia Warbler	I			cde	cde	cde	CDE	cde	cde	CDE	cde	cde	cde	CDE	cde	cde	cde	CDE	CDE	CDE	cde	cde	cde	cde
Mourning Warbler	A	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	AB	ab	AB	ab	ab	ab	AB	AB	AB	ab	ab	ab	ab

Table 2. (continued)

Common Name	Area Sens.[1]	ES11	ES12	ES13	ES14	ES15	ES16	ES17	ES18	ES19	ES20	ES21	ES22	ES23	ES24	ES25	ES26	ES27	ES28	ES29	ES30	ES31	ES32	ES33
		Ecosite Type																						
Nashville Warbler	U	bcd	bcd	bcd	bcd	bcd	bcd	bcd	bcd	bcd	bcd	bcd	bcd	BCD	bcd	bcd	BCD	BCD	bcd	bcd	bcd	bcd	bcd	bcd
Northern Parula	A						cd			cd				cd				cd	cd	cd				
Northern Waterthrush	A							cde				cde	cDE	CDE	cde	cde	cde	cde	cde	cde	cde	CDE	CDE	cde
Orange-crowned Warbler	?	||||||	**Deciduous component of mixedwoods, brushy thickets, riparian areas**																					
Ovenbird	A	cde	cde	cde	cde	cde	cDe	cde	cDe	cDe	cde	cde	cde	cDe	cde	cde	cde	cDe	cDe	cDe	cDe	cde	cde	cDe
Palm Warbler	?				ab						ab		ab				ab					ab		
Pine Warbler	I	cde		cde		cde			cde						cde	cde								
Tennessee Warbler	?	cde	cde	cde	cde	cde	CDE	cde	cde	CDE	cde	cde	cde	CDE	cde	cde	cde	cde	CDE	CDE	CDE	cde	cde	cde
Wilson's Warbler	?			abc	abc	abc	abc	abc	abc	abc	abc	abc	aBC	aBC	abc	abc	abc	abc	abc	abc	abc	aBC	aBC	abc
Yellow-rumped Warbler	U	cde	cde	cde	CDE	cde	cde	cde	cde	cde	CDE	cde	CDE	cde	cde	cde	CDE	cde	cde	cde	cde	CDE	cde	cde
Yellow Warbler	U			ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab
Scarlet Tanager	A						de							de					de	de	cDE			de
Rose-breasted Grosbeak	A						b-e			b-e				b-e				b-e	b-e	b-e	b-e		de	b-e
Indigo Bunting	I						abc			abc				abc					abc	abc	abc			abc
Chipping Sparrow	U	cde	cde	cde	cde		CDE			CDE	cde	CDE	cde	cde	CDE	cde	cde	de	cde	cde	cde	cde	CDE	cde
Clay-coloured Sparrow	?	||||||	**Thickets, shrubby fields**																					
Dark-eyed Junco	?	a-e	a-e	a-e	ABcde	a-e	a-e	a-e	a-e	a-e	ABcde	a-e	ABcde	a-e	a-e	a-e	ABcde	a-e	a-e	a-e	a-e	ABcde	a-e	a-e
Le Conte's Sparrow	?	||||||	**Wet meadows, bogs**																					
Lincoln's Sparrow	?			abc	abc						abc	ab	ABC	ab		ABC	ABC					aBC	abc	
Savannah Sparrow	?	||||||	**Marshes, bogs, grasslands**																					
Song Sparrow	I	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab
Swamp Sparrow	U	||||||	**Lake and marsh edges, riparian areas**																					Vesper
Sparrow	?	a				a	a																	
White-throated Sparrow	U	abe	ab e	abe	abe	abe	abe	abe	abe	abe	abe	abe	abe	abe	abe	abe	abe	abe	abe	abe	abe	abe	abe	abe
Baltimore Oriole	I																				de			

Table 2. (concluded)

Common Name	Area Sens.[1]	Ecosite Type																						
		ES11	ES12	ES13	ES14	ES15	ES16	ES17	ES18	ES19	ES20	ES21	ES22	ES23	ES24	ES25	ES26	ES27	ES28	ES29	ES30	ES31	ES32	ES33
Brewer's Blackbird	?	▥	**Shrubby fields, burns**																					
Brown-headed Cowbird	I	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab			ab	ab	ab	ab	ab	ab	ab			
Common Grackle	I																						cd	
Red-winged Blackbird	I	▥	**Marshes, occasionally near forest edges**																					
Rusty Blackbird	?	▥	**Riparian areas, bogs**																					
American Goldfinch	I	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a
Evening Grosbeak	?	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde	cde
Pine Grosbeak	?	cde	cde	cde	cde	cde					cde	cde	CDE	cde	cde	CDE	CDE	cde	cde	cde		CDE	cde	cde
Pine Siskin	?	de	de	de	de	de		de	de		de	de	de		de	DE	de	de				de	de	de
Purple Finch	U				cde		CDE				cde	CDE	cde		CDE	cde	cde	cde	cde	cde	cde	CDE	CDE	cde
Red Crossbill	?	DE				DE			DE			de			DE			de					de	
White-winged Crossbill	?	de	de	DE	DE	de		de	de		DE	de	DE		de	DE	DE	de				DE	de	

1. **Area sensitivity:** A = more likely to occur in large habitat units I = equally likely to occur in small and large habitat unit

U = unknown (Freemark and Collins 1992) ? = unknown and not covered by Freemark and Collins (1992)

2. **Hatching** = not included in ES11–ES33 of Racey (1996), descriptions from Godfrey (1986), Ehrlich *et al.* (1988), and Birds of North America Series

Foraging Matrix

Food availability is one of the most important determinants of bird density (Welsh 1981). The ways that bird species respond to changes in food availability (e.g., altered territories or clutch sizes) may be initiated or increased by management activities. These responses will vary with the diets and foraging behaviours of species and the structural and floristic consequences of management activities. Although seeds, fruit and nectar are important to many birds, the diet of most breeding passerines and their young is predominately invertebrates, primarily insects. The diet preferences of each species, along with preferred feeding locations and methods, are identified in Table 3. Foraging locations and methods of each species were defined after Ehrlich *et al.* (1988) and canopy zone preferences were based on DeGraaf *et al.* (1985). Birds foraging in subcanopy zones do so in shrubs, saplings, and the lower crowns of trees. Birds foraging in the upper canopy feed among tree crowns forming the main canopy. Shrub and subcanopy areas are often the most important foraging zones in strongly deciduous forests, while the upper canopy is the primary feeding area in the spruce and fir stands (Erskine 1977). Gleaning birds pick up food items while standing, perching, or moving on the ground, among the foliage, or on tree boles. Some birds hover while picking food items from plant surfaces, while others fly from a perch to capture insects from the air.

Nesting Matrix

Successful reproduction requires a substantial investment by each pair of birds and is obviously one of the most important contributors to long-term population maintenance. Forest management can have profound effects on bird communities through the provision or removal of appropriate and safe nesting sites. Birds that typically establish nesting territories in fields, clearcuts, or along the transition between these and forested habitats, are classified as ***edge*** species (Table 4). Birds that nest within the forest and distant from edge habitats are referred to as ***interior*** species, and those that nest within the forest but also use edge habitat are classified as ***interior-edge*** species (Freemark and Collins 1992). The effects of forest management on nest site availability can also vary according to where nests are located (e.g., cavity in snag) or whether breeding activity, which includes territory establishment and fledging as well as nesting, overlaps temporally with forestry activities. The safety of a particular nest site from mammalian or avian predators is influenced by many factors, some of which can be affected by forest management; these include the proximity and abruptness of edge habitat, the density and composition of cover around the nest site, nest height, and the types and densities of predators (Wiens 1989).

Applications and Conclusion

A creative approach, perhaps based on expanding the questions listed below as well as those in Weeber (1999), is recommended to identify how management plans might be modified to provide habitat for particular species or groups of bird species. Applications of the principles discussed in Weeber (1999) and the species-specific information in this paper can be simplified by assembling a list of passerines occurring, or likely to occur, on the management area. If local species lists are unavailable, Erskine's (1977) description of the avifauna typical of various forest types, James' (1991) account of species' ranges, and the

Table 3. Foraging matrix for boreal mixedwood passerine birds.

Common Name	Diet[1]			Location/Method[2]					Notes[3]
	Inverts	Seeds	Other	Ground Glean	Foliage Glean	Bark Glean	Hover & Glean	Flycatch	
Alder Flycatcher	2		1		1			2	fruit
Eastern Kingbird	2		1		1		1	2	fruit
Eastern Phoebe	1							1	often feeds over water
Eastern Wood-Pewee	1						1	2	
Great Crested Flycatcher	2		1		1			2	fruit
Least Flycatcher	2		1		1		2	1	fruit
Olive-sided Flycatcher	1							1	
Yellow-bellied Flycatcher	2		1		1		1	2	fruit
Bank Swallow	1								aerial forager
Tree Swallow	2		1		1				fruit; primarily aerial forager
American Crow	1	1	1	1					omnivore
Blue Jay	1	1	1	2	1uc			1	omnivore, including eggs; stores food
Common Raven	1	1	1	1					omnivore
Gray Jay	1	1	1	2	1uc				stores food
Black-capped Chickadee	2	1	1		2sc	1			conifer seeds, fruit; budworm
Boreal Chickadee	2	1			2sc	1			
Red-breasted Nuthatch	1					2		1	(+) budworm density
Brown Creeper	2	1				2		1	
House Wren	1			2	1sc				
Sedge Wren	1			2	1				
Winter Wren	1			2	1				
Golden-crowned Kinglet	2		1		2sc		1	1	tree sap, fruit; (+) budworm density
Ruby-crowned Kinglet	2		1		2sc		1	1	tree sap, fruit; budworm (Welsh1983)
American Robin	2		1	2	1				fruit
Brown Thrasher	1	1	1	2	1sc				omnivore
Eastern Bluebird	2		1	1	1			2	fruit
Gray Catbird	2		1	2	1sc				fruit
Hermit Thrush	2		1	2	1		1	1	fruit; (+) budworm density
Swainson's Thrush	2		1	1	2sc		1	1	fruit; budworm
Veery	2		1	2	1sc			1	fruit
Cedar Waxwing	1		2		2uc			1	fruit
Philadelphia Vireo	2		1		1uc		2	1	fruit
Red-eyed Vireo	2		1		1uc			2	fruit; budworm

Table 3. (continued)

Common Name	Diet[1]			Location/Method[2]					Notes[3]
	Invertebrates	Seeds	Other	Ground Glean	Foliage Glean	Bark Glean	Hover & Glean	Flycatch	
Solitary Vireo	1				2sc			1	(+) budworm density
American Redstart	1				1sc		2	1	budworm (Welsh 1983)
Black-&-white Warbler	1					2		1	
Bay-breasted Warbler	2	1			2uc			1	(+) budworm density
Blackburnian Warbler	1				2uc	1	1	1	(+) budworm density
Black-throated Blue Warbler	1				1sc		2	1	
Black-throated Green Warbler	1				2uc	1	1	1	(+) budworm density
Canada Warbler	1			1	1sc		2	1	
Cape May Warbler	1				2uc			1	(+) budworm density
Connecticut Warbler	1			2	1				
Common Yellowthroat	1				2sc	1	1	1	
Chestnut-sided Warbler	2		1		2sc		1	1	berries; gleans underside of leaves
Magnolia Warbler	1				1sc	1	2		especially underside of leaves; (+) budworm density
Mourning Warbler	1			1	2				territory size decreases with budworm
Nashville Warbler	1			1	2sc		1		budworm
Northern Parula	1				2uc		1	1	budworm
Northern Waterthrush	1			2	1			1	especially aquatic invertebrates
Orange-crowned Warbler	2		1		1sc				fruit, nectar, tree sap; budworm (Welsh 1983)
Ovenbird	1			1					territory size decreases with budworm
Palm Warbler	2		1	2	1			1	berries, nectar
Pine Warbler	2	1	1		1	2		1	fruit
Tennessee Warbler	2		1		1uc				fruit; abundant with budworm (Erskine 1977)
Wilson's Warbler	1				2sc	1	1	1	
Yellow-rumped Warbler	2		1		2sc		1	1	berries; opportunistic; (+) budworm density
Yellow Warbler	1				2sc	1	1	1	
Scarlet Tanager	2		1		1uc		2	1	
Rose-breasted Grosbeak	2	1	1		2uc	1	1	1	fruit, buds
Indigo Bunting	2	1	1	1	2sc				fruit
Chipping Sparrow	2	1		2	1			1	
Clay-coloured Sparrow	2	1		2	1sc				
Dark-eyed Junco	1	2		1				1	(+) budworm density

Table 3. (concluded)

Common Name	Diet[1]			Location/Method[2]					Notes[3]
	Inverte-brates	Seeds	Other	Ground Glean	Foliage Glean	Bark Glean	Hover & Glean	Flycatch	
Le Conte's Sparrow	2	1		1					
Lincoln's Sparrow	2	1		1					
Savannah Sparrow	2	1		1					
Song Sparrow	2	1		2	1sc				
Swamp Sparrow	2	1		1					
Vesper Sparrow	2	1		1					
White-throated Sparrow	2	1	1	2	1			1	fruit; (+) budworm density
Baltimore Oriole	2	1	1		2uc			1	fruit, nectar
Brewer's Blackbird	2	1	1	2	1			1	fruit
Brown-headed Cowbird	2	1		1					
Common Grackle	1	1	1	2	1				omnivore
Red-winged Blackbird	2	1		2	1			1	
Rusty Blackbird	2	1		1					
American Goldfinch	1	2		1	2sc				especially thistle seed
Evening Grosbeak	1	2	1	2	1uc				fruit; abundant with budworm (Erskine 1977)
Pine Grosbeak	1	2	1	1	2uc				buds, fruit
Pine Siskin	1	2		1	2uc				
Purple Finch	1	2	1	2	1uc				fruit; (+) budworm density
Red Crossbill		2	1		1uc				buds; especially conifer seeds
White-winged Crossbill		1		1	2uc				mostly conifer seeds

1. 1 = use, 2 = preference, 'Other' diet items identified in 'Notes' column (Ehrlich *et al.* 1988)
2. 1 = use, 2 = preference (Ehrlich *et al.* 1988); sc = subcanopy, uc = uppercanopy (DeGraaf *et al.* 1985)
3. Ehrlich *et al.* (1988) except where noted; budworm = consume large numbers of spruce budworm, (+) budworm density = among those species that increase consumption of budworms with increased larval density (Crawford and Jennings 1989)

Table 4. Nesting matrix for boreal mixedwood passerine birds.

		Nest Site[2]			Location of Elevated Nests[2]						
Common Name	**Territory[1]**	**Ground**	**Tree**	**Shrub**	**Conifer**	**Deciduous**	**Alive**	**Dead**	**Height (m)**	**Nesting Period[3]**	**Notes[4]**
Alder Flycatcher	E		1	1	1	2	1		≤1	July	usually moist sites
Eastern Kingbird	E		1	1	1	2	2	1	2-4	JJ	
Eastern Phoebe	IE								1-3	AMJJ	nest among tree roots, on cliff, bank or buildings
Eastern Wood-Pewee	IE		1		1	2	2	1	5-9	JJ	prefers open area near nest
Great Crested Flycatcher	IE		1		1	2	1	2	2-5	June	cavity
Least Flycatcher	E		1		1	2	2	1	3-8	JJ	prefers open area near nest
Olive-sided Flycatcher	I		1		2	1	2	1	7-10	June	usually in moist site
Yellow-bellied Flycatcher	IE	1								July	especially on sphagnum hummocks
Bank Swallow	E								2-5	MJ	in burrow into steep banks of soil, sand; colonial
Tree Swallow	E		1		1	2	1	2	2-6	MJJ	cavities and nest boxes; often in loose colonies
American Crow	E		2	1	2	1	2	1	6-11	MAMJ	usually in upper third of tree
Blue Jay	IE		2	1	2	1	2	1	2-5	MJ	will take nest from other passerines
Common Raven	I		1		1	1	2	1	12-24	MAM	nest site usually near open space, cliffs preferred
Gray Jay	IE		1		1		1		2-6	MA	usually in black or white spruce, balsam fir
Black-capped Chickadee	IE		1		1	2		1	1-4	MJ	cavity
Boreal Chickadee	I		1		1	2	1	2	1-4	June	cavity
Red-breasted Nuthatch	I		1		1	2	1	2	3-9	May	cavity; pitch around entrance (purpose unknown)
Brown Creeper	I		1		1	1	1	2	1-4	MJ	nest built under loose bark, also in cavity
House Wren	E		1		1	1	1	1	1-3	MJJA	variety of cavity types
Sedge Wren	E								≤1	JJ	among standing grasses, sedges
Winter Wren	I		1		1	1	1	1	≤1	June	especially in tree roots, fallen logs, stumps
Golden-crowned Kinglet	I		1		1		1		9-12	?	
Ruby-crowned Kinglet	I		1		1		1		3-7	June	
American Robin	E		1	1	1	1	1		1-3	AMJJ	variety of nest sites
Brown Thrasher	E	1	1	2	1	2	1		1-2	MJJ	

Table 4. (continued)

Common Name	Territory[1]	Nest Site[2]			Location of Elevated Nests[2]					Nesting Period[3]	Notes[4]
		Ground	Tree	Shrub	Conifer	Deciduous	Alive	Dead	Height (m)		
Eastern Bluebird	E		1			1	1	2	1-4	AMJJA	cavity; nest boxes important in population recovery
Gray Catbird	IE		1	2	1	2	2	1	1-2	MJJA	
Hermit Thrush	I	2	1	1	1	1	1		≤1	MJJA	often in moist site
Swainson's Thrush	I		1	2	2	1	2	1	1-2	JJ	often in moist site; usually in small trees
Veery	I	2		1	1	2	1		≤1	MJJ	often in moist site
Cedar Waxwing	E		1	1	1	1	2	1	2-4	JJAS	
Philadelphia Vireo	IE		2	1		1	1		3-15	JJ	often in areas with understory of alder
Red-eyed Vireo	IE		1	1	1	2	1		2-4	JJ	
Solitary Vireo	I		1		2	1	1		2-4	JJ	
American Redstart	I		1	2	1	2	2	1	2-4	JJ	density of understory vegetation important
Black-&-white Warbler	I	1								JJ	also in stumps, among tree roots
Bay-breasted Warbler	I		1		1		1		4-6	June	clutch size inc. with budworm; understory density import.
Blackburnian Warbler	I		1		1		1		6-12	June	nest usually near top of tree
Black-throated Blue Warbler	I		1	2	1	1	1		≤1	JJ	territory size decr. with dense, heterogenous shrub layer
Black-throated Green Warbler	I		1		2	1	1		3-8	JJ	
Canada Warbler	I	1								June	among dense undergrowth, brush piles
Cape May Warbler	IE		1		1		1		9-15	?	nest usually near top of tree
Connecticut Warbler	E	2		1	1	1	1		low	?	breeding biology poorly understood
Common Yellowthroat	IE	1		2	1	1	1		≤1	JJ	
Chestnut-sided Warbler	E		1	2	1	2	1		≤1	JJ	
Magnolia Warbler	I		2	1	2	1	1		1-2	JJ	often in openings with dense coniferous understory
Mourning Warbler	E	2		1	1	1	1		≤1	JJ	nest also among brushpiles, thickets
Nashville Warbler	E	1								JJ	usually among dense ground cover
Northern Parula	I		1		1	1	1		2-30	?	requires epiphytes (moss, lichens) for nest

Table 4. (continued)

Common Name	Territory[1]	Nest Site[2]			Location of Elevated Nests[2]					Nesting Period[3]	Notes[4]
		Ground	Tree	Shrub	Conifer	Deciduous	Alive	Dead	Height (m)		
Northern Waterthrush	I	1								June	also upturned tree roots or low cavities
Orange-crowned Warbler	IE	2		1	1	1	1		low	?	remote areas of northern Ontario, few nests found
Ovenbird	I	1								JJ	among leaf litter below closed canopy
Palm Warbler	E	1								June	nests on bog surface, often under small conifer
Pine Warbler	I		1		1		1		9-15	June	
Tennessee Warbler	IE	1								JJ	clutch size increases with budworm density
Wilson's Warbler	IE	1								June	few nests found; on grass or moss clumps of wet areas
Yellow-rumped Warbler	I		2	1	2	1	2	1	2-6	JJ	
Yellow Warbler	E		1	2	1	2	1		1-2	JJ	
Scarlet Tanager	I		1		1	2	1		4-9	June	
Rose-breasted Grosbeak	IE		1	1	1	2	1		2-4	MJJ	often in upper portion of shrub or small tree
Indigo Bunting	E		1	2	1	2	1		≤1	JJA	
Chipping Sparrow	E		2	1	2	1	1		1-2	MJJ	
Clay-coloured Sparrow	E	1	2	2	2	1	1		≤1	JJ	
Dark-eyed Junco	IE	2		1	1		1		≤1	MJJ	often nests in existing crevices or depressions
Le Conte's Sparrow	E	1								J	nesting ecology poorly understood
Lincoln's Sparrow	E	1								JJ	often on moss, grass or sedge clump
Savannah Sparrow	E	1								MJJ	
Song Sparrow	E	2	1	1	1	1	1		≤1	MJJA	
Swamp Sparrow	E	1		2	1	1	1		≤1	MJJ	often in standing grass, sedge or cattail
Vesper Sparrow	E	1								MJJ	usually dry sites, often with sparse ground cover
White-throated Sparrow	E	2		1	1	1	1		≤1	JJ	often under low shrubs or trees
Baltimore Oriole	E		2	1	1	2	2	1	6-11	JJ	
Brewer's Blackbird	E	2	1	1	1	1	1	1	1-2	MJ	in small, loose colonies

Table 4. (concluded)

Common Name	Territory[1]	Nest Site[2]			Location of Elevated Nests[2]					Nesting Period[3]	Notes[4]
		Ground	Tree	Shrub	Conifer	Deciduous	Alive	Dead	Height (m)		
Brown-headed Cowbird	E	1	2	1	1	2	2	1	1-3	MJJ	obligate nest parasite (does not build nest)
Common Grackle	E		2	1	1	2	2	1	1-4	AMJ	nests singly or in loose colonies
Red-winged Blackbird	E		1	1	1	1	1	1	1-2	MJJ	primarily in emergent vegetation of marshes
Rusty Blackbird	IE		2	1	2	1	1	1	1-2	MJ	in loose colonies
American Goldfinch	E		1	1	1	2	2	1	1-2	JJAS	late nesting coincides with seed crop
Evening Grosbeak	I		1		2	1	1		9-15	June	nests seldom found
Pine Grosbeak	IE		2	1	1		1		?	?	nests seldom found
Pine Siskin	I		1		1		1		4-6	MAMJJ	timing of nesting variable; occasionally in loose colonies
Purple Finch	IE		1		1		1		2-8	JJ	usually in upper portion of tree
Red Crossbill	I		1		1		1		7-11	?	timing of breeding variable; few nests found
White-winged Crossbill	I		1		1		1		6-13	?	timing of breeding variable; few nests found

1. Territory: I = Forest interior, E = Forest perimeter or open habitats, IE = Forest interior and edge (Freemark and Collins 1992) and Godfrey (1986) for species not covered by Freemark and Collins (1992)
2. 1 = use, 2 = preference;
3. range of months during which eggs are present (Peck and James 1987)
4. Peck and James (1987), Ehrlich *et al.* (1988)

Ontario Atlas of Breeding Birds (Cadman et al. 1987) can help to create a list of species that may occur on the site. The Canadian Landbird Priority-setting Database, currently being developed by Birds Studies Canada, the Canadian Wildlife Service, and the Ontario Ministry of Natural Resources (OMNR), will provide a tool for ranking species according to rarity and the degree to which they are typical of a particular region (LePage et al. 1998; M. McLaren, OMNR, pers. comm.). The database will contain conservation rankings for birds at several spatial scales including the province, OMNR Districts, and Forest Management Areas.

Given the species likely to occur in the management area and a species ranking by conservation priority, the habitat matrices can be used to identify potentially affected species and to begin estimating the effects of management. Some initial questions might be:

- Which ecosite types and successional stages will be changed by the management activities?
- Which ecosite types and successional stages will result?
- What size are the management areas?

The foraging matrix can be used to refine the expected responses by considering for example:

- Which food resources will be affected and how will their availability change?
- How will the effects on food resources differ among the various foraging locations?
- How will changes in structural or other aspects restrict or facilitate foraging methods?

The nesting matrix can be used to gauge the effects of forest management on breeding success. Some initial questions might be:

- What type and amount of edge will result?
- What nesting locations will be affected and how will the type and complexity of nesting cover be changed?
- Will the structure and composition of the forest change enough to affect nesting?
- Can management activities be scheduled to occur outside the breeding period?

Creative use of the information in the matrices will allow flexibility in terms of the numbers of species and the spatial and temporal scales considered, and in the degree of certainty attached to various conclusions. The autecology of many bird species is poorly understood or known for limited parts of their range. Boreal populations of some species may respond to habitat disturbances differently from more southern populations of the same species, for example, area sensitivity may differ (Welsh 1987). Forest planning should incorporate these uncertainties (see also Weeber 1999) by implementing management strategies that develop a range of forest types, sizes, and age classes while providing for species dependent on rare habitat types, elements, or sizes.

Appendix 1. Common and scientific names and migration strategies for bird species covered in the matrices.

Common Name	Scientific Name[1]	Migration[2]
Alder Flycatcher	*Empidonax alnorum*	LD
Eastern Kingbird	*Tyrannus tyrannus*	LD
Eastern Phoebe	*Sayonoris phoebe*	SD
Eastern Wood-Pewee	*Contopus virens*	LD
Great Crested Flycatcher	*Myiarchus crinitus*	LD
Least Flycatcher	*Empidonax minimus*	LD
Olive-sided Flycatcher	*Contopus borealis*	LD
Yellow-bellied Flycatcher	*Empidonax flaviventris*	LD
Bank Swallow	*Riparia riparia*	LD
Tree Swallow	*Tachycineta bicolor*	LD
American Crow	*Corvus brachyrhynchos*	WR
Blue Jay	*Cyanotcitta cristata*	WR
Common Raven	*Corvus corax*	WR
Gray Jay	*Perisoreus canadensis*	WR
Black-capped Chickadee	*Parus atricapillus*	WR
Boreal Chickadee	*Parus hudsonicus*	WR
Red-breasted Nuthatch	*Sitta canadensis*	WR
Brown Creeper	*Certhia americana*	WR
House Wren	*Troglodytes aedon*	SD
Sedge Wren	*Cistothorus platensis*	SD
Winter Wren	*Troglodytes troglodytes*	SD
Golden-crowned Kinglet	*Regulus satrapa*	SD
Ruby-crowned Kinglet	*Regulus calendula*	SD
American Robin	*Turdus migratorius*	SD
Brown Thrasher	*Toxostoma rufum*	SD
Eastern Bluebird	*Sialia sialis*	SD
Gray Catbird	*Dumetella carolinensis*	LD
Hermit Thrush	*Catharus guttatus*	SD
Swainson's Thrush	*Catharus ustulatus*	LD
Veery	*Catharus fuscescens*	LD
Cedar Waxwing	*Bombycilla cedrorum*	SD
Philadelphia Vireo	*Vireo philadelphicus*	LD
Red-eyed Vireo	*Vireo olivaceus*	LD
Solitary Vireo	*Vireo solitarius*	LD
American Redstart	*Setophaga ruticilla*	LD
Black-&-white Warbler	*Mniotilta varia*	LD
Bay-breasted Warbler	*Dendroica castanea*	LD
Blackburnian Warbler	*Dendroica fusca*	LD
Black-throated Blue Warbler	*Dendroica caerulescens*	LD
Black-throated Green Warbler	*Dendroica virens*	LD
Canada Warbler	*Wilsonia canadensis*	LD
Cape May Warbler	*Dendroica tigrina*	LD
Connecticut Warbler	*Oporornis agilis*	LD
Common Yellowthroat	*Geothlypis trichas*	LD

Appendix 1. (continued)

Common Name	Scientific Name[1]	Migration[2]
Chestnut-sided Warbler	*Dendroica pensylvanica*	LD
Magnolia Warbler	*Dendroica magnolia*	LD
Mourning Warbler	*Oporornis philadelphia*	LD
Nashville Warbler	*Vermivora ruficapilla*	LD
Northern Parula	*Parula americana*	LD
Northern Waterthrush	*Seiurus noveboracensis*	LD
Orange-crowned Warbler	*Vermivora celata*	LD
Ovenbird	*Seiurus aurocapillus*	LD
Palm Warbler	*Dendroica palmarum*	LD
Pine Warbler	*Dendroica pinus*	SD
Tennessee Warbler	*Vermivora peregrina*	LD
Wilson's Warbler	*Wilsonia pusilla*	LD
Yellow-rumped Warbler	*Dendroica coronata*	LD
Yellow Warbler	*Dendroica petechia*	LD
Scarlet Tanager	*Piranga olivacea*	LD
Rose-breasted Grosbeak	*Pheucticus ludovicianus*	LD
Indigo Bunting	*Passerina cyanea*	LD
Chipping Sparrow	*Spizella passerina*	SD
Clay-coloured Sparrow	*Spizella palida*	SD
Dark-eyed Junco	*Junco hyemalis*	WR
Le Conte's Sparrow	*Amodramus leconteii*	SD
Lincoln's Sparrow	*Melospiza lincolnii*	LD
Savannah Sparrow	*Passerculus sandwichensis*	SD
Song Sparrow	*Melospiza melodia*	SD
Swamp Sparrow	*Melospiza georgiana*	SD
Vesper Sparrow	*Pooecetes gramineus*	SD
White-throated Sparrow	*Zonotrichia albicollis*	SD
Baltimore Oriole	*Icterus galbula*	LD
Brewer's Blackbird	*Euphagus cyanocephalus*	SD
Brown-headed Cowbird	*Molothrus ater*	SD
Common Grackle	*Quiscalus quiscula*	SD
Red-winged Blackbird	*Agelaius phoeniceus*	SD
Rusty Blackbird	*Euphagus carolinus*	SD
American Goldfinch	*Carduelis tristis*	SD
Evening Grosbeak	*Coccothraustes vespertinus*	SD
Pine Grosbeak	*Pinicola enucleator*	WR
Pine Siskin	*Carduelis pinus*	WR
Purple Finch	*Carpodacus purpureus*	SD
Red Crossbill	*Loxia curvirostra*	WR
White-winged Crossbill	*Loxia leucoptera*	WR

1. From James (1991)
2. Based on descriptions in Godfrey (1986): LD = long distance migrant, winters south of central Mexico,
SD = short distance migrant, winters south of Ontario, but north of central Mexico,
WR = winter resident of Ontario

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Responses of Forest Passerine Birds to Boreal Mixedwood Silviculture and Spruce Budworm

HABITAT

To reduce the effects of forest management on passerine birds, forest managers need to understand avian responses to anthropogenic and natural disturbances.

Introduction

Boreal forest birds are important contributors to the biodiversity of mixedwood forests and are affected by two of the major disturbance agents currently shaping boreal forests: harvesting and associated forest management practices, and infestations of the eastern spruce budworm (*Choristoneura fumiferana*). Resource mangers are faced with several questions when trying to assess and minimize the effects of these disturbances on birds.

How are birds likely to respond to changes in habitat? Which avian species or groups of species are most sensitive to particular changes? What can be done to reduce the effects? This note is an overview of current answers to these questions in relation to passerine (perching bird) responses to boreal mixedwood silviculture and spruce budworm outbreaks, two very different disturbances. A companion technical note (Weeber 1999) summarizes the habitat, foraging, and nesting requirements of mixedwood forest passerine species.

Silvicultural Practices

The relationship between birds and forest management is the subject of a large body of literature (see Nietfeld and Telfor 1991). However, only a few of the studies described in this literature were conducted in predominantly forested landscapes (e.g., King *et al.* 1996, Hagan *et al.* 1996), and only a small portion of

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these occurred in boreal forests (e.g., Welsh 1987, Machtans *et al.* 1996, Kirk *et al.* 1996, 1997, Norton and Hannon 1997, Schmiegelow *et al.* 1997). Current efforts to shape forest management to accommodate boreal birds must therefore incorporate concepts from other forest zones and more settled landscapes. Although the habitat requirements of many species are constant across their range, there is evidence that at least a few boreal birds differ in their habitat needs from southern populations of the same species (Welsh 1987, Monkkonen and Welsh 1994, Welsh and Lougheed 1996). Because experimental studies of breeding boreal passerines are so few, some of the management recommendations described in this technical note may need revision as additional, boreal-specific, research questions (e.g., Thompson and Welsh 1993) are addressed.

Forest managers seeking to reduce the impacts of harvesting and forest management on passerines must be aware of direct and indirect bird responses to these activities and the consequences of alternative silvicultural measures. This technical note summarizes:

- Responses to forest harvesting and related activities. These include: a) vegetation responses (i.e. structure, floristics); b) avian responses (e.g., community composition and species dominance, guild responses), and c) other responses (e.g., predators, competitors, food sources).
- Potential modifiers of expected responses. These include: a) size, configuration, and intensity of harvest; b) selection and intensity of related silvicultural practices (e.g., planting, tending); and c) the effects of fire and fire control efforts.

Responses and modifiers should be considered in light of what occurs at various temporal scales (i.e., immediately and with regeneration) and spatial resolutions (e.g., within the management area, in adjacent areas, and with respect to the regional forest mosaic and bird populations).

The emphasis in this note is on clearcutting and alternative harvesting methods, with some suggestions about other silvicultural activities. This focus was selected because harvesting causes the most dramatic changes to bird habitats and relatively few published accounts deal with avian responses to the wide range of potential post-harvest activities. Although fire and fire control efforts are important elements of boreal forest succession and management planning (Johnston 1996, MacDonald 1996), the assumption that harvest patterns can mimic the effects of wildfire on boreal bird populations has only recently been evaluated (e.g. Gurd 1996) and a review of this topic is beyond the scope of this note.

Silvicultural Methods

Wedeles *et al.* (1995) presented a detailed description of silvicultural systems using clearcut and alternative harvesting techniques, and reviewed their application in Ontario boreal mixedwoods. Although not ? and deal from a t. Commercial clearcutting, involving the removal of all the merchantable timber from the site, is the dominant harvesting method in Ontario boreal mixedwoods. Alternatives to the clearcutting system (termed partial cutting hereafter) including modified clearcutting (i.e., seed-tree, strip-cut, and two-pass systems) and the shelterwood and selection systems are beginning to be applied in ? scenerios. Wedeles *et al.* (1995) provided an excellent overview of the methodological considerations and vegetative responses associated with each of these systems.

Silviculture and Forest Birds

Responses to the Clearcutting System

Within a commercial clearcut, virtually all the vertical and horizontal structure is removed resulting in a loss of habitat for most of the birds previously occupying the site (e.g., Norton and Hannon 1997). As vegetative succession occurs in the clearcut area, changes in species composition also occur in the bird community (Erskine 1977, Welsh 1988, Kirk *et al.* 1996, 1997). Factors such as pre-harvest forest composition, slope, soil moisture, and soil fertility are important determinants of the rate and outcome of vegetation and bird species turnovers on a given site (Welsh and Fillman 1980, Welsh 1988). The open habitat of a recent clearcut favours early successional and edge species, particularly those nesting and foraging on the ground or in low shrubs (e.g., Lincoln and Song Sparrows, American Goldfinch)[2]. As shrubs and trees become established and vertical structure diversifies, other early successional species in colonize use move in the harvested area (e.g., Chestnut-sided Warbler, Alder Flycatcher). Young forests, particularly those with dense understory vegetation, typically contain species that prefer mid-successional stages (e.g., American Redstart, Rose-breasted Grosbeak). Unless large trees or dead and dying trees are exempted from harvest, habitat for many canopy and cavity nesting species (e.g., Blackburnian and Cape May Warbler, Boreal Chickadee, Brown Creeper) will disappear until a mature forest reestablishes. However, some clearcut sites may never provide their original habitat functions due to hydrology, soil erosion, or loss of seed sources (Thompson and Welsh 1993).

Responses to Fragmentation Caused by Clearcutting

Recent evidence suggests that some birds breeding in the boreal forest may differ in their resilience to certain disturbances from more southern populations of the same species (Welsh 1987, Monkkonen and Welsh 1994, Kirk *et al.* 1996, 1997). Concepts relating to bird conservation in southern forests (e.g., forest fragmentation, corridors) may not apply or may need to be applied differently in the more frequently disturbed (e.g., fire, spruce budworm) boreal landscape.

One of the few boreal studies designed to examine the response of birds to forest fragmentation was conducted in old (80 to 130 years old) mixed stands in north-central Alberta (Schmiegelow *et al.* 1997). Fragments of various sizes (1 to 100 ha) were created by clear-cutting 200 m strips in contiguous forest areas. These fragments were compared to control areas in nearby, intact forest the year before, and for two years following, harvest. Fragments were isolated by cut strips or were connected to other fragments with 100 m wide riparian buffer strips.

Fragmentation did not affect overall bird species richness but did change species composition and the abundance of some species. Species turnover was highest in the small, isolated fragments where year-round resident species disappeared after

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[2] See Weeber (1999) for habitat associations. Scientific names of bird species are provided in Appendix I.

cutting. Fragments contained high bird numbers relative to controls in the first year following fragmentation, but not in the second. This *crowding effect* was most pronounced among long-distance migrants, presumably because these birds have less time to prospect for new nesting sites than short distance migrants and residents (see Weeber 1999 for species' migration strategies).

Although the crowding effect was temporary, the structure of bird communities in fragments and in control blocks remained different into the second year following fragmentation. These differences appeared to be related to bird species' requirements for particular forest age classes. During the second year, seven of the 10 bird species who had lower abundance in fragments than in controls were those preferring older forests. The four species that increased in fragments either used younger forests more or were not typical forest species. Although differences were small, bird communities in connected fragments were less affected by fragmentation than those in the isolated blocks, suggesting that forested corridors may have a function in boreal bird movements (see also Machtans *et al.* 1996) and that clearcut areas of more than 200 m across may represent barriers to the movement of breeding forest birds. Schmiegelow *et al.* (1997) concluded by noting that the fragmentation effects they observed were smaller and more temporary than those observed in nonforested landscapes, suggesting that boreal birds may be resilient to forest fragmentation (see also Welsh 1987). However, Schmiegelow *et al.* (1997) cautioned that long-term studies, particularly those controlling for regional forest age and composition and focusing on bird breeding productivity at various spatial scales, are still needed before the impacts of fragmentation on boreal bird populations will be understood.

Responses to Size, Shape, and Timing of Clearcuts

Fragmentation studies should be complemented by projects that examine the effects of a clearcut on bird communities in the surrounding uncut or regenerated forest. Relatively few of these studies have been conducted. Crowding effects have been shown to extend from a clearcut area into the surrounding forest following the displacement of many of the original occupants from the harvested area (Darveau *et al.* 1995, Hagan *et al.* 1996). This is similar to patterns observed in fragmented forests. High Ovenbird densities have lead to lower pairing success and decreased overall reproductive success in high density areas (Hagan *et al.* 1996). Such observations suggest that, for some birds (e.g., Black-throated Blue Warbler, Ovenbird), clusters of clearcuts have the potential to act as large-scale centres of demographic disturbance (King *et al.* 1996, Hagan *et al.* 1996).

The recolonization of the harvested area by the original bird species largely depends on the pattern and scale of resettlement after spring migration. The resettlement process is poorly understood but appears to be influenced by survival and site fidelity, dispersal distances of repeat and first-year breeders, the proximity of robust potential (source) bird populations, the size and presence of appropriate habitat patches within the harvested area, and the distance between similar habitat patches (Wiens 1989, Villard *et al.* 1995). Successfully breeding passerines tend to return to within about 400 m of their previous nest site; dispersal distances of first-time breeders are probably greater, but actual distances have not been measured (Villard *et al.* 1995, Hagan *et al.* 1996). Harvested areas are more likely to be colonized if they are large, close to potential source populations, and connected by corridors of habitat similar to patches holding source populations (Wiens 1989, Machtans *et al.* 1996).

As clearcut areas regenerate, those with lower edge:area ratios (i.e., tending toward round) are more likely to be occupied by forest interior species (Hunter 1992). Predation rates are often higher near forest edges (Paton 1994), although this is not always true in primarily forested landscapes (e.g. King *et al.* 1996, Darveau *et al.* 1997). Edge effects forest structure and floristics and will reduce the amount of habitat for birds preferring forest interior conditions particularly in small clearcuts, (Darveau *et al.* 1995, Schmiegelow *et al.* 1997, Weeber 1998).

Modifiers of Responses to Clearcutting

The timing, spatial patterns, and forest harvesting methods can be changed to reduce their effects on boreal bird species. Although birds can be extremely mobile in their annual movements, most breeding birds are closely associated with particular sites from the time of territory establishment through, and often beyond, the time that chicks fledge. Forestry activities scheduled between September and April are less likely to directly affected the productivity of breeding passerines (see Weeber 1999 for nesting dates).

Many silvicultural practices (e.g. planting, tending) lead to second growth forests that are floristically and structurally less complex than the forests they replace; this simplification provides fewer available niche spaces and often leads to a reduced diversity of wildlife species (Thompson and Welsh 1993). This is where proper mixedwood management is an advantage, more structure left, more diversity. Whenever possible, practices that maintain habitat complexity should be selected. Slash left across the harvested area can help reduce predation on the ground nests of early colonizers (Martin 1992) and, can increase invertebrates available to insectivorous birds. Skidding and scarification techniques that reduce damage to residual vegetation and preserve coarse woody debris will enhance the structural complexity of ground and shrub nesting and foraging zones (Thompson and Welsh 1993, Machmer and Steeger 1995, Wedeles and VanDamme 1995). Large diameter dead and dying trees retained in the harvested area (Thompson and Welsh 1993, Naylor *et al.* 1996), will provide important sites for foraging, nesting, and roosting for many snag-dependent species (e.g., Eastern Bluebird, chickadees; see Weeber 1999) through all stages of succession.

Although herbicides appear to have relatively few direct impacts on bird abundance or species composition, the immediate and long-term vegetative changes that follow herbicide applications will affect avian nesting and foraging resources (Freedman *et al.* 1981). These indirect effects on birds have not been studied but may have important consequences (e.g., reduced reproductive success) (Freedman *et al.* 1981), therefore herbicide use should be minimized and applied well outside the nesting season whenever possible (see

Weeber 1999) since herbicide use is ? in mixedwood management.

The distribution of clearcut sizes should mimic the scale of historical disturbances to boreal forests, perhaps consisting of many small cuts and a few very large (e.g., greater 10,000 ha) clearcuts (Hunter 1992, Thompson and Welsh 1993). The timing of harvesting across the landscape should be planned to provide variety of successional stages, including old growth, required to support a wide range of bird species (Harris 1984). Impacts on bird communities in forests adjacent to clearcuts (e.g., crowding, edge related effects) will be reduced if these neighbouring forested areas are sufficiently large and mature to absorb displaced individuals (King *et al.*, 1996, Hagan *et al.* 1996). High quality habitat patches that support potential source populations of birds should be retained as important features of the landscape; source patches that are likely to become relatively scarce (e.g., large blocks of old growth spruce) are particularly valuable (Baker *et al.* 1996).

Corridors between boreal habitat patches probably serve a somewhat different function than forested links in an agricultural landscape, These connections are important for the movement of juvenile birds (Machtans *et al.* 1996) and appear to moderate some of the effects of fragmentation on breeding birds (Schmiegelow *et al.* 1997). Although untested and probably specific to particular bird species, a series of patch types (e.g., old, coniferous forests) connecting similar habitat across a landscape of other forest types (e.g., deciduous-dominated second growth) could conceivably serve some longer term corridor-like functions. More information on spring resettlement patterns of birds and juvenile movements is needed before the spatial attributes of clearcutting can be directed to promote the successful recolonization of harvested areas, maintain gene flow between local bird populations, and protect the birds of source patches from demographic disturbances.

Responses to Partial Cutting Systems

Much less is known about the responses of forest birds to modified clearcut, shelterwood, and selection systems than to clearcutting (see Wedeles *et al.* 1995 for definitions). Crawford *et al.* (1981), developed a model to predict ? responses to varying intensities of harvestin Appalachian hardwood forests. They classified birds in five groups ranging from *closed canopy obligatory* to *open canopy obligatory* species. According to their model, closed canopy obligatory species (e.g., Ovenbird) are favoured by low intensity harvesting like selection cutting, while open canopy obligatory birds (e.g., Eastern Bluebird) will respond favourably to more intensive cutting such as seed-tree or clearcuts. Intermediate harvesting intensities were predicted to benefit a wide range of species. Freedman *et al.* (1981) reported that bird species composition patterns in thinned and strip-cut blocks that were intermediate between uncut and clearcut areas in Nova Scotia were consistent with Crawford *et al's (1981).* model.

More recent studies have investigated bird community composition and abundance patterns in greater detail. A study conducted in mixedwood boreal forests of north-central Alberta monitored passerine birds before and after harvesting in clearcut, partial cut, and intact, control blocks (Norton and Hannon 1997). Species richness and abundance were lower in harvested sites than in control sites. Richness and abundance were much lower in clearcuts than controls and intermediate in partial cuts. Forty-one percent of the species present in clearcut blocks decreased in abundance after logging, 31% of those in partial cuts decreased, while only 3% of birds in control blocks decreased. Most species that declined in abundance after harvesting were foliage gleaning, and shrub and tree nesting, birds (see Weeber 1999 for definitions). In general, the numbers of ground foraging and ground nesting birds were minimally affected by harvesting; logging did have an impact, however, on the relative proportions of these species, increasing the dominance of open habitat species (e.g., Lincoln's Sparrow). Eight species that had been abundant were absent following clearcutting; seven of these species remained follwoing partial cuts but at lower abundance than in controls.

While concluding that partial cutting can help moderate many of the impacts of clearcutting on bird community composition, Norton and Hannon (1997) emphasized that the loss of canopy volume and the associated declines in insect biomass might affect the long term densities and reproductive potential of birds breeding in even partially cut forests. Until data relevant to these long-term impacts are collected, practices that retain about 40% of the vegetation seem to be useful management tools for reducing the impacts of harvesting on forest bird communities.

The high species richness of intermediate harvesting intensities predicted by Crawford *et al.* (1981) was supported by a recent meta-analysis of several field studies conducted in the Oregon Cascades (Hansen *et al.* 1995). Bird distributions among clearcuts, retention sites (i.e. dispersed large trees left during harvest), young closed-canopy plantations, mature stands, and old growth stands were linked to canopy closure and the structural complexities of habitats. Retention of large canopy trees, roughly analogous to the use of seed-tree or shelterwood systems, resulted in a rich assemblage of bird species, including some typical of mature and old growth stands. Computer simulations suggested the high bird species richness of retention stands relative to that of clearcuts would be maintained for over a century following harvest which bodes well for stand managed as mixedwoods.

Modifiers of Responses to Partial Cutting

Relative to clearcut harvesting, partial cutting appears to reduce many of the effects of forest harvesting on bird communities. However, the studies discussed above indicate that the composition of the bird community and the abundance of some bird species are altered by even moderate intensity logging. The removal of canopy biomass and large tree boles can be expected to affect mature forest inhabitats, upper canopy foliage gleaners, and canopy nesting birds. Most of the previously occurring species will be present after partial cutting, although probably in lower numbers than in unharvested forest (Hansen *et al.* 1995, Norton and Hannon 1997). Along with the intensity of tree harvest, damage to the shrub layer during logging operations will have important effects on shrub nesting birds and those foraging in lower canopy areas. As the vegetation responds to reduced canopy closure, however, shrub dependent birds might be expected to benefit from the increased shrub layer complexity. Many of the modifications described for clearcutting (e.g. timing of harvest, snag and woody debris retention) also apply to partial cutting.

Many issues must be addressed before bird responses to specific intensities, methods, and configurations of boreal mixedwood partial cutting are clear. A recent three-year study in boreal mixedwood forests near Black Sturgeon Lake in northwestern Ontario should provide some of this information. Bird abundance was monitored in a large control stand and in 33 logged and uncut blocks (9 to 10 ha) one year before, and for two years after, harvesting. Harvesting methods included clear cut, partial cut (60% removal), and a combined patch/strip cut (20% removal). Preliminary analyses suggest that different harvesting intensities had species-specific effects on birds (e.g., Ovenbird, Swainson's Thrush) (K.F. Abraham, pers. comm.)[3].Other important questions include whether partially cut forest provides suboptimal habitat for forest-dependent birds and how bird communities will respond as partially cut forests regenerate (Norton and Hannon 1997). The habitat requirements of some bird species will not be met in partially cut stands, suggesting that many different silvicultural approaches will be necessary to provide for all bird species (Hansen *et al.* 1995).

Spruce Budworm

Relative to natural processes, forest harvesting is a recent source of disturbance to boreal forest passerines (Monkkonen and Welsh 1994). Fire and periodic spruce budworm infestations, probably occurring every 30 to 100 years, have been a primary driving force in the evolutionary history of boreal forests (Blais 1985, Johnston 1996). Boreal birds and budworm populations are related directly through bird predation on larvae and moths, and indirectly through forest responses to budworm infestations. An understanding of these relationships is important to anticipating bird responses to budworm outbreaks and incorporating those responses in management planning.

Spruce Budworm and the Forest

Budworm Ecology and Population Dynamics

Budworm population cycles are characterized by periods of extremely low densities (endemic levels), a sharp increase in larval abundance (transitional levels), ten or more years of fluctuation around very high densities (epidemic levels), and finally a period of decline toward endemic levels (Blais 1985, Nealis and Ortiz 1996). Declines in budworm populations are thought to be driven by several factors, including increased mortality due to food shortages, predation, parasites, and budworm control measures (Nealis and Ortiz 1996). Budworm moths are active during their mating and egg laying period in July and early August, and small first instar larvae are active for only a short time between hatch and hiber-nacula construction. Following an overwintering moult, second instar larvae emerge in April or early May, disperse to feeding sites where they often remain through the final larval and pupal stages, and emerge as moths in early to mid-July (Sanders 1991).

Impacts of Budworm Outbreaks on the Forest

Balsam fir (*Abies balsamea*) is the tree species most vulnerable to budworm attacks, followed by white spruce (*Picea* *glauca*), black spruce (*Picea mariana*) and the pines (*Pinus* spp.) (Johnston 1996). Large stands dominated by mature balsam fir, particularly those on very wet or very dry sites, suffer the most intense damage (MacLean 1996a). Trees that survive budworm attack often undergo a large increase in shoot production and a corresponding increase in needle biomass early in their recovery (Ostaf and MacLean 1995). If severe defoliation is sustained, however, a large proportion of host trees can be killed (Nealis and Ortiz 1996). Colonization by fungi, lichens and beetles occurs during and after tree death, accelerating rates of decomposition of dead host trees and adding fallen woody debris to the forest floor (Fowle 1983).

Death of host trees increases vertical and horizontal forest complexity as shade tolerant tree, shrub, and herbaceous species are released (Nealis and Ortiz 1996). The occurrence of patches of high tree mortality following a heavy budworm infestation enhances forest structural complexity at the stand and landscape scales (MacLean and Piene 1995). Whether these patches and surrounding, less damaged forest areas are subject to long-term floristic shifts is debated. Arguments have been made for an increase in host species (see Fowle 1983), a shift toward resistant species (Johnston 1996, Nealis and Ortiz 1996), and for no change in composition (Blais 1985, MacLean 1996a) following a budworm infestation. The large proportion of dead biomass present following a budworm outbreak and its potential to increase the occurrence and severity of forest fire may also lead to successional changes (Johnston 1996).

Management Responses to Budworm Outbreaks

Several authors have reviewed the range of techniques available for spruce budworm population control. The spraying of insecticides was summarized by Armstrong (1985) and the use of biorationals, including budworm parasites, diseases and hormones, was reviewed by Cunningham (1985). Various silvicultural techniques have been described by Jennings *et al.* (1985), Wedeles *et al.* (1995), and MacLean (1996a,b). Integrated pest management techniques are discussed by Simmons and Montgomery (1985).

Spruce Budworm and Forest Birds

Many boreal bird species capitalize on budworm population cycles. Bird responses to increased food resources are the most obvious and well documented of the potential relationships between birds and budworm populations. The influence of bird predation on budworm populations is complex and restricted to certain conditions. Indirect relationships may be important but have not been directly investigated through field studies. Studies currently underway in mixedwood forests of northern Ontario (C.J. Sanders, pers. comm.)[3] should contribute to our understanding of these relationships.

Direct Relationships

Bird responses to increased prey availability can be classified as either numerical or functional (Otvos 1979). Numerical responses by forest birds to budworm outbreaks are well

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documented and due to one or both of the following: movement into the infested area or increased breeding success (Otvos 1979, Welsh 1983).

Erskine (1977) noted a few additional species and much higher densities of birds in forests with spruce budworm relative to uninfested areas. Working in northeastern Ontario, Welsh (1983) and co-workers observed that bird densities increased from 2.7 pairs per ha to 14.5 pairs per ha during a three-year period of building budworm numbers. Studies in northwestern Ontario have shown average bird densities of 3.04 pairs per ha at endemic budworm levels in the middle and late 1960s, less than half of the average 7.88 pairs per ha reported for the same area during a budworm outbreak 20 years earlier (Sanders 1970). Continued census work in these study plots through 1995 has shown a doubling of bird populations concurrent with the budworm outbreak of the last two decades (C.J. Sanders, pers. comm.). These high densities of birds are often dominated by one or several of the budworm specialists (i.e. Bay-breasted, Blackburnian, Cape May, and Tennessee Warblers), but may also consist of large numbers of other species (e.g. Chestnut-sided, Magnolia, Nashville, and Yellow-rumped Warblers, Golden-crowned Kinglets, Red-eyed Vireos, and White-throated Sparrows) (Sanders 1970, Crawford and Titterington 1979, Welsh 1983, see also Weeber 1999).

Clutch sizes of some birds have been observed to increase during years of high budworm densities (see Weeber 1999). Research in mixedwood stands in northern Ontario (Welsh 1985) and in spruce-fir stands of the northeastern United States (Crawford and Jennings 1989) has demonstrated that the period of abundant, large and active budworm larvae occurs while the food requirements of birds are at their greatest (i.e. feeding nestlings and foraging fledglings), potentially contributing to chick growth and survival.

Functional responses by birds to budworm outbreaks involve behavioural adjustments that increase the proportion of budworm in their diet as larval densities increase (Otvos 1979). At epidemic levels, these changes in prey consumption can result in over 40% of the diets of some birds consisting of budworm larvae (Otvos 1979). Working in Maine and New Hampshire, Crawford and Jennings (1989) conducted a detailed study of functional responses of birds to different spruce budworm densities. Study plots contained budworm densities ranging from endemic through transitional levels (80 x 10^3 to >22 x 10^6 larvae per ha). Twenty-two species of birds consumed budworm larvae and pupae, with estimates of >25,000 budworm per ha consumed by both Blackburnian and Cape May Warblers over a 41-day period. As a group, birds were able to locate and consume budworm larvae at even the lowest larval densities and consumption increased with increasing budworm numbers. When birds were classified according to similar feeding patterns, three of the four classes showed significant functional responses to budworm numbers. The most important of these was the group composed of six canopy foraging warblers (Bay-breasted, Blackburnian, Black-throated Green, Cape May, Magnolia, and Yellow-rumped) and the Golden-crowned Kinglet. Other examples of avian behavioural responses to increasing budworm densities include a reduction in the size of territories defended (Welsh 1983) and a shift in foraging location and behaviour (Otvos 1979).

Although forest birds may help reduce the frequency of budworm outbreaks, bird populations are not effective at controlling budworm numbers once the infestation has reached epidemic levels (Welsh 1983, Sanders 1991, Machmer and Steeger 1995). Crawford and Jennings (1989) showed that consumption of budworm larvae by the birds on their plots declined from 84% of the large larvae present at low budworm densities (100,000 larvae per ha) to 22% at transitional densities (approximately 550,000 larvae per ha). These authors suggested that the bird community exerts a powerful influence on budworm populations only with high bird and low larval densities, and that relatively small changes in budworm survival or bird densities (e.g., through a change in weather) can reduce this influence. Other authors (Machmer and Steeger 1995) point out that some birds (e.g. Black-capped Chickadees, flycatchers) may influence populations through the consumption of adult insects during moth dispersal flights, prior to oviposition.

Indirect Relationships

Many indirect relationships may exist between spruce budworm infestations and bird species composition and abundance. Some control measures (e.g., insecticide application: Fairchild and Eidt 1993) used during a budworm outbreak will have detrimental effects on the food resources of insectivorous birds, apart from reducing bud-worm densities. Other measures (e.g., strip-cutting; Jennings *et al.* 1985) will have some positive effects on portions of the bird community but will also negatively affect invertebrate prey availability. Interspecific dominance, predation, diseases, and parasites are important variables in avian communities (Wiens 1989). How these forces change with budworm-induced shifts in habitat complexity, bird density, and community composition remains poorly understood.

Among the most important changes to the forest following a spruce budworm epidemic are the shifts in vegetative complexity, composition, and age distribution, which lead to changes in forest bird communities (Wiens 1989, Martin 1992). Birds preferring mature stands, particularly forests with strong fir or spruce components (e.g., Ecosite 32, or Site Type 6; Weeber 1999) are less likely to occur following a budworm outbreak until mature conifers are once again dominant. Birds specializing in coniferous food resources (e.g., crossbills) or nesting habitat (e.g., Gray Jay) may suffer from both short- and long-term shifts in tree species composition, while species nesting in budworm resistant trees (e.g. Philadelphia Vireo) may benefit from long-term shifts.

The release of shade intolerant tree, shrub, and herbaceous plants in patches of high fir or spruce mortality will contribute to the diversity of the recovering forest, benefiting species with broad habitat requirements. These same vegetative changes will provide a range of foraging substrates and food items for foliage gleaners and may help reduce predation on shrub and ground nests (Martin 1992). Abundant dead and rotting trees will provide foraging and nesting locations for some species (e.g., chickadees, nuthatches) and, through increases in epiphytic lichens and fungi, important nesting materials for others (e.g., Northern Parula Warbler) (Welsh 1983).

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Spruce Budworm, Forest Birds and Management

Spruce budworm outbreaks clearly benefit many bird species. Because these benefits can translate into population growth for some species (e.g., through increased fledgling success), these benefits should be incorporated into decision-making processes about the use of budworm control measures. When considered along with the costs associated with control efforts, the benefits to bird populations may suggest that some control efforts (e.g., those that are unlikely to succeed due to extremely high budworm densities) may not be worth pursuing. The potential for population- level benefits is particularly important for bird species that are highly rated in terms of conservation priority (see below).

Many boreal birds provide an important service by consuming large proportions of endemic spruce budworm populations. This service can be protected by providing habitat for the budworm specialists and other birds mentioned above (also see foraging matrix in Weeber 1998). Many of these birds prefer mature or old growth successional stages, particularly mixedwoods with at least moderate proportions of spruce or fir. Through the dispersal of budworm-consuming birds to areas with endemic or transitional budworm densities, these patches of mature forest may play an important role in reducing the frequency of budworm outbreaks occurring in a region. Maintaining these source habitat patches near known or anticipated spruce budworm population growth centres may help avoid or postpone a budworm outbreak. Welsh (1981) noted that the foraging niches of many coniferous specializing birds, including many budworm specialists, are filled by other bird species when partial cutting causes a shift in canopy dominance from conifers to deciduous trees. He speculated that budworm specialists such as Blackburnian and Cape May Warblers may not be able to regain those upper canopy foraging niches after the return of conifers to the canopy and that their exclusion may have lasting consequences for local insect population dynamics.

If Welsh's hypothesis is correct, a prudent approach to managing a landscape that is vulnerable to budworm outbreaks would include partial cutting practices that retain some conifers in the canopy, thereby encouraging the continued presence of many budworm-consuming birds. These and other competitive relationships among boreal passerine species remain poorly understood but are important in projecting bird community succession relative to forest management and spruce budworm population dynamics.

Summary and Implications for Management

Clearly, anticipating responses of boreal mixedwood passerines to disturbances such as forest management and spruce budworm outbreaks is not a simple task. Boreal field observations and experimental studies (e.g., Welsh 1987, Schmiegelow *et al.* 1997) are needed to assess the similarities and differences in how boreal and non-boreal birds respond to human-induced and natural disturbances. Predictions are complicated by the role that site-specific historical, edaphic, and topographical features play in boreal vegetative succession (Welsh and Fillman 1980) and the complex responses of birds to both structural and floristic characteristics (Wiens 1989). Although habitat disturbances often elicit species-specific responses, other processes such as predation or competition can be equally, if not more, important to bird abundance or distribution (Wiens 1989, Martin 1992).

Bird communities of boreal mixedwoods can contain many species that have a wide range of life history strategies. Approaches based on resource guilds and featured or indicator species have been important tools in coping with many species simultaneously, but are criticized as too coarse, poorly defined (Simberloff and Dayan 1991), and likely to overlook the long-term requirements of some species (Thompson and Welsh 1993). As described in Weeber (1999), the proposed *Canadian Landbird Priority-setting Database* (LePage *et al.* 1998, M. McLaren, pers. comm.^{5}) should reduce the set of bird species to those requiring the most conservation attention, allowing for a more focused approach to management.

Although many of these complexities will persist regardless of the number of species considered, the following questions, along with species-specific information (e.g., Weeber 1999), may help to anticipate bird responses. In light of the planned management actions:

1) How will the resource base (i.e., habitat, foraging, nesting) of passerines be changed? Consider structural and compositional changes as well as spatial and temporal aspects.
2) Which groups of species are likely to suffer? Which will benefit? Consider defining groups by a variety of requirements, for example: habitat type, edge/interior, nesting substrate, nest height, foraging location. Birds requiring cavities or large, mature, or rare types of forest are often the most vulnerable.
3) How are avian (e.g., Blue Jay, American Crow) and mammalian (e.g., Red Squirrel [*Tamiasciurus hudsonicus*]) nest predation intensities likely to change? How is competition likely to change? Which of the groups defined in (2) are most vulnerable? Highest predation rates are associated with open nests (as opposed to those in cavities), and nests on or close to the ground, at forest edges, or under canopy gaps (Wiens 1989). Resource scarcity can increase competition between species, resulting in decreased reproductive success if mates, territories, or nest sites are limiting (Wiens 1989).
4) Which bird species fit poorly into, or are left out of, the groups defined in (2)? How will the resource base of these species change?
5) How can harvesting intensities and configurations, or budworm control efforts, be modified to minimize effects or enhance benefits for groups of birds or individual species? In areas where budworm outbreaks are likely, how can nearby stands be managed to provide a source of budworm specialist birds that could move into infested areas?
6) How do areas of high spruce budworm densities influence the availability and quality of bird habitat at the landscape scale? How will this change when budworm populations decline?

Because older forests are usually selected for harvest, and regeneration of boreal forests often leads to deciduous tree dominance on formerly coniferous sites, birds requiring mature and old forests, and those dependent on rare forest types will be the most vulnerable to harvesting (Welsh 1987, Thompson and Welsh 1993, Kirk *et al.* 1996, 1997, Schmiegelow *et al.* 1997). Providing for these and the many other species of birds dependent on boreal mixedwoods will require a landscape of stands varying in ages, age structures (i.e. even- and uneven-aged), tree species composition, and structural complexity (Thompson and Welsh 1993, Kirk *et al.* 1996, 1997). Partial cuts, multi-pass systems, shelterwood harvesting, and snag retention are a few of the techniques that will be important in providing this landscape (Thompson and Welsh 1993). Creative thinking, along with a willingness to accommodate complex species responses, will be required to ensure that the mixedwood forests of the future will contain a healthy and diverse community of boreal passerines.

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boreal mixedwood Notes
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The Ecology of Northern Ontario Black Bear in Relation to Mixedwood Forests

by Lucille Brown[1], Martyn Obbard[1], and William D. Towill[2]

> *Black bears rely on a variety of forest habitat types to meet their seasonal requirements of space, food, water, den sites, escape cover, and concealment (Hugie 1979).*

Introduction

Black bears (*Ursus americanus*) are present throughout much of North America where an estimated 450,000 animals survive in the wild (Fuller 1995). In parts of the United States, some black bear populations are currently considered threatened (U.S.D.A 1991); however, populations are stable or increasing in Ontario. In 1996, the black bear was declared not at risk in Ontario and classed as 'Not In Any Category' by the Committee On The Status Of Species At Risk in Ontario (COSSARO). In 1997, the black bear was classed as 'Not At Risk' in Canada by the Committee On the Status of Endangered Wildlife In Canada (COSEWIC).

Black bears are ecologically and economically important components of many northern boreal forest ecosystems. The value of the black bear as a game animal in Ontario has increased dramatically over the past 15 years; for example, direct expenditure by black bear hunters in 1993 was approximately $12.6 M. This contributed about $20.8 M to the gross provincial income (Legg 1995). There is growing concern that increased hunting pressure and success rates, combined with increased human activity in the forest, could significantly influence the regulation and spatial distribution of black bear populations throughout northern Ontario. Hunting pressure on black bear populations in Ontario has increased steadily since the early 1960's due to declining bear populations and increased hunting restrictions in the northern United States. Hunting bears using bait has greatly improved hunter success over the years and is now common practice in most areas of northern Ontario.

Black bears rely on a variety of forest habitat types to meet their seasonal requirements of space, food, water, den sites, escape cover,

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and concealment (Hugie 1979). Timber management activities such as fire suppression, harvesting, regeneration treatments, and vegetation management, at both stand and forest levels, change forest habitat by changing forest structure, which in turn affects bears. The quality and diversity of black bear habitat in Ontario is currently maintained through habitat guidelines for moose (*Alces alces*) (OMNR 1988) and white-tailed deer (*Odocoileus virginianus*) (Voigt *et al*. 1997) since the black bear is not classified as a "featured" species (Baker and Euler 1989). *Forest management guidelines for the emulation of fire disturbance patterns* (OMNR in. prep.) may help to ensure a supply of quality black bear habitat in the future as they are intended to conserve biological diversity at forest and landscape scales.

This technical note (1) documents the importance of boreal mixedwood habitat and forage to black bears, (2) outlines the effects of current timber management practices on black bear populations, (3) presents information on how to improve habitat for black bear and mitigate adverse effects of timber harvest management on the quality and quantity of suitable black bear habitat, and (4) highlights areas where research is still needed.

Importance of Boreal Mixedwoods

Boreal mixedwoods (MacDonald 1996) comprise an estimated 15.8 million hectares of Ontario's 38 million hectares of unreserved production forest (based on 1996 provincial inventory data). They are an important forest condition that represents 53% of the productive forest (Towill 1996).

Successional mixedwood forests, created by a variety of timber harvesting operations, are favoured by many species of birds and mammals (Boyle 1992). Aspen-dominated mixedwood forests are widespread throughout the boreal forest and have one of the most diverse communities of breeding vertebrates on the continent (Robbins *et al*. 1986). Old (>100 years) aspen-dominated forests may have more resources for vertebrates that use canopies of large trees, or that forage on arthropods within decaying wood, than do young (<30 years) aspen-dominated stands (Schieck *et al*. 1996). Mature and over-mature aspen-dominated mixedwood conditions, containing super-canopy white spruce (*Picea glauca* (Moench.) Voss), and white and red pine (*Pinus strobus* L.; *Pinus resinosa* Ait.), generally have larger trees, more large snags (standing dead trees), and more down woody materials (DWM) than do young forests. In addition, mature and over-mature mixedwood forests have greater spatial complexity of live and dead material (snags and standards) than young aspen and mixedwood forests (Peterson and Peterson 1992). Thus, the complexity of live and dead vegetation in fire-origin aspen-dominated mixedwoods may be moderate in young forests, decline as fire-origin snags disappear and as the forest approaches maturity, and then increase to the highest level in over-mature, older forests (Lee *et al*. 1995). The resulting complexity of such vegetation may allow more wildlife species to coexist.

In the past ten years, commercial interest in Ontario's boreal mixedwood forests has increased dramatically. Ontario's forest industry is just beginning to experience medium-to long-term declines in economic fibre supply. For the most part, they are due to historic age-class imbalances, but they are exacerbated by a lack of silviculture and ever-increasing distances of harvesting operations from the mill (OMNR 1997b). As a result, the demand for hardwood fibre has increased by 52%, and to meet this growing demand, mixedwood ecosystems previously by-passed or not allocated are being targeted. Similarly, total softwood fibre demand for pulp and paper is projected to increase by more than 24% (OMNR 1997b).

With the projected increases in fibre demand and timber harvesting, and the recent placing of the black bear on the CITES Appendix II list, OMNR needs to carefully consider and report the effects of timber harvesting practices on black bear populations. Many foresters have made allocation, harvesting, and silvicultural decisions based on the idea that good timber management is good wildlife management. An inherently higher level of ecological diversity and high biological productivity generally result in higher carrying capacities for mammals such as the black bear (Beecham 1980). Standing mature and overmature boreal mixedwood stands occurring in geographic proximity to each other, to recent cutovers, and to polewood size stands, provide space, food, water, den sites, escape cover, and concealment for black bears in northwestern Ontario.

Species Description

Black bears belong to the family Ursidae of the order Carnivora. Of the 3 species of bears currently inhabiting North America, only the American black bear evolved on this continent and is found exclusively here (Fair 1990). Whereas grizzly bears (*Ursus horribilis*) and polar bears (*Ursus maritimus*) currently inhabit open areas, black bears evolved as forest dwellers and remain dependent on the forest for survival. Although the black bear was once widespread throughout forested regions of North America, including the mountainous regions of northern Mexico, their current distribution is much reduced and patchy (Pelton 1982). Habitat fragmentation by roads; loss of forest habitat to development, logging, and agriculture; and increased access and hunting pressure continue to threaten black bear numbers, especially in the southern and eastern United States (Maehr 1984). The black bear is no longer found in southern parts of Canada; however in more remote northern forests, wherever sufficient tree cover remains, black bears still occupy 85% of their historic range (Kolenosky and Strathearn 1987). In Ontario, black bears are still found in most forested regions with highest densities in the central and northwestern sections (Smith and DeAlmeida 1990).

Except for females with cubs, black bears spend most of their time alone (Stirling 1993). Their formidable size and strength, preferred food types and distribution, generally govern bear behaviour. They have little need for group protection and defense of seasonal food items, especially important fall fattening foods, which are usually scattered over a large area, is energetically uneconomical. Males and females do remain together for several days at a time during the breeding season (mid-June to mid-July), and groups of bears may be seen together at dumps or other areas where food is abundant, but for the most part they are solitary.

Reproductive rates of black bears are the lowest of any North American land mammal, with the possible exception of the grizzly bear (Jonkel 1987) and the muskox (*Ovibos moschatus*) (Jonkel and Cowan 1971). The reproductive potential of the black bear appears to be nutritionally regulated and density-independent (Bunnel and Tait 1981, Rogers 1987). Where there is an abundance and variety of high quality summer and fall foods such as acorns, beechnuts, fruits, and berries, females may produce a first litter at 3 to 5 years of age (Spencer 1955, Stickley 1961, Lindzey and Meslow 1977, Alt 1980, Beecham 1980, Kordek and Lindzey 1980, Rogers 1987, Kolenosky 1990). However, in more northern parts of their range where protein-rich nuts are rare, and where food in general is less diverse, scarcer, and available over a shorter period, females may not have their first litter until they are 6 to 8 years of age (Obbard unpubl. data). When high quality foods are consistently available from year to year, a mature female will produce a litter of 1 to 4 cubs every 2 years (Alt 1980, Kordek and Lindzey 1980). Where periodic food shortages are common, few females maintain a regular 2-year reproductive cycle (Obbard unpubl. data).

Average weight of black bears varies depending on climatic and habitat features (especially quantity and quality of food). Black bears also vary in size depending on age, sex, and season. Where bears have access to foods rich in protein, starch, and sugar, mean weights may be greater. On average, males weigh between 120 to 280 kg (Kolenosky and Strathearn 1987), although individuals as heavy as 360 kg have been reported (Barber 1991). For a given age, females generally weigh less, usually between 45 to 182 kg. In northern regions, black bears may be in positive energy balance for only 2 months of the year, yet they may double their weight between mid-summer and fall, building up critical fat reserves for winter (Obbard unpubl. data).

Black bear diet is largely determined by the seasonal availability of food items. Bears have no caecum or rumen and cannot break down cellulose. In general, they are opportunistic omnivores with a diet dominated by easily digestible vegetative foods (Rogers 1976). Grasses, sedges, leaves, buds, catkins, and flowers eaten early in the spring provide only minimal nutrition until more beneficial foods like berries and nuts become available (Romain 1996). Colonial insects, such as ants (Formicidae) and wasps (Vespidae), are also an important source of protein in the spring and early summer (Boileau *et al.* 1994). Black bears will eat carrion and have been known to prey on young deer and moose calves early in the season (Franzmann *et al.* 1980, Ozaga and Verme 1982, Wilton 1983, Obbard and Austin unpubl. data). Successful predatory attacks on adult moose have been reported (Austin *et al.* 1994) but are probably rare, and suspected black bear predation on woodland caribou (*Rangifer tarandus caribou*) in eastern Quebec could not be proven (Boileau *et al.* 1994).

Black bears show strong fidelity to seasonal ranges. Within a given home range, black bears find food, mates, den sites, and care for their young. Females have a well-defined home range that is maintained throughout their lives, whereas range use by males is more variable. Some home range overlap does occur, however, specific areas are seldom used simultaneously. Young females may share part of their mother's home range, but young males generally disperse at about 1 or 2 years of age (Jonkel and Cowan 1971, LeCount 1982).

Home range size has been studied in a number of black bear populations inhabiting a variety of habitat types (Erickson and Petrides 1964, Jonkel and Cowan 1971, Poelker and Hartwell 1973, Amstrup and Beecham 1976, Lindzey 1976, Young 1976, Lindzey and Meslow 1977, Rogers 1977, Kolenosky 1978, Alt *et al.* 1980, Fuller and Keith 1980, Kelleyhouse 1980, Garshelis and Pelton 1981, Young and Ruff 1982, Lamb 1983, Manville 1983, Grenfall and Brody 1986, Pelchat and Ruff 1986, Klenner 1987, Kolenosky and Obbard 1991, Obbard and Kolenosky 1993, Pacas and Paquet 1993, Wooding and Hardisky 1994). Home range size seems to depend largely on habitat type, more specifically the relationship between nutritional needs and food availability and abundance (Garshelis and Pelton 1981). Sex and age of the bear also affect home range size. Home ranges of males are usually large and may encompass the ranges of 2 or more females (Rogers 1987, Seaman 1993, Stirling 1993). Home range size for adult males is generally less than 200 km^2 and for adult females less than 75 km^2, but home range sizes as large as 465 km^2 for males and 295 km^2 for females have been reported (Pacas and Paquet 1993). Two other studies reported males travelling distances of over 1,500 km^2 (Kolenosky and Strathearn 1987) and 1,721 km^2 (Hugie 1982). In northeastern Ontario, summer ranges of adult females varied from 25 to 50 km^2, with younger females averaging only 20 km^2 (Kolonosky 1994). Summer ranges of adult males exceeded 100 km^2 but some life ranges may have been greater than 1,600 km^2.

To gain valuable weight before denning up, black bears often make seasonal trips in late summer and fall outside their home range to areas where they find berries, other fruits, and nuts in abundance (Schorger 1949, Jonkel and Cowan 1971, Amstrup and Beecham 1976, Rogers 1977, Hugie 1982, Lamb 1983, Manville 1983, Elowe 1984, Pelchat and Ruff 1986, Klenner 1987, Rogers *et al*. 1988, Kolenosky and Obbard 1991, Schwartz and Franzmann 1991, Obbard and Kolenosky 1993, Boileau *et al*. 1994, Wooding and Hardisky 1994). In a current study of black bears near Chapleau, Ontario, seasonal movements of 25 to 105 km, to late summer foraging areas such as cutovers and open areas created by wildfire, have been documented for adult females (Obbard and Kolenosky 1993). Annual variation in the timing of bear movements was related to the phenology of blueberry fruit production. Rogers (1977) reported that black bears in northeastern Minnesota moved up to 200 km beyond their normal ranges in times of extreme food scarcity, presumably in an attempt to meet dietary demands. Although black bears rely heavily on known food sources to build sufficient fat stores for winter, they will explore new areas. This capacity for learning may benefit them in years when food resources are scarce in traditional use areas. Extended parental care also allows females to pass this information on to their offspring (Garshelis and Pelton 1981, Rogers 1987).

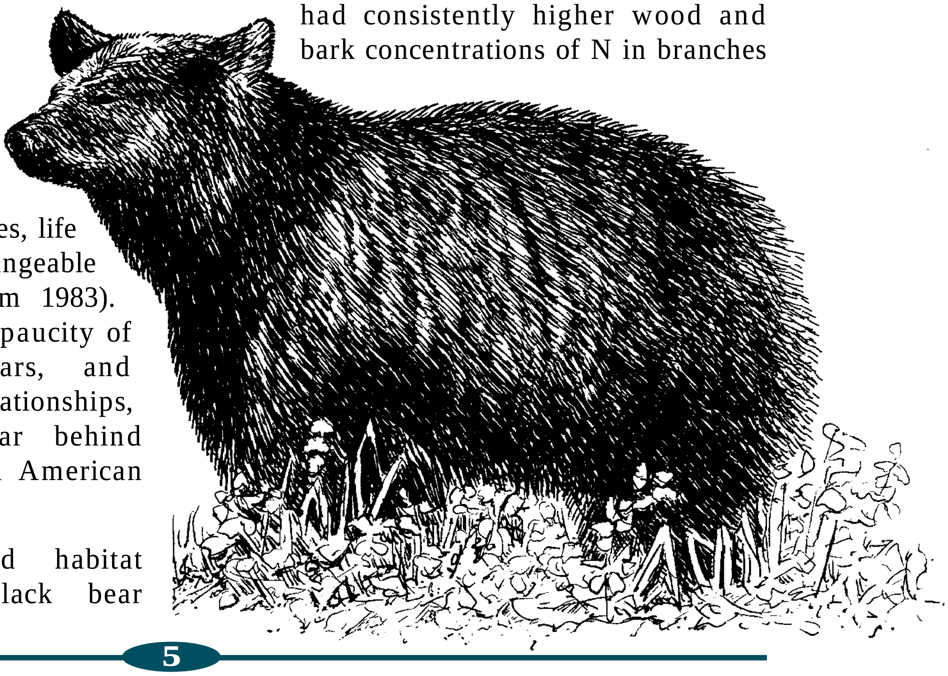
Recognized Black Bear Populations/Research

Black bear populations have been studied across most of their historical range; however, because they inhabit such a wide range of climatic and habitat types, life history data are often not interchangeable among different areas (Beecham 1983). Until recently, there has been a paucity of published literature on bears, and particularly black bear habitat relationships, and the information lags far behind comparable literature for North American ungulates (Schoen 1990).

Few studies have described habitat availability and use for black bear populations in Canada (Young 1976, Fuller and Keith 1980, Young and Ruff 1982, Pelchat and Ruff 1986, Klenner 1987, Pacas and Paquet 1993, Boileau *et al*. 1994). In Ontario, black bear population dynamics and ecology were first studied in the Great Lakes-St. Lawrence forest region near North Bay (Kolenosky 1978). Information from this study has been used to estimate the province's black bear population and to set provincial hunting quotas. A second study was initiated near Chapleau to learn more about life history parameters of black bears in boreal mixedwood forests (Kolenosky and Obbard 1991) and to provide a database from which an effective management program can be formulated. Since our current knowledge of Ontario black bear habitat relationships in the boreal mixedwood forest is limited, information presented in the following sections is a review and synthesis of findings from a variety of studies within Canada and the United States.

Habitat Use and Movements

Boreal mixedwoods are of particular interest to wildlife managers because of their higher nutritional content relative to conifer forests (Peterson and Peterson 1992). Comparative studies of aspen, white birch, white spruce, red pine, and white pine near Chalk River, Ontario revealed that aspen and birch had consistently higher wood and bark concentrations of N in branches



than the conifers (Hendrickson 1987). In the Chapleau study area, black bears commonly fed on newly emerged leaves of aspen in spring when the leaves had their highest N content (Romain 1996).

Prime black bear habitat is characterized by a variety of forest habitat types which together provide seasonal and annual requirements of space, food, water, den sites, escape cover and concealment (Hugie 1979). Seasonal changes in habitat use by black bears, especially in the summer and fall, have been widely documented and are largely governed by seasonal variation in food availability.

In spring, black bears in boreal and mixedwood forests feed mainly on green vegetation such as vetchling (*Lathyrus ochroleucus* L.), aquatic grasses (Graminae sp.), buds and catkins of balsam poplar trees (*Populus balsamifera* L.), newly emerging leaves of trembling aspen, roadside flowers, and small rodents (Pelchat and Ruff 1986, Rogers *et al*. 1988, Romain 1996). Black bears made similar use of aspen buds and catkins in Colorado (DeByle 1985). In northeastern Minnesota and several other forests in the northern United States, they have also been found to feed on large-leafed aster (*Aster macrophyllus* L.), false lily-of-the-valley (*Maianthemum canadense* Desf.), smooth bedstraw (*Galium sp*. Michx.), interrupted fern (*Osmunda claytoniana* L.), peavine (*Lathyrus* sp.), corms, jack-in-the-pulpit (*Arisaema* sp.), and young skunk cabbage (*Symplocarpus foetidus* L.) leaves (Elowe 1984, Rogers *et al*. 1988). Ants and wasps that become active in May may be an important early source of protein (Boileau *et al*. 1994) but in the Chapleau study area they were more commonly fed upon later in the summer (Romain 1996). Ant abundance depends on the number of dead trees and fallen logs (McLaughlin *et al*. 1986).

Berries and other fruits are major summer food items, although bears continue to eat grasses and forbes through to the fall (McLaughlin *et al*. 1986). Important summer foods are strawberries (*Fragaria vesca* L.), serviceberries *(Amelanchier alnifolia* (Pursh) DC.), skunk currant (*Ribes glandulosum* Grauer), pin cherries *(Prunus pensylvanica* L. fil), and raspberries (*Rubus idaeus* L.) (Romain 1996). Later in the summer and fall, bears feed heavily on blueberries (*Vaccinium sp*.), wild sarsaparilla (*Aralia nudicaulis* L.), bristly sarsaparilla (*Aralia hispida* L.), bearberry (*Arctostaphylos uva-ursi* (L.) Spreng.), mountain ash (*Sorbus* sp.), and beaked hazel nuts (*Corylus cornuta* Marsh.) when they are available (Romain 1996). Few of these species are shade tolerant. In the boreal mixedwood forest, which covers much of the northern portion of the black bear's range, protein-rich nuts are scarce and critical fat reserves are gained primarily from berries and fruits high in sugars and carbohydrates (Rogers and Allen 1987, Usui *et al*. 1994, Romain 1996).

When hazelnuts, ants and most species of berries become scarce in September, bears return to eating vegetation such as clover (*Trifolium* sp.) and peavine and weight gain slows. Acorn-producing stands containing bur oak (*Quercus macrocarpa* L.) are uncommon in Ontario except in the Boreal-Great Lakes-St. Lawrence forest transition zone or in areas near Rainy Lake and Lake of the Woods that support a prairie savannah condition. Bears that find these stands of oak may attain superior growth and reproduction because acorns allow them to extend their annual foraging period well into the fall. South and east of Lake Superior, more fall foods are available due to a greater variety and prevalence of oak species, the presence of beech (*Fagus grandifolia* L.), and the occurrence of feral apples. Oak and beech are the primary producers of fall mast crops in the Great Lakes-St. Lawrence forest zone.

In addition to food, black bears need unrestricted access to water throughout the non-denning period. Wetland and riparian habitats provide essential seasonal foods (Landers *et al*. 1979, Alt *et al*. 1980, Kelleyhouse 1980, Reynolds and Beecham 1980, Elowe 1984, Young 1984, Rogers and Allen 1987), but just as importantly they provide opportunities for cooling

(Kelleyhouse 1980, Rogers and Allen 1987). Bears were observed to drink water frequently when feeding on vegetation, nuts, or insects, but less when the diet switched to berries (Rogers and Allen 1987). Wetlands also provide important escape and security cover (Smith 1985, Manville 1983, Landers *et al*. 1979, Lindzey *et al*. 1976) and are often used as travel corridors (Elowe 1984, Kelleyhouse 1980).

Black bears require adequate cover year-round primarily for concealment and escape, but also for thermoregulation. In Gaspesie, Quebec, black bears were found to use dense escape cover throughout the non-denning period, especially during the hunting season (Boileau *et al*. 1994). The presence of tree species with deeply creviced bark, such as large white and red pine associated with mature to over-mature mixedwoods, and adjacent to wetlands, are major factors determining habitat selection in the spring, especially by females with cubs (Rogers 1991, Kolenosky and Strathearn unpubl. data). In North Bay, Ontario, some pregnant females denned within 50 to 100 m of appropriate sanctuary trees (Kolenosky and Strathearn unpubl. data). Rogers *et al.* (1988) observed that sows with cubs in northern Minnesota nearly always fed within 175 m of white pine with diameters greater than 50 cm. Large super-canopy white and red pine are used as refuges for the resting cubs. Large trembling aspen and white spruce seem to be less favoured as refuge trees due to their smooth or flaky bark, which makes climbing difficult for young cubs. White pine grows on approximately 350,000 ha of land in northwestern Ontario (Bowling and Niznowski 1996). Most of the white pine in the boreal mixedwood forest of Ontario is older than 80 years and occurs with aspen, balsam fir and white birch, but exists only as a 10% occurrence in other working group stands.

In a study examining the relationships between mammal biodiversity and stand age and structure in aspen mixedwood forests in Alberta, black bear were found to prefer mature stands over young or overmature stands (Roy *et al.* 1995). Two-thirds of all detections of black bears occurred in mature hardwood-dominated mixedwood stands. Black bear abundance during summer months was positively associated with the density of shrubs and saplings in the understory, the volume of dead woody material (large trees, snags and down woody material), and the number and size of canopy gaps. Species diversity, in general, was associated with vertical diversity but not with horizontal diversity of a stand. Thus, gap dynamic processes may be important for maintaining viable populations of mammals in aspen mixedwood forests.

In late fall, bears usually return to their summer home range to den. In boreal mixedwood forests, black bears overwinter in a dormant state often within a den excavated into a mound or brush pile or under the root-mass of a fallen tree. Occasionally they will den in a hollow tree or rock crevice, or on the surface near a blown down tree (Obbard upubl. data). Excavated dens seem to be more common in second-growth forests where few trees are large enough to provide suitable cavities. Tree dens are used more in the southern United States where trees are larger and the risk of winter rains and spring flooding is greater (Pelton *et al.* 1980, Lentz *et al.* 1983). A variety of forest types within the range occupied by black bears will ensure a range of suitable den site possibilities.

Effects of Timber Harvesting and Related Activities

Historically, fire has been the principal ecological factor shaping and maintaining the character, vigour, and floral and faunal diversity of boreal mixedwoods in Ontario (Day 1981). Timber harvesting and related activities also influence both the structure and plant species composition at stand, forest, and landscape scales. Their effects may be either beneficial or detrimental to black bear populations depending on the manner in which seasonal foods, cover, space, and den sites are influenced.

Since black bear habitat selection is strongly influenced by food availability, wildfire and logging generally benefit black bears by providing large areas of early successional growth containing a much greater variety and quantity of food than mature forests (Cumming 1972, Lindzey 1976, Manville 1983). Shade intolerant plant species such as blueberry, pin cherry, bristly sarsaparilla, mountain ash, raspberries, serviceberries, and strawberries are important high-energy summer and fall foods for black bears (Manville 1983, Costello and Sage 1993, Obbard and Kolenosky 1993, Romain 1996). These plants either bank seed in the duff or root in the upper organic and mineral soil layers and often flourish following the removal of the overstory canopy (OMNR 1988). Light intensity surface fires, or prescribed fires following a harvest operation, will strongly promote the regeneration of these berry-producing plants. Aspen, an important food source for bears in early spring, also regenerates well under these conditions, and ants, an important source of protein in spring through to fall, may be more abundant in cut-over areas associated with the presence of downed woody material and standing snags and standards (Boileau *et al.* 1994).

Although several studies report black bears exploiting berry-producing plants and shrubs in these early successional communities, the time during which a cutover area is of use to them seems to vary. In a number of studies, black bears avoided clearcuts for approximately 10 years following timber harvest after which they frequented such sites (Jonkel and Cowan 1971, Lindzey and Meslow 1977, Kelleyhouse 1980). In contrast, Ontario cutovers up to 12 to 15 years post-establishment were identified as important foraging areas (Obbard and Kolenosky 1993, Usui 1994). Martin (1983) reported that in northwestern Montana, the most productive areas for bears had been clearcut and broadcast burned 8 to 15 years earlier, whereas on Long Island, Washington, Lindzey (1976) found that bears made frequent use of areas clearcut 14 to 21 years earlier. Lindzey (1976) speculated that this was because they provided more cover. In other parts of the United States, shrub species important to black bear were found where selective logging had occurred 20 to 40 years earlier (Jonkel and Cowan 1971, Lindzey and Meslow 1977). These differences may be due to forest type and available seed stock and/or variation in harvesting methods and post-harvest treatments.

Precommercial and commercial thinning practices let more light reach the forest floor, which can stimulate berry production. In one controlled study, shade intolerant species, such as blueberry, pin cherry, choke cherry (*Prunus virginiana L.*), raspberry, serviceberry, and strawberry, produced more fruit in natural openings, or where the forest canopy was thinned to less than 800 trees per ha, than they did under denser tree canopies; only wild sarsaparilla was more productive in more mature stands (Arimond 1979). In the boreal forest of Ontario, open areas created by clearcut timber harvesting on upland sites appeared to provide important forage for at least 10 years post-harvest (Obbard and Kolenosky 1993, Usui 1994). However, the amount of aboveground berry-producing biomass may be limited by site conditions following harvest. For example, in some of these areas, the biomass of blueberry plants dropped dramatically following application of the herbicide Vision (Usui 1994, Obbard unpubl. data).

Black bears rely heavily on cover for concealment, escape, and thermoregulation during warm periods, therefore, some consideration should be given to the size and shape of clearcuts. Benefits of clearcuts decrease with increasing size because of the reluctance of black bears to move far from forest cover. In New England, black bear home ranges seldom included large open areas (McLaughlin *et al.* 1986), and Hugie

(1982) found that radio-tracked bears in Maine did not venture more than 125 m from forest cover. Thus, large clearcuts might interfere with movements to and from fall feeding areas because of the absence of shade and/or escape and concealment cover, or central portions of the cuts may not be exploited, despite an abundance and variety of bear foods (Jonkel and Cowan 1971). Black bears may make better use of large open areas if scattered green patches or islands, which emulate natural disturbance patterns such as fire, are left during the timber harvesting process (Lindzey and Meslow 1977).

Logging roads may have both positive and negative effects on black bears. Roads constructed during timber harvest provide human access to new areas, which can increase the harvest of black bears (Lindzey 1976, Brody and Pelton 1989) and increase the chances of people or dogs disturbing winter dens (Rogers and Allen 1987). On the other hand, roadside clearings favour the growth of many important food plants, such as clover, dandelions (*Taraxacum officinale* Pursh.), peavine and vetch, which are not found in old growth stands or old burns (Jonken and Cowan 1971, Lindzey and Meslow 1977, Manville 1983, Hellgren *et al.* 1991). Bears will also use low traffic roads as travel corridors (Manville 1983, Young 1984, Obbard unpubl. data) and to escape from insects.

Other activities associated with timber management, such as site preparation and herbicide application following harvest, can directly and indirectly affect black bears. Mechanical site preparation methods that do not remove or destroy underground stems may stimulate regeneration of important black bear food plants such as currants, raspberry, serviceberry, and beaked hazel by promoting sprouting from roots and shoots (Buse and Bell 1992). Cultivation may also stimulate the growth and vigour of blueberry bushes and sedges by segmenting rhizomes which then produce new plants (Buse and Bell 1992). The growth of species such as blueberry and raspberry, whose predominant method of vegetative reproduction is from root and basal sprouts, can be promoted by either removing the L and F parts of the litter layer or by chopping and mixing the LFH and mineral soil horizons (OMNR 1997a). This scalping method produces a favourable germination site for seed stored in the soil seed bank. On the other hand, mechanical site preparation techniques that create trenches, furrows, or intermittent inverted soil caps, may discourage the successful reproduction of these species. Inverting or mixing of soil caps may damage the parent stem and root system of certain plants but can promote the growth of species such as beaked hazel which sprouts from shoots. Brush piles or bulldozed windrows left after cutting may benefit bears by providing potential den sites.

In contrast, broadcast chemical site preparation using herbicides, may have detrimental effects on black bear food supply and hence populations. Even if important food plants are not killed directly, the quality of forage may be reduced if the resprouting plants produce new growth containing a variety of “anti-oxidants” such as tannins (Lautenschlager 1993). Herbicide applications may also disrupt or eliminate important mid-successional forest stages in stand development by killing important hardwoods in the tree and shrub layers. For example, applications of 2,4-D and 2,4,5-T often kill pioneer tree species such as white birch and pin cherry immediately (McNicol and Timmermann 1981).

Many species of fruit and nut-producing plants important to black bears are susceptible to herbicides. In one study, aerial applications of herbicides, for either chemical site preparation or tending treatments, ended blueberry, raspberry, hazelnut, and cherry production for up to 4 years after treatment (Arimond 1979). Longer-term studies examining the effects of a variety of operational and experimental herbicide applications in Ontario also document reductions in the abundance of these fruit- and berry-producing plant species. Specifically, silviculturally effective applications of herbicides containing either 2,4-D or glyphosate reduced the density and cover of pin cherry, red elderberry (*Sambucus pubens*), serviceberry, mountain ash, beaked hazel, trembling aspen, blueberry and raspberry for 1 to 2 years post-treatment. Effective vegetation control, regardless of the plant species treated or herbicide used, seldom lasted for more than 3 years and was often limited to 1 year after treatment. Vision did not affect the ability of red raspberry seeds in the soil seed bank to germinate following removal of the overstory and it quickly reoccupied the site (Chourmouzis *et al.* 1997). Selective or spot application of herbicides on the ground may be a way to ensure the survival and growth of berry-producing species and enhance fruit production (McComb and Hurst 1987). However, if herbicides are applied to promote growth of economically important tree species, then the time that fruit and berry plants are available to bears may be reduced. Published literature outlining the various effects of herbicides on black bears, and foods important to them, is sparse; however, the consensus is that the overall effect is negative.

Many plant species found in boreal mixedwoods are adapted to survive fire disturbance and to regenerate following fire (e.g., blueberry). Most species are able to reproduce both vegetatively and from seed. Vegetative regeneration has the advantage over seed regeneration that it does not depend on seedbed or germination conditions and is supported by the parent root system (Zasada 1971). Plants in the boreal mixedwood region often produce more seed on disturbed sites than those growing on undisturbed sites.

Habitat Management

Timber production and wildlife needs may be compatible if habitat requirements of animals are considered during the planning process and throughout the implementation of forest management and production activities (Thomas 1979). Based on results from studies in the United States and Canada, recommendations can be made that prevent, mitigate, or remedy negative impacts of timber harvesting and related activities on black bears.

Forest harvesting should not be viewed as a disturbance tool in isolation but in context with adjacent forest sites and across a forested landscape. Old, structurally complex stands are important to many wildlife species (Roy *et al.* 1995). Provisions to create or maintain these forest types can be made in the harvest planning process by deferring cuts of some stands until much later by leaving residual snags, dead woody material, and patches of trees of different sizes during harvest.

The size and configuration of cuts and post-harvest treatments should also be considered. Mammals of the boreal forest are adapted to natural processes and patterns that have shaped the landscape they inhabit. We need to approximate natural patterns and processes by organizing and structuring our harvest blocks using landscape-level criteria. A high forest edge to cutover area ratio provides abundant forage and berry crops in close proximity to cover. Rogers and Allen (1987) suggested that the size and shape of cutovers be planned so that the distance from forested escape is less than 250 m. Black bear habitat can also be enhanced by creating irregularly shaped cuts to maximize the amount of young, shrubby edge habitat, and using linear instead of rectangular cuts to provide a higher edge to area ratio (Bourgeois *et al.* 1995). Islands or peninsulas of forested habitat within larger cuts would benefit bears by providing important thermal, escape, and concealment cover (Lindzey and Meslow 1977). *Guidelines for the emulation of natural disturbance by fire* (OMNR in Prep.) should help promote a landscape approach to cut block size, distribution, orientation, layout, and patch retention that will help to avoid unnecessary forest fragmentation.

For Arizona black bears, Mollohan and Lecount (1989) proposed that wooded corridors be retained between useable blocks of forest habitat to permit protected access to seasonally important food supplies. Forested stands should be left near clearcuts until cover is established in the cutover, and sanctuary trees left in and around potential feeding areas (Rogers *et al*. 1988, Rogers 1991*). Interim guidelines for conserving old growth red and white pine in Ontario* (OMNR 1993) require that red and white pine trees be retained in all harvested areas containing these sources. as seed sources and genetic reservoirs. Old growth structural characteristics, such as snags, trees with dead or dying tops, and downed logs (dead woody debris), should also be retained in harvested areas. In addition, components of each species and age group in multi-layered stands should be left intact on disturbed sites.

Mechanical site preparation usually has less effect on black bear food production than chemical site preparation on boreal mixedwood sites, and spot or banded applications of herbicides are preferable to broadcast treatments (Rogers and Allen 1987). A more controlled application of herbicides may reduce their adverse effects on berry-producing species and enhance the production of fruit (McComb and Hurst 1987).

The recommendations for maintaining and/or enhancing the quality of black bear habitat in Ontario were made based on studies conducted in a variety of forest regions. None of the studies were conducted in the boreal forest. At this time, there is little published information on the effects of timber management practices on black bear populations in the boreal forest zone and we, therefore, cannot make any solid recommendations about specific harvesting and forest renewal practices for Ontario's boreal mixedwoods. In general though, site preparation and renewal treatments should be chosen so as to conserve or stimulate fruit-bearing plant species, especially if they do not represent a significant source of competition for site resources. Wetlands should be protected whenever possible as they provide important sources of water for drinking and cooling, and may be used as travel corridors. These areas also provide alternate foods in the spring and summer. Areas of mature mixedwoods and other forested ecosystems should be maintained whenever possible, especially adjacent to and between cutover areas, for year-round cover and for winter denning (Rudis and Tansey 1995, Wooding and Hardisky 1994). Also, areas providing seasonally important food sources, such as sucker (*Catostomus* sp.) spawning streams and concentrations of mountain ash or bur oak, should be avoided when planning harvests (Noyce and Coy 1990).

After timber harvesting, the value of a logged area to black bears may be enhanced by the occasional planting of legumes or fruit-producing species (Irwin and Hammond 1985, Jonkel and Cowan 1971). Additional foods can be provided by seeding old timber roads, log decks, and skid trails with grasses and clover. Specific cover crops may also be used to minimize the ingress of less desirable plant and woody shrub species. Prescribed burns after harvest can also set the stage for a succession of plant communities that provide important black bear foods. Monoculture planting of conifer tree species is not recommended where the goal of habitat management is to increase site variability or favour early successional mixed forest conditions (McNicol and Timmermann 1981). Limiting public access to logging roads and skid trails would also benefit bears by allowing undisturbed use of roads and roadside margins as feeding and travel corridors (Hellgren *et al*. 1991). It may be necessary to close old logging roads and trails where increased hunting threatens local black bear populations.

A set of habitat matrices for modelling habitat supply using Ontario's Strategic Forest Management Model (SFMM) has been prepared for each region of Ontario (e.g., D'Eon and Watt 1994, Racey 1996). A habitat matrix is used to identify broad habitat linkages to land cover. Management strategies that inventory and modify land cover can be evaluated based on the relative availability of basic habitat components. However, the matrices and SFMM cannot be used to predict habitat availability or population status of wildlife species. Two matrices are currently available, one based on the ecosite classification for northwestern Ontario and the other based on Ontario's Forest Resource Inventory (FRI). Requirements for black bear forage and black bear cover are treated separately. All FRI-defined forest units in the pre-sapling stage of stand development are considered marginal for forage. Lowland eastern white cedar (*Thuja occidentalis* L.) and tamarack (*Larix laricina* L.) stands are not considered to have any value for forage although they are important for summer cover. Forest units preferred for cover and forage include:

FU 6	Hardwoods, except black ash (*Fraxinus nigra* Marsh.), greater than 50% B.A.; SC 2,3 [ecosites 16,19]
FU 8	Balsam fir, white spruce working groups with conifer content greater than 50% B.A.; SC 2,3 [ecosite 21]
FU10	Balsam fir, white spruce working groups with conifer content greater than 50% B.A.; SC 1 [ecosite 27,32]
FU11	Hardwoods, except black ash, greater than 50% B.A.; SC 1 [ecosites 23,33,28,29]
FU12	Black ash working group [ecosites 30,38]

All stages of stand development (pre-sapling, sapling, immature, mature and late successional), in each of these boreal mixedwood forests, were considered to be preferred habitat for black bear, and reflect the adoption of a precautionary approach to understanding black bear habitat.

Knowledge Gaps

If black bear habitat needs are to be incorporated into Ontario's forest management planning, we need a comprehensive database with which to work, especially for northern populations of black bears inhabiting boreal mixedwood forests. There is still much to be learned about the habitat needs of black bears in this forest region and how timber harvesting and associated activities alter black bear habitat and behaviour.

Spatial criteria relative to the different forest cover conditions have not yet been incorporated into the SFMM model and habitat matrices still need to be refined to reflect spatial arrangements. We do know that the basic habitat needs of food, cover, water, and protection for black bears are met only over a large area and in forests with a diversity of tree species and age classes. However, the minimum habitat size and mix necessary for maintaining black bear populations at desired or viable levels is still unknown. We need to know if females prefer to raise cubs in particular types of habitat. We need to know whether bears have traditional travel routes to and from important feeding areas, and if so, will they readily take alternate routes if traditional ones are blocked or changed. We also need to know how large clearcut areas affect established home ranges of individual bears. A temporal analysis of black bear home range that coincides with changes in plant phenology, weather patterns, and a variety of forestry practices, could highlight some of the more important influences of timber harvest activities on black bear populations.

There is still much to be learned about the effects of commonly used herbicides on black bears, and the effects of these herbicides and various application techniques on non-target plants, such as blueberry, which are often important bear foods in northern Ontario. Post-harvest chemical treatments and alternatives to conventional aerial applications should be explored in greater detail and their effects monitored. The spatial implications of vegetation management in adjacent operating blocks, whose successional stages of development are similar, also need to be modelled and new strategies developed. Lastly, if nutritional factors are as important in regulating black bear populations as they appear to be, then we need a better understanding of (1) the nutritional requirements of black bears, (2) the seasonal nutritional quality of foods eaten by black bears in boreal mixedwood forests, (3) how changes in food quality affect bear survival and reproductive success, (4) how food shortages affect vulnerability of cubs and the cannibalistic tendencies of other bears, (5) what comprises prime summer and fall feeding habitats, and (6) how far bears will move to find them.

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boreal mixedwood *Notes*

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boreal mixedwood Notes

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Habitat Considerations in Boreal Mixedwood Forests

by D. Schroeder*

> *Incorporating BMW stand- and forest-level objectives into forest management plans supports sustainable forestry by ensuring that habitat diversity is maintained on the landscape...*

Introduction

Boreal mixedwood (BMW) forests provide habitat for many wildlife species that occur in Ontario. Wildlife species richness can be higher in BMWs than in other types of boreal forests (James 1984). As BMW stands undergo succession, habitat type and thus the associated wildlife changes as well (Welsh 1981). Incorporating BMW stand- and forest-level objectives into forest management plans supports sustainable forestry by ensuring that habitat diversity is maintained on the landscape. This note reviews considerations important to managing wildlife habitat in Ontario's BMW forests. Species-specific habitat information is available in other BMW notes and OMNR forest management guides.

Management scale

Temporal scale

Temporal scale refers here to the time over which a stand or forest is managed. Short temporal scales are used to express optimal rotation age for commercial trees; for example, in determining the age for clearcut harvesting. However, one objective of BMW management is to allow long-term succession patterns to occur over portions of the forest. These management timeframes, which are long relative to commercially optimal rotations following clearcutting, will benefit species that require structurally old forests.

Recently, the temporal scale used by foresters has been changing from commercial rotations to emulating natural disturbances using timeframes based on average known fire return cycles (OMNR 2002). Managing BMW stands for long-term succession fits well into this paradigm because fire frequency varies across landscapes (Burton et al. 1999, Harvey et al. 2002). Those areas where fire is less frequent may be good candidates for long-term BMW management. Fire frequency also affects mixedwood species dynamics (Bergeron et al. 2001) requiring BMW management strategies to vary within different fire regimes.

Spatial scale

Spatial scale refers to landscape size (extent), resolution, and extent-resolution interaction (Turner et al. 1989). As with temporal scale, the importance of spatial scale is based on our observations of wildlife habitat use. For example, animals with larger body mass tend to require larger home ranges than smaller animals (Holling 1992, McLaren et al. 1998). As well, specific habitat elements, such as birthing or denning areas, may be considered for their local importance or as a component of overall

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habitat needs. In the first example, extent is relatively small (e.g., less than 10 ha) and the component is nested in a larger overall habitat (e.g., 1000s ha). Although resource managers are required to manage habitat requirements that may extend across large areas they must also deal with the reality of political boundaries that limit spatial extent. It may therefore be simpler for managers dealing with individual forest management units to emphasize specific habitat elements that can be managed at a fine resolution.

Resolution (or grain) here refers to the spatial size of elements being observed. For example, pixel size in a digital image is an indicator of resolution. An image of Ontario's entire boreal forest using fine resolution (e.g., 1 m by 1 m pixels) would be more difficult to interpret than an image with coarse resolution (e.g., 500 m by 500 m pixels). Most available forest inventories lack the information needed to assess BMW habitat potential at fine resolution; information about amount of understory vegetation, snags, and downed trees is often not available. Dussault et al. (2001) suggest that forest inventory is useful for broad-scale habitat description (stand level and higher), but fine-scale description inevitably requires ground surveys. Often age class information, which is readily available, is used as a surrogate when fine resolution information is needed (e.g. Naylor et al. 1999).

Interaction of Temporal and Spatial Scale

The cumulative effect of forestry practices across Ontario's boreal region influences broad-scale forest dynamics (Elkie and Rempel 2001). A recent example is fuel accumulation in some forest types following decades of fire suppression across large areas of western North America. One decade of accumulation did not noticeably affect fire patterns, but after as many as five decades effects are more noticeable. An example in Ontario are the *Timber management guidelines for the provision of moose habitat* (OMNR 1988), which have been implemented within some management units for almost 3 decades, and the cumulative effects are now apparent across these management areas. A cumulative effect can result in broad-scale change across landscapes (Perera and Baldwin 2000) and thereby affect habitat. Because forest management techniques can be extensively and rapidly implemented across the boreal region, potential effects on habitat must be considered regionally.

Coarse and fine filters

A more recent approach being used in forest management is the coarse filter-fine filter approach described by Hunter (1990). Coarse filters are meant to provide habitat that will benefit many species, whereas fine filters address specific species or habitat targets. For example, the Forest Management Guide for Natural Disturbance Pattern Emulation (OMNR 2002) does not target a particular species or habitat type, and can therefore be considered a coarse filter approach. Conversely, the *Forest management guidelines for the provision of white-tailed deer habitat* (OMNR 1997) provides specific directions for managing wintering areas to benefit deer — a fine filter guide. These filters are not scale-dependent; e.g., managing for large patches of mature conifer overstory or maintaining large snags are both considered coarse filters. More details about coarse and fine filters are provided in OMNR guides (OMNR 1998, 2002).

This section reviews habitat considerations for BMWs using the coarse-filter approach (Figure 1). Each sub-section discusses the filter inputs (clear ovals in Figure 1) based on their importance to wildlife and desired forest condition(s). Fine-filter habitat considerations are discussed in other OMNR guides and BMW notes for managing specific species.

I. Coarse Filter - Broad Scale

a) Abundance of cover types within forest mosaic

Importance: Abundance of forest cover types is one of the most important landscape features for wildlife habitat (Venier 1996, Fahrig 1997). For example, a study by Drapeau et al. (2000) in northwestern Quebec found that forest harvesting reduced the abundance of late seral, conifer-dominated mixedwoods affecting the abundance of songbird species dependent on this cover type.

Desired condition: Wherever possible, forest landscapes are managed within the bounds of natural variation as per the Crown Forest Sustainability Act (Statutes of Ontario 1995). Managing landscapes for a range wildlife habitat and other forest uses may limit this variation to a subset of what would occur naturally. Recent spatial

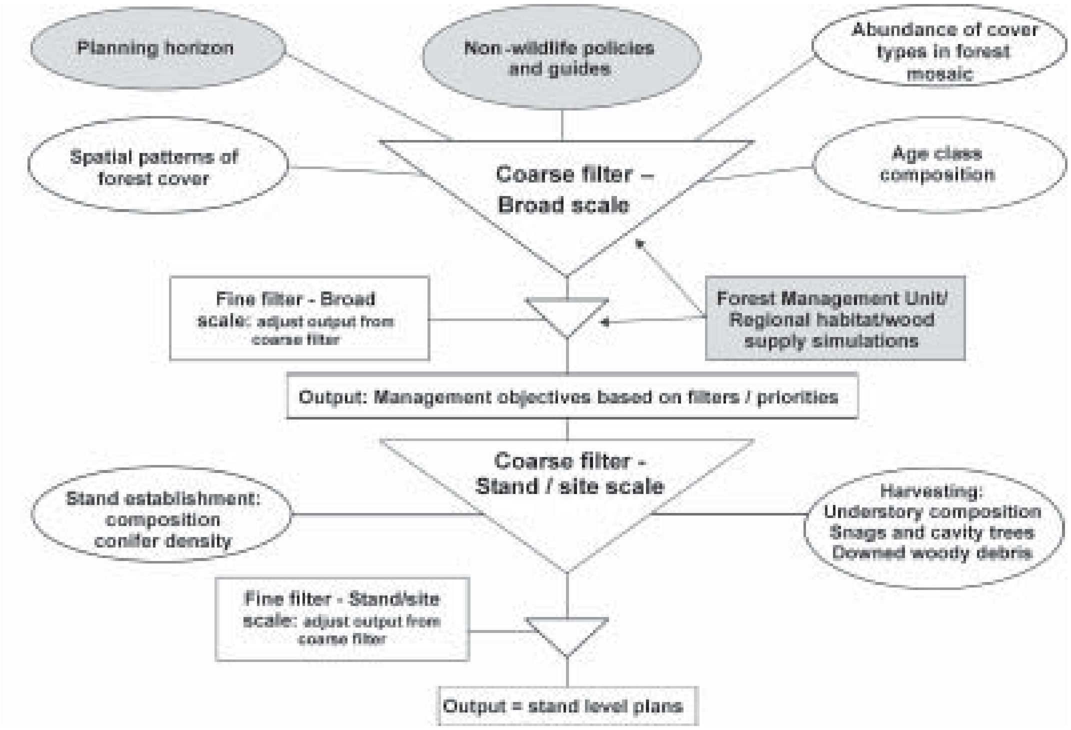

Figure 1. *Boreal mixedwood management considerations in relation to coarse filter - fine filter approach.*

patterns resulting from wildfire are being used as a guide for natural variation (see OMNR 2002) and to guide forest harvesting patterns. As these areas regenerate some are expected to form large, contiguous forest tracts of old conifer forests, a strategy that links directly to marten sustainability in the managed boreal region (Thompson 1994, Chapin et al. 1998). Guidelines for marten core areas were developed to meet the broad-scale habitat needs of marten and other species dependent on forest interiors (Watt et al. 1996) and are considered coarse filters. BMW management fits well with this strategy as it includes longer rotations and succession to older conifer-dominated forest.

Post-disturbance remnant patches within disturbances provide shelter and cover for species that use newly disturbed sites for foraging. For example, DeLong and Kessler (2000) found that remnant patches of older forests in northern British Columbia had greater vertical structural diversity than mature even-aged forests. This diversity benefits many wildlife species, so approaches to managing these remnant patches will affect wildlife habitat across disturbed landscapes.

Relevance to BMW management: Goals for forest cover type abundance will be influenced by habitat requirements.

Fire frequency is a driving factor in boreal forest cover and landscape pattern management decisions. Variations in fire frequency affect forest cover type abundance, including BMWs (Frelich and Reich 1995). Succession patterns for naturally occurring mixedwoods are discussed in other BMW notes (see Arnup 1998; Towill et al., in prep.). Through time, the dynamics of individual stands will collectively affect the abundance of cover types across a management area.

Harvesting regimes also affect cover type abundance. Even if silviculture treatments are predominantly aimed at regenerating commercial conifers, mixedwood forests are often created by default, usually favouring hardwoods and balsam fir over spruce (Carleton and MacLellan 1994).

To assess cover type abundance:

- Use Ontario's sustainable forest management model (SFMM) to model habitat supply based on BMW scenarios by creating mixedwood forest units and setting constraints on BMW management techniques (e.g., minimum 20% partial cutting in overmature aspen-conifer stands)
- Although SFMM is a non-spatial wood supply model, some pseudo spatial habitat/wood supply

analyses are possible. For example, BMW stands can be categorized into sub-units based on their potential value to a specific species or group of species. Potential value may be determined in part on the spatial characteristics of BMW stands (e.g., stand size or proximity to other BMW stands). The SFMM model can then be used to analyze wood supply (see example in Schroeder 2003b).

b) Age class distribution

Importance: Forest age class is important because it is used as a surrogate for forest structure in management planning (D'Eon and Watt 1994) (Figure 2). Wildlife isn't particular about the age of a tree/forest as long as it provides the food shelter they need. Multi-story, old forests are critical to some wildlife (e.g., Drapeau et al. 2000) and are valuable to other species that may use them as a component of their habitat. Crites and Dale (1998) also found that time since disturbance is important to species dependant on old downed woody debris in aspen mixedwoods.

Desired condition: Recently, Bergeron and Harvey (1997) and Burton et al. (1999) advocated planning age class to match the inverse J-shaped age-class distribution curve described by Van Wagner (1978). Harvey et al. (2002) refined this idea by proposing a method that divides forest units into cohorts with different management strategies (Figure 3). Their system for managing mixedwoods is based on three cohorts, where a portion of each cohort is harvested to promote succession and uneven-aged management, or to initiate even-aged management. The proportion of the landbase allocated to each cohort is based on historical fire data.

Relevance to BMW management: Some management techniques produce structure normally associated with older age classes early in stand development by encouraging multi-layered canopies. Caution is advised when age class alone is used to define habitat value for BMW stands with multi-layered canopies. Burton et al. (1999) advocate setting quantifiable thresholds for critical structures (see stand/site scale) as an alternative to relying on age class. As well, some conditions associated with very old stands cannot be emulated with silviculture, so representative older stands must be maintained across landscapes.

Managing stands with mixedwood objectives may be best accomplished by defining them as uneven aged rather than even aged, as is typically the case for age class-based management in the boreal region.

c) Spatial patterns of forest cover

Importance: Patch geometry (e.g., shape, size) of forest cover across the boreal forest is heterogeneous and dynamic (Schroeder and Perera 2001). Since wildlife are adapted to this shifting mosaic (Hunter 1990), managing and monitoring landscape patterns is an important part of habitat management.

Desired condition: Emulate spatial patterns of forest cover that result from the combined influences of environment and natural disturbance.

Some spatial pattern criteria to consider include:

- Patch size
- Patch density
- Dispersion and interspersion of similar forest cover types
- Patch shape, including edge

Relevance to BMW management: The value of

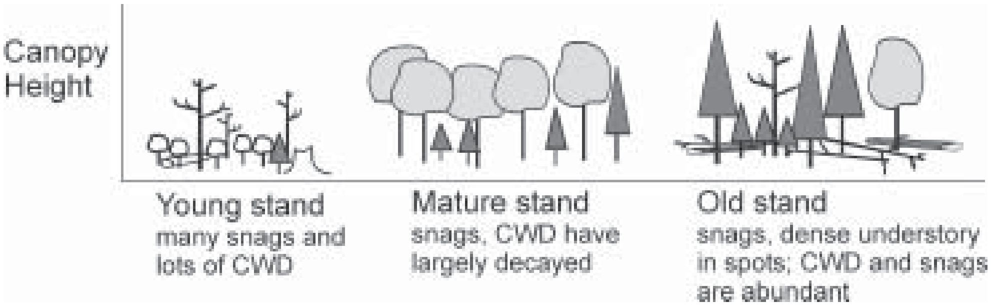

Figure 2. *Generalized relationship between forest age and structure for naturally regenerating post-fire boreal forest stands.*

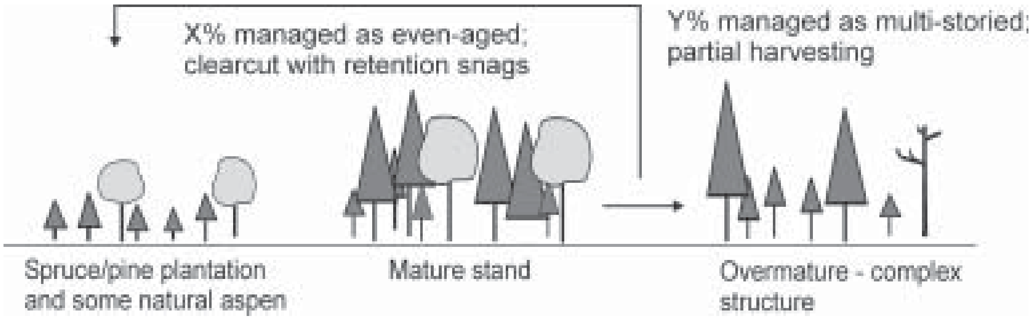

Figure 3. *Simplified landscape partitioning scenario for managing boreal forests, where X and Y are based on historical fire disturbance patterns (adapted from Harvey* et al. *2002).*

BMW patches as wildlife habitat is affected by their spatial placement; e.g.:

- Patch size and density: Small, isolated stands have less value than stands that can easily be reached by wildlife. Isolation is affected by patch size, interspersion of patches, and travel corridors.
- Patch shape and aggregation: Complex BMW patches (i.e., high edge density) located adjacent to or within recently disturbed stands also benefit wildlife as they offer shelter near forage.
- Fragmentation: Managed boreal forests are not permanently fragmented and are better described as a shifting state of forest cover types (age and composition) (Baker 1989). However, the use of clearcutting in some areas may still be viewed as a disturbance that fragments forests. Managing some stands with mixedwood objectives (e.g., maintaining partial overstories) may mitigate this problem, and at the same time provide valuable wildlife habitat and commercial timber.

II. Coarse Filter - Stand/Site Scale

a) Snags and cavity trees

Importance: Snags are important to a variety of wildlife species for forage, roosting, and shelter (e.g., D'Eon and Watt 1994). They are valued in mixedwood stands because of the variety of surrounding plant species and heterogeneous stand structure.

Desired condition: Snags are commonly categorized as: (1) declining tree, (2) dead tree, (3) bark loosening, (4) clean snag - no bark, (5) decaying trunk, (6) stub, or (7) stump. Wildlife species use of snags varies within these categories; maintaining conditions that allow a diversity of snag types will thus benefit wildlife. Some important standards:

- Snag density should be based on fire emulation guidelines (OMNR 2002)
- Typically, an aspen snag is > 6 m high while a stub is < 6 m high

Relevance to BMW management: Mature aspen become excellent snag and cavity trees as BMWs succeed from pioneer to mid- and late-seral stages. Balsam fir does not make good snags because it rarely grows very large; once dead it falls over easily and rots away quickly relative to other species. Conifer snags other than balsam fir are the longest lasting among boreal trees (B. Naylor, pers. comm.[1]).

- Emulating post-fire snag density: Creating high densities of snags during harvesting is not feasible, therefore reduce salvage intensity in some burned landscapes (Hobson and Schiek 1999). Alternatively, burn some residual mixedwood clumps in cutovers; this is a trade-off as residual clumps are also useful for providing patches of over-mature forest as previously mentioned.
- Retaining large snags: Retention patches with mature trees are an excellent way to ensure large snags for the future. Leaving large aspen as snags makes economic sense as these trees are likely to be old and partially rotted.
- Retaining supercanopy trees: These emerge above the main canopy of the stand and typically have very large diameters (> 60 cm DBH in Great Lakes-St. Lawrence; OMNR 1998). Supercanopy trees are especially beneficial to large birds for nesting and perching. Current guidelines

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recommend retaining supercanopy trees within 400 m of lakes occupied by eagles or ospreys at a density of 1 supercanopy tree per 650 m of shoreline (Penak 1983, OMNR 1987). BMWs managed over long periods are good sources of potential supercanopy trees.

b) Understory composition - dense conifers

Importance: Understories with dense conifer cover provide shelter and cover for many species (Jackson et al. 1991, D'Eon and Watt 1994).

Desired condition: Maintain patches of dense conifers in the shrub layer of BMW stands.

Relevance to BMW management: In mid- to late-seral stages, BMWs may have dense conifer patches. These patches may also develop following disturbance, particularly on sites with abundant mineral soil exposure and seed sources.

- Natural conifer regeneration is often very dense around seed trees and can be enhanced by mechanical site preparation.
- Aerial seeding can provide dense conifer regeneration and is a much less expensive than planting.
- Where tracked machines are used for harvesting and skidding, delimbing trees at the stump can enhance seed distribution and expose mineral soil for germination.
- Pre-commercial thinning reduces shelter and is not recommended for areas being managed to benefit wildlife (Litvaitis et al. 1985).

c) Downed or coarse woody debris (DWD)

Importance: Downed (DWD) and coarse woody debris provides important shelter for many vertebrates (Hunter 1990, McComb and Lindenayer 1999) and a source of nutrients and shelter, for example for mice, voles, and red-backed salamander (D'Eon and Watt 1994)

Desired condition: Maintain abundant stumps, downed trees, and large branches on site following harvesting and site preparation; the larger the downed trees the better.

Relevance to BMW management: Uneven-aged mixedwoods may provide a more continuous supply of DWD than even-aged plantations. Crites and Dale (1998) found that old aspen mixedwoods in Alberta had the greatest diversity of downed woody material (size and stage of decay) and provided more diverse substrate for non-vascular plants compared to younger mixedwoods. BMWs will also produce large DWD sooner than single-species stands (B. Naylor pers. comm.).

- DWD can be increased by leaving poor quality trees on site. Training machine operators to generate DWD by leaving live overmature trees is the best way to achieve desirable habitat conditions, as individual-tree marking is not feasible in boreal forests.
- The placement and subsequent rate of decay of DWD can also be managed (i.e., material on the forest floor decays more rapidly than stems suspended in the air).

Knowledge Gaps / Recommendations

Although much is known about wildlife habitat needs in relation to boreal mixedwoods as evidenced above, gaps remain. Examples of areas where additional data and knowledge are required to improve BMW management for wildlife include:

- Data: The use of Forest Resource Inventory data to determine habitat suitability is limited by lack of accuracy, soils data and understory species information. However, perfect data are not likely to be available in the near-term and inventory data are useful for describing habitats at coarse scales (Dussault et al. 2001). Improving available data sets is best accomplished continuously. In Ontario, much could be accomplished through collaboration between OMNR and industry. For example, where opportunities exist, summer students working in forestry but with an interest in wildlife could collect sound replicated data as part of their summer projects or as part of their thesis. These data could then be disseminated through the Natural Resources and Values Information System (NRVIS) database. Ongoing development of this database is encouraged.
- Spatial models: Spatial models that can be used to assess potential wildlife habitat are available only for marten in the boreal region; however, models for other species are under development. In addition to local wildlife habitat knowledge, tabular models are available and being used for reference in management planning. Again, further development of the NRVIS database is encouraged.

- Geographic base: Much of the wildlife habitat research results stem from outside boreal Ontario, requiring caution in applying them locally. However, because basic habitat needs (e.g., marten need complex vertical structure) apply universally, the principles of results from other areas can be applied until more local information becomes available.
- Long-term effects: Most studies of broad-scale forest management-related habitat changes are recent and long-term effects of broad-scale forestry practices are uncertain: A big unknown is the minimum area of specific forest cover types needed to support viable wildlife populations (I. D. Thompson, comm.[2]).

Emulating natural ecosystem processes is suggested as the way to meet the needs of multiple forest users and to ensure sustainable ecosystems—wildlife populations in particular—but the effectiveness of this approach will only become apparent over time. In the interim, maintaining diversity in forest types, composition, and age class structure is advocated to ensure adequate wildlife habitat quantity and quality.

Conclusions

One approach to ensure that sufficient wildlife habitat quantity and diversity are maintained in the boreal region is to emulate the spatial and temporal disturbance patterns that would result from a natural wildfire regime. This management paradigm includes a need to allow substantial forested areas to evolve well beyond mean disturbance cycles. BMW management advocates the use of techniques that allow long-term natural succession patterns to occur and offers opportunities for timber harvesting while providing important wildlife habitat.

Some habitat considerations specific to BMW management are:

- Plan for and manage abundant late-successional BMW stands
- Manage spatial patterns of these stands to maximize habitat availability
- Use management techniques that promote snags, patches of dense conifer understory, and large diameter downed trees
- Provide fine-scale habitat features as described in species-specific BMW notes and forest management guides

Forest managers are encouraged to consider the effects of their management plans beyond Sustainable Forest License borders and to collaborate with adjacent licensees to manage habitats that are regionally important (e.g., marten core areas could be enhanced by planning across management units). Any management technique or strategy (beneficial or harmful) widely implemented across individual management units in the boreal region will have broader-scale cumulative effects on habitat availability and quality.

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Vertebrate Herbivory Effects on Boreal Mixedwood Regeneration

by Kimberly Taylor and Stan Vasiliauskas[1]

> *Herbivory is defined as the consumption of plant material such as leaves, twigs, buds and bark by mammals...*

Introduction

Ontario's ecosystem management objectives include both regenerating forests and providing wildlife habitat. These objectives sometimes conflict. Although herbivory is not presently a frequent problem in the boreal forest (McNicol 2001), research in boreal forests outside Ontario indicates some potential for increased damage, especially to regeneration, when shelterwood and partial cutting are used in forest management (Thompson et al. 1989, Nystrand and Granstrom 2000). Since these silvicultural techniques are proposed as options for managing mixedwoods, herbivory may become a problem in forest management in Ontario in the near future.

For the purposes of this note, herbivory is defined as the consumption of plant material such as leaves, twigs, buds, and bark by mammals. Herbivory problems can be the result of large-scale landscape and demographic patterns (Senft et al. 1987). For example, silvicultural practices may combine with other landscape-scale factors (e.g., lack of predators) to provide a herbivore with optimal conditions (food, thermal cover, hiding places, access to water and birthing areas), allowing populations to increase above normal levels. Since many herbivores have distinct natural population cycles (Banfield 1974), attempting to regenerate a stand when a known herbivore (e.g., snowshoe hare, *Lepus americanus*) is at the peak of its cycle won't likely be successful. As well, if herbivory caused previous regeneration failures, knowing the herbivore population cycles within a management area and avoiding cyclic peaks may increase success.

This note provides a general overview of the effects of herbivory on stand development and describes some herbivores common to boreal mixedwood stands and their effects on regeneration. Possible damage mitigation measures are suggested.

Role of Herbivory During Mixedwood Stand Development

Herbivory effects in boreal mixedwood stands vary with stand development stage (Table 1) (Newton et al. 1989, Ford et al. 1993, Reimoser and Gossow 1996):

- Stand initiation and canopy closure stages are very susceptible to herbivore damage due to the proportion of a tree that may be

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consumed at these stages; for example, an herbivore can consume an entire seedling at the initiation stage or cause lethal damage at the exclusion stage.

- In mature stands, herbivores may strip bark or break branches allowing pathogen entry, which may or may not kill the tree (McNicol 2001).

The dietary choices of herbivores can greatly influence the species composition of a stand in the initiation and stem exclusion stages, for example:

- By selectively browsing conifers (Telfer 1972, Joyal 1976, Rodgers and Sinclair 1997, Timmermann 1998a,b), herbivores may cause the stand to shift towards deciduous species, typical of the early stages of mixedwood succession.
- By selectively browsing deciduous growth, herbivores may cause the stand to shift towards conifers, typical of the latter stages of mixedwood succession.
- Herbivory can facilitate stand growth by reducing understory competition.

Generally, herbivory is not uniform within a stand (Adler et al. 2001). If the browse species is uniform throughout the stand (e.g., aspen suckers), browsing patchiness is a function of herbivore behaviour. If the preferred forage species is patchy, feeding will be concentrated in these areas to minimize energy expenditure (Senft et al. 1987). These patterns may combine to either increase or decrease the heterogeneity of vegetation (Adler et al. 2001).

Table 1. *Herbivory effects on stand successional trajectory in boreal mixedwoods. Susceptibility to herbivore damage is indicated by the grey scale where darker indicates higher susceptibility. Arrows indicate the direction of compositional change in relation to stand development stage (e.g., left arrows indicate compositional shift to an earlier stage of stand development).*

		Stand Development Stage			
		Stand Initiation	**Stem Exclusion**	**Canopy Transition**	**Gap Dynamics**
Susceptibility to Herbivore Damage		**High**	**Medium**	**Low**	**Medium**
Herbivore	Moose	Trembling aspen White birch ←	Trembling aspen White birch ←	Balsam fir ← Trembling aspen White birch →	Balsam fir ←
	Deer	Trembling aspen White birch ←	Trembling aspen White birch ←	Balsam fir ← Trembling aspen White birch →	Balsam fir ←
	Snowshoe Hare	Trembling aspen White birch ←	Trembling aspen White birch ←	Balsam fir ← White spruce ← Black spruce ← Trembling aspen	Balsam fir ← White spruce ← Black spruce ←

Herbivory-Related Knowledge from Other Areas

Herbivory research outside boreal Ontario in areas where shelterwood and partial cutting techniques are used indicates that herbivory influences forest regeneration more under these silvicultural systems than under clearcut systems. However, this research occurred in areas with high ungulate densities; a correlation between the silvicultural system used and ungulate damage doesn't necessarily exist. In general, boreal mixedwood conifers are not preferred browse species for ungulates. Balsam fir (*Abies balsamea*) is heavily browsed by moose in Newfoundland, but not in Ontario, and deer browse fir only when other foods are scarce. Whether or not herbivory will become a problem on a given site depends to some extent on the need to protect balsam fir.

Research findings related to herbivory from boreal forests around the world can be summarized as follows:

- In Sweden, Nystrand and Granstrom (2000) found that herbivory was highest in shelterwood stands, followed by unlogged stands, and was lowest in clearcut stands. They attribute this to shelterwood management or other partial harvesting methods retaining herbivore habitat and opening the canopy to increase available light and promote shrub and sapling growth, further increasing habitat availability.
- In Austria, differences in browse availability were compared between clearcuts and shelterwoods (Reimoser and Gossow 1996). Clearcutting created a peak in available browse within the first 20 years after cutting. Other researchers in North America found the same pattern. In shelterwood stands, browse availability increased when the stands were between 80 and 120 years of age. Opening the canopy at this time promoted the growth of advanced regeneration and other browse species, which will likely attract more herbivores.
- In Newfoundland, a comparison of moose browsing between thinned and unthinned balsam fir stands found that moose (*Alces alces*) prefer thinned stands (Thompson et al. 1989). Chemical analyses showed that fir twigs in the thinned stand had higher protein and lower secondary metabolites levels. The latter is considered a plant defense against browsing.
- In spruce-fir forests in Maine, a study of browse availability after conifer release (Newton et al. 1989) showed that a number of silvicultural practices (precommercial thinning and clearcutting) increased the amount of available browse for moose, white-tailed deer (*Odocoileus virginianus*) and hares, at least in the first few years after they were applied. Higher browse availability will likely lead to an increase in herbivore populations and increased herbivory.

Decisions on wildlife management in boreal mixedwoods need to balance the intrinsic value of wildlife with any impacts on regeneration. If herbivory becomes a problem for boreal mixedwood management, research specific to Ontario boreal mixedwoods will be required. Since the factors that create herbivory problems occur at the landscape rather than the individual stand or cut block level, research will need to incorporate landscape management principles into the experimental design while monitoring individual stands.

Considerations Related to Common Herbivores in Boreal Mixedwoods

MOOSE (*Alces alces)*

Browsing preferences

Moose dietary preferences change with the season, with hardwood mixedwoods and aspen-spruce mixedwoods preferred in the summer, while aspen-spruce mixedwoods and conifer stands are preferred in the winter (D'Eon and Watt 1994). The summer diet is mainly aquatics and herbaceous vegetation often found in association with mixedwoods (Peterson 1953, Thompson and Vukelich 1981, Timmermann and McNicol 1988, Timmermann 1998a). In late summer and autumn, moose move to mature mixedwood stands where they browse on red osier dogwood *(Cornus stolonifera)*, willow (*Salix* sp.), beaked hazel (*Corylus cornuta)* and aspen leaf litter. The winter diet consists of woody material from deciduous trees, shrubs, and balsam fir.

Although moose browsing of tree seedlings is widely reported in the literature (Pimlott 1963, Bergerud and Manuel 1968, Bedard et al. 1978, Risenhoover and Maass 1987, Brandner et al. 1990, McInnes et al. 1992, Thompson and Curran 1993, McLaren and Janke 1996), it only occurs in areas where moose populations are higher than those normally found throughout Ontario. Moose do not consume either black (*Picea mariana*) or white spruce (*P. glauca*), preferring balsam fir, trembling aspen (*Populus tremuloides*), and white birch (*Betula papyrifera*) along with several tall shrub species (mountain maple *(Acer spicatum)*; American mountain-ash *(Sorbus Americana);* showy mountain-ash *(S. decora)*; beaked hazel; red osier dogwood commonly found in boreal mixedwood stands (Krefting 1974a, b; Peek 1974; Joyal 1976; Timmermann 1998a). Since white birch, trembling aspen and balsam fir are generally considered easy to regenerate and tall shrubs compete with crop trees, moose browsing is not considered a significant problem. This may change if birch or balsam fir become more important commercially in Ontario. Abitibi Consolidated (Thunder Bay) has identified moose browsing as a problem with aspen regeneration on private land in the Thunder Bay area (R. Gollat, pers. comm.,[2]).

Browsing trends by successional stage and soil texture

Moose browsing patterns are seasonal. Early successional stages (initiation and stem exclusion) of boreal mixedwoods provide an abundance of browse and are preferred in summer, autumn, and early winter. In late winter, the later successional stages of mixedwoods (particularly the transition stage) with a significant conifer component provide fir and woody shrub browse as well as thermal cover (Krefting 1974a, b; Cumming 1987). In the spring, these same stands provide protection from the sun.

Patterns in moose herbivory associated with soil texture are not commonly reported in the literature and no Ontario studies are available. A study from the balsam fir-white birch forest of central Newfoundland (Bergerud and Manuel 1968) found that moose damage was highest on the most fertile sites and decreased as fertility decreased. This may be due to the increased availability of browse on fertile sites or possibly due to higher nutrient levels in the browse.

Types of damage

Moose, because of their large body mass, are able to browse twigs up to 5 mm in diameter (unlike the smaller, younger twigs consumed by most herbivores), and leave ragged, splintered twig ends. Feeding is concentrated on stems from 0.5 to 3.0 m tall, but moose can also walk over taller stems or push them over with their necks and break them (Telfer and Cairns 1978). Trampling damage can be considerable, particularly in areas where thermal cover is good and moose activity is concentrated. Antler rubbing damage has been reported, but is not usually significant. Moose have affected forest regeneration on Isle Royale (Krefting 1974b, Brandner et al. 1990), throughout Newfoundland (Thompson and Curran 1993), and in Algonquin Park, Ontario (Vasiliauskas 1995).

Possible mitigation measures

Mitigative measures are not usually required in Ontario since moose numbers are low enough that any damage is not significant (McNicol 2001). Hunted areas in northern Ontario usually have mean moose densities of 0.1 to 0.3 moose per km^2, while protected areas such as Chapleau Crown Game Preserve have densities of 1 moose per km^2. In areas where moose have been a problem, such as Newfoundland, where densities range from 3 to 6 moose per km^2 (Bergerud and Manuel 1968, Thompson and Curran 1993), Thompson (1988) suggested that the impact of moose on thinned balsam fir stands could be reduced by (1) ensuring that all stand edges were straight, thus decreasing the edge: area ratio; (2) reducing the percentage of fir within a stand; leaving deciduous species during thinning; and (3) delaying thinning until the trees are 3 m tall and less vulnerable to browsing damage. Hamilton et al. (1980) found that moose preferred to browse within 80 to 260 m of cover. Based on this finding, ensuring that regeneration and cover do not occur in proximity may help reduce browsing of regenerating trees.

Brusnyk and Gilbert (1983) found that in late winter, moose preferred the cover and browse of shoreline reserves over feeding in cut areas where the snow was often too deep. In late winter at least, moose herbivory should not be an issue in cut areas.

SNOWSHOE HARE (*Lepus americanus*)

Problems with snowshoe hare damage to tree seedlings are not as widely reported in the literature as ungulate damage. When damage is reported, it is usually associated with peak hare populations (John and Turkington 1995). The 10-year cycle in snowshoe hare populations is considered one of the classic examples of herbivore population cycling (Keith 1983). Predicting peaks in the hare population may be more difficult in forests where habitat is fragmented or insular. The population cycle may be dampened or replaced by irregular fluctuations due

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to changes in predation caused by changes in available prey and sustained predation of fragmented hare populations (Keith 1983).

Browsing preferences

Snowshoe hares use most boreal forest communities as habitat but prefer mixedwoods (D'Eon and Watt 1994). Hares are considered generalist herbivores (Rodgers and Sinclair 1997). In the summer they eat a variety of grasses and herbs, but in the winter switch to a diet of buds, twigs, bark, and the evergreen leaves of woody plants (Banfield 1974). Hares prefer white and black spruce, balsam fir, jack pine (*Pinus banksiana*) and trembling aspen but will browse other tree species found in mixedwoods (Rodgers and Sinclair 1997, Telfer 1972). Their preference for white and black spruce may affect regeneration success when hare populations are high.

Browsing trends by successional stage and soil texture

The availability of cover is one of the factors influencing snowshoe hare habitat usage. Preferred habitats are forests with dense understories (0.5 – 2 m tall) that provide food, shelter, escape and thermal cover, good horizontal visibility, and refuge during cyclic lows (Holloway et al. 2004). Slash piles or any other features that provide cover will increase the desirability of the site to the hares (Munro and Churcher 1998). Clearcutting may create undesirable conditions for the hares when the site is first cut and cover has been removed. In Quebec, Ferron et al. (1998) found that hares don't use black spruce stands cut with CPRS, cut with protection of regeneration, (equivalent to CLAAG, careful logging around advance growth, in Ontario) for up to 4 years after harvest. This may change as sapling and shrub regrowth create more favorable conditions.

Hares prefer early successional forest (stand initiation to canopy closure stages) with dense understories interspersed with patches of old forest and gaps (Newton et al. 1989). Stem density is more important than species composition (Holloway et al. 2004). Koehler (1990) found that snowshoe hares in north-central Washington preferred forest less than 25 years old. Habitat suitability may change as stands shift from deciduous to conifer-dominated through succession. An increase in the conifer component of a stand will increase the amount of conifer browse and thermal cover available and the value of the stand for hares. Rogowitz (1988) found that during the winter hares preferred sites with a well-developed overstory of mature spruce but preferred adjacent early successional areas for browsing. In summer, hares move into more open habitats that have dense herbaceous cover. Boreal mixedwoods that provide these conditions will be used by hares.

There is no evidence in the literature of differences in snowshoe hare herbivory in relation to soil texture. However, fine-textured soils are expected to provide more browse as they are richer in nutrients.

Types of damage

Damage by snowshoe hares is characterized by a clean, angled cut on a twig. This helps to separate gnawing mammal damage (e.g., beaver (*Castor canadensis*), hares, mice) from ungulate damage (McNicol 2001). Hares will consume the terminal shoots and branches of all of the mixedwood species and can completely girdle stems. They prefer branches that are up to 3 mm in diameter, but at peak populations will eat branches up to 15 mm in diameter (McNicol 2001). Damage usually occurs on trees less than 1 m tall (Munro and Churcher 1998). Snow conditions allow access to taller trees and higher branches (pers. observ.).

Possible mitigation measures

Mitigative measures are not usually required as the damage by hares is not usually significant. Radvanyi (1987) provides a good review of a number of methods that can be used to decrease herbivory by snowshoe hares based on experience in the prairie provinces. These strategies are: consider the population cycles and landscape, manipulate habitat, use physical and chemical deterrents, and plant larger seedlings.

Since hares have cyclic population levels, one of the best ways to minimize damage is to ensure regeneration doesn't coincide with the peaks. Waiting until the populations are decreasing may greatly increase regeneration success without any other interventions. Unfortunately, this is not always practical, as regeneration delays can increase vegetative competition problems.

Clearcutting creates conditions conducive to hare browsing by promoting the dense resprouting of aspen and shrubs. Since no studies have been done in Ontario to compare hare preference for clearcut vs. partial cutting systems it is difficult to predict whether the partial cutting systems that may be used in boreal mixedwood management will increase or decrease available cover. They may in fact create less forage compared to clearcuts, because although more light will reach the understory compared to undisturbed stands, light levels are lower than in clearcuts. This would be quite different than the impact on cover for larger mammals (deer and moose), where the remaining trees provide suitable cover and the increase in understory growth increases the available browse.

Hares, like deer and moose, prefer browsing in areas interspersed with thermal cover and cover from predators. Conroy et al. (1979) found that hares prefer cover within 200 to 400 m of cutover areas where they browse. If hare browsing is limiting successful tree regeneration, reducing the edge-to-area ratio and decreasing the amount of interspersion of cover may help reduce damage. However, this approach does not comply with natural disturbance pattern emulation guidelines (OMNR 2002). When hare damage is a concern, manipulating habitat to reduce cover may help. Disposing of slash piles after harvest and reducing the amount of available cover through site preparation and tending will help to reduce the hare habitat and thus minimize damage.

Radvanyi (1987) suggests that to reduce hare damage, seedlings need to be protected until they are at least 1.5 m tall. Physical barriers such as hare-proof fencing are most effective but also costly. Individual seedlings may also be protected with wire or plastic mesh, or plastic sleeves. Seedlings or the protective barrier can also be coated with a repellent. Rangen et al. (1993a, b) investigated the use of the fungicide Thiram as a taste repellent for deterring herbivory by snowshoe hares on white spruce. Developing an aversion to Thiram took some time and the aversion did not last. They concluded that the required reapplication of Thiram would not be economically feasible, and during the time required for the aversion to develop, conifers would still be susceptible to damage making this a less than ideal approach.

Radvanyi (1987) also suggests using extra-large seedlings to promote rapid growth. However, other studies have shown that fertilized seedlings are preferred by hares (Nams et al. 1996). To offset this, Radvanyi (1987) suggests that fertilizer be used sparingly during the additional transplant years.

In British Columbia, Rodgers et al. (1993) found that snowshoe hares preferentially browsed nursery-grown white spruce seedlings over naturally regenerated white spruce. They suggest this is due to the lower camphor content in the nursery-grown seedlings. This would suggest that when trying to create mixedwoods with a white spruce component, natural regeneration may be more successful in areas where hare browsing is expected.

WHITE-TAILED DEER (*Odocoileus virginianus*)

Throughout most of Ontario, and particularly in the boreal forest where deer numbers are low, white-tailed deer browsing damage is not a major concern for regeneration. However, in certain parts of Ontario, white-tailed deer significantly affect forest regeneration. Most areas with deer browsing problems are south of the boreal forest, with Rondeau and Pinery Provincial Parks (Bartlett 1958, McNicol 2001) experiencing serious impacts on trees, shrubs and herbaceous species. Most of the damage to nursery and seed-orchard stock occurs in the Great Lakes-St. Lawrence forest (McNicol 2001). The only area in northwestern Ontario where deer damage is a concern is a band stretching along the north shore of Lake Superior (Towill, pers. comm.)[3] from Terrace Bay, Nipigon, and Thunder Bay, to Atikokan, Dryden and Kenora (parts of ecodistricts 3W5, 3W3, 3W2, 4W3, 4W1, 4S4, 4S6 and all of ecodistricts 4S5 and 5S2). Here, the moderating influence of Lake Superior combined with the continental air mass makes the climate suitable for deer. A small population of white-tailed deer exists in Kirkland Lake District but little damage is reported. Deer problems are usually restricted to winter deer yards where high seasonal densities can restrict regeneration of some species.

Browsing preferences

Many of the preferred browse species for white-tailed deer, such as red maple (*Acer rubrum*) and eastern white cedar (*Thuja occidentalis*) (Verme 1965), are not considered boreal mixedwood crop trees, but occasionally occur in boreal mixedwood stands. Mixedwood tree species, such as trembling aspen and white birch, are browsed along with several common mixedwood shrub species such as mountain maple, beaked hazel, serviceberry (*Amelanchier* spp.), red osier dogwood, bush honeysuckle (*Diervilla*

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[3] Towill, B. 2002. Ont. Min. Nat. Resour., Northwest Sci. Info., Thunder Bay, ON

lonicera), and green alder (*Alnus crispa)* (Timmermann 1998b). Balsam fir and black and white spruce are not preferred browse species and are only consumed when food is scarce (Rogers et al. 1981, Smith and Borczon 1977). Deer are more likely to limit browsing to the current year's growth compared to moose that will browse material up to two years old (Trottier 1984). Deer also feed on the arboreal lichens *Usnea* and *Evernia* in the winter (Hodgman and Bowyer 1985). Deer can sometimes facilitate silviculture where a conifer-dominated stand is the desired result by reducing hardwood competition, such as aspen and white birch.

Browsing trends by successional stage and soil texture

White-tailed deer habitat selection and dietary preferences change with the seasons. In the spring and summer, deer prefer to browse deciduous shrubs and trees from upland deciduous and mixedwood areas (Timmermann 1998b), feeding on a variety of foods, including herbaceous vegetation, flowers and leaves from growing seedlings and saplings. This pattern is reflected in their preference for hardwood mixedwoods and aspen-spruce mixedwoods ecosites (D'Eon and Watt 1994). In the winter, thermal cover is important and stands with a higher conifer component, such as conifer stands on moist soils and aspen-spruce mixedwoods, are preferred (D'Eon and Watt 1994). Browsing shifts to the current annual growth of hardwood trees and cedar foliage and twigs, in addition to the other species consumed during the spring and summer (Timmermann 1998b).

In the spring and summer, feeding is concentrated in the initiation, canopy closure and transition stages of stand development. In the winter, stands in the transition and gap phases become more important with the increase in the conifer component through succession. In general, stands at initiation and stands at the transition or gap phases, have more available browse compared to stands in the canopy closure stage (Johnson et al. 1995). Canopy closure stands have very little light at the forest floor and this limits shrub and tree regeneration. Differences in browsing in relation to soil texture are not directly reported in the literature, but more browse is thought to be available on richer sites (Bergerud and Manuel 1968), suggesting that stands on finer soils should have more available browse and thus would be subject to higher damage levels.

Types of damage

White-tailed deer leave a ragged, splintered twig break, similar to moose. The leaders and lateral branches up to 3 mm in diameter of young trees are browsed with the current year's growth preferred. Browsing is concentrated on stems from 0.5–2.0 m off the ground in an average winter. Young seedlings can also be trampled or uprooted while being browsed (McNicol 2001). Deer start to move to "deer yards" when snow depths are 20 cm and movement becomes difficult when snow depths reach 50 cm, where they remain confined to well-defined trails within the yard area. Within these yards the level of browsing can be very high as the deer remain there for the thermal cover, eating what is available. Deer yards are used for decades and gradually shift through time as food availability changes. Deer will not move to other areas even when available browse is scarce. Over time this activity will actually decrease the amount of thermal cover in the stand as canopy conifers die and are not replaced by regeneration (McNicol 2001, Smith and Borczon 1977).

In northern Michigan, Switzenberg et al. (1955) found that even though browsing damage in hardwood stands may be severe, the impact on a stand lasts for only a few years. The trees quickly recover and the resulting quantity and quality of the timber produced was not affected. In the Hudson Valley of New York, Canham et al. (1994) found that even with severe winter browsing over several years, impact on tree growth was minimal. Late spring and early summer browsing, however, affected both growth and mortality. It is not known whether this also applies in boreal mixedwoods. Heavy browsing over decades has been shown to change forest composition by limiting regenerating species to those not browsed by deer, such as beech (Bartlett 1958, Graham 1958, Beals et al. 1960, Butt 1984, Frelich and Lorimer 1985).

Possible mitigation measures

As with moose and snowshoe hare, action is usually not required since damage is minimal and the costs of mitigation outweigh the benefits. However, on a number of occasions in Ontario damage levels have warranted steps to protect regenerating trees. This has been mainly in seed and fruit orchards and nurseries where investments are high. In these cases a great deal of creativity has been shown in trying to find solutions.

Fencing has been successfully used (McCormick et al. 1993) with multi-strand electric fences found to be most effective. Protection of individual trees with bud caps and leader tubes as well as various repellents (blood meal, human hair and predator urine) have been tried with varying success and cost. McNicol (2001) provides a review of some of these methods with illustrations of some of the physical barriers.

When regenerating stands, the best mitigation seems to be prevention. Awareness of the status of the white-tailed deer populations will help resource managers to schedule regeneration when populations are low. Minimizing the edge-to-area ratio when laying out cutblock will help to ensure that harvest planning does not result in "great deer habitat". Areas of adequate browse interwoven with a patchwork of conifer shelter offer the best habitat for white-tailed deer (Smith and Borczon 1977). Beyond cutting patterns, the nature of the landscape is also important. Coniferous stands on south-facing slopes, especially the upper portions, and those adjacent to large lakes are considered prime deer habitat (Telfer 1978). Extra consideration may be necessary when trying to regenerate stands in these landscape positions when white-tailed deer numbers are high.

St-Louis et al. (2000) examined whether partially cut stands provided good browse for deer (approximately 40% canopy removal concentrated on removal of deciduous species to release the conifer understory). They found that the deer only took advantage of the additional browse from hardwood tops left after logging when their home range was directly adjacent to the cut area. The released conifer stand was not used much after cutting since the snow was too deep. If crown closure is reduced to 50%, the stand is no longer suitable for yarding (Verme 1965). Cuts that create too little browse are also avoided as they are rapidly overbrowsed. Strip shelterwoods, where cover and browse are adjacent, were used the most by deer (Verme 1965). This suggests that deer browsing of conifers after any partial cuts may depend on the residual conifer cover for thermal protection and movement. If the snow is too deep and the conifer stand does not provide adequate shelter, then the deer will likely not use the stand. Good winter habitat for deer consists of clumps of 3 to 5 conifers spaced about 10 to 30 m apart. Higher light levels between the clumps promote woody growth for browse, and deer will maintain a trail network between clumps (Voigt et al. 1997).

Knowledge Gaps

Essentially no research is currently available that looks at the effects of silvicultural techniques on herbivory in Ontario's boreal mixedwoods. The knowledge is based on patterns seen outside the boreal forest, or outside Ontario, or with silvicultural techniques that differ from those proposed for use in Ontario. If herbivory becomes a problem for boreal mixedwood management, research specific to Ontario boreal mixedwoods will be required. This need is particularly strong for the partial cut or multiple-entry silvicultural techniques, which are not well documented in the literature.

Factors that interact to create herbivory problems do not happen at the individual stand or cut block level, but rather at the landscape level. To understand herbivory impacts, research that incorporates landscape management principles into the experimental design and is conducted across landscapes is required.

Summary

Generally, herbivory has not been an issue in boreal forest management. Problems that have arisen have usually been local. Where necessary, up to four preventative strategies can be applied when herbivory problems do exist (Table 2):

- time operations so that herbivore population peaks do not coincide with regeneration times
- locate operations so that optimal conditions for herbivores, such as adjacent cover and browse, are not being created
- use silvicultural practices that reduce browse, such as timing of harvest, herbicides
- set aside openings within cuts specifically for browse production to attract herbivores to these areas and reduce damage in adjacent plantations

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Table 2. *Summary of damage type and possible mitigation strategies for common herbivores of boreal mixedwood stands.*

Species	Damage Type	Mitigation Measures
All herbivores	All	**Usually no action taken. Options are:** ▪ **Timing** operations so that population peaks do not coincide with regeneration times ▪ **Locating** operations so that optimal conditions for herbivores are not created ▪ Ensuring that cover and browse for the herbivore of concern are not being created in **proximity**
Moose	▪ Trampling ▪ Browsing ▪ Antler rubbing	**Usually no action taken. Options are:** ▪ Decreasing edge: area ratio ▪ Applying browse repellent (e.g., skoot) to trees near the plantation edge ▪ Installing wire mesh around seedlings
Snowshoe hare	▪ Browsing (clipping leader or lateral shoots, girdling) ▪ Removing bark from the base of stems and low branches of both coniferous and deciduous seedlings, saplings, and trees up to 15 mm diameter	**Usually no action taken. Options are:** ▪ Not attempting regeneration when hare populations are at their peak ▪ Decreasing edge:area ratio ▪ Decreasing available cover by disposing of slash piles and controlling vegetation through site preparation and tending ▪ Applying paste repellent (e.g., thiram) to seedlings ▪ Installing hare-proof fencing ▪ Installing individual seedling protection ▪ Planting extra-large seedlings ▪ Relying on natural regeneration
White-tailed deer	▪ Browsing current annual leader growth and branches up to 3 mm in diameter ▪ Trampling seedlings ▪ Uprooting seedlings while browsing	**Usually no action taken. Options are:** ▪ Installing fencing ▪ Installing scent bags of blood meal, human hair, or predator urine ▪ Reducing edge:area ratio by changing cut block configuration

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SILVICULTURAL OPTIONS

Commercial Utilization of the Boreal Mixedwood Forest

by G. Blake MacDonald[1] and Robert G. Cormier[2]

> *The utilization of formerly ignored mixedwood species is increasing because mixedwood stands offer an attractive source of high-quality fibre relatively close to mills*

Introduction

Ontario's Boreal Mixedwood Forest can help address the wood shortages associated with the declining availability of harvestable and accessible stands of conifers. Boreal mixedwood sites are highly productive and often support good quality timber that was bypassed in the search for pure stands (MacDonald 1995). The increasing demand for hardwood fibre is focusing commercial interest on mixedwood stands, which often contain a high proportion of trembling aspen (*Populus tremuloides* Michx.).

The objective of this note is to describe the current commercial utilization of the main boreal mixedwood tree species and outline factors that may change the relative utilization rates of these species in the future. Recommendations are made for improving the utilization of the mixedwood resource, with an emphasis on value-added conversion. Commercial utilization is defined as the quantity and quality of product recovery from harvestable stands. The issue of wasteful practices is not addressed.

Current Utilization

Estimates of the allocated and harvested volumes for Ontario’s commercially important boreal mixedwood species are presented for 1996 (the most current figures available) in Table 1. Total volumes from all districts in the Northwest and Northeast Regions were included. This may have resulted in overestimates of the volumes on mixedwood sites for species such as jack pine

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(*Pinus banksiana* Lamb.) and black spruce (*Picea mariana* (Mill.) B.S.P.), which produce significant volumes on non-mixedwood sites. However, this inaccuracy cannot be resolved because the inventory system does not identify boreal mixedwood sites. The allocated volumes were estimated from Forest Resources Inventory information and the area allocations in the plans for all relevant management units. The harvested volumes were obtained from the Timber Scaling and Billing System. Spruce and pine, the traditional mainstays of the forest industry in boreal Ontario, continue to be highly utilized (Table 1). Despite localized supply constraints, the allowable harvest volumes of balsam fir (*Abies balsamea* (L.) Mill.) and poplar are largely uncommitted on a provincial basis. While the small allocation of tamarack (*Larix laricina* (Du Roi) K. Koch) is overutilized, only negligible proportions of the white birch (*Betula papyrifera* Marsh.) and eastern white cedar (*Thuja occidentalis* L.) allocations are harvested.

Table 1. Estimated volume utilization for boreal mixedwood species in 1996.

	Net Merchantable Volume		
Species	Allocated (m^3)	Harvested (m^3)	Utilized (%)
Spruce spp.[1]	11,185,048	8,359,795	74.7
Jack pine	6,155,662	6,180,667	100.4
Balsam fir	1,234,831	505,166	40.9
Poplar spp.[2]	6,799,774	3,868,960	56.9
White birch	2,272,059	159,007	7.0
Eastern white cedar	101,064	3,757	3.7
Tamarack	5,479	8,121	148.2

[1] Primarily black spruce

[2] Primarily trembling aspen

Future Trends

Shortages of accessible coniferous fibre will foster increased utilization of balsam fir during the next 20 years. Although balsam fir is the least preferred boreal mixedwood conifer in Ontario, it can produce good quality pulp and paper (Bedell 1962). Faster growth and more vigorous root development allow fir seedlings to become established on thicker layers of litter and survive longer periods of drought, compared to spruce. However, the information to properly manage fir is lacking in Ontario. For example, its growth and yield projections are often inaccurate because they are based on data for black spruce (MacDonald 1991). Provincial silvicultural guidelines seldom promote balsam fir management and utilization, and unmanaged fir is more susceptible to insect and disease damage. These problems could be reduced by applying management techniques suited to the silvics of the species, such as thinning young stands and lowering the rotation age, supplemented by selective use of biological insecticides.

During the early 1990s there was a sharply increased commitment of the hardwood resource for new and expanded mills producing pulp and paper, lumber and oriented strandboard (Cormier 1996). This hardwood resource is composed mainly of trembling aspen, with smaller volumes of white birch, largetooth aspen (*Populus grandidentata* Michx.) and balsam poplar (*Populus balsamifera* L.). Aspen wood can be pulped by most of the commercially important processes and is well suited for use in hardboard, insulation board, particle board and structural flakeboard (waferboard and oriented strandboard).

Nearly two decades ago, Clarke *et al.* (1981) predicted that underutilized hardwood species such as trembling aspen and white birch would be the raw material of the future because of conifer supply constraints and an increasing demand for fibre. They indicated that the abundant hardwoods could be processed into value-added products by integrated industrial complexes that fully utilized the hardwood fibres. In line with their prediction, aspen utilization in Ontario rose from 0.7 million m^3 in 1976 to 2.7 million m^3 in 1986 (Armson 1988), and the trend continues as demand for structural flakeboard and hardwood pulp increases.

The volume of poplar species (mainly trembling aspen) harvested in northern Ontario had risen to 3.8 million m^3 by 1996, and this represented only a 57% utilization rate (Table 1). Thus, the economic potential of this species is largely unrealized in northern Ontario, which contains 50% more aspen volume than the entire United States (Einspahr and Wyckoff 1990).

From an operational standpoint, the degree of boreal hardwood utilization depends on the quality and species composition of the harvestable stands. For example, high proportions of veneer logs or conifer volume may be required to generate sufficient revenue to justify operating in some stands (G. King, Norbord Industries, pers. comm.).

The utilization of formerly ignored mixedwood species is increasing because mixedwood stands offer an attractive source of high-quality fibre relatively close to mills (MacDonald 1995). Mixedwood stands tend to produce larger trees than pure stands, making them an attractive source of sawlog and veneer material (Denney 1988, Opper 1981). The low delivered wood costs and the high productivity of boreal mixedwood sites are strong economic incentives for maximizing the utilization of mixedwood species (Ketcheson 1981). For example, mature mixedwoods in north-central Ontario produce about 268 m^3 per ha, compared to 188 m^3 per ha for average black spruce stands (Opper 1981). There is evidence from northern Europe that a birch component improves the growth of conifer stands, and the mixed-species effect is most pronounced for vertically stratified mixtures (Burkhart and Tham 1992, Nyyssonen 1991). The size class diversity typical of these mixtures may necessitate multiple harvest entries for efficient volume utilization.

Advanced wood products technology permits a shift from managing one species to managing for maximum production from multiple species (Debyle 1991). This strategy enhances industrial stability by maximizing the wood supply potential from the available land base. Furthermore, complete species utilization opens additional land base that would be uneconomical when operated only for conifers (Denney 1988).

Accelerated increment on the coniferous components of mixedwood stands will be important during the next 50 years before plantation timber becomes available in significant amounts. This acceleration can be achieved in part by modified harvesting and thinning to release conifer understories in mixedwood stands (Palmer 1991).

Cutting practices have increased the proportion of small trees on some cutover boreal mixedwood sites in Ontario. The lower tree volumes necessitate more complete utilization to address wood supply pressures. Operators with computer-assisted equipment in their woodlands and mills can economically process the small trees that formerly would have been left unharvested. Many value-added products are being developed to capitalize on the prevalence of small-dimension raw material.

The Importance of Value-Added Products

A value-added wood product is one whose commercial value has been enhanced through creative design and sophisticated processing. Commodity-based operations emphasize manufacturing efficiency and high volume production of traditional products, often leaving distribution to wholesalers. In contrast, value-added operations rely more on automated processing equipment, staff training, and product research and development, and often exercise more control over packaging, marketing, and distribution (Cormier 1996). Value-added revenues are generally more stable than commodity revenues. Decreased employment at the value-added production level is offset by increased employment in product design, marketing, and distribution. The new jobs are usually closer to the markets than to the primary production sites.

Canada, China, and the former USSR countries produce mainly commodities such as pulp and paper from their boreal forests, and Canada maintains a strong global position in commodity wood production (Table 2). However, it lags behind other jurisdictions such as Scandinavia and South America in value-added production (Cormier 1996). From a global perspective, boreal mixedwood forests are relatively slow growing and remote from primary commodity markets. Wood-based commodity production is increasingly supplied by fast growing plantations in the tropics and mid-latitude regions. The effects of this competition could be minimized by adopting proactive management and value-added processing of all the major mixedwood species.

Table 2. Trends in share of solid wood products by boreal region. Data compiled from Kuusela (1990).

	Industrial Wood (% of world total)			Sawn Lumber (% of world total)		
Region	1962	1980	1987	1962	1980	1987
Canada	8.7	10.6	11.3	6.0	9.8	12.3
Scandinavia	8.1	6.7	6.0	4.8	5.3	4.3
Former USSR	24.6	19.1	17.9	31.2	21.8	20.3

Examples of Boreal Mixedwood Value-Added Industries

Scandinavian forest companies emphasize the superior wood density that results from the slow growth of many boreal mixedwood species when marketing their value-added products. These products include furniture and window components, flooring, engineered wood, customized plywood, machine stress-rated lumber, prefabricated building components, decorative panels and moldings, and specialty papers.

The Nordic countries are supplying a growing market for prepackaged composite hardwood flooring, which can be made from the small trees that are common in many mixedwood stands. New technologies have cut labour costs and automated production, resulting in a cheaper product that performs comparably to solid flooring. Two Finnish forest companies have developed new markets for specialty birch and spruce plywood that sells at three times the price of commodity and construction grade plywood. Mills in northern Europe also produce finger-jointed window components, machine stress-rated lumber and glue-laminated beams from mill ends or low grade lumber, using automated processing equipment with laser scanning capabilities.

Trus Joist MacMillan of Boise, Idaho has developed a commercially successful composite product called Timber Strand™ from aspen flakes that are oriented in the same direction and remanufactured into various engineered wood products. The company's success relies on active product development, marketing and distribution.

There are some encouraging examples of Canadian forest companies increasing their value-added production. For example, Tembec Forest Products in Ville Marie, Québec converted its commodity plywood mill into a laminated veneer lumber plant that uses poplar raw material formerly destined for pulping (Figure 1). Devon Mills Ltd. in Chapleau, Ontario produces prefabricated log homes from poplar and pine and markets them internationally. E.B. Eddy Forest Products in Espanola, Ontario has a corporate goal of increasing the proportion of value-added products manufactured, with an emphasis on specialty paper grades (E.B. Eddy Group 1994).


Figure 1. Tembec's laminated veneer lumber used as support structures in Forintek Canada's new laboratory and research centre in Québec City, Québec.

Norbord Industries, Inc. of Cochrane, Ontario has changed from a former commodity-based sheathing mill to a value-added operation supplying the furniture and cabinet markets. The company obtains a large proportion of its hardwood veneer logs from boreal mixedwood sites and is attempting to process more balsam poplar, a species that is virtually unutilized in the Northeast Region (G. King, Norbord Industries, pers. comm.).

Practical Implications

Local competition for land use and global competition for market share threaten the economic viability of commodity-based forest companies in Ontario. Thus, the industry requires a shift from a commodity volume approach to a value approach based on modern concepts of product innovation, quality control, and targeted marketing.

Competing land uses will continue to reduce available boreal mixedwood harvest volumes, requiring improved management and utilization of those stands remaining allocated to timber production. Such efforts would rely on an enhanced inventory that identifies boreal mixedwood sites and stands. Management practices should also aim at improving log quality in mixedwood stands to increase the potential range of end products. Unsuitable management practices and underutilization of some species have resulted in many commercially degraded mixedwood stands in northern Ontario. Research is required to develop effective approaches for regaining optimum productivity in such stands.

Forest companies should harvest and process as many of the available mixedwood species as possible and make their long-term mill production compatible with the projected species balance (Smith 1988). Improved mill integration and wood exchange between companies should be promoted to allow full utilization of all mixedwood successional stages. The reliance of mixedwood management on low-impact practices such as partial cutting and natural regeneration can help to secure sales in markets that prefer wood products from ecologically sustainable operations.

Partial cutting systems developed in Alberta (Brace Forest Services 1992) cannot be applied in the complex mixedwood forests of northern Ontario without extensive testing and modification. For example, the prominence of fir and aspen in Ontario's Boreal Mixedwood Forest necessitates specialized thinning and harvesting techniques designed to maintain productive species compositions and densities and reduce insect and disease losses. Research to address some of these issues has been initiated (MacDonald 1996, Scarratt *et al.* 1996).

Forest management guidelines for boreal Ontario often require the enhancement of non-timber resource values through the retention of residual mature trees after harvesting (Naylor *et al.* 1996, Watt *et al.* 1996). Mixedwood stands may provide the option of leaving a commercially undesirable species such as balsam poplar or balsam fir on site to satisfy these non-timber values. This strategy would not be considered a wasteful practice if it was part of a silvicultural prescription in an approved forest management plan (OMNR 1998).

The machinery used in Ontario for thinning, partial cutting, and skidding is generally inappropriate for optimizing mixedwood utilization. Equipment is often imported from Scandinavia, where the terrain and stand structures differ from those typical of Ontario's boreal mixedwood sites. Improved operator training is required to minimize damage to the site and residual trees, while maintaining commercially acceptable productivity.

Conclusion

The following actions are recommended to improve boreal mixedwood utilization in Ontario:

1. Implement proactive boreal mixedwood management practices to maximize sustainable yields.
2. Use a lower rotation age for balsam fir than for spruce. Manage mixedwood stands to avoid prolonged suppression of fir, which should be harvested before age 60.
3. Promote careful logging of multiple species to enhance utilization on appropriate mixedwood sites.
4. Expand wood exchange agreements among companies to maximize the management and utilization of the component species, size classes, and quality classes.
5. Improve the high technology component of mill processing to optimize the conversion of mixedwood species into a range of products at globally competitive costs.
6. Use a systems approach for planning value-added mixedwood utilization; address raw material characteristics, product design, employee training, and marketing strategies.

Ontario's Boreal Mixedwood Forest represents considerable unrealized potential for enhanced economic returns through improved utilization. Achieving this economic potential will require the concerted efforts of resource policy-makers, management planners, industry decision-makers, forest and mill workers, and marketing specialists.

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Boreal Mixedwood Logging Methods and Strategies

by M. Kenney[1] and W.D. Towill[2]

Logging methods and strategies are a cornerstone of managing boreal mixedwood sites and stands. Choice of an appropriate logging method is influenced by forest stand characteristics, site conditions, choice of silvicultural system, the need to protect understory advance growth and manage the amount and distribution of logging residue, and health and safety considerations.

Introduction

Logging is the commercial removal of wood from the forest, and includes cutting, initial processing, and extraction (Canadian Forest Service 1995; DeByle and Winokur 1985; OMNR 1996). As the first operation in a silvicultural system, it has a major impact on the site and its subsequent regeneration.

Harvest method is the term used to define the harvesting component of a silvicultural system (OMNR 1997). Harvest methods used with the clearcut silvicultural system are conventional, strip, block, patch, and seed-tree.

Logging method refers to the extent of initial wood processing that occurs in the cutover, and the form in which the wood is delivered to a logging access road. The most common logging methods in eastern Canada are full-tree, tree-length, and cut-to-length (Pulkki 1997).

Logging methods have evolved since the first commercial tree-harvesting operations. Early logging operations involved felling the trees with an axe, bucking with a crosscut saw, and transporting the logs with horses. That system has progressed through many stages of mechanization into an extremely efficient mechancial system involving feller-bunchers and skidders for full-tree and tree-length logging, and single-grip harvesters and forwarders for cut-to-length logging. In selecting a logging method for a forest stand, resource managers must consider not only past and present management activities at the stand, forest, and landscape levels, but also management objectives, silvicultural systems, forest stand and site characteristics, and the desired future forest.

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The objectives of this note are:

- to assist resource managers in linking current and desired forest stand condition with various logging methods
- to describe factors affecting the choice of a logging method, and
- to present literature relevant to logging in boreal mixedwood stands and on boreal mixedwood sites.

Logging Methods

Full-tree logging

Full-tree logging involves cutting and transporting trees to roadside where they are topped and delimbed (Figure 1). The trees are then further processed at roadside or hauled as is to a central processing location. Roadside processing can include chipping or cutting to desired lengths (Pulkki 1997). Reduced slash loads on a cutover may influence the long-term nutrient budget for the site, the potential for natural regeneration from vegetative or seed sources, and ease of access for artificial regeneration (Bowling and Goble 1994; Pulkki 1997).

Between 1990 and 1994, the use of full-tree logging decreased in eastern Canada as a result of increased processing at the stump. Gingras (1995) predicts that this trend will continue.

Tree-length logging

Tree-length logging consists of felling, topping, and delimbing trees at the stump before they are transported to roadside (Figure 2). The tree lengths may then be cut to length at roadside, or hauled to a central processing plant (Pulkki 1997). With tree-length logging, tops and

Figure 1. Full-tree logging showing roadside processing.

Figure 2. Tree-length logging.

Figure 3. Slash from cut-to-length logging.

Figure 4. Single-grip harvester.

branches are distributed evenly or in piles throughout the cutover. Tree-length logging accounted for 17% of the wood volume harvested in eastern Canada between 1980 and 1990 (Gingras 1995).

Cut-to-length logging

Cut-to-length logging involves felling, topping, delimbing, and cutting trees to desired lengths at the stump. The wood is usually transported to roadside using forwarders (Pulkki 1997). This method produces the greatest amount of slash (Figure 3), which is either scattered throughout the cutover or piled in windrows. Prior to 1950, cut-to-length was the most common logging method in eastern Canada. With the advent of mechanization, use of this method declined rapidly. The introduction of single-grip harvesters (Figure 4) in 1990, however, has resulted in a small resurgence of cut-to-length logging (Gingras 1995).

Selecting a Logging Method for Boreal Mixedwood Stands

The mechanized logging operations of today can create considerable site disturbance and damage to residual stems, particularly during movement of the felled trees to roadside. Site disturbance from logging may encourage the regeneration of competitive non-crop species, damage or crush advance regeneration, and cause physical damage to the site. Knowledge of various logging methods and their effects on site and stand conditions will enable resource managers to control the degree of harvest disturbance, thereby influencing the amount and type of post-harvest vegetation and site damage (Archibald *et al.* 1997; Buse and Bell 1992; Dyrness 1974; Myketa *et al.* 1998). When selecting a logging method for boreal mixedwood stands, resource managers should consider:

- silvicultural system
- forest stand characteristics
- site conditions
- desired future forest condition (composition, structure)
- presence of advance growth
- amount and distribution of slash, and
- roadside landing requirements.

Table 1 presents an overview of the most common logging methods in northern Ontario, and their applicability to specific forest management planning considerations.

The species composition, age structure, and successional relationships of boreal mixedwood stands may present opportunities to implement modified harvest methods. These include strip cutting to promote regeneration in the harvested strips, two-stage harvesting with the removal of the hardwood (usually aspen) overstory and protection of the conifer understory, and patch cutting (Navratil *et al.* 1994; Pulkki 1996). Full-tree, tree-length, and cut-to-length logging can all be adapted for use with these modified harvest methods.

Table 1. Criteria for selecting a logging method.

Criteria	Full-tree logging	Tree-length logging	Cut-to-length logging
Silvicultural system	Applicable to the clearcut and modified clearcut silvicultural systems.	Applicable to the clearcut and modified clearcut silvicultural systems and, to a lesser extent, the shelterwood system and thinning treatments (Pulkki 1997).	Applicable to the clearcut, modified clearcut, selection, and shelterwood silvicultural systems, as well as mid-rotation thinnings (Pulkki 1997).
Forest stand characteristics	Suitable for stands with smaller trees due to the multiple tree-handling ability of feller-bunchers. Inefficient for sawlog production unless tops (material under 15 cm diameter) can be used for pulpwood (DeByle and Winokur 1985).	Reduced soil disturbance promotes post-harvest vegetation that closely resembles pre-harvest vegetation (Dyrness 1974).	Reduced soil disturbance promotes post-harvest vegetation that closely resembles pre-harvest vegetation (Dyrness 1974).

Criteria	**Full-tree logging**	**Tree-length logging**	**Cut-to-length logging**
Site conditions	On sites with marginal fertility (i.e., dry or shallow) removal of slash may result in nutrient loss (Archibald *et al.*1997; Gingras 1994; Pulkki 1997). Potential for rutting and compaction on saturated, fine-textured soils during the frost-free period. Harvesting on frozen ground or use of low-impact equipment is recommended when soils are saturated. More site disturbance since machines travel over a greater proportion of stand (Gingras 1994).	Increased slash reduces risk of soil erosion on susceptible sites. Potential for rutting and compaction on saturated, fine-textured soils during the frost-free period. Harvesting on frozen ground or use of low-impact equipment recommended when soils are saturated.	Single-grip harvester travels on slash mats in the cutover protecting site from damage. Potential for rutting and compaction on saturated, fine-textured soils during the frost-free period. Harvesting on frozen ground or using low-impact equipment is recommended when soils are saturated.
Amount and distribution of slash	No slash is left in the cutover; all slash is located at roadside.	Limbs and tops are left in the cutover. Slash is generally spread in piles throughout cutover.	Produces the greatest amount of slash. Slash is spread throughout cutover or piled in windrows.
Desired future forest	Reduced slash facilitates site preparation, planter access, vegetation management treatments; improves seedbed/plantable spot availability and receptivity. Reduced slash promotes rapid soil warming, faster nutrient release, and aspen suckering. Soil disturbance increases invasion by off-site, wind-borne seeds (e.g., fireweed, Canada blue-joint grass) and the germination of seed banking species (e.g., pin cherry, raspberry) (Dyrness 1974; Myketa *et al.*1998). Soil surface is exposed to greater temperature extremes, which can result in injury or death of conifer seedlings.	Increased slash reduces soil temperature decreasing aspen suckering. Increased slash reduces effectiveness of site preparation treatments, availability and receptivity of plantable spots/seedbed, and planter accessibility. Cone-bearing tops left on site may contribute to natural jack pine and, to a lesser extent, black spruce regeneration (Bowling and Goble 1994; Bowling *et al.*1997). Slash can benefit shade-tolerant seedlings such as white spruce and balsam fir by moderating microclimate (McInnes and Roberts 1991). Decreased disturbance intensity reduces sucker (e.g., aspen) and sprout (e.g., alder, hazel, mountain maple) production (Buse and Bell 1992). Reduced disturbance of the L, F, and H layers will inhibit invasion by off-site, wind-borne seeds (e.g., fireweed, Canada blue-joint grass) as well as suppressing the germination of seed-banking species (e.g., pin cherry, raspberry) (Dyrness 1974; Myketa *et al.*1998).	Increased slash reduces soil temperature decreasing aspen suckering. Concentration of slash in rows by single-grip harvesters may result in uneven distribution of aspen suckers. Increased slash reduces effectiveness of site preparation treatments, availability and receptivity of plantable spots/ seedbed, and planter accessibility. Use of single-grip harvesters and forwarders in small diameter stands promotes regeneration in seed-tree cuts (Howard et al. 1993). Cone-bearing tops left on site may contribute to natural jack pine and, to a lesser extent, black spruce regeneration (Bowling and Goble 1994; Bowling *et al.*1997). Slash can benefit developing shade-tolerant seedlings, such as white spruce and balsam fir, by moderating microclimate (McInnes and Roberts 1991). Decreased disturbance intensity reduces sucker (e.g., aspen) and sprout (e.g., alder, hazel, mountain maple) production (Buse and Bell 1992). Reduced disturbance of the L, F, and H layers will inhibit invasion by off-site, wind-borne seeds (e.g., fireweed, Canada blue-joint grass) as well as suppressing the germination of seed-banking species (e.g., pin cherry, raspberry) (Dyrness 1974; Myketa *et al.*1998).

Criteria	Full-tree logging	Tree-length logging	Cut-to-length logging
Presence of advance growth	Potential for crushing and breaking advance growth since machines travel over a greater proportion of cutover (Gingras 1994). Feller-bunchers equipped with continuous saw heads can sever advance growth (Archibald *et al.* 1997; Pulkki 1996).	Can be used to protect advance growth if right equipment and cut layout are used. Feller-bunchers equipped with continuous saw heads can sever advance growth (Archibald *et al.* 1997; Pulkki 1996).	Provides good protection of advance growth since fewer passes are made across cutover (Gingras 1994). Slash mats from single-grip harvesters help to protect advance growth.
Roadside landing requirements	Large roadside landing area required, reducing productive forest area.	Moderate roadside landing area required.	Minimal roadside landing area required.

Navratil *et al.* (1994) report that in a 2-stage harvesting operation in an aspen-white spruce stand, feller-bunchers working with grapple skidders caused minimal damage to residuals growing between skid trails because the operator could control felling direction and bunching location. The single-grip harvesters used in the cut-to-length operation damaged significantly more residual stems than the feller-bunchers because the mature overstory stems were felled among the immature residuals. However, the narrower stance of single- and double-grip harvesters resulted in less damage to trailside residuals than was caused by feller-bunchers. Protection of the understory increased with both feller-bunchers and single-grip harvesters as more intensive protection measures were adopted (i.e., operating felling and skidding equipment on the same trails, leaving rub posts alongside skid trails, delimbing stems before skidding, and re-piling decks before delimbing). Pulkki (1996) states that full-tree and tree-length logging result in approximately the same amount of damage to residuals (10-20% is not uncommon). Current mechanized cut-to-length methods cause less damage (as low as 2%) and are well-suited to partial and small patch harvesting. In addition, a cut-to-length method using forwarders to move wood to roadside requires less road and creates less soil disturbance (Figure 5).

Implementing a Logging Method

Resource managers must implement the selected logging method in an effective and efficient manner, while simultaneously protecting the site and ensuring the successful establishment of desirable post-harvest regeneration. The effects of logging on a site depend on many factors (Archibald and Arnup 1993), including:

- felling equipment
- transportation equipment
- maximum off-road transport distance of equipment
- access road requirements
- season of harvest
- cut layout
- soil bearing strength, and
- ground pressure from equipment.

Felling and transportation equipment vary in their effects on the site and the future stand, depending on the logging method. Table 2 presents a summary of the equipment variables to consider when planning a logging operation.

Additional factors to consider when implementing a logging method include:

Season of harvest

Logging on frozen soil reduces the amount of site and soil disturbance minimizing the potential for compaction and rutting damage, erosion, and disruption of drainage patterns (Archibald *et al.*1997). Low levels of mineral soil

Table 2. Equipment variables for 3 logging methods.

Component of Logging Operation	Full-tree and Tree-length	Cut-to-length
Felling method	Feller-bunchers most common. Feller-bunchers with continuous saw heads may sever competitive non-crop species and cause rapid resprouting. Saw heads may also sever or crush advance growth. Feller-bunchers may damage butts of sawlog trees and residuals (Mattson 1988; Pulkki 1997). Feller-bunchers can cut wood on sensitive areas (e.g., wet or steep slopes) and then place piles on less sensitive areas where skidders can pick them up.	Chainsaws; single-grip harvesters. Single-grip harvesters cannot be used for large aspen. Single-grip harvesters promote site protection by travelling on slash mats produced by cutting trees in front of machine.
Transportation method	Cable, grapple, or clam-bunk skidders. Clam-bunk skidders have booms that can reach 7 metres to the side; therefore cause less site disturbance because they work on skid trail. Clam-bunk skidders can handle larger loads; therefore require fewer passes across cutover. Cable skidders can use winch to pull wood across wet areas.	Forwarders. Forwarders create less soil disturbance since trees are not dragged but fully supported to roadside. Forwarders work along access trails, minimizing site disturbance.
Maximum off-road transport distance	Cable and grapple skidders - 300 metres; clam-bunk skidders - 600 metres (Pulkki 1997).	Forwarders - 600 metres.
Access road requirement	Cable and grapple skidders - 16.7 m.ha^{-1}; clam-bunk skidders - 8.3 m.ha^{-1} (Pulkki 1997).	Forwarders - 8.3 m.ha^{-1} (Pulkki 1997).

Figure 5. Cut-to-length wood being transported by forwarder.

disturbance during winter harvesting also maintain an intact organic layer, thereby inhibiting invasion by non-crop seed-banking and wind-borne species (Buse and Bell 1992; Myketa *et al.*1998). Compacted, intact organic layer associated with lowland black spruce will provide a receptive seedbed for black spruce and tamarack. However, Buse and Bell (1992) report that winter logging stimulates suckering by aspen and sprouting by green alder. Logging on sites with a snow cover helps to protect advance regeneration by preventing crushing and breaking by equipment (Figure 6).

Winter harvesting can help to preserve the nutrient capital on nutrient-poor deciduous sites (Archibald *et al.*1997). If summer logging occurs in areas with organic soil, equipment with high flotation tires should be used.

Cut layout

Effective cut layouts can restrict site disturbance to logging and skidding trails. Skid trails should be as straight and narrow as possible, although excavator-type feller-bunchers require wider (>3 metres) trails (Navratil *et al.*1994). Skid trails should not be located in wet pockets and other sensitive areas such as moderate to steep slopes (Archibald *et al.*1997). Locate main trails in areas with the highest load-bearing capacity (Archibald *et al.*1997). Leave rub posts at tight corners on skid trails to reduce damage to residuals (Navratil *et al.*1994). Feller-buncher operators should cut swaths perpendicular to the haul road, and pile the felled trees in a fish-bone pattern along the cut trail. The skidder operator can then pick up the piles and remove the trees along the cut trail, thereby limiting site disturbance.

Cut layout also affects the loss of productive land to road construction (Archibald *et al.* 1997). Careful road location, location of landings on non-productive areas, and using a backhoe instead of a bulldozer to minimize width of the disturbed area, are all effective ways to prevent the loss of productive land.

Soil-bearing strength/ground pressure from equipment

Soil-bearing strength and ground pressure from logging equipment directly influence the amount of physical damage (i.e., rutting and compaction) that occurs on a site during a logging operation. Soil compaction following full-tree logging is greater than that following tree-length logging (Pulkki 1997).

Equipment with wide tires or tracks exerts less pressure than conventional equipment of the same weight, and consideration should be given to using this type of equipment in areas with low soil-bearing strength. The load bearing capacity of soil can also be increased through the use of slash mats on heavy traffic areas; cut-to-length logging using single-grip harvesters that place the slash in front of the machine is best for sites with low weight-bearing capacity (Archibald *et al.*1997).

Management Interpretations and Strategies

Management interpretations and strategies will assist the resource manager in selecting a logging method to achieve desired management outcomes for boreal mixedwood sites. For example, northwestern Ontario boreal mixedwood sites that support healthy, productive mixedwood stands are:

Figure 6. Winter harvesting with high flotation equipment.

- ES 19 Hardwood-Fir-Spruce Mixedwood on Fresh, Sandy-Coarse Loamy Soil
- ES 21 Fir-Spruce Mixedwood on Fresh, Coarse Loamy Soil
- ES 23 Hardwood-Fir-Spruce Mixedwood on Moist, Sandy-Coarse Loamy Soil
- ES 27 Fir-Spruce Mixedwood on Fresh, Silty-Fine Loamy Soil
- ES 28 Hardwood-Fir-Spruce Mixedwood on Fresh, Silty Soil
- ES 29 Hardwood-Fir-Spruce Mixedwood on Fresh, Fine Loamy-Clayey Soil
- ES 30 Black Ash Hardwood on Fresh, Silty-Clayey Soil
- ES 32 Fir-Spruce Mixedwood on Moist, Silty-Clayey Soil
- ES 33 Hardwood-Fir-Spruce Mixedwood on Moist, Silty-Clayey Soil

In northeastern Ontario, those ecosites which support healthy, productive mixedwood stands include:

- ES3 White Birch-Trembling Aspen-Black Spruce-Coarse Soil
- ES6f Black Spruce-Trembling Aspen-Fine Soil
- ES6m Trembling Aspen-Black Spruce-Balsam Fir-Medium Soil
- ES6c Trembling Aspen-Black Spruce-Jack Pine-Coarse Soil
- ES7f Trembling Aspen-White Spruce-White Birch-Fine Soil
- ES7m Trembling Aspen-White Birch-Medium Soil
- ES7c Trembling Aspen-White Birch-Coarse Soil
- ES10 Trembling Aspen-Black Spruce-Balsam Poplar-Moist Soil

The interpretations and strategies are based primarily on information found in the Silvicultural Guide to Managing for Black Spruce, Jack Pine and Aspen on Boreal Forest Ecosites in Ontario, Book II (OMNR 1997). A Mixedwood guide is planned for 2003.

Resource managers can use the management interpretations and strategies, presented in Table 3, in conjunction with a knowledge of site and stand conditions to plan effective logging operations.

Table 3. Management interpretations and strategies for boreal mixedwood sites in northern Ontario.

Stand and Site Characteristics	Management Objective	Logging Method			Comments
		Full-tree	Tree-length	Cut-to-length	
Conifer-dominated mixedwood stands Fine- textured soils	1. Maintain current species composition	++	++	-	Harvest on frozen ground to minimize compaction and rutting. Slash on site from tree-length or cut-to-length logging may reduce soil temperature and aspen suckering production. Windrowed slash from single-grip harvesters may result in uneven distribution of aspen suckers. Heavy slash will reduce seedbed availability and receptivity. Careful logging techniques will result in a mixedwood stand with a significant balsam fir component. These sites can also be managed to support white birch and/or white spruce in combination with balsam fir. Black and white spruce seed trees, combined with site preparation to expose mineral soil, can augment conifer regeneration levels. Use prescribed fire after harvesting to eliminate dense balsam fir advance growth and create plantable spots or stimulate aspen suckering.
	2. Increase conifer component	+++	++	-	
	3. Increase hardwood component	+++	+	+	
Coarse- textured soils	1. Maintain current species composition	++	++	-	Slash on site from tree-length or cut-to-length logging may reduce soil temperature and aspen sucker production. Windrowed slash from single-grip harvesters may result in uneven distribution of aspen suckers. Careful logging techniques will result in a mixedwood stand with a significant balsam fir component. These sites can also be managed to support white birch and/or white spruce in combination with balsam fir. Black and white spruce seed trees, combined with site preparation to expose mineral soil, can augment conifer regeneration levels. Use prescribed fire after harvesting to eliminate dense balsam fir advance growth and create plantable spots or stimulate aspen suckering. Harvest on frozen ground to minimize compaction and rutting.
	2. Increase conifer component	+++	++	-	
	3. Increase hardwood component	+++	+	+	

Stand and Site Characteristics	Management Objective	Logging Method			Comments
		Full-tree	Tree-length	Cut-to-length	
Hardwood-dominated mixedwood stands Fine-textured soils	1. Maintain current species composition	+++	+++	+++	High levels of competition will develop following logging. Potential for heavy slash loading will reduce soil temperature and sucker production. The main post-logging species is balsam fir due to a lack of spruce seed, reduced seedbed receptivity, and smothering by hardwood litter. Careful logging will result in a mixedwood stand with a significant balsam fir component. These sites can also be managed to support white birch and/or white spruce in combination with balsam fir. Black and white spruce seed trees, combined with site preparation to expose mineral soil, can augment conifer regeneration levels. Use prescribed fire after harvesting to eliminate dense balsam fir advance growth and create plantable spots or stimulate aspen suckering. These sites are productive for all major tree species.
	2. Increase conifer component	+++	++	-	
	3. Increase hardwood component	+++	+++	+++	
Coarse-textured soils	1. Maintain current species composition	+++	+++	+++	Potential for heavy slash loading will reduce soil temperature and sucker production. High levels of competition will develop following logging. Low levels of natural conifer regeneration; large planting stock preferred to maintain conifer component. Use prescribed fire after harvesting to eliminate dense balsam fir advance growth and create plantable spots or stimulate aspen suckering. Careful logging will result in a mixedwood stand with a significant balsam fir component.
	2. Increase conifer component	+++	++	-	
	3. Increase hardwood component	+++	+++	+++	

+++	Highly recommended
++	Recommended
+	Conditionally recommended
-	Not recommended

Summary

Today's logging methods create considerable site disturbance, influencing not only the physical site, but also the amount and type of post-harvest vegetation. Resource managers can manage the degree of disturbance on sites allocated for harvest by selecting the logging method best suited to site and stand conditions and their management objectives.

Selecting an appropriate logging method can protect the physical site. The greatest potential for site damage in logging operations occurs during transport of cut trees to roadside. Skidders, used in full-tree and tree-length operations, drag trees from the stump to roadside, causing considerable soil disturbance; on the other hand, forwarders, used in cut-to-length logging, carry tree lengths fully supported to the roadside, reducing organic layer disturbance. In addition, damage to residuals along access trails is minimized with forwarders. Felling equipment also affects site disturbance; single-grip harvesters, commonly used in cut-to-length logging, operate on slash mats created in front of the machines, enhancing the load bearing capacity of the soil and reducing compaction and rutting problems. Whereas the potential for nutrient depletion is considerable with full-tree logging, particularly on shallow or dry sites, cut-to-length logging protects the nutrient capital of the site.

Logging method also influences post-harvest vegetation. Disturbance of the organic layer, maximized by full-tree logging, promotes the invasion of both crop and non-crop species. A post-harvest invasion of aspen may help resource managers attain management objectives for the hardwood component of future stands. Full-tree logging, with its resultant lack of slash in the cutover, may increase the conifer component of future stands. Since site preparation treatments are more effective, plantable spots are increased, and planter accessibility is improved. Cut-to-length logging, with its resultant heavy slash loadings, may reduce soil temperatures and aspen suckering, provide fewer plantable spots, and make planter access difficult. In general, researchers report that on cutovers with the least soil disturbance, post-harvest vegetation most closely resembles pre-harvest vegetation (Buse and Bell 1992; Dyrness 1974; Myketa *et al.* 1998). Cut-to-length logging will help to protect advance growth on sites where it is significant enough to achieve regeneration objectives. Full-tree logging frequently crushes and severs advance growth, and is therefore not recommended on sites where advance growth constitutes the desired future crop.

Other considerations that influence the site and future stand conditions include season of harvest, cut layout, and soil bearing strength. These components affect the potential for damage from compaction, rutting, erosion, and loss of productive land to roads.

An understanding of the ecology of the sites being managed combined with knowledge of current logging methods, and their effects on sites, will enable resource managers to prepare effective and biologically appropriate silvicultural treatment packages.

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SILVICULTURAL OPTIONS

Intensive Forest Management Considerations for Managing Boreal Mixedwood Stands in Ontario

by D. Schroeder*

> *The task of balancing the needs of forest industry while managing non-timber values within Ontario's forest management policy framework requires strategic planning...*

Introduction

Increasing timber production through more intensive forest management has become an important component of strategic forest planning in Ontario (OMNR 1999a). Silvicultural investments on boreal mixedwood (BMW) sites may offer good returns since these sites often produce higher fibre yields than other boreal site types. Vegetation communities associated with BMW sites also provide valuable non-timber resources within stands and across forested mosaics. Forest managers must consider these competing values, when deciding on how to managing these stands.

The task of balancing the needs of the forest industry while also managing non-timber values within Ontario's forest management policy framework requires strategic planning. One strategy for conserving and maintaining biological diversity is to emulate natural disturbances (OMNR 2001a). While this strategy focuses on many forest values, it does not specifically address timber production concerns (OMNR 1999a).

This note will discuss the use of intensive forest management techniques to support timber productivity in BMWs.

What is intensive forest management?

As yet, no official definition of intensive forest management (IFM) has been agreed on in Ontario; however, IFM is seen as a way to increase timber productivity (OMNR 1999a, b). Some site/tree combinations may provide optimum timber production using relatively low intensity management; thus, IFM does not necessarily imply more silviculture. However, degraded mixedwood sites may require IFM simply in order to achieve desirable species composition and regulation (Day and Bell 1988). As well, IFM may be used to manage forests for non-timber values such as wildlife habitat.

The following definition by Towill and Archibald (2000) reflects the use of the term IFM for the purpose of this note:

"IFM is the implementation of a suite of biologically effective and economically efficient forest management activities that contribute to a broad array of forest-level objectives. Intensive silviculture refers to specific treatments used to increase timber volume or value above the normal timber yield, reduce time to minimum operability, and increase average piece size."

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If the above definition is put into the context of a managed forest landscape, we may assume that boreal forests are mosaics of stands that include those (a) left to evolve on their own, (b) managed intensively to meet a broad array of forest level objectives, and (c) managed for increased yield, value, or decreased rotation. BMW stands, managed using various strategies and techniques, can play an important role in achieving (b) and (c) as discussed below.

In Ontario, intentional management of boreal mixedwoods is a relatively new strategy. Historically, pure species stands were preferred to meet timber needs. With the emphasis shifting to ecosystem management, focus on maintaining and restoring a variety of mixedwood stand conditions has increased in order to help meet a broader range of forest management goals (OMNR 2003). Based on the above, IFM techniques may be used to achieve ecosystem management goals.

Boreal mixedwood management objectives

Forest-level objectives

BMW stands may be composed of a mixture of species or a single species that succeeded following natural stand progression (Figure 1). Management of individual stand dynamics within BMW forest mosaics requires consideration of site, disturbance, and climate. Since BMWs change over time, as do all forests, the spatial patterns of forest cover types within BMW forest mosaics also change (e.g., single-species stands may merge into a mixed-species stand).

Broad-scale forest management objectives include:

- Maintaining sustainable supply of high quality timber (OMNR 1999a)
- Ensuring long-term ecosystem health by maintaining diversity within bounds of natural variation (*Crown Forest Sustainability Act*)
- Supporting multiple non-timber forest resource use

BMWs can help resource managers to meet the above objectives by:

- Providing valuable habitat for plants and wildlife across managed landscapes through strategic location of stands and timing of forest operations
- Contributing to overall wood supply through the diversity of tree species
- Affording the option of practicing alternative silviculture systems where aesthetics are an issue

Stand-level objectives

Intensive forest management has focused mainly on single species grown on economic rotations (e.g., Davis and Johnson 1987). In contrast, mixedwood management emphasizes multiple species and natural succession patterns grown on biological rotations (MacDonald 1995). How these differ is outlined below.

Objectives for single-species stands

Single-species timber production optimizes harvest cycles (Figure 2a). Stands typically consist of a desired commercial species and have a uniform structure throughout the rotation (Figure 2b). Intensifying management can lead to greater yields than produced by natural stands (e.g., Nyland 1996).

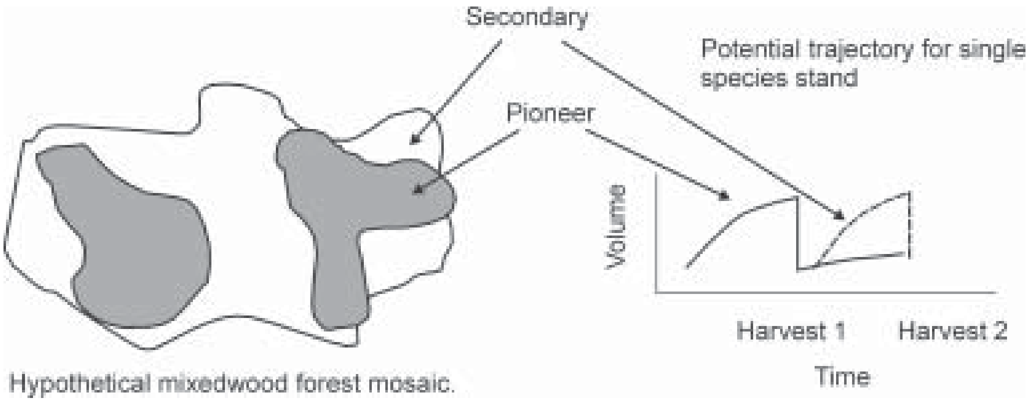

***Figure 1**. Generalized example of mixedwood objectives with single-species stands.*

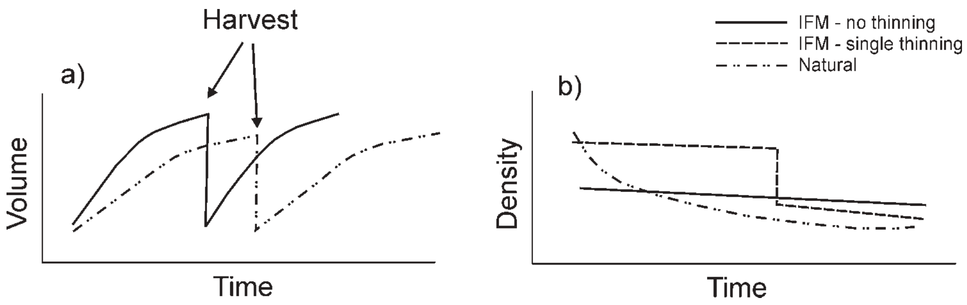

Figure 2. (a) Potential effect of IFM on volume produced in single-species stands, and (b) generalized density changes in intensively managed single-species versus natural stands.

Objectives for mixedwood stands

On the other hand, BMWs are managed based on natural succession patterns (Fig. 3a) and structural complexity (MacDonald 2000). This requires managing both overstory and understory species (Brace and Bella 1988) and can reduce the time to harvest a second crop compared to two single-species rotations (Navratil *et al.* 1991).

Stand structure on a mixedwood site following a major disturbance is characterized by a gradual decline of pioneer species (e.g., intolerant hardwood species), which are replaced by mid- and late-successional species (e.g., mid-tolerant and tolerant conifer species) (Fig. 3b). For details, refer to Arnup (1998), and Towill *et al.* (in prep.).

Comparing single-species crops with mixedwoods

A brief comparison of single species versus mixedwood management outcomes follows:

- Nutrient losses can occur in single-species conifer stands, whereas nutrient cycling in mixedwood stands can maintain or even enhance soil productivity potential (Gordon 1983). However, species utilization can affect nutrient levels following harvesting of mixedwood stands. For example, Morrison and Wickware (1996) found that removing hardwoods increased nutrient losses more than harvesting only conifers from BMW sites.
- Mixedwood management may produce two crops in less time than is required for two single-species crops (Navratil *et al.* 1991). However, the overall planning period for BMWs is longer than that for single-species crops.
- Mixedwoods may contribute more to local and broad-scale non-timber values compared to single-species stands (e.g., Welsh 1981).
- Managing BMW stands using partial cutting might allow harvesting in areas otherwise not available for harvest, for example, within viewsheds (OMNR 2001b).
- Some BMW management techniques remain in the testing stage in Ontario (e.g., MacDonald 2000) while management approaches for single-species, even-aged production are well known. Also, mixedwood management may be viewed as an added cost with unknown returns, whereas the costs of managing single-species stands are well documented. Nonetheless, the potential, for example for partial harvesting and shelterwood to reduce regeneration costs, should encourage forest managers to pursue mixedwood management.

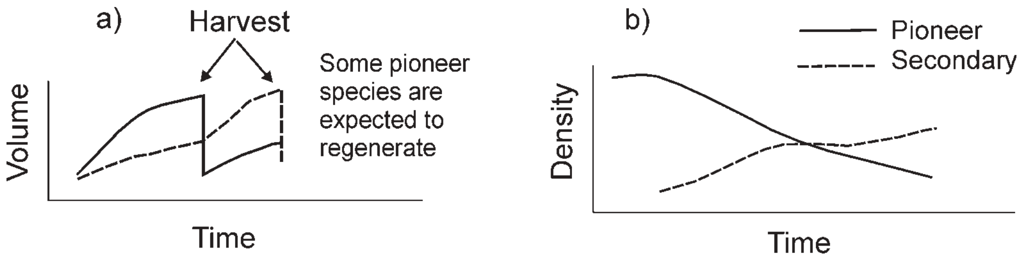

Figure 3. (a) Generalized example of mixedwood management incorporating understory, (b) Generalized example of naturally occurring stand density changes over time in boreal mixedwoods.

For details see note on economics of boreal mixedwood management (Schroeder 2003).

- Planting a mixedwood site to spruce and leaving hardwoods where conifers have failed ensures full stocking and the benefits of hardwood/conifer mixtures (Man and Lieffers 1999). Many conifer plantations in Ontario have some natural deciduous component and become mixedwoods by default (B. Klages[1], *pers. comm.*).

Strategies for BMWs within a managed forest mosaic

The abundance and spatial placement of mixedwood and single-species stands is critical to achieving biodiversity goals in forested mosaics. Forest-level planning is the first step in proactive intensive mixedwood management.

As mentioned, historical natural disturbance patterns are presently the basis for guidance for managing spatial patterns of forest cover in Ontario. Since mixedwoods often remain unburned or form partially burned islands and peninsulas within a larger fire disturbance, they can comprise an important component of post-fire spatial patterns (Cumming and Schmiegelow 2001, Kafka *et al.* 2001). However, it is not yet clear how intensively managed stands fit within landscapes where natural disturbance patterns are being emulated.

Forest planners also must consider spatial factors other than those resulting from natural disturbances, such as economics, multiple resource use, and non-timber values. For example, prescriptions to manage viewsheds may differ from those resulting from natural disturbance patterns to enhance remote wilderness businesses. Some spatial factors important to resource managers along with associated BMW management considerations are listed in Table 1.

BMW productivity

Forest managers have recognized differences in growth potential between BMW and pure black spruce stands in Ontario for some time now (Opper 1981) but BMW growth and yield data remain limited (M. Penner[2], *pers. comm.*). Evert's (1975) data indicate that deciduous stands have the highest yield potential, followed by mixedwoods, and mixed conifer stands (Figure 4).

What is not shown in Figure 4 is the potential for understory management in mixedwoods to decrease time between harvest. Also, mixedwoods may mitigate growth losses from insects, pathogens, and environmental changes because of their inherent species, age, and structural diversity (Man and Lieffers 1999). This information is not well represented in existing growth and yield studies.

Species considerations

This section presents individual tree species productivity considerations for major BMW species in Ontario that may be affected by managing them within BMW stands. Detailed discussion of BMW silviculture strategies and techniques can be found in the *Silviculture Guide to Managing Spruce, Fir, Birch and Aspen Mixedwoods in Ontario's Boreal Forest* (OMNR 2003.) and other *Boreal Mixedwood Notes* (OMNR 2000c). Specific autecology information for boreal species is also provided in other Boreal Mixedwood Notes.

Aspen

Some aspen management considerations related to mixedwood management include:

- Manage aspen stands on a pathological rotation of at most 60 years because of trunk rot vulnerability (John McLaughlin[3], *pers. comm.*). However, naturally regenerated stands are deficient in large diameter trees at this age

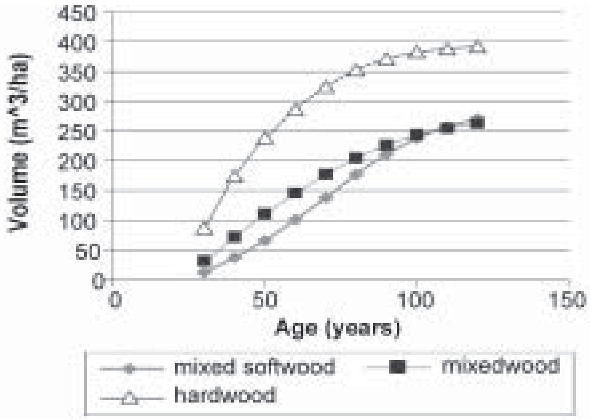

Figure 4. *Yield for North Central Ontario Forest types (n=347) (Evert 1975).*

---

[1] Bill Klages, Bowater Inc., Thunder Bay, ON

[2] Margaret Penner, Forest Biometric Consultant, Huntsville, ON

[3] John McLaughlin, Ontario Ministry of Natural Resources, Sault Ste. Marie, ON

Table 1. Spatial factors to consider when managing mixedwoods within an intensive forest management framework.

Spatial factor	Boreal mixedwood management considerations
Proximity to access roads	Some BMW management techniques, such as two-coupe harvesting, require multiple stand entries resulting in increased costs where roads have to be maintained between operations. However, an extensive permanent road network exists in Ontario (Elkie *et al.* 2000) and road and FRI data layers can be used to determine stands with potential for multiple-entry management.
Proximity to recreation areas	Recreation areas where road access is desirable may benefit from aesthetic and wildlife habitat values resulting from mixedwood management. Conversely, areas where the management objective is to limit road access may not be suitable for techniques that require multiple stand entries.
Proximity to mills	Locating stands managed intensively for fibre near mills makes economic sense. Managing these stands for BMW objectives may not be the best option if these objectives don't include maximizing timber value.
Isolation from or proximity to other forest stands and connectivity	In boreal forests, stand isolation is temporary and generally the result of spatially heterogeneous stand-replacing disturbances. Landscape planning should aim to minimize stand isolation to ensure for example cover for wildlife and seed sources for regeneration. BMWs are important in this context because they often form islands within natural disturbances and work well as travel corridors between openings.Timber supplies might be protected and management costs reduced if BMWs can be used as buffers to protect commercially valuable stands. Mitigating the effects of disturbances may be possible by strategically planning forest operations based on disturbance risk of different forest cover types (Hirsch *et al.* 2001).
Forest cover types (composition and age class)	Forest cover type abundance affects present and future wood supply and is also important for ecological reasons, especially the provision of wildlife habitat (see boreal mixedwood notes on habitat considerations, i.e., Timmermann 1998a, b, c; Weeber 1999a, b; Brown *et al.* 1999). For example, late seral BMWs would be more important where marten habitat and not timber production is the primary management objective, yet by managing BMWs across large extents, managers can support both objectives. Forest cover type abundance may also affect forest disturbances. Deciduous-dominated BMWs are less vulnerable to fire than conifer stands. Susceptibility to spruce budworm damage is influenced by stand composition (Su *et al.* 1996), and can now be assessed at a forest level using a spatial decision-support tool (MacLean and Porter 1995). Planning the location and extent of intensively managed stands has to be done with the knowledge that maintaining some mature and overmature conifer stands is necessary within a forest mosaic. As well, in a landscape where intensive silviculture is practiced, BMWs can be used to mitigate potential concerns for biodiversity.
Indices of forest cover spatial patterns **·stand size (patch)** **·core area** **·edge** **·shape** **·aggregation of stands**	Indices of forest cover spatial patterns are useful for quantifying potential wildlife habitat. For example, edge density is important to some shrub browsers such as moose. See the BMW notes on habitat considerations of individual species (Timmermann 1998a, b, c; Weeber 1999a, b; Brown *et al.* 1999), as well as the *Forest Management Guide for Natural Disturbance Pattern Emulation* (OMNR 2001a).In accordance with MacDonald's (1995) definition, an aggregation of single-species stands in small patches on a mixedwood site may constitute a BMW forest. Presumably patch mosaics within BMW sites are heterogeneous because of the variety of factors that influence regeneration composition.
Edaphic conditions **·soil depth** **·moisture** **·surficial geology** **·texture**	Knowledge of edaphic conditions aids in strategic planning for prime site (site potential independent of location) and prime land (site potential and location).Because of interactions between sites, vegetation, and disturbance, the geographic placement of soils helps planners to determine management strategies. Relationships between site and boreal vegetation types are well documented (Chambers *et al.* 1997, Sims *et al.* 1997, Taylor *et al.* 2000). Fire is also affected by site because of variable flammability among vegetation types (Kafka *et al.* 2001). Logically, wet sites and their associated cover types are less flammable than dry sites.
Policy	Forest policies are used to determine restrictions on forest activities and access to potential stands before planning treatments. For example, managing stands with BMW objectives may allow some harvesting in areas of concern prescribed by guidelines (e.g., partial harvesting is allowed in riparian zones, OMNR 1988), while some land use designations have access restrictions (OMNR 1999b).

(Steneker 1964); therefore, thinning decisions should be based on the desired product (Navratil *et al.* 1991, Rice *et al.* 2001).

- Thin aspen stands before 30 years of age to achieve best post-treatment growth response (Steneker 1967).
- Do not establish intensively managed aspen close to ungulate habitat to reduce browse damage (Weingartner 1991).
- Grow aspen on short rotations (30 years) to eventually deplete its regeneration capability (Stiell and Berry 1986) and increase potential for long-term conifer conversion. Compared to traditional methods, stand conversion to conifers may require reduced vegetation management after several short rotation aspen crops. This approach may be useful for sites with medium growth potential, where conversion with repeated tending is too costly.
- Harvesting small aspen may be cost effective if on-site chipping is used. In Ontario, site chipping is used to harvest marginal stands that have been damaged by spruce budworm (B. Klages, *pers. comm.*). However, Armillaria incidence could increase with shortened rotations.
- Maintain a partial overstory to reduce aspen sucker density (MacDonald 2000) and possibly the need for future vegetation management, if conifer reestablishment is a management objective. This may also reduce future pre-commercial thinning costs (Brown 1991).
- Use a strip thinning technique with herbicide (Figure 5). This method does not damage residual trees in overstocked conifer sites and can be used to release conifers in untreated strips in aspen stands.

Spruce

Black spruce dominates Ontario's boreal landscape, whereas white spruce is less abundant. A comparison of their response to a few key management factors are provided in Table 2.

White spruce does not naturally occur in pure stands in Ontario; therefore, growing it in stands with mixedwood objectives is preferred. Selecting white or black spruce for mixedwood management may be a trade off between growth potential and damage hazard (Figure 6).

Balsam fir

Balsam fir is a mid- to late-seral mixedwood species with an important role in BMW management. It is also used by many wildlife species (Timmermann 1998 a, b, c; Weeber 1999 a, b; Brown *et al.* 1999) but is not a preferred commercial species (MacDonald and Cormier 1998). Some mixedwood stands should be allowed to progress toward balsam fir dominance, but stand management objectives will influence the importance of balsam fir in a management strategy.

Since balsam fir regenerates abundantly following clearcutting, any wildlife habitat requirements can be easily met without management intervention. However, because of its susceptibility to spruce budworm, strategies to reduce its abundance may be necessary. Balsam fir is also vulnerable to root rot, which may affect timber supply, and increase damage to adjacent tree species.

Given a trend for increasing spruce budworm outbreaks (Howse 1995, Scarr *et al.* 2001) it seems inevitable that balsam fir will incur damage at some time during a rotation. It is not known to what extent balsam fir must be removed from a given area so that the associated hazard risks are significantly reduced. The best known control for balsam fir is fire (G. Howse[4], *pers. comm.*); under fire suppression scenarios balsam fir may proliferate. Prescribed burns can be used to limit balsam fir if it can be done in a cost-effective manner.

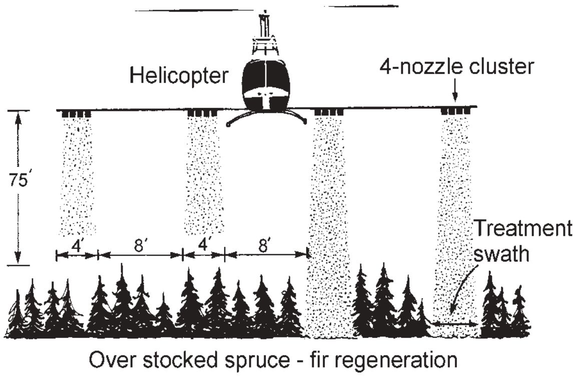

Figure 5. Aerial application for chemical thinning (adapted from MacKay 1991).

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[4] Gordon M. Howse, Leader, Forest Health Monitoring Unit, Canadian Forestry Service, Sault Ste. Marie, ON

Table 2. *Comparison of black and white spruce productivity factors.*

Factor	Comparison	Comments
Growth	**White spruce growth rates are higher.**	**Unfortunately, spruce species were not separated in traditional yield tables.**
Establishment*	**Black spruce is adapted to a wider range of site conditions and does not require exposed mineral soil for natural regeneration in lowland conditions. White spruce requires exposed mineral soil for germination.**	**Stands managed intensively for timber production should occur on the best sites, i.e., where the adaptability of black spruce is not an advantage. Intense fire or scarification is needed to expose mineral soil for white spruce seed germination.**
Shade tolerance*	**White spruce is more shade tolerant.**	**White spruce is better adapted to growing through aspen canopies.**
Budworm	**White spruce is more susceptible and vulnerable to spruce budworm and frost than black spruce.**	**Growing white spruce under a partial canopy may reduce spruce budworm hazard (Man and Lieffers 1999).**
Frost		**Maintaining a partial canopy and judicious site selection by planters (avoid low spots) can reduce frost hazard.**

*See also mixedwood autecology notes (Miller 1995 a, b)

It has been suggested that pest damage can be mitigated by aspen-spruce mixedwoods (Navratil 1991). However, the addition of balsam fir to mixedwoods may influence the severity of pest damage to other species.

BMWs and forest management planning

Challenges involved in incorporating mixedwood management into forest management plans include:

- New approach: Mixedwood management has not been formally included in management plans to date (B. Polhill[5], *pers. comm.*); however, Ontario's Strategic Forest Management Model (SFMM) allows for succession and management of understory as part of mixedwood objectives.

- Age class structure: The Forest Management Planning Manual (FMPM) does not clearly state how partially harvested stands should be classified in the inventory data in part because the inventory only includes even age classes. It may be advantageous to manage BMWs as uneven-aged stands rather than even-aged stands to better capture the structurally diverse character of mid- to late-seral successional stages. Even-aged management models do not account for multi-aged structures, hence discounting many potential ecological and economic benefits.

- Location: Pre-harvest silviculture surveys provide resource managers with site information needed for planning silvicultural treatments. For example, stands with abundant understory conifers are good candidates for partial cutting. Not all stands scheduled for harvesting need to be intensively surveyed. Local knowledge, aerial photography, and spatial data allow managers to stratify their landbase for stands that merit ground surveys. Another method to assess understory lies with satellite-based imagery. Studies using Landsat Thematic Mapper data in northern Alberta (Ghitter *et al.* 1995, Hall *et al.* 2000) showed 74% and 71% accuracy, respectively, indicating that classified data of this kind is useful at broad strategic levels, but not useful for operational inventory/planning needs.

Knowledge gaps

- *Prime sites*: Fine scale prime site data are needed to ensure returns on intensively managed mixedwoods.
- *Inventory*: Include understory and soils information in forest inventories.

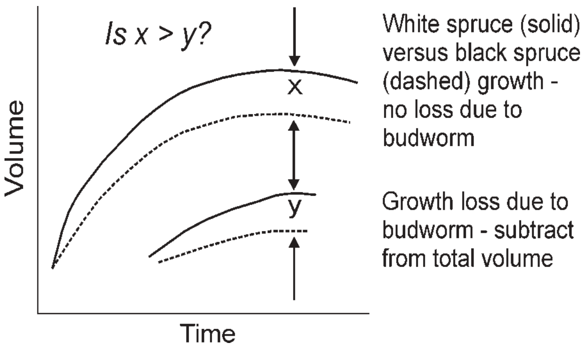

Figure 6. *Possible yield trade off between white and black spruce in the event of spruce budworm damage.*

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[5] Brian Polhill, Forest Management Planning Improvement Specialist, OMNR, Sault Ste. Marie, ON

- *Growth and yield*: Better growth and yield data are needed for plantations (pure or mixedwood), for pre-commercial and commercial thinning, as well as for losses due to pest and pathogens.
- *Techniques*: Test BMW management techniques being used in other boreal forests to demonstrate whether or not they work in Ontario.
- *Planning*: Need a better understanding of influence of climate, economics, market conditions, and probability of plantation success to strategically plan IFM locations and techniques.

Conclusions

BMW sites are highly productive for both timber and other values. These sites can be managed to support multiple forest values. As a first step in the planning process, spatial analyses are needed to identify areas where:

- BMWs can maintain desired levels of broad-scale forest diversity.
- Intensified silviculture (in pure and BMW stands) is appropriate and viable.
- Policies affect forest management and silvicultural options. Some silvicultural techniques combined with BMW objectives will allow harvesting within areas that would otherwise be unavailable for forestry.
- Long-term roads (now common across the managed boreal region) will allow low-cost repeated entry to stands for management techniques such as partial harvesting.

Species-specific considerations in intensively managed BMWs, with timber production as the goal, may differ from single-species stands as follows:

- Except for habitat trees, grow aspen on less than 60-year rotation.
- Since white spruce generally produces greater yield than black spruce, emphasize the former species in BMWs.
- Minimize balsam fir abundance.

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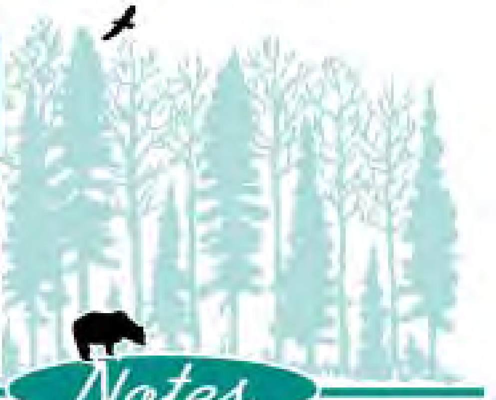

Site Preparation Strategies to Assist the Regeneration of Boreal Mixedwood Sites

C.L. Palmer and W.D. Towill[1]

> *The type, intensity, severity, and distribution of seedbed disturbance resulting from site preparation influences the likelihood of achieving a desired future mixedwood stand condition...*

Introduction

Silvicultural systems and treatments that result in partial canopy removal are being considered for managing Ontario's boreal mixedwoods. The resulting stand structure and need for specific understory environmental conditions favourable to the regeneration and growth of white (*Picea glauca* (Moench) Voss) and black spruce (*Picea mariana* (Mill.) B.S.P.) will make effective site preparation a challenge and will necessitate access to a broader array of tools and approaches than those currently used in Ontario.

Mixedwood site and stand conditions are an important element of Ontario's boreal forest, occurring on over 52% of the forested area (Towill *et al.* 2004 a). In recent decades, as demand for forest-related products and services has both increased and changed, Ontario's boreal forest industry has seen a marked change from management of almost exclusively conifer-dominated conditions towards management of both hardwood and mixed-species conditions.

The historic focus on conifer species often resulted in boreal mixedwood stands being clearcut and converted to conifer-dominated plantations. Partial harvesting or high-grading commonly occurred where other species in the boreal mixedwood condition were unmerchantable. Recent improvements to 'traditional' mixedwood silviculture that include retaining some of the original overstory (e.g., selection systems, shelterwood systems, compositional treatments, or pre-commercial thinning) have been motivated by changes in utilization of forest resources and an increased understanding of species ecology and forest succession (Navratil *et al.* 1991).

Ontario's Crown Forest Sustainability Act (CFSA) (Statutes of Ontario 1995) and Ontario's Forest Management Planning Manual (OMNR 1996) both identify that large, healthy, diverse and productive forests are essential to the environmental, economic, social and cultural well-being of Ontario both now and in the future. The CFSA also requires that forest practices (including renewal) emulate nature.

Forest renewal involves some combination of site preparation and regeneration treatments. Site preparation disturbs the forest floor, upper soil horizons, and/or vegetation prior to regeneration to create receptive microsite conditions for seed germination and/or seedling survival and growth.

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Ontario

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Site preparation to create microsites suited to the natural or artificial regeneration of desired tree species can improve regeneration success (Sutherland and Foreman 1995). Shade tolerant spruce and balsam fir (*Abies balsamea* (L.) Mill.) survive best on low porosity seedbeds that have high moisture retention and hydraulic capacity (i.e., where water can rise freely via capillary action). Studies in western Canada have indicated that seedbed preparation to expose mineral soil is essential for ensuring natural white spruce regeneration (Phelps 1951; Crossley 1955; Quaite 1956; Lees 1970; Waldron 1966; Hughes 1967; Kolabinski 1994; Waldron and Kolabinski 1994; Bella and Gal 1995).

Microsite quality, its continued availability during seedling recruitment, and the growth of newly established spruce and fir seedlings may be compromised by the localized presence and competitive vigour of non-crop vegetation. The inherent fertility of Ontario's boreal mixedwood soil and site conditions (Morris 2003) supports increased stand-level species and structural diversity compared to other boreal forest conditions (Taylor and Arnup 2003a, b). The phenological attributes, reproductive strategies, and juvenile growth characteristics of many mixedwood tree, woody shrub and plant species make them preferential competitors for growing space, light (McKinnon and Kayahara, 2003), moisture, and nutrients compared to the slower growing spruce seedlings.

The intensity, severity, and distribution of the seedbed disturbance caused by site preparation will influence the vigour and abundance of competetive species, and thus post-disturbance stand composition, structure, and development, and therefore the success of a forest manager in achieving the desired future mixedwood stand condition (MacLean 1960, Scarratt 1992). Post-harvest boreal mixedwood stand development in relation to disturbance type, intensity and frequency is reviewed by Arnup (1998a) and Towill *et al.*(2004 b).

This note provides an overview of site preparation techniques and their potential application to boreal mixedwood silviculture and management in Ontario. Factors that may influence the choice of site preparation methods are also discussed.

General Applications and Considerations for Site Preparation

Site preparation is regularly considered during the development of silvicultural ground rules (SGRs) and associated treatment packages in each forest management plan in Ontario (OMNR 1996). Silvicultural treatment packages describe the range of acceptable site-specific treatments (harvest, renewal, tending) for a given management unit that resource managers can apply to achieve the desired or target future forest condition. These treatments can be applied throughout the life of a forest stand.

The main categories of site preparation are manual, mechanical, chemical, and prescribed burning. Each can be used alone, or in combination, to assist in achieving species composition, stand structure, and productivity objectives following harvest.

The goal of site preparation is to create sufficient numbers of suitable, well-spaced microsites for the recruitment, survival and growth of seedlings, either planted or natural (von der Gönna 1992). More specifically, site preparation is used to create suitable substrates (texture distribution and moisture retention) and to promote suitable above- and belowground microclimatic conditions.

This is accomplished by:

- reducing the amount of organic matter
- exposing or cultivating mineral soil
- reducing compaction or improving drainage and aeration of surface soil
- redistributing, realigning and, in some cases, reducing slash
- reducing or suppressing competing vegetation

Site preparation activities may also (Sutton 1985, Kennedy 1988, Sutherland and Foreman 1995, OMNR 1998b) be used to:

- improve planter access
- reduce the hazard from fire
- reduce the need for subsequent tending operations
- reduce overall establishment costs

When improperly applied, site preparation treatments can have negative effects, including:

- increased availability and receptivity of seedbeds suitable for wind-dispersed seed of competitive non-crop species
- increased resprouting of undesired hardwood trees and woody shrubs (MacKinnon and McMinn 1988)
- loss of nutrients through displacement or leaching
- increased soil drying
- increased soil erosion and compaction (Corns 1988)
- increased frost heaving
- increased damage to advance growth
- decreased species diversity

Other factors influencing the efficacy of the treatment includes local site and stand conditions, the timing, intensity, and severity of the site preparation disturbance in relation to site characteristics, and the silvics of crop and non-crop vegetation (Table 1).

The resource manager's choice of site preparation treatment and timing in relation to site and stand conditions is critical to avoiding possible negative effects (OMNR 1998a). The following physical site limitations affect the choice of site preparation methods (OMNR 1998a):

- depth of the forest floor
- soil depth and texture
- moisture regime
- coarse fragment content and bedrock exposure
- number and distribution of wet pockets within otherwise suitable areas
- erosion hazard
- topography
- cover and depth of residual slash and stumps
- number and distribution of residual trees
- size of treatment area,
- access

External factors include available time, labour, equipment, and resources, as well as any restrictions imposed by law or policy (Sutton 1985).

The interval between site preparation and seeding or planting of the conifer crop species also influences the success regeneration efforts. Microsites can either degrade over time or mature and be improved after a period of settling or weathering. Encroaching non-crop vegetation often competes with crop trees for available resources, such as moisture and nutrients (Sutherland and Foreman 1995). In boreal mixedwood conditions, the reestablishment of an aspen (*Populus* spp.) leaf litter layer, which impedes germination of desired crop species, can occur in the same growing season as mechanical site preparation.

Table 1. *Major silvicultural characteristics of crop tree species occurring in boreal mixedwood stands (from Delong 1991).*

Characteristic	Shade Tolerant Species			Shade Intolerant Species		
	Black spruce	White spruce	Balsam fir	Jack pine	White birch	Aspen
Regenerates under closed canopy conditions	L	H	H	L	L	L
Regenerates after light disturbance	L	L	L	L	H	H
Regenerates after heavy disturbance	H	H	H	H	H	H
Susceptible to damage by fire	H	H	H	H	H	H
Rate of juvenile growth	L	L	M	M	H	H
Susceptible to insect damage	L	L	H	M	L	H

Rating: L - low, M - moderate, or H - high

Site Preparation Methods

Site preparation can be carried out either pre- or post-harvest, using manual or motor-manual techniques, mechanical equipment, chemicals (herbicides) (Rudolf and Watt 1956), prescribed burning (Van Wagner 1993, McRae *et al.* 1994), or some combination (Table 2).

Pre-harvest site preparation can be effective for controlling vegetation on sites targeted for natural regeneration. Ideally, pre-harvest site preparation should occur in conjunction with a good seed year so that suitable microsites of sufficient extent, distribution, and quality are available immediately prior to seed release. Natural regeneration from seed requires the successful completion of a chain of events involving flowering, cone development, seed dispersal, germination, establishment and early seedling growth. If this chain is broken (e.g., drought limits seedling establishment), regeneration failure and a delay in renewing the stand can result. Success can be achieved when a good seed year is combined with a suitable seedbed and adequate moisture during the growing season. Once the target crop tree species is regenerating, options for further site preparation are restricted by the need to protect these seedlings (Wagner and McLaughlan 1996). Ensuring natural regeneration prior to harvest helps to maintain the genetic potential of a stand (OMNR 1998a).

Post-harvest site preparation can be used with both natural and artificial regeneration. Its primary objective is to disturb the forest floor sufficiently to improve post-harvest establishment and survival of germinants and/or planted stock. This may involve (Brand 1991):

- increasing nutrient mineralization rates (increasing nutrient availability)
- increasing soil temperature
- improving aeration and drainage
- suppressing competing vegetation

Scarification may be necessary to ensure natural or artificial seeding success at canopy transition or gap-stage (i.e., when the stand opens up through mortality and windthrow) because insufficient suitable low porosity seedbeds are available. Scarification techniques to ensure successful vegetative reproduction of trembling aspen (*Populus tremuloides* Michx.) are described by Bella (1986), Doucet (1989), Bates *et al.* (1993) and Lavertu *et al.* (1994).

Post-harvest site preparation both facilitates seed dispersal by distributing the cone-bearing slash of serotinous, e.g., jack pine, or semi-serotinous, e.g., black spruce, species over newly prepared seedbeds during site preparation operations and improves access for ease of planting or direct seeding.

Timing post-harvest site preparation with a good seed year is also critical if natural regeneration of the conifer component is desired since competing vegetation quickly invades many sites disturbed by logging. If the site is to be planted, site preparation should occur immediately before planting (OMNR 1998a). Seedbed and microsite creation on any site are reduced in both extent and quality as the amount of residual stand cover, residual slash cover and depth, rock cover, and number of stumps increase (Kelertas 1978). Site preparation treatment intensity must be relative to the type and amount of competing vegetation and the requirement for either seedbed or planting sites (Smith 1986, White

***Table 2**. Comparative effects of common site preparation methods (adapted from Stewart 1978).*

Method	Removes debris	Reduces competition	Exposes mineral soil	Mixes organic and mineral soil
Manual	ü	ü	ü	ü
Mechanical	ü	ü	ü	ü
Prescribed burning	ü	ü	ü	
Chemical		ü		
Combination	ü	ü	ü	ü

2004). The four main categories of site preparation: manual, mechanical, chemical, and prescribed burning, are described below.

1. Manual Site Preparation

Manual

Manual site preparation involves workers using hand tools, such as mattocks, grub hoes, axes, brush hooks, shears, Sandviks, or machetes to prepare the site for seeding and planting, or for additional site preparation treatments such as chemical applications (herbicides) or prescribed burning. Harvey *et al.* (1998) describe available manual tools and their use. Although site preparation using manual tools means that a range of sites and site conditions can be accessed, it is costly, labour intensive, and may cause rapid regrowth of sprouts from non-crop species.

Other manual site preparation techniques include boot screefing and manual trampling or binding of competing vegetation. Boot screefing is a common manual site preparation technique used in both partial harvest and clearcut conditions on boreal mixedwood sites, usually where the forest humus layer is less than 5 to 10 cm thick. Boot screefing prevents damage to advance growth and residual crop trees and minimizes disturbance of the seedbank and the organic-mineral soil interface.

Experimental manual trampling or binding of competing vegetation has been attempted to reduce competitive woody shrubs on boreal mixedwood sites subject to partial cutting. Aubin and Messier (1999) and Kneeshaw *et al.* (1999) describe experimental treatments where patches of mountain maple (*Acer spicatum* Lam.) in and around areas of regenerating fir or spruce trees in the understory of aspen and jack pine stands were trampled. Preliminary results indicate that trampled mountain maple stems are slow to regain their size or dominance in the understory.

Motor-manual

Motor-manual tools can be used where biological, operational, or financial constraints make conventional site preparation methods unfeasible. These tools can include brush and chain saws (Harvey *et al.* 1998), as well as motor-manual scarifiers mounted on brushsaws. These scarification tools enable spot scarification under various levels of canopy retention. Several motor-manual scarification devices are evaluated by Cormier (1989). Site conditions, including type and abundance of ground vegetation, determine the efficacy of brushsaw-mounted scarifiers, and dictate the choice of the most appropriate scarifier attachment. As with manual site preparation, cost is a limiting factor and cutting can cause rapid regrowth of some species from dormant basal buds, reducing effectiveness on some sites.

2. Mechanical Site Preparation

Mechanical site preparation involves the use of machinery with self-propelled prime movers to modify a site to provide favourable conditions for artificial regeneration and/or to improve access (Smith 1986, Sutherland and Foreman 1995). This type of site preparation exposes and mixes more of the soil than manual or motor manual techniques.

Mechanical site preparation treatments are broadly classified into 5 groups: screefing (upland), inverting, trenching, mixing, and sub-soiling (for details see Table 3). Sutherland and Foreman (1995) provide further guidance as to the classification of site preparation equipment into each class. Where removal of brush is the primary objective, mechanical brushing tools (described by Harvey *et al.* 1998) can also be used for site preparation.

Mechanical site preparation alone generally provides only short-term control of competing vegetation, so it is often combined with one or more herbicide applications. Potential negative effects of mechanical site preparation include increased soil erosion or compaction (McLaughlan 1992), accelerated nutrient depletion, decreased long-term soil productivity (MacKinnon and McMinn 1988), increased mineralization and nitrification (Vitousek and Matson 1985, Fox *et al.* 1986, Smethurst and Nambiar 1990, Vitousek *et al.* 1992, Munson *et al.* 1993), reduced available phosphorus (Krause and Ramlal 1987, Schmidt *et al.* 1994) and reduced nitrogen and carbon in surface soils (Tuttle *et al.* 1985, Munson *et al.* 1993, Schmidt *et al.* 1994). MacDonald *et al.* (1996) observed that improved foliar nutrient status of planted white spruce occurred shortly after site preparation, but that the effect was short lived.

***Table 3**. Mechanical site preparation (SIP) techniques used on boreal mixedwood sites in Ontario (Dominy 1987, Bell et al. 1992, Hallman 1993, Sutherland and Foreman 1995, OMNR 1998a).*

	Screefing (Upland)	Inverting	Trenching	Mixing
Goal	• removal or displacement of the organic layer to expose and/or lightly scarify the underlying mineral soil (can be done in spots, in a series of patches, or as a broadcast treatment)	· organic layer is inverted but left intact or is broken over the adjacent and undisturbed LFH layer · either with or without the underlying mineral soil cap · result is screefed or scalped spot or strip, and can include mounded mineral soil over mineral soil and/or mounded mineral soil over inverted LHF (duff) · used to exclude major competitors and create elevated microsites that provide tree seedlings with potentially higher soil temperatures, better aeration, and well-drained conditions	· organic layer and some underlying mineral soil are removed and deposited in berms beside the resulting trench · layers are in a roughly mixed state over the undisturbed forest floor beside the trench	· incorporation of organic layer into the underlying mineral soil · mulches vegetation and slash on-site
Equipment used	· tractor-mounted blades or V-blades · light barrel drags · anchor chains or tractor pads · blades/blade attachment (i.e. blade rakes, Young's teeth) · plows · disc or cone trenchers on shallow setting · patch or spot scarifiers · shearblades	· disc trenchers - spot inverting - continuous inverting	· disc trenchers · cone trenchers · heavy barrel drags	· agricultural-type discs · bedding plows · rotary mixers
Timing or other considerations	· avoid extensive removal of organic material, particularly on infertile, coarse-textured soils with a thin organic layer, or on silty or clayey soils prone to glazing (closure of soil pore structure) or frost heaving · useful where erosion may be a concern	· mounded mineral soil may be prone to periodic desiccation	· side berms may be prone to periodic desiccation	· coarse mixing may encourage resprouting of non-crop vegetation
Limitations	· not effective where build-up of slash is large	· lower productivity where there are large boulders or excessive slash · caution required to avoid damage to residual trees	· not effective where there are large boulders · caution required to avoid damage to residual trees	· productivity lower on sites with excessive slash · unsuitable for sites with large boulders or extreme stoniness
Effects on seedbed and competing vegetation	· good competition control possible in patches, although exposed mineral soil will also provide a good seedbed for competitor seeds · number of root suckering species present before treatment can increase between patches	· depends on depth of disturbance to soil layers and amount of organic layer displacement · can create good seedbed for natural regeneration · may stimulate dormant seeds in seed bank and root suckering species	· can provide a good seedbed within the trenched areas · if root suckering species are present before treatment, numbers may increase between trenches · competition control may be good within trenches, but exposed mineral soil can produce a good seedbed for competing species	· creates good seedbed for natural regeneration · may stimulate dormant seeds in seedbank and root suckering species · controls sprouting of shrubs and undesirable hardwood stems · may create suitable seedbed for competing species on moist sites

Mechanical site preparation treatments may also alter microbial community structure (Ohtonen *et al.* 1992), although the effects of these treatments on soil fauna are not well understood (Shaw *et al.* 1991). For example, organic matter content is important for soil respiration; because screefing removes organic matter, it can lead to reduced soil respiration, reduced organic matter decomposition, and thus poor nutrient cycling. However, Mallik and Hu (1997) suggested that soil mixing has the potential for improving soil nutrient status by increasing organic matter decomposition through better soil water and aeration conditions.

Boreal mixedwood management activities that emulate natural disturbances, including partial canopy removal, underplanting conifers in uncut hardwood stands and understory scarification prior to harvesting in good seed years, require modifications to current mechanical site preparation techniques. Equipment must be maneuverable to efficiently go around residual trees or through uncut stands and avoid advance growth, while at the same time producing plantable or seedable microsites. Satisfying these primary objectives is difficult with current mechanical site preparation equipment and prime movers because of their size and weight. Limited experience involving understory scarification in conjunction with partial canopy retention or selection harvest exists for Ontario boreal mixedwood conditions. In the 1960s and 1970s, tunneling with small bulldozers beneath selectively logged mixedwoods was found to be effective in preparing sites for planting large white spruce under the residual poplar canopy (Wedeles *et al.* 1995). Recently, studies have been implemented in other provinces to investigate mechanical site preparation techniques for partial harvest or understory scenarios in boreal mixedwood stands (e.g., Man and Lieffers 1999, Stewart *et al.* 2000). Results show that blading as well as mixing/crushing treatments can increase soil temperature, decrease seedling mortality, and improve conifer crop tree diameter growth.

Wedeles *et al.* (1995) have suggested the use of small excavators in conjunction with a shelterwood silviculture system. Small excavators can reach from skid trails into areas of the shelterwood to create seedbeds, uproot balsam fir, and create mounds of mineral soil. Root raking has also been suggested as a recommended mechanical site preparation method for understory scarification to promote natural spruce and balsam fir regeneration in boreal mixedwood stands prior to harvesting in a mast seed year (Bulley and Cormier 1995, Cormier 1996, Cormier 2001). Because spot scarification is often used in partial cuts, Cormier (2001) suggests conducting site preparation in conjunction with mechanized felling.

Other site preparation techniques that have been tried for partial harvest or understory regeneration scenarios include high-speed elevated bed and scalp treatments on excavator and skid-steer loader prime movers (D. Sidders, pers. comm.[2]).

3. Chemical Site Preparation

Chemical site preparation involves applying herbicide to a site prior to regeneration to provide establishing natural or artificial regeneration with increased growing space, light, moisture, and nutrients. This treatment is time-efficient and economical (Desrochers and Dunnigan 1991) and does not eliminate particular plant species, but rather controls those that may be competitors of crop trees for the first few years after establishment (OMNR 1998a). Chemical site preparation generally provides better control of existing competing vegetation that reproduces vegetatively than either mechanical site preparation or prescribed burning. The use of chemical site preparation without simultaneous or progressive mechanical site preparation is limited to sites where competing vegetation is susceptible to the chosen chemical, slash density is low, and litter is not a barrier to crop tree success (OMNR 1998b). Chemical site preparation does little to create seedbeds (OMNR 1998b), nor does it affect the distribution of slash (OMNR 1998a).

The effects of chemical site preparation on forest productivity, health and overall condition depend on the specific ecosite conditions and harvesting system being used. This treatment regime causes minimal disturbance to soil structure, organic matter, water movement (Cantrell 1985), and downed woody material (OMNR 1998a). Chemical site preparation may result in (Brand 1991):

- increased foliar nitrogen in crop tree seedlings
- increased soil temperature
- increased light intensity at seedling level
- increased water availability to tree seedlings

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Herbicides can have negative effects, including the suppression of some plant species that may be important components of wildlife habitat and potential delays in 'green-up' following treatment (Maynard 1997). Increased concerns about the potential negative effects of herbicides on wildlife species and habitat, even when properly applied for silvicultural purposes in boreal mixedwoods, led to a major review by Lautenschlager and Sullivan (2002). Sutton (1993) was not able to detect any effect on the floristic composition of a boreal mixedwood stand10 years following for chemical site preparation with hexazinone. Otchere-Boateng *et al.* (2000) indicated that a single application of glyphosate prior to planting white spruce increased seedling growth without adversely affecting vascular plant community diversity. Harper *et al.* (1997), however, observed lower species diversity associated with fewer broadleaf species 12 years after aerial applications of hexazinone and glyphosate.

The silvicultural efficacy of herbicides depends on the mode of action of the herbicide, application systems used, target species' susceptibility, timing of application, and weather conditions in the immediate area. Table 4 presents mode of action and application information for the major herbicides used as site preparation treatments on boreal mixedwood sites in Ontario.

Herbicide application methods

Chemical site preparation of boreal mixedwood sites can be accomplished by broadcast spraying herbicides from the air using fixed-wing aircraft or helicopters or from the ground. Ground broadcast application of herbicides usually involves the use of vehicle-mounted ground sprayers or motor-manual or manual sprayers. Ground application methods include directed foliar, streamline basal, and stumps sprays, soil spot application or stem injection (Kidd 1987, Wagner *et al.* 1995). Aerial application is only suitable for conventional clearcut sites; manual and motor-manual sprayers and certain vehicle-mounted ground sprayers can be used for site preparation in understory or partial harvest scenarios. However, manual, motor-manual, and ground application methods are more costly than aerial applications.

Aerial

Broadcast herbicide applications (from fixed-wing spray aircraft or helicopters) are less expensive and provide longer-term control than mechanical removal of hardwoods and shrubs that sprout after clearcutting, even for conifer-dominated mixedwood sites (Mallik *et al.* 1997). However, this approach requires consideration of factors such as off-target deposition, weather, seasonal restrictions, and public concerns (Mallik *et al.* 1997). In addition, broadcast control of competing vegetation may not always be compatible with mixedwood management objectives. To promote mixedwoods, ground application by directed methods to allow selective control of unwanted stems and/or species may be the preferred approach (Bell *et al.* 1996).

Manual and motor-manual

Hand-held herbicide applicators, such as sprayers and stem injectors, can be used for selective removal of vegetation before planting or seeding (Otchere-Boateng and Ackerman 1990). This technique is applicable where, for example, hardwood stands need to be thinned or where selective vegetation removal is required to achieve adequate light levels prior to underplanting conifers.

Cut stump treatments at time of harvest, where herbicide is applied to the freshly cut surface of the stump including the cambial layer immediately after harvest, can provide selective control of sprouting species, and reduce the cost and/or need for subsequent tending treatments (Kidd 1987). Mallik *et al.* (1997) have reviewed the available herbicides and their effectiveness, as well as application equipment available for cut stump treatments.

Ground

Ground sprayers can be used to effectively apply herbicide as liquid sprays or granules in broadcast bands or spot applications, depending on the type of herbicide and equipment. Only 5 herbicides currently registered in Canada for forest applications may be applied by a ground sprayer; these include glyphosate, hexazinone, simazine, 2,4-D, and triclopyr (Desrochers and Dunnigan 1991).

Certain types of ground sprayers apply liquid herbicide from an applicator attached to a brush cutter (e.g., Lucas-64 spray system) or shearing or felling head (e.g., CST and CPFP herbicide sprayers) for cut stump treatment (Mallik *et al.* 1997). The most common types of vehicle-mounted ground sprayers are boom, cluster nozzle, high-pressure gun, airblast, wick, and granular applicators (Desrochers and Dunnigan 1991).

Table 4. *Herbicides used for chemical site preparation on boreal mixedwood sites in Ontario.*

Characteristic	Herbicide		
	2, 4-D	**Glyphosate**	**Hexazinone**
Mode of Action	· foliar · phenoxy family herbicide for broadleaved weeds and woody species	· foliar · selective broad spectrum herbicide for most annual, perennial, and woody species	· principally root absorbed, but minor effects on foliage · soil-active selective herbicide for broad spectrum of annual, perennial, and woody species (Ont. Weed Comm. 1995)
Application: · Method	· aerial application · ground application	· aerial application · ground application	· aerial application · ground application
· Timing and other considerations	· application can be made from May - September, but maximum herbicidal efficacy if applied beginning of June to third week of July, under normal weather conditions (Expert Committee on Weeds 1984, 1986) · higher rates can be used, and application should be after full leaf expansion and during period of active growth (Otchere-Boateng and Ackerman 1990) · will harm all conifers if applied during period of active growth (Schacht and Hansen 1963)	· application can be made from mid-May to beginning of October, but maximum efficacy if applied to actively growing vegetation beginning of June to mid-September · apply after hardwoods have reached full leaf, and prior to the onset of full fall colouration, major leaf fall (Expert Committee on Weeds 1984, Cantrell 1985) or killing frost in undesirable brush and tree species (Cantrell 1985) · late summer application followed by planting the next spring provide good control of target vegetation and crop safety (Vanden Born 1984) · for NW Ontario sites, preferable approach is to wait for two years following site disturbance, such as mechanical SIP, to apply glyphosate, and plant in third year (Carruthers and Towill 1997)	· apply in spring before weed emergence or prior to full leaf expansion of target species (Cantrell 1985) · plant in same season as early spring application of hexazinone at low rates (Expert Committee on Weeds 1984, 1986) · very site sensitive - prescription according to soil organic content and texture, and weed species composition (Cantrell 1985)
· Factors affecting use		· application of glyphosate in third year after SIP ensures most of the early pioneer species are well-controlled and little remains of the initial on-site seedbank (*ibid.*) · possesses long term herbicidal efficacy with best control of target vegetation often occurring two years after application (Vanden Born 1984)	· not to be used on wet soils, but >5 cm of rainfall is needed to move herbicide into soil profile after application (Cantrell 1985) · not recommended on clay soils or soils high in organic matter (Cantrell 1985) · broadcast sprays used for control of shrubby and herbaceous species · spot application of concentrated liquid formulation controls aspen, cherry, alder, birch and maple · residual activity can reduce sprouting of certain species, and reduces germination of wind-borne seed and seed banking species (McLaughlan *et al.* 1996)

4. Prescribed Burn Site Preparation

Fire is a natural component of boreal forest ecosystems. It is the disturbance agent that most affects forest dynamics (Engelmark *et al.* 1993), causing large-scale stand replacement typically under short fire cycles (Heinselman 1981, Johnson 1992, Payette 1992). Sites supporting boreal mixedwood stands are moderately susceptible to fire (MacLean 1960). Wiltshire and Archibald (1998) describe the ecological role of fire in boreal mixedwoods; here we focus on its use as a tool in boreal mixedwood management.

Prescribed burning is defined as the knowledgeable application of fire to a specific land area to accomplish predetermined land management objectives (OMNR 2002). In Ontario, prescribed burning is primarily used for silvicultural purposes, namely, site preparation for planting and seeding (McRae 1985b). On boreal mixedwood sites, management objectives for prescribed fire can include (Wiltshire and Archibald 1998):

- promoting vegetative reproduction of trembling aspen
- controlling vegetative competition to facilitate planting or seeding of conifer species
- encouraging natural regeneration of jack pine and black spruce
- converting stands of budworm killed balsam fir

The effects of prescribed fire on forest health, condition, and productivity depend on the ecological site type and harvest system used. The use of various harvest systems and equipment types result in different species composition and density of non-crop vegetation, soil compaction and disturbance, erosion potential and post-harvest fuel loading (Wiltshire and Archibald 1998). Prescribed burning, as part of a silvicultural prescription, is relatively cost-efficient if applied to an area larger than 10 ha. This is especially true where large areas can be treated in single operations – several burnings can be done for the cost of one broadcast herbicide application. However, the costs of burning small tracts, areas with irregular boundaries, or narrow strips are high (Smith *et al.* 1997). Other disadvantages of broadcast prescribed burning include that effectiveness is subject to the variability and uncertainty of weather and it is not selective, that is it is more difficult to avoid areas of concern than with other methods. Considerable skill and planning are required to execute prescribed burns successfully (OMNR 1998b).

Depending on desired objectives, prescribed fire can be used pre- or post-harvest. The purpose of pre-harvest prescribed fire is to prepare receptive seedbeds and control competing vegetation. Post-harvest prescribed fire is used on sites where regeneration is usually assisted by seeding or planting, and any mortality of residual overstory trees is not a concern (OMNR 1998a).

Pre-harvest prescribed fire

The primary objectives of this technique are to produce a good seedbed by removing much of the forest floor L and F layers (duff) and to control undesired vegetative competition from various shrubs, conifer, and hardwood species through the use of low intensity surface fire in the understory. Understory prescribed burning prior to harvest has been recommended for red and white pine (McRae *et al.* 1994). In contrast, little related research has occurred on boreal mixedwood sites, although surface fires are recognized as having a role in white spruce regeneration recruitment following initial canopy closure. Haeussler (1991) and Wedeles *et al.* (1995) suggest that the thin-barked, shallow-rooted, fire-sensitive nature of boreal mixedwood conifers may make underburning inappropriate as a site preparation technique in boreal mixedwood stands.

Fires beneath standing crop trees must be of sufficiently low intensity to minimize damage to canopy trees, though some mortality is inevitable where accumulations of dead woody material occur under large crop trees. Injury to the cambial layer of the trees, damage to the roots, or scorching of crowns may adversely affect the overstory. Season of burning is a critical factor in controlling the burn. Understory prescribed burns are generally scheduled for the spring, since it is more difficult to get the fire to spread in the understory once the foliage of the overstory and understory layers have emerged and ground level moisture and relative humidity increases (McRae *et al.* 1994). Opening the overhead canopy and carrying out the burn in a good seed year maximizes the chances for successful natural regeneration (OMNR 1998a). Harvesting occurs once regeneration is established.

Although conifers in the understory are easily killed by fire, most hardwood trees and many shrubs resprout vigourously (Buckman 1964). Understory prescribed burning may stimulate germination of buried seed, which may increase the abundance and distribution of species that were previously unimportant on the site (Ahlgren 1979, Abrams and Dickmann 1984). A manual or chemical treatment may be required after burning to adequately control hardwoods in certain stands (Buckman 1964, Van Wagner 1993, McRae *et al*. 1994).

Post-harvest prescribed fire

Post-harvest fire usually involves broadcast burning of woody and herbaceous material spread over an open area, such as a clearcut. The objectives of post-harvest prescribed fire are to create suitable sites for natural or artificial regeneration by (Kiil 1970, OMNR 1998b):

- reducing the amount of debris or slash from harvest operations
- reducing depth of organic matter
- controlling and discouraging some species of competing vegetation (including balsam fir)
- reducing the smothering effect of non-crop leaf accumulations on crop trees
- improving access for tree planters

Post-harvest prescribed burning has been shown to be as effective as mechanical site preparation in improving conditions for regeneration establishment and growth in northeastern Ontario (McRae 1985a, Arnup 1989) and can be superior to mechanical site preparation in northwestern Ontario (Towill, pers. observ.). The survival rate of conifer germinants depends upon seedbed, rainfall, and rate of recovery of competitive species (Ahlgren 1970).

An experimental burning program was conducted in the Claybelt Region of northeastern Ontario from the late 1970s to early 1980s to investigate post-harvest fire behaviour and its effect on harvested boreal mixedwood sites (McRae 1985b). Results indicated that slash in boreal mixedwood stands tends to be a very discontinuous fuel type, i.e., breaks in fuel distribution create barriers to fire spread. McRae (1985b) recommended that prescribed burns be carried out under higher Fire Weather Index (FWI) System codes and indices than previously recommended, to ensure that the objectives of fire spread and fuel consumption are met. Prescribed burns have often been conducted on boreal mixedwood sites under fire index conditions that were too low to meet management objectives.

Summary

Disturbance caused by forest management activities should be planned to mimic, as closely as possible, those natural disturbances and processes that affect species recruitment and the development of stand structure on boreal mixedwood sites. Resource managers must determine how site preparation strategies can contribute to achieving future stand and forest conditions (species composition, age structure, vertical and horizontal structure, and productivity).

Site preparation emphasizes seedbed conditioning and competition management, using activities that disturb the site. It offers one of the best opportunities to fulfill silvicultural objectives because of the many options available (Wagner and McLaughlan 1996). Knowledge of site and stand conditions, silvics of relevant crop and non-crop vegetation, and site- and stand-specific objectives, combined with economic considerations and forest-level objectives will direct the timing, types, and extent of site preparation to be conducted in renewing Ontario's boreal mixedwood sites.

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SILVICULTURAL OPTIONS

Regeneration Techniques for the Management of Boreal Mixedwood Stands

by C.L. Palmer and W.D. Towill[1]

> *Boreal mixedwood stands are particularly suited to partial canopy removal and natural regeneration management techniques, which permit the resource manager to maintain or create a variety of desired stand compositions and structure...*

Introduction

Mixedwood site and stand conditions are an important element of Ontario's boreal forest, occurring on over 52% of the forested area (Towill and McKinnon, *et al*. 2004 a). In recent decades, Ontario's boreal forest industry has seen a marked change from management of almost exclusively conifer-dominated conditions towards management of both hardwood and mixed-species conditions in response to both increases and changes in demand for forest-related products and services.

Historically, boreal mixedwood stands in Ontario were clearcut and converted to conifer-dominated plantations. Partial harvesting or high-grading also commonly occurred where other species in the boreal mixedwood condition were unmerchantable. Recent approaches and improvements to 'traditional' mixedwood silviculture have been motivated by changes in utilization of the forest resource. Acceptance of hardwood species as commercially important and worthy of regeneration has caused increased interest among resource managers in managing species mixtures (Navratil *et al*. 1991).

Ontario's Crown Forest Sustainability Act (OMNR 1995) and Ontario's Forest Management Planning Manual (OMNR 1996) both identify that large, healthy, diverse and productive forests are essential to the environmental, economic, social, and cultural well-being of Ontario both now and into the future. Seeking to maintain a forest's landscape pattern, composition, and age class structure so that it approximates the pre-fire suppression forest conditions characteristic of an ecoregion is one approach to maintaining the biodiversity and ecological sustainability of Ontario's forests. This strategy has significance for future forest- and stand-level boreal mixedwood silvicultural decisions, especially when considered in the context of other direction provided by the Crown Forest Sustainability Act. For example, the Act also requires that forest practices (including harvesting) emulate nature.

Dynamics of Boreal Mixedwood Forest and Stand Conditions

Historically, all forests originated through natural regeneration without human intervention. Changes in structure and composition were driven by self-

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thinning, age-related mortality, or response to natural disturbances such as fire, blowdown, and insect attack. Left to renew naturally, the post-disturbance mixedwood stand may be considerably different from the pre-disturbance mixedwood stand. For example, softwood or pure hardwood stands may regenerate to support a greater variety of species (Yang and Fry 1981). However, when timber is harvested, changes to seedbed conditions, seed supply, and environmental conditions can occur that alter regeneration dynamics (Bergeron *et al.* 1999). Silvicultural intervention is often required at the renewal stage (NRCan 1995) to achieve desired stand composition.

In general, the natural succession of boreal mixedwoods involves a transition of stand types with differing canopy compositions and vertical structures, rather than a cyclical rotation of similarly composed stands (MacDonald 1995). After disturbance, early successional stages favour the production of closed canopies dominated by the rapid regrowth of white birch or trembling aspen. Usually, mixedwood sites are moderate to rich in nutrients, so they produce diverse and vigorous shrub and herb communities in early successional stages. Black spruce (*Picea mariana* (Mill.) B.S.P.) and white spruce (*Picea glauca* (Moench) Voss) have relatively slow growth rates, compared to white birch (*Betula papyrifera* Marsh.) and trembling aspen (*Populus tremuloides* Michx), and tend to become dominant only in mid-successional stages. Later successional stages of boreal mixedwood forests are typically dominated by balsam fir (*Abies balsamea* (L.) Mill.) (Lieffers and Beck 1994, MacDonald 1995). On some sites, pure conifer or pure hardwood stands may occur at each stage, as a natural result of succession. Two components required for maintenance of biodiversity and long-term productivity in the mixedwood forest are the replacement of species over time and the presence of a natural mosaic of stands at the landscape level (Bergeron and Harvey 1997).

Regeneration Techniques for Boreal Mixedwood Sites

Forest renewal normally includes site preparation and regeneration treatments, which are used to establish a new cohort of trees (OMNR 1996). The establishment of a new cohort of trees occurs by natural (self-sown seed or vegetative) or artificial (direct seeding or planting) means.

Boreal mixedwood stands and species are particularly suited to management techniques, such as partial canopy removal and the planned use of natural regeneration (MacDonald 1995), which permit the resource manager to maintain or create a variety of desired stand compositions and structures. Partial canopy removal results in a modified understory environment that enables a new cohort (or generation) of trees to establish in the understory of the existing stand (Lieffers 1995).

Regeneration techniques and other silvicultural options will vary according to the existing site and stand-specific conditions, which should be determined through a pre-harvest assessment (Navratil *et al.* 1991). Subsequent silvicultural prescriptions are formulated to imitate successful natural regeneration by providing the appropriate conditions (e.g., seedbed, seed supply, moisture and light) to encourage desired tree species (NRCan 1995).

Some factors affecting regeneration success include:

- Site quality (Morris 2003)
- Species autecology of the desired crop (target) species, associated species, and competing vegetation (e.g., seeding habits, seedbed requirements, potential for vegetative reproduction) (Miller 1995a, b, c, d, e, f, g; McKinnon and Kayahara 2003)
- Stand composition and structure prior to disturbance compared to desired post-disturbance stand composition and structure (e.g., availability of advance growth, seeds, and asexual propagules for different species) (OMNR 2003)
- Pre-harvest/current stand condition and health – disease and/or insect problems may affect the vigour of the existing stand and influence future stand conditions (Griefenhagen 2003, McLaughlin 2003)
- Harvesting system used to create disturbance – various systems produce full or partial canopy removal and partial canopy removal may protect shade tolerant species from sudden exposure following harvest and facilitate their release (Palmer and Towill 2004)
- Logging method – the volume and distribution of slash following harvest alters microsite availability and site access (Kenney and Towill 1999)

- Season of harvest system application – spring/summer versus winter, and its relative effect on site condition, hardwood sprouting activity and damage to softwood advanced growth (Kenney and Towill 1999)
- Availability of sufficient receptive microsites

Site and stand constraints often limit the use of natural regeneration. Combinations of natural and artificial regeneration, known as blended regeneration, may be used under some conditions.

Many regeneration techniques are applicable to boreal mixedwood stands. Those currently used in Ontario's boreal mixedwoods are:

- Natural seeding of conifers and birch
- Reliance on advance conifer growth
- Natural vegetative regeneration of intolerant hardwoods
  - Root suckering of aspen
  - Stump sprouting (coppice) of birch
- Planting conifers
  - Intensive
  - Fill planting (area-based)
- Direct seeding conifers
  - Intensive
  - Fill seeding (area-based)

These regeneration techniques are described below and summarized in Table 1. Note that use of any technique that promotes conifer regeneration, including natural and artificial seeding and planting, frequently requires site preparation and/or subsequent tending of the target crop. For information on site preparation and tending practices in boreal mixedwoods, refer to Palmer and Towill (2004) and McKinnon *et al.* (2004).

Table 1. *Regeneration techniques currently used for boreal mixedwood management in Ontario. Species codes: Sw, white spruce; Sb, black spruce; Bf, balsam fir; Cw, white cedar; Bw, white birch; Po, poplar (trembling aspen and/or balsam poplar).*

Regeneration Technique	Objective	Applicable Species	Considerations
Natural seeding	▪ Maintain or enhance the conifer component of a stand ▪ Regenerate birch	Sw, Sb, Bf, Bw	▪ Requires understanding of a number of ecological factors: seed production (mast seed years); seed dispersal (distance from seed source and wind direction); and the effect of seedbed on juvenile survivorship ▪ Scarification is usually necessary to meet conifer stocking goals ▪ Expect birch to take advantage of the same receptive seedbeds [1]
Advance conifer growth	▪ Secure adequate stocking and density of conifer regeneration that is well adapted to the site	Sw, Sb, Bf, Cw	▪ Sufficient advance growth must be present and be protected during harvesting ▪ Advance growth must be able to respond positively to overstory removal [2, 3]
Planting conifers	▪ Maintain or enhance the conifer component ▪ Often used to produce a future fully stocked conifer or conifer-dominated stand	Sw, Sb	▪ Some form of site preparation and tending is often required to control competition from intolerant hardwoods
Direct seeding	▪ Maintain or enhance the conifer component when seed trees are not adequate for natural seeding, or there is little advance growth present	Sw, Sb	▪ Site preparation is recommended to ensure good distribution, extent and duration of receptive seedbeds ▪ Not recommended on sites where a well-developed herbaceous or graminoid component exists
Natural vegetative reproduction of intolerant hardwoods	▪ Use after a clear-cut to obtain a hardwood or a hardwood-dominated mixedwood	Po, Bw	▪ Works best with light disturbances ▪ Aspen suckering potential does not decrease with stand age, though the proportion of aspen in the canopy decreases [4,5] ▪ Sprouting ability of birch declines after 70 years; natural seeding takes over as the primary mode of reproduction of birch when mature[6, 7, 8]

[1] Zasada *et al.* 1978; [2] Ferguson 1984; [3] Ruel *et al.* 2000; [4] Lavertu *et al.* 1994; [5] Frelich and Reich 1995; [6] Perala and Alm 1989; [7] Bell 2000; [8] Zasada 2000

Regeneration Methods

Natural seeding

Natural seeding of boreal mixedwood conifers (and birch) can be used where conditions are suitable. Important considerations include:

- seed availability (seed production and viability periods)
- seed dispersal distances
- appropriate seedbed availability and environmental conditions

Seed production in boreal conifers varies widely from year to year. Seed years in Ontario generally occur every 4 years for black and white spruce (Hughes 1967). A mast seed year, where the seed crop is greater than or equal to the 10-year mean, occurs about once every 3.5 years, although there is no distinct cycle. In a decade, the 3 best years of cone production will account for about 80% of all the cones (Messier et al. 2000). Therefore, when regenerating white spruce and balsam fir using seed trees within or adjacent to the site, harvesting should occur as soon as possible after a mast seed year.

Location of any residual seed source is also important. Natural regeneration from seed in a large clearcut or burn seldom gives adequate stocking beyond 25 to 75 m from a forest edge, even when the species of interest has a strong residual source (large basal area). Stewart *et al.* (1998) recommend that white spruce seed trees be within 100 m, and preferably upwind of receptive microsites, if increased stocking is desired. Due to prevailing westerly and northwesterly winds in the boreal forest, seed deposition from the west and north sides of a clearing will be 2 to 4 times greater than dispersal from the south or east (Haavisto 1979, Stewart *et al.* 1998).

The type, amount, and distribution of receptive seedbeds also greatly influence regeneration success. To obtain good stocking, 10 to 30% of the harvested area should provide good seedbeds (Messier *et al.* 2000). Spruce and fir survive best on low porosity seedbeds, which have high moisture retention capacity and hydraulic capacity (i.e. water can rise freely via capillary action). These include rotted wood, exposed mineral soil, and humus. Due to the low percentage of suitable low porosity seedbeds available at the canopy transition or gap-dynamics stages of boreal mixedwood stand development (technical rotation age), scarification may be necessary to meet even moderate stocking goals.

Reliance on advance conifer growth

Advance growth refers to stems of vegetative (layer) or seed origin, which are typically uneven in height and age, and which are suppressed at the time of logging (Horton and Groot 1987). In Ontario's boreal mixedwoods, advance growth consists mainly of balsam fir, black spruce, white spruce, and/or white cedar (*Thuja occidentalis* L.). The protection of advance growth during harvesting operations on upland sites (including boreal mixedwood sites) has been termed Careful Logging Around Advance Growth (CLAAG) or, more generally, protection of advance growth. This technique is a low-cost alternative to secure adequate stocking and density of a regenerating species that is well adapted to the site. It is useful where the management objective is to maintain or enhance the conifer component of a stand. The objective is to protect desirable, non-merchantable stems (usually less than 10 cm DBH) during the removal of overstory stems.

The amount of advance regeneration protected can be controlled by the choice of harvesting equipment, equipment operating techniques, and levels of planning and supervision (Froning 1980, Brace Forest Services 1992, Sauder 1992, Pulkki 1996, Silvatech and Peacock 1997). Greene *et al.* (2002) note that 3,500 stems ha^{-1} are required to achieve minimal conifer stocking while 26,000 stems ha^{-1} are needed to achieve full stocking (60%). This concurs with the findings of Zelasny and Hayter (1991) that advance regeneration prior to harvest should be about 30,000 stems ha^{-1} for black spruce or balsam fir.

Shallow-rooted species and those that root in the LFH-mineral soil interface are especially prone to drought and dessication following removal of the overstory canopy. This often contributes to high levels of seedling mortality immediately following harvesting. In boreal mixedwood silviculture, advance growth may be used to supplement other regeneration treatments such as planting and seeding.

Natural vegetative reproduction of intolerant hardwoods

Natural vegetative regeneration of aspen by root suckering or of birch by stump sprouting (coppice) can be relied on following a clearcut when the management objective is to obtain a hardwood-dominated mixedwood. According to Perala (1977) and Doucet (1979), only about 5 m^2 ha^{-1} basal area (about 125 stems ha^{-1}) of aspen are needed to produce a fully stocked stand if the individuals are well distributed. In north central Ontario, if a stand contains 20% of its initial basal area as well-distributed aspen stems before harvest, 80% stocking to aspen will establish after the harvest (B. Towill, unpubl.). Poor aspen regeneration has been noted on fresh to moist, fine-textured mineral soil conditions where the humus layer is extremely thick (>20 cm). Methods to ensure successful vegetative regeneration of aspen (e.g., season of cutting, scarification) are described by Bella (1986), Doucet (1989), Bates *et al.* (1993), and Lavertu *et al.* (1994).

Planting conifers

Compared to other regeneration methods, planting provides the greatest control over future stand composition, stand density, and structure to achieve management objectives. Planting of black or white spruce at densities ranging from 1,800 to 2,700 stems ha^{-1} is commonly used after a conventional clearcut harvest of productive and competitive boreal mixedwood sites. Fill planting can occur where natural or artificial seeding or the protection of advance growth has not resulted in desired target densities and stocking or where initial planting stock survival is less than desired.

Direct seeding

Direct seeding is a regeneration technique that can be used as an alternative to conventional planting. The composition, density, and distribution of species and stems in direct-seeded stands may closely approximate those of natural stands (Fleming *et al*. 2001).

The biological requirements for direct seeding are more rigourous than for planting because both successful seed germination and seedling establishment are required. Seeding is most successful on sites where competition from other vegetation is minimal. Site preparation and vegetation management will likely be required on any boreal mixedwood site where direct seeding is the primary means of regeneration. Direct seeding

Figure 1. *White spruce regeneration resulting from planting in small clearcut patches in a 54 - year old hardwood dominated mixedwood condition, Lakehead Forest – Nipigon. (Photo Credit: W.D. Towill)*

Table 2. *Spatial and temporal variations in renewal techniques: new applications proposed for boreal mixedwood sites in Ontario. Species codes: Sw, white spruce; Sb, black spruce; Bf, balsam fir; Cw, white cedar; Bw, white birch; Po, poplar (trembling aspen and/or balsam poplar).*

Renewal Technique	Objective	Applicable Species	Considerations
Natural seeding of conifers before harvest following understory scarification in a mast seed year	▪ Alternative to conventional planting or seeding where natural sexual reproduction of BMW conifers is desired [1]. ▪ Can be used to accelerate the natural development of a BMW stand from hardwood- to conifer-dominated	Sw, Sb, Bf	▪ Never used operationally in Canada, but several studies have shown that it is an effective technique in association with scarification during mast years [2, 3, 4] ▪ Requires understanding of seed production (exact mast year), dispersal, and seedbed effects on juvenile survivorship ▪ Tending will likely be required
Conifer planting combined with intolerant hardwood vegetative reproduction	▪ Used to create mosaics of softwoods and hardwoods		
▪ Cluster planting	▪ Used to create mixedwood stands of Sw and Po following clearcutting, or to regenerate mixedwoods in strip cut aspen or mixedwood stands [5]	Sw, Po	▪ Used in British Columbia ▪ Varying the percentage of area occupied by the aspen and spruce components will produce desired mixtures ▪ Clusters of spruce will reduce overall plantation costs
▪ Alternate strip / patch planting	▪ Planting conifers in alternate strips or patches and allowing natural vegetative reproduction of intolerant HW to create a mixed stand in the remaining strips or patches [6]	Sw, Sb, Bf, Po, Bw	Two options: ▪ Strip cut, plant and tend conifers in the cut strips and allow natural regeneration in the second cut strip ▪ Clearcut, plant and tend conifers in strips and allow natural regeneration in untreated alternate strips (similar to cluster planting)
Underplanting spruce in hardwood	▪ Can be used to accelerate the natural development of a BMW stand from hardwood- to conifer-dominated	Sw	▪ Initiated several decades ago in Europe and has recently been tested for BMW management in Ontario [7]

[1] Greene *et al.* 2002; [2] Lees 1963, 1970; [3] Desjardins 1988; [4] Stewart *et al.* 2000; [5] BCMOF 2000; [6] MacDonald and Thompson 2003; [7] MacDonald 2000

is not advised on sites where Canada blue-joint is expected to compete with the germinants. This grass is a serious competitor of both white (Lieffers *et al.* 1993) and black (Bell *et al.* 2000) spruce.

Two types of direct seeding are broadcast (i.e., using aerial or ground-based equipment) and precision (i.e., using a precision seeding attachment in conjunction with mechanical or chemi-mechanical site preparation). Precision seeding in conjunction with mechanical or chemi-mechanical site preparation is significantly less expensive than broadcast seeding, as far less seed are required and a more even distribution of seeds along the furrows can be obtained. Where required, receptive microsites can be fill seeded manually.

New Applications: Spatial and Temporal Variations in Regeneration Methods

Several spatial and temporal variations of the regeneration methods described above have been used in other jurisdictions and are proposed for use in Ontario's boreal mixedwood conditions. These include:

- Natural seeding of conifers before harvest following understory scarification in a mast seed year
- Conifer planting combined with intolerant hardwood vegetative reproduction to create mosaics of mixedwoods:
  - Cluster planting
  - Alternate strip/patch planting
- Underplanting spruce in hardwood stands

These proposed renewal techniques are described in detail below and summarized in Table 2.

Natural seeding of conifers before harvest following understory scarification in a mast seed year

Timing pre-harvest understory scarification with a seed year and delaying clearcut harvest until after seed release increases the chance of securing successful natural regeneration of spruce, particularly white spruce. The accurate prediction of an impending mast seed year is critical to the success of this teechnique. Understory site preparation must occur prior to the onset of white spruce and/or balsam fir seed release in early fall. In addition, harvesting activities must be scheduled for the late winter or early spring (January to April) once seed release is complete. Although there is great variation in the timing of seed abscission for white spruce and balsam fir, about 90% of the crop tends to be dispersed between September 15 and December 15 (Greene and Johnson 1997). Pre-harvest understory scarification may also be implemented in a non-seed year. However, the harvest should be delayed for 4 years.

A target of 35% mineral soil exposure or mixed mineral soil with humic organic materials is required (Hughes 1967) for optimum germination and establishment. Root raking has been suggested as a method of understory scarification to promote natural spruce regeneration on boreal mixedwood sites prior to harvesting in a seed year (Greene *et al.* 2000).

Accurate methods of predicting mast years more than 2 years in advance are not yet available. However, potential seed production of white spruce and fir can be evaluated by assessing the number of pre-formed buds or the abundance of cones in May-June of the year before harvesting (Messier *et al.* 2000). MacLean (1959) and Hughes (1967) observed this seasonal influence on white spruce seed production in mixedwood stands in northwestern Ontario. Since the same climatic influences act on seed production for both balsam fir and white spruce (Randall 1974, Raymond 1998), any treatment that takes advantage of a mast year for either species will simultaneously be encouraging the natural recruitment of both species.

Greene *et al.* (2002) present a model that predicts the minimum amount of residual basal area for either white spruce or balsam fir that must be retained on site for natural seeding to be successful. This model considers the expected relationship between seed production, juvenile survivorship and scarification intensity.

Conifer planting combined with intolerant hardwood vegetative reproduction to create mosaics of mixedwoods

The spatial arrangement of conifers and hardwoods can be varied to produce mosaics of conifers and hardwoods. Two techniques that can be used to create different spatial patterns are cluster planting and alternate strip/patch planting of conifers.

Cluster Planting

Cluster planting involves planting groups of trees in patches within the regenerating stands. With this technique, white spruce is established by planting clusters of seedlings along pre-determined transects, while aspen regenerates naturally in the areas between the transects and the clusters. Thus, the white spruce and aspen are basically the same age. The objective of this arrangement is to promote a hardwood-conifer mixedwood where the hardwood and conifer components are managed in pre-determined proportions. If conifer advanced growth exists on the site, it can also be included as part of the spruce strips. Although it might also be possible to use black spruce for cluster planting, this has not yet been attempted with this species.

The orientation of the cluster transects should take into account prevailing winds, as well as visual impact. Transects do not have to be straight lines and the distance between transects can be varied to reduce uniformity across the landscape. Aspen is likely to grow faster than white spruce, and thus can be harvested earlier (i.e., during the first pass of a future 2-stage removal planned harvest). Commercial thinning of spruce can occur during the first pass.

The design and arrangements of cluster-planted white spruce will determine the relative percentage of area occupied by the spruce and aspen components. The inter-tree distance (between the spruce) can range from 1.0 to 1.4 m (BCMOF

Figure 2. *White spruce regeneration established in narrow strip cuts in a 54-year old hardwood dominated mixedwood condition, Lakehead Forest – Nipigon. (Photo Credit: W.D. Towill)*

2000). Less than normal inter-tree spacing is acceptable as trees will be subjected to little or no competition from trees outside the cluster. Clusters have a minimum of 6 and a maximum of 10 trees. Expected mortality can be accounted for by increasing the number of clusters or number of trees per cluster. The number of clusters per hectare is controlled by varying the number of transects per 100 m and the inter-cluster distance. When the inter-cluster distance is less than 12 m, the entire area between clusters can be allocated to spruce, although this would not generally be desired for mixedwood management. When the inter-cluster distance is greater than 12 m, aspen will regenerate between clusters.

Alternate Strip/Patch Planting

Planting of conifers in alternate strips or patches and allowing natural vegetative reproduction of intolerant hardwoods to create a mixed stand in the remaining strips or patches has also been suggested (MacDonald and Thompson 2003).

Underplanting spruce in hardwood stands

Pre-harvest underplanting creates a distinct, 2-tiered stand structure which is compatible with 2-stage harvesting or shelterwood harvest. Underplanting takes advantage of the moderated understory microclimate, which favours white and black spruce establishment and protects the new cohort from insects and disease. Underplanting hardwood stands with spruce increases the understory conifer component on sites where the absence of a seed source, inadequate seedbeds, or vegetative competition limits natural ingress. Underplanting of aspen stands with white spruce for example can increase the white spruce understory cohort to a desirable level while harnessing the beneficial aspects of the aspen nurse crop. The viability of this approach has been established in studies in northeastern British Columbia (Kabzems and Lousier 1992, Tanner *et al.* 1996, Coopersmith *et al.* 2000, Delong 2000), Alberta (Lees 1963, 1970; Stewart *et al.* 2000), Manitoba (Dyck 1994) and Ontario (Wang and Horton 1968, MacDonald 2000). The successful underplanting of conifers in white birch stands has also been investigated (Comeau *et al.* 1998, 1999).

Considerations and Recommendations

- Plan for understory site preparation if competing understory will be a problem
- Use large quality nurse stock that is suitable for understory conditions
- Plan for access to sites well in advance of harvest of the overstory
- Target or provide for > 25% full sunlight (Greene *et al.* 2002) by manipulating overstory density (e.g., Comeau 2000)
- May randomly locate planting microsites, but seedlings should be planted at least 1 m from any live dominant stems

Overstory aspen should not be removed before the spruce seedlings are tall enough to withstand post-harvest competition and changes in their above- and belowground micro-environments. Greene *et al.* (2002) suggest that understory conifers be planted 20 years prior to a planned harvest. However, if the overstory is a mature aspen stand, it may be harvested as early as 10 to 15 years after underplanting (Brace and Bella 1988, Delong 1997).

To ensure that the understory spruce will be large enough to compete with aspen root suckers and Canada bluejoint (reedgrass) (*Calamagrostis candensis* L.), Johnson (1986) and Bell (1991) recommend that a minimum conifer height of 2.5 m should be achieved before aspen are harvested. However, Yang (1989) has found that on some sites, white spruce requires a minimum height of 3.4 m to withstand vigorous aspen sucker competition. Messier *et al.* (1999) suggest that after overstory harvest, the new mixed spruce-aspen stand that develops can be harvested after 80 to 100 years (or longer) after which a pure aspen stand will regenerate that can be underplanted (Tanner *et al.* 1996), as described earlier, continuing the cycle.

Summary

Successful regeneration at the stand level depends on the ability of resource managers to predict vegetation dynamics following disturbance. Variables relating to site type, environment, biotic features and operations have implications to regeneration techniques and must be included in the study of forest dynamics (Harvey *et al.* 1995, Arnup 1998, Wiltshire and Archibald 1998, Towill *et al.* 2004 b).

To maintain the capacity for successful regeneration and species diversity in mixedwood ecosystems, a range of regeneration options should be developed (and applied) that balance the use of extensive and intensive regeneration methods and silviculture systems. Ecosystem considerations, rather than short-term economics, should form the basis for ensuring that appropriate regeneration and silviculture systems are selected (Navratil et al. 1991). Forest practices should emulate natural disturbances and landscape patterns and minimize impacts on residual vegetation, soil, water, wildlife habitat and other forest values (MacDonald 1995).

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Reproduction Cutting and Harvest Methods and Applications in Boreal Mixedwood Forests

by C.L. Palmer[1], L. MacMillan[2], and W.D. Towill[1]

> *The choice of a specific reproduction cutting and associated harvest method is based on the autecology and reproductive strategies of the species present, the stand's vigour and age, site conditions, and the desired future stand composition...*

Introduction

The Crown Forest Sustainability Act (Statutes of Ontario 1995) and Ontario's Forest Management Planning Manual (OMNR 1996) both identify large, healthy, diverse, and productive forests as essential to the environmental, economic, social, and cultural well-being of Ontario both now and in the future. Seeking to maintain a forest's landscape pattern, composition, and age-class structure so that it approximates pre-fire suppression forest conditions characteristic of an ecoregion is one approach for maintaining the ecological sustainability of Ontario's Crown forests. This strategy has significance for future forest- and stand-level boreal mixedwood (BMW) silvicultural decisions, especially in the context of other direction provided by the Crown Forest Sustainability Act. The Act also requires that forest practices (including harvesting) emulate natural disturbances and landscape patterns, within the bounds of species silvicultural requirements and natural disturbances.

Given that natural disturbance regimes play a role in controlling landscape pattern and mediating ecological function by influencing species composition, stand structure and development, and ecosystem processes, emulation of natural disturbance has been proposed as one template for ecosystem management. Silvicultural systems that mimic natural disturbance regimes can maintain or enhance boreal mixedwood sites and associated stand conditions in a variety of developmental stages and ages across a landscape within established bounds of natural variation.

A silvicultural system is a cycle of activities by which a forest stand is harvested, regenerated, and tended over time. A reproduction cutting method is the component of a silvicultural system that describes the procedure by which a stand is established or renewed, and includes both a specific harvest and regeneration method. Traditional reproduction

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Ontario

cutting methods that have been applied in the boreal forest (Smith *et al.* 1997) result in the development of either even- or uneven-aged future forest conditions. Even-aged reproduction cutting methods produce stands that have essentially uniform, single-canopy conditions with a distinct understory. Uneven-aged methods create stands with substantial vertical structure and multiple crop tree age classes. The amount of main forest canopy that may be removed with any particular reproduction cutting method ranges from near complete to minimal. The methods used, tree species present, and other ecosystem variables result in a range of forest structures and compositions (Graham and Jain 1998).

The selection and application of a specific reproduction cutting method is dependent upon the autecology of the boreal mixedwood tree species(s), their reproductive strategies and stand vigour, stand age, current horizontal and vertical stand structure, site conditions and desired future stand composition and structural attributes. Boreal mixedwood silviculture emphasizes the protection of advance growth or partial canopy removal to promote desired stand structure and composition.

The purpose of this technical note is to provide resource managers with an overview of the reproduction cutting methods and associated harvest methods that can be applied in the BMW forests of Ontario. These methods are either currently in use or are proposed for use in Ontario's BMWs (OMNR 2003). Some economic considerations for each silvicultural system are outlined.

Current Reproduction Cutting and Harvest Methods

Retaining some level of stand structural complexity is thought to be necessary to maintain forest ecosystem function and biological diversity (Harmon *et al.* 1986, Franklin 1993, Franklin *et al.* 1997, 2002). The natural disturbance pattern emulation guide (NDPEG) (OMNR 2001) requires that clearcuts in Ontario retain structural elements from the original stand, including a minimum amount of the merchantable overstory, snags, and downed woody debris so as to better reflect the structural patterns normally found after fire.

The current approach to managing Ontario's boreal mixedwood forests most often involves the application of one of the following harvest methods within the clearcut reproduction cutting method (Table 1):

- Conventional Clearcut
- Seed Tree

Each of these clearcut variations emulates a stand-replacing natural disturbance, such as fire, and produces an even-aged conifer- or hardwood-dominated stand with minimal structural complexity. Regeneration develops in a fully exposed microclimate, allowing maximum growth to be achieved. These clearcut harvest methods incorporate either natural regeneration (seeding, coppice), protection of advance growth, artificial regeneration (planting or seeding), or a combination of these techniques. Tending is often required to help achieve desired future stand composition and structure objectives. The variables that affect the decision of whether or not to tend the stand include: silvics of the crop and competing species; sensitivity of advance regeneration to additional disturbances; stand accessibility; availability of materials, equipment and personnel; and cost.

Conventional Clearcut

The conventional clearcut method traditionally involved the removal of all merchantable and marketable trees in the stand in a single intervention (Smith *et al.* 1997). The NDPEG guide requires that a minimum percentage of the original stand area be retained as residual green patches and as individual live and dead trees to increase structural complexity in future stands (OMNR 2001). However, overstory retention should not negatively affect the establishment and growth of subsequent regeneration.

The regeneration objective associated with the conventional clearcut method is most often the creation of even-aged stands. Artificial regeneration has typically been used to establish conifers on conventionally clearcut mixedwood sites using white spruce (*Picea glauca* (Moench) Voss), black spruce (*Picea mariana* (Mill.) B.S.P.), and jack pine (*Pinus banksiana* Lamb.) (Wedeles *et al.* 1995)). Conventional clearcutting can also be used to secure natural aspen (*Populus tremuloides* Michx)

Table 1. *Summary of clearcut harvest methods appropriate for use in Ontario's boreal mixedwood forest.*

Clearcut Harvest Method	OBJECTIVE	BENEFITS	LIMITATIONS	COMMENTS/CONSIDERATIONS
Conventional	Create a softwood-dominated or leading, or hardwood-dominated or leading even-aged stand with minimal structural complexity	· Suitable for rehabilitating stands that are degraded · Artificial regeneration, broadcast site preparation and tending easiest and least expensive on conventional clearcuts · Maximum growth of regeneration is promoted by a fully exposed microclimate · Lower regeneration costs when natural regeneration used	· Intrinsic fertility of BMW sites increases probability of competitor species and undesired hardwoods invading the site when the canopy is removed · Artificial regeneration generally required to maintain a conifer component · Risk of frost damage to planted seedlings (especially white spruce) with large clearcuts · Risk of windthrow with strip cuts	· Requires careful logging for protecting advance growth· Natural regeneration by coppice can be used to promote a hardwood-dominated or leading mixedwood · Clearcutting may occur in strips, blocks or patches · Strip cuts can be combined with natural regeneration (by seeding) to promote a conifer or conifer-dominated mixedwood; strip width must ensure effective seed dispersal; strip orientation should discourage windthrow · Intensity of site preparation is relative to the type and amount of competing vegetation (non-desired tree species, shrubs and grasses)
Seed Tree	Create a spruce- or birch-dominated or leading even-aged stand with minimal structural complexity	· Local gene pool is maintained · Lower regeneration costs· Maximum growth of regeneration is promoted by a fully exposed microclimate · Provides some vertical structure that can contribute to wildlife habitat	· Potential damage during harvest increases risk of disease · Site preparation is more expensive since seed trees must be avoided · Further site preparation and tending may be necessary if estimate of good seed year is incorrect · Windthrow of seed trees is a risk; group seed tree method only should be used for black spruce · Seed predation by squirrels may limit success	· Consider genetic quality of seed trees · Consider spatial arrangement and density of seed trees to minimize squirrel predation Success dependant on: · Adequate seed availability (one or two seed crops per five-year interval: requires harvest timing flexibility) · Adequate seed dispersal on well prepared seedbeds (consider dominant wind direction and distance from seed trees) · Survival of seedlings in early stages

regeneration from coppice (Davidson et al. 1988, Peterson and Peterson 1995).

Although regeneration of white birch (*Betula papyrifera* Marsh.) has not been a common objective in Ontario, conventional clearcuts can be used to secure natural birch regeneration through coppicing in younger stand conditions (Peterson *et al.* 1997, Zasada 2000). Cluster planting is a unique mixedwood management technique that combines group planting of conifers and vegetative regeneration of hardwoods. This can be used with conventional clearcutting to encourage the development of mixedwood stands (BCMoF 2000).

Protection of balsam fir (*Abies balsamea* (L.) Mill.) and black spruce advance growth is often applied in conjunction with conventional clearcutting. However, the limited abundance of black spruce advance growth on most upland BMWs means that this regeneration approach must be supplemented by other approaches (Walsh and Wickware 1991). Protection of advance growth typically involves the protection of small, non-merchantable, shade-tolerant conifer stems (usually less than 10 cm dbh) during harvest. This approach requires harvest practices to be modified to minimize damage to advance growth, and to be successful requires that advance growth respond positively to release. With careful logging practices, much of the advance growth can be preserved (Walsh and Wickware 1991, Groot 1995). The ability of black spruce and balsam fir advance growth to respond positively to release is related to the pre-harvest live crown ratio (Ruel and Doucet 1998, Ruel *et al.* 2000a, Matthias *et al.* 2003).

Seed Tree Clearcut

Although the seed tree method is traditionally considered a separate reproduction cutting method (Smith *et al.* 1997), Ontario's Forest Management Planning Manual (OMNR 1996) classifies it as a clearcut harvest method. This method can be used to regenerate white and black spruce and white birch in BMWs. With the seed-tree method, all trees are removed except for a relatively small number of previously identified high quality seed trees that are left standing either singly or in small groups or strips across the site to facilitate regeneration through natural seeding. Additional stems may need to be retained to satisfy the requirements of the NDPEG guidelines, although their influence on the establishment and growth of regeneration will be minimal. The success of this clearcut harvest method requires adequate seed availability and distribution and adequate receptive seedbeds.

One or two good spruce seed crops can generally be expected within any five-year period (OMNR 1977, Greene *et al.* 2002). Abundant birch seed crops are not as variable as those of white and black spruce, although seed production of all three species is moderately synchronized (Randall 1974). Since reproduction from seed does not become predominant in birch until after age 40, stand age is an important consideration when the seed tree method is used to regenerate birch (Peterson *et al.* 1997). The effective seeding distance from seed source to seedbed determines the density and distribution of seed trees to be retained. Effective seeding distance for both black and white spruce is between 50 and 100 m (Groot *et al.* 2001). Although most white birch seed is usually dispersed within 100 m of the source, it can easily be dispersed over 200 m (Peterson *et al.* 1997). Since suitable seedbeds are limited following harvesting of BMWs, site preparation to expose mineral soil is recommended to ensure successful natural seeding for both spruce and birch (Groot *et al.* 2001, Peterson *et al.* 1997).

The required density of seed trees depends on biological considerations as well as desired stocking in the future stand. On the basis of white spruce seed tree studies in scarified Ontario spruce-fir-aspen or spruce-fir-birch BMWs, Lyon and Robinson (1977) recommend retaining 5 to 12 large, full-crowned dominant white spruce seed trees per ha to secure stocking of between 55 and 90%. Greene *et al.* (2002) suggest that 6.6 m^2 ha^{-1} basal area of white spruce is required to obtain full stocking of white spruce in Alberta aspen-white spruce BMWs on the basis of 10 m^2 assessment plots. This basal area equates to about 75 40-cm diameter trees per ha. For moderate spruce stocking (50%), the recommended basal area density is 2 m^2 ha^{-1} while for minimal (30%) conifer stocking it is 1 m^2 ha^{-1}. The recommended seed tree basal area densities consider seed production and juvenile survivorship, and assume a 35% net mineral soil exposure following scarification. Groot *et al.* (2001) recommend leaving groups of black spruce seed trees 10 to 15 m in diameter with an inter-group spacing of 70 to 90 m. Greene *et al.* (2002) suggest that because birch is such a prolific seeder and very well dispersed, only 1 m^2 ha^{-1} of seed tree basal area is necessary to obtain full stocking. Previous recommendations from the northeastern U.S. have been to leave 7 to 12 high quality, sawlog-size trees with well-developed crowns per ha (Safford 1983, Safford and Jacobs 1983).

Although seed predation is thought to limit the potential for white spruce regeneration, this has only recently been investigated. White spruce natural regeneration in Alberta BMWs subject to the seed tree method was significantly reduced by seed predation by red squirrels (*Tamiasciurus hudsonicus* Erxleben) (Peters *et al.* 2003). Based on the results of this study, the timing of harvest, as well as the spatial arrangement and density of seed trees should be considered to minimize the loss of white spruce seed to squirrel predation. Peters *et al.* (2003) suggest that harvests be timed to coincide with mast seed years so that an excess of seed is available for squirrel consumption, that retention of seed trees be low enough to prevent squirrels from maintaining territories in and adjacent to cutblocks, and that seed trees be left as isolated singles instead of in patches. Leaving single white spruce seed trees has resulted in less squirrel predation (McKinnon 2000) and may allow better seed distribution, although it increases windthrow risk.

Because windthrow of individual seed trees is a major risk, stems being retained must be chosen based on windfirmness as well as seed-producing ability. Canopy-dominant or super-dominant trees may be less prone to windthrow, have larger seed crops, and may be phenotypically superior. The slenderness coefficient, which is expressed as a height to diameter ratio, serves as an indicator of resistance to windthrow (Navratil 1995), and can be used to identify potentially windfirm seed trees. Windthrow risk may also be reduced by using the group seed tree method when appropriate. Because windthrow risk is greater for black than white spruce (Robinson 1970), Groot *et al.* (2001) recommend using only the group seed tree method for black spruce.

Spatial Variation of Clearcut Harvest Methods

Several spatial variations can be used in conjunction with either of the current clearcut harvest methods. These variations include strip, block, and patch cutting, described below.

Strip Cutting

Strip cutting involves harvesting a stand in alternate or progressive strips. Because strip cutting leaves a seed source adjacent to the felled and disturbed area, this method is most often used to facilitate natural regeneration. Once the regeneration in the felled strips has been established, the leave strips can then be harvested. Strip cutting is also used to protect fragile sites. In Ontario, strip cutting has most often been used to regenerate black spruce naturally from seed on poor or sensitive sites rather than on fertile BMW sites (Groot *et al.* 2001). However Hughes (1967) recommends the use of strip cutting to promote the natural regeneration of white spruce and balsam fir in Ontario BMWs.

To ensure effective seed dispersal, strip widths should be from two to six times the height of the adjacent trees from which seed will be obtained (Groot *et al.* 1997). At these widths, the leave strips do not affect the growth of the regeneration, which is still able to develop in a fully exposed microclimate. Strips should be oriented perpendicular to the prevailing wind direction to encourage maximum seed dispersal and to minimize the risk of windthrow (Flesch and Wilson 1999a,b).

Block Cutting

Block cutting involves the removal of trees, typically in a checkerboard pattern, with blocks of uncut timber separating the harvest blocks. Block width is determined by site and seed dispersal considerations similar to those identified for strip cutting. Individual blocks rarely exceed 10 ha.

Patch Cutting

Patch cutting involves the removal of stands in irregularly shaped harvest areas. Patch cuts are well suited to harvesting in broken terrain or in stands that lack uniformity in species distribution or site conditions. Patch configurations are often a reflection of the mosaic in the original forest and can vary greatly in size. Some boreal species are more easily regenerated in small patch cuts than in large clearcuts (Vincent 1965). Patch cuts may provide a higher edge-to-area ratio than block cuts and maximize natural regeneration from adjacent seed sources.

Proposed Reproduction Cutting and Harvest Methods

Proposed methods for BMW management in Ontario include the following innovative harvest methods within the clearcut reproduction method as well as several partial canopy removal methods (Table 2):

- Clearcut
    - With standards
    - Two-stage harvesting
- Partial Canopy Removal Methods
    - Shelterwood method
    - Selection method
    - Enhanced overstory retention

These proposed methods contribute to maintaining or enhancing non-timber values such as wildlife, aesthetics, and recreation. Artificial regeneration costs for these proposed methods may be greatly reduced or eliminated entirely since they are designed to secure vigorous natural regeneration. Nonetheless, these approaches often involve additional challenges, such as increased risk of windthrow of the residual stems. Other factors to be considered are the potential site and stem damage that can occur due to repeated stand entry associated with most partial canopy removal

Table 2. Summary of proposed reproduction cutting and harvest methods appropriate for Ontario's boreal mixedwood forest.

		HARVEST METHOD	OBJECTIVE	BENEFITS	LIMITATIONS	COMMENTS/CONSIDERATIONS
Reproduction Cutting Method	Clearcut	▪ With standards	▪ Create an aspen-leading or aspen-dominated or softwood-dominated or leading even-aged mixedwood stand with minimal structural complexity	▪ Reduced post-harvest sucker density to increase productivity and quality ▪ Reduced aspen density may facilitate introduction of conifer component ▪ Lower regeneration costs ▪ Maximum growth of regeneration promoted by a fully exposed microclimate	▪ Loss of volume due to retention of merchantable aspen stems	▪ Requires adequate abundance and distribution of aspen ▪ Clearcutting may occur in strips, blocks or patches
	Clearcut	▪ Two-stage harvesting	▪ Create an even-aged softwood-dominated or leading, or hard-wood-dominated or leading mixedwood with minimal structural complexity	▪ Increased productivity[1,2,3,4,5] and reduced crop rotation times ▪ Lower regeneration costs ▪ Improved biodiversity maintenance[6]	▪ Increased costs due to multiple stand entries and subcanopy protection ▪ Can promote development of balsam fir-dominated stand when fir comprises most of the subcanopy ▪ Only suitable for stands with two-tiered structure and windfirm subcanopy	▪ Requires careful logging practices to protect subcanopy advance growth ▪ Requires a two-tiered stand structure; where lacking, this structure can be created artificially by underplanting when understory light levels are adequate ▪ Requires that subcanopy windthrow risk is below critical thresholds ▪ Clearcutting may occur in strips, blocks or patches
	Shelterwood	▪ Uniform ▪ Group ▪ Strip	▪ Create an even-aged softwood-dominated or leading or hardwood-dominated or leading mixedwood with temporarily enhanced structural complexity	▪ Improved conditions for establishing regeneration ▪ Partial overstory can reduce understory competition ▪ Lower regeneration costs with natural regeneration	▪ Increased costs due to multiple stand entries and residual protection ▪ Temporary growth reduction in regeneration due to presence of partial overstory ▪ Partial canopy removal increases windthrow risk of residuals ▪ Alternative site preparation and tending treatments required	▪ Requires adequate seed availability and effective dispersal for natural seeding ▪ Site preparation generally required to provide receptive seedbeds for natural seeding ▪ Underplanting and seeding can be used when natural seed source is limited ▪ Residuals must be windfirm ▪ Strip shelterwood requires that strips be oriented to reduce windthrow risk ▪ Natural regeneration by coppice can be used to promote a hardwood component when shelterwood openings are large enough ▪ Requires careful logging practices to minimize damage to residuals and advance growth ▪ Ensure high-grading does not occur!
	Selection	▪ Single-tree ▪ Group	▪ Create or maintain an uneven-aged softwood-dominated or leading mixedwood with a reverse J-shaped size- and age-class distribution or a mosaic of small even-aged stands with enhanced structural complexity	▪ Improved conditions for establishment of regeneration ▪ Lower regeneration costs with natural regeneration ▪ Continuous enhanced structural complexity contributes to biodiversity maintenance ▪ Minimal windthrow risk [7]	▪ Single-tree selection is suitable only for the regeneration of shade-tolerant species ▪ Can promote development of balsam fir-dominated stand when balsam fir comprises most of the advance growth; leads to increased risk of spruce budworm infestation ▪ Increased costs due to multiple stand entries and presence of residuals ▪ Risk of site, residual, and advance growth damage ▪ Alternative site preparation and tending treatments required[8]	▪ Group selection can be used to regenerate both shade-tolerant and shade-intolerant species ▪ Requires practices to encourage spruce and discourage balsam fir regeneration ▪ Requires careful, low-impact logging practices ▪ Requires formal control of basal area retention and/or light estimation ▪ Ensure high-grading does not occur!
Enhanced Overstory Retention		▪ Applied with any shelterwood or selection harvest method	▪ Create an uneven-aged mixedwood where the primary objective is biodiversity ▪ Secondary objective is regenerating new crop	▪ Improved conditions for establishment of regeneration ▪ Lower regeneration costs with natural regeneration ▪ Continuous enhanced structural complexity contributes to biodiversity maintenance	▪ Reduced wood yield ▪ Reduced growth of regeneration when applied with shelterwood method due to presence of continuous overstory ▪ Partial canopy removal can increase windthrow risk of residuals ▪ Alternative site preparation and tending treatments required[8]	▪ Requires careful logging practices to minimize damage to residuals and advance growth ▪ Ensure that high-grading does not occur!

[1] Légaré *et al.* 2004; [2] Chen *et al.* 2003; [3] MacPherson *et al.* 2001; [4] Man and Lieffers 1999; [5] Lieffers *et al.* 1999; [6] Bradbury *et al.* 2003; [7] Navratil 1995; [8] Wedeles *et al.* 1995

methods and the increased costs and lost revenue associated with partial harvesting. Partial harvesting also involves more planning and supervision than conventional clearcutting. Increased harvesting and renewal costs associated with the operational constraints of working around residual trees should be considered.

Clearcutting Methods

Clearcut with Standards

Clearcut with standards is a clearcut harvest method that can be used to promote high quality aspen vegetative regeneration. This method was originally proposed for aspen regeneration in the north central US (Ruark 1990). It involves retaining 20 to 25 scattered aspen stems per ha to improve the quality of the regenerating suckers relative to conventional clearcutting. Retaining some aspen stems reduces immediate post-harvest sucker density, since apical dominance, which inhibits suckering, is not completely removed. Inhibitory auxins from the remnant stems reduce aspen sucker density to a level that can increase initial stand productivity, since site resources that are otherwise lost due to self-thinning are directed to crop tree growth. Although sucker density is reduced, maximum height growth is maintained. Sucker height growth is mostly related to light availability (Huffman *et al.* 1999), which is not reduced by the few remaining overstory stems. The loss of volume that occurs by retaining some stems may be compensated for by an increase in sawlog quality material in subsequent rotations and reduced time to reach minimum piece-size. Retained stems could also be harvested along with the new cohort. The spatial variations already described for current reproduction cutting and harvest methods are also relevant to this harvest method.

Two-Stage Harvesting

Two-stage harvesting, also known as understory protection or the natural shelterwood, is a clearcut harvest method that consists of two harvest and regeneration cycles typically aimed at softwood and hardwood production from the same site (Navratil *et al.* 1994). Eligible stands for this approach have a distinct two-tiered stand structure with a well-developed near-merchantable (e.g., 10 to 15 cm dbh) conifer subcanopy. This two-tiered stand structure is predominant in western BMWs where two-stage harvesting is used operationally in aspen-white spruce mixedwoods (Lieffers and Grover 2004). The two-tiered stand structure most often develops post-fire when white spruce regenerating from seed initially grows more slowly than the vegetatively regenerated aspen. The objective of two-stage harvesting is to remove the shade-intolerant overstory while maintaining the conifer subcanopy in an undamaged condition for future removal. Although two-staged harvesting is used predominantly in aspen-white spruce mixedwoods, the approach is applicable in any stand with a two-tiered intolerant-tolerant structure, including those with a conifer overstory.

Two-stage harvesting is a modified clearcut system because most of the merchantable timber is harvested in the first felling. As with the other clearcut variations, this method produces an even-aged stand structure. The overstory is harvested in the first pass at about age 60 (or anywhere between 30 to 80 years) when the subcanopy is 20 to 60 years old, depending on stand characteristics (Peterson and Peterson 1992, Navratil 1996, MacDonald 1996). All larger subcanopy conifers (e.g., greater than 25 cm dbh) can also be harvested in this first pass. Following the harvest, shade-intolerant hardwoods will regenerate in the available spaces, resulting in a mixed stand. The second pass harvest, scheduled decades later, targets both the initially released understory spruce as well as the regenerated hardwood component. After the second harvest, the stand can be managed as a mixedwood, hardwood, or conifer.

Two-stage harvesting may be carried out using any of the spatial variations previously described. Two-stage harvesting requires the use of careful logging practices to protect small advance growth and minimize damage to the subcanopy. Recommended operational practices for two-stage harvesting are outlined by Lieffers and Grover (2004). Several studies have indicated that a positive growth response occurs in subcanopy white spruce advance growth that has been released from an aspen overstory, even if the spruce has been suppressed for an extended period (Yang 1991, Brace Forest Services 1992, Navratil *et al.* 1994, Greenway *et al.* 1996, Man 2002). Lieffers and Grover (2004) suggest that the live crown ratio of the spruce should be evaluated as an indicator of the potential response of the advance growth to release.

Preliminary research indicates that two-stage harvesting may support the maintenance of biodiversity. Bradbury *et al.* (2003) found that Alberta BMW stands harvested with subcanopy protection had more snags as well as vascular plant, fungal, and songbird communities, and densities of red and flying squirrels (*Glaucomys sabrinus* Shaw) similar to unharvested mixedwood stands. Macdonald and Mourelle (2004) found increased vascular plant species richness several (3-13) years after two-stage harvesting compared to unharvested stands.

A major concern about the possible use of two-stage harvesting in Ontario BMWs is that the extremely shade-tolerant balsam fir often comprises most of the subcanopy advance growth on upland sites where fire has been excluded. Balsam fir regeneration has not been a common forest management objective in Ontario because of susceptibility to eastern spruce budworm (*Choristoneura fumiferana* Clem.) and stem and root rots. In addition, many Ontario BMWs do not exhibit the distinct two-tiered stand structure that is necessary for the successful application of this method. One way to address both of these concerns is to artificially create a two-tiered stand structure by underplanting mature hardwood stands with white spruce about 10 to 20 years before harvest. Underplanting white spruce in mature aspen stands is a successful operational practice in western BMWs (Stewart *et al.* 2000, Lieffers and Grover 2004). However underplanting requires a minimum of 20% of full sun in the understory to ensure white spruce survival and moderate growth (Lieffers and Stadt 1994, Constabel and Lieffers 1996, Lieffers *et al.* 2002). Information on the availability of understory light in intolerant hardwood stands in Ontario is limited. Although Groot (1999) observed that understory light in a mature aspen stand in northeastern Ontario was 23% of full sunlight, a further reduction to only 6% on the forest floor resulted from multiple canopies of tall and low woody shrubs. Understory vegetation control will likely be necessary for successful underplanting in Ontario aspen stands. No information is currently available on understory light levels in mature birch or mixed birch-aspen stands in Ontario. Such information will be necessary to consider underplanting as a precursor to two-stage harvesting in birch-dominated mixedwoods.

The greatest potential difficulty with two-stage harvesting is the risk of losing much of the released subcanopy to windthrow (Navratil 1995), sunscald, or drought. Because subcanopy trees develop in low light conditions in the absence of strong winds, these trees have higher slenderness coefficients (height to diameter ratios) than those that develop in the open. White spruce understory trees taller than 7 m and with slenderness coefficients greater than 100 are at substantial risk of windthrow after overstory removal (Navratil 1996). Before implementing two-stage harvesting, an evaluation of post-harvest windthrow risk should be undertaken based on subcanopy stand structure and site location and conditions. Where two-stage harvesting is considered appropriate, specific cutblock designs can be used (e.g., MacIsaac *et al.* 1999, Lieffers and Grover 2004) and other modifications applied (e.g., Navratil *et al.* 1994, Navratil 1995, Lieffers *et al.* 2003) to minimize the risk of windthrow. It may be necessary to accept a tradeoff between subcanopy conifer growth response to release and wind protection. If windthrow risk is considered too great (e.g., if most subcanopy trees have slenderness coefficients greater than or equal to 100), strip clearcutting or a shelterwood system should be considered instead (Navratil *et al.* 1994).

Partial Canopy Removal Methods

Recent studies have indicated that there are mid- and late-successional phases of boreal forests that are able to regenerate and maintain themselves through non-fire disturbances including insect and disease outbreaks and wind (Kuuluvainen 1994, Kneeshaw and Bergeron 1998, 1999; Gauthier and Degrandpré 2003; Pham *et al.* 2004; D'Aoust *et al.* 2004). This is contrary to the traditionally held view that stand-replacing disturbances such as fire are required to re-initiate succession that would favour spruce and other early successional species. On the basis of these studies, partial canopy removal methods are suggested for use in boreal stands at mid- and late-successional stages to better emulate natural processes and recreate a forest structure and composition more comparable to natural stands (Bergeron *et al.* 1999, 2001, 2002; Burton *et al.* 1999; Harvey *et al.* 2002; Kneeshaw and Gauthier 2003). Partial canopy removal methods have already been successfully implemented in the boreal forest of Fennoscandia (Andreassen 1995; Lähde *et al*. 1999, 2002) and in peatland black spruce stands in northeastern Ontario (Groot 2002).

The shelterwood reproduction cutting method is recommended for use in mid-successional stands to promote an even-aged structure. In contrast, the selection reproduction cutting method is recommended for use in late-successional stands to maintain the uneven-aged complex stand structure that develops at this stage as a result of gap dynamics. Gap dynamics occurs when the removal of one or more canopy trees due to damage from wind, snow, insects or disease, or age-related mortality creates a sufficiently large opening to allow the establishment of new regeneration (Shugart 1984, Platt and Strong 1989). The use of these partial canopy removal methods at the appropriate successional stages accords with ecosystem management objectives. Enhanced overstory retention (EOR) (above the levels that would typically occur with the shelterwood or selection methods) can be applied in conjunction with either of these traditional methods when the primary BMW management objective is to conserve biodiversity (Franklin *et al*. 1997, Mitchell and Beese 2002).

Partial canopy removal methods focus primarily on securing regeneration through natural seeding or the protection of advance growth, although coppice can also be encouraged to meet certain BMW objectives. Natural regeneration of conifers from seed requires the retention of sufficient seed trees in the overstory and adequate receptive seedbeds. Understory scarification will be required on most BMW sites to prepare adequate seedbeds. Artificial regeneration (planting or seeding) is also applicable when natural regeneration alone will not achieve the desired future stand condition. Underplanting conifers is a useful technique when the objective is to increase the conifer component and adequate advance growth or a seed source is lacking. Understory vegetation management will also be required on most sites. Although the establishment of a new crop is most often the primary objective of partial canopy removal methods, removal of part of the original canopy can also accelerate growth of the residual canopy trees, increasing yield in future harvests.

To determine the level of partial canopy removal required to meet management objectives, consideration should be given to the amount of advance growth present in the stand, site conditions, and whether additional harvesting of the original canopy will occur. The residual canopy should provide sufficient light to allow establishment of desired species but prevent both temperature extremes and the invasion of light-demanding competitive species (Lieffers 1995, Lieffers *et al.* 1999). The recent development of computer models such as MIXLIGHT (Stadt and Lieffers 2000) and SORTIE (Coates *et al.* 2001) predict light in partially cut stands on the basis of tree size, crown characteristics, and stem densities. Such models are useful tools for determining the level of partial canopy removal required.

Windthrow risk and the potential for highgrading the stand must be considered for all partial canopy removal methods. Windthrow of residual stems is a risk with partial cutting because the removal of a portion of the main canopy increases wind penetration into a stand (Savill 1983, Ruel 1995). To reduce windthrow risk, residual overstory trees should be selected on the basis of windfirmness (e.g., low slenderness coefficient) and measures undertaken to reduce windthrow. Such measures may include modifying harvest intensity (MacDonald 2000, Ruel *et al.* 2000b, 2003) and pattern (Franklin *et al.* 1997, Gilles 2001, Rollerson and McGourlick 2001, Rowan *et al.* 2001) and branch or top pruning to reduce the wind-capturing surface (Stathers *et al.* 1994, Gilles 2001, Rollerson and McGourlick 2001, Rowan *et al.* 2001).

All partial canopy removal methods have the potential to become highgrading, which is the removal of only the most commercially valuable trees or stems. Highgrading can result in a residual stand composed of undesirable species or trees of both poor condition and genetic quality (Joyce *et al.* 2001). This approach conflicts with sustainable ecosystem management as it can have negative long-term health, biodiversity and economic impacts.

Shelterwood Method

The shelterwood reproduction cutting method removes the canopy in successive stages at reasonably close intervals between harvest interventions to secure even-aged natural or artificial regeneration under the protection of a partial forest canopy or "shelterwood" (Smith *et al.* 1997). One or more initial preparatory cuts may occur to promote the seed-producing potential of preferred trees. A seed cut, which removes from 30 to 70% of the overstory, is then carried out before or during seed dispersal. This cut is usually planned to occur in conjunction with operations to improve seedbed conditions for seedling establishment (e.g., mineral soil scarification and removal of understory vegetative competition). The retention of up to 70% of the overstory during this stage creates an understory microenvironment that affects the survival and growth of the regeneration. Although the presence of a partial overstory does reduce the initial growth of the regeneration, the effect is temporary, and is offset by the positive effects of enhanced seedling establishment and survival associated with the presence of a partial canopy.

A partial canopy improves conditions for establishing regeneration by providing cooler daytime and warmer nighttime temperatures, higher relative humidity, lower vapour pressure deficit, and lower frequency and severity of night frosts (Childs and Flint 1987, Groot *et al.* 1997, Man and Lieffers 1997). Since light levels typically range from 20 to 60% of full sunlight in the understory during the early stages of shelterwoods (Dey and MacDonald 2001), adequate light is available for growth of the regenerating cohort. Once the regeneration is established, remaining overstory trees (except those required to meet biodiversity objectives as required by the NDPEG guidelines) are harvested in one or more cuts, called the removal and final cuts. After the final cut, the regenerating trees grow in open-light conditions throughout the remainder of the rotation. Natural regeneration secured through shelterwood cutting can also be supplemented by seeding or planting.

Several spatial variations exist for the shelterwood method including uniform, strip, and group shelterwood methods (Table 3). The choice of spatial harvest pattern depends in part on stand conditions and operability. With uniform shelterwood cutting, the entire stand is harvested uniformly throughout to obtain a desired level of basal area reduction and uniform inter-tree spacing. With strip shelterwood cutting, harvesting occurs in a series of strips. Strips are either cut entirely clear, if they are narrow enough to provide shelter and seed from adjacent uncut strips, or with sheltering trees retained throughout the cut strips during the initial harvests. Although strip width varies depending on the species being promoted, it does not generally exceed two tree heights (Groot *et al.* 1997), so that a sheltering effect still occurs. As with strip clearcutting, strips should be oriented perpendicular to the direction of the prevailing wind to facilitate even seed dispersal across the harvested strip. Strip cutting advances progressively throughout the stand over the regeneration period (Smith 1986, Navratil 1995, Flesch and Wilson 1998). The group shelterwood method involves the progressive harvesting of the stand in patches of one to two tree heights in diameter, often where existing advance growth exists.

The shelterwood method can be used in BMW management to promote the natural regeneration of any of the defining mixedwood species, including mixtures of these species. In Quebec, Brais *et al.* (2004) found that in first-cohort aspen-dominated stands, a uniform removal of 61% of overstory basal area promoted a future stand composition that more closely resembled older, more structurally complex mixedwood stand types. This level of canopy removal allowed both the regeneration of a vigorous cohort of aspen and increased growth of residual softwood stems in response to increased light levels. Raymond *et al.* (2000) found that a low intensity seed cut (e.g., 25% canopy removal) for all three variations of the shelterwood method increased the abundance of white spruce, balsam fir, and birch seedlings in balsam fir-dominated mixedwoods in Quebec.

Managing understory light regimes with the shelterwood method can be an effective means to control undesirable shade-intolerant trees, woody shrubs, grasses and herbs to minimize their regeneration and growth (Bell 1991, Lieffers and Stadt 1994, Groot *et al.* 1997, MacDonald 2000). Retaining 50% of overstory basal area reduces the development of red raspberry (*Rubus ideaus* L.) (Horton 1962, Kelty and Nyland 1981) and can effectively reduce the proportion of undesirable tree species, such as balsam fir (Baldwin 1977) and aspen (Prévost and Pothier 2003). Shade from the residual trees discourages aspen suckering by

Table 3. *Objectives, applicable harvest methods, renewal options, and appropriate current stand conditions for applying shelterwood management in boreal mixedwoods.*

OBJECTIVE(S)	APPLICABLE HARVEST METHOD(S)	RENEWAL OPTION(S)	CURRENT STAND CONDITION
Creation of even-aged, softwood-dominated or leading mixedwoods	▪ Uniform ▪ Strip ▪ Group	▪ Natural and /or direct seeding ▪ Protection of small and/or subcanopy advance growth ▪ Underplanting	▪ Even-aged, aspen-dominated or leading mixedwoods ▪ Even-aged, birch-dominated or leading mixedwoods ▪ Even-aged, softwood-dominated or leading mixedwoods
Creation of even-aged, birch-dominated or leading mixedwoods	▪ Uniform ▪ Strip	▪ Natural seeding	▪ Even-aged, birch-dominated or leading mixedwoods
Creation of even-aged, aspen-leading mixedwoods	▪ Uniform ▪ Strip ▪ Group	▪ Coppice	▪ Even-aged, aspen-dominated mixedwoods

reducing soil temperature (Peterson and Peterson 1995, MacDonald 2000).

The uniform or strip shelterwood method is recommended an alternative to two-stage harvesting, when the objective is to protect large, unstable advance growth at high risk of windthrow (Lieffers *et al.* 1996, Navratil 1995, 1996). The initial removal of no more than 50% of the canopy, and at least two subsequent harvests with intervals of at least five years is suggested to gradually improve the stability of subcanopy spruce before final removal (Navratil *et al.* 1994, Navratil 1995).

Extensive research on the use of the shelterwood method combined with either natural or artificial regeneration has proven this method is effective for promoting white spruce. Mature and overmature stands with moderate to low stocking and emergent white spruce are the best candidates for the shelterwood method, since the retained trees will be more windfirm (Wedeles *et al.* 1995).

Shelterwood studies in western Canada and the U.S. have shown that two-stage uniform shelterwood cuttings with initial retention of 9 to 20 m^2 ha^{-1} residual basal area have been effective for natural regeneration of white spruce in BMWs where scarification is used to create mineral soil seedbeds (Waldron 1966, Lees 1970, Waldron and Kolabinski 1994, Bella and Gal 1995, Ball and Walker 1995, 1997, Wurtz and Zasada 2001). The preparatory cut should leave mainly white spruce and eliminate aspen and balsam fir stems (Wedeles *et al.* 1995). Retention of up to 9 m^2 ha^{-1} basal area provides 45% of full sunlight in the understory, which allows maximum white spruce height growth. Spruce survival and growth will not generally be compromised until basal area retention is greater than 18 m^2 ha^{-1} (Dey and MacDonald 2001).

Information about the use of group shelterwood cutting to promote white spruce natural regeneration is lacking. However, this method has the potential to promote an irregular stand structure with a significant white spruce component. Ruel *et al.* (2003) have suggested that group shelterwoods be used to mimic the small windthrow events that are an important mechanism for the natural regeneration of white spruce in Quebec's balsam-fir dominated mixedwoods. Group shelterwood trials in aspen-white spruce mixedwoods in northeastern British Columbia have been implemented to investigate the survival and growth of naturally seeded white spruce in two sizes of group shelterwood openings, although results are not yet available (Kabzems 1998).

Underplanting white spruce seedlings can be effectively combined with the shelterwood method since shelter from the partial canopy protects the seedlings from frost damage (Carlson and Groot 1997, Man and Lieffers 1999). This approach requires that canopy basal area is reduced to ensure adequate light transmission to the understory for seedling growth. This technique, investigated in aspen and birch stands in western Canada

(Comeau *et al.* 1999, Comeau 2001, Simard and Hannam 2000), can be used to increase the white spruce component in hardwood stands where conifer seed source or advance growth are lacking. A uniform shelterwood with the same level of canopy retention as recommended for natural regeneration of white spruce (Groot 1999, Man and Lieffers 1999), or the group or strip shelterwood methods with either medium-sized strips or circular canopy openings coupled with underplanting and early vegetation management (Groot and Carlson 1996, Groot *et al.* 1997, Groot 1999, Kabzems 1998) have been used successfully for regenerating white spruce.

Although direct seeding white spruce in conjunction with the shelterwood method has been investigated, success tends to be hindered by the dense understory vegetation layer common in productive BMWs (Groot *et al.* 1997). For success, white spruce seeding requires an adequate sowing rate and intensive site preparation to remove vegetation and provide receptive seedbeds.

Limited investigation of shelterwood cutting to promote natural black spruce regeneration has occurred. However a uniform shelterwood study in a spruce-aspen-fir mixedwood has been initiated as a component of the Black Sturgeon Boreal Mixedwood Research Project in northwestern Ontario to investigate the potential of this method for the natural regeneration of both black and white spruce (Cameron *et al.* 1999).

Uniform and strip shelterwood approaches are effective on dry sites to promote the regeneration of white birch by natural seeding. Temporary retention of a partial canopy ameliorates the droughty conditions that often limit birch regeneration following total canopy removal (Perala and Alm 1990). Birch seedlings cannot tolerate drought, but they are able to endure up to 90% shade for a few years following establishment. The final cut must be completed as soon as the birch regeneration is established, usually within three to five years following the initial shelterwood harvest, so that adequate light is available for maximum growth (Perala and Alm 1989, 1990). To promote birch regeneration with one of these shelterwood variations, Perala and Alm (1989, 1990) recommend removing 60 to 80% of the crown cover in the seed cut. This level of overstory removal is higher than that typically recommended for white spruce to allow more light to reach the more shade-intolerant birch seedlings and to promote good wind dispersal of birch seed. Scarification to control competing vegetation and to provide a suitable seedbed is also required for the successful regeneration of white birch from natural seeding.

It is also possible to promote aspen vegetative regeneration through the use of small group shelterwood openings (Groot et al. 1997, Kabzems 1998). Openings as small as one tree height (18 m) in diameter can provide adequate light for both survival and growth of aspen suckers. However, it is not known whether different patterns of self-thinning will occur in these openings than conventional clearcuts due to different light conditions.

Selection Method

The selection reproduction cutting method involves the continuous removal of trees in all size classes at relatively short intervals (e.g., 10 to 25 years) (Smith *et al.* 1997). This method provides for high canopy retention, typically more than 70% (Franklin *et al.* 1997). The resulting stand structure generally has reverse J-shaped size and age-class distributions, with three or more distinct age or size classes. This method, which emulates the small canopy gaps created by tree mortality during the gap dynamics stage of stand development, can be used to create or maintain an uneven-aged stand structure. The selection method usually relies on natural regeneration, although artificial regeneration (underplanting or seeding) can also be used when a seed source or advance growth are lacking. Leiffers *et al.* (2003) note that to maintain an uneven-aged stand structure and encourage a new cohort of regeneration after each cutting, formal control of basal area retention and/or light estimation should be undertaken to ensure regeneration.

Variations of the selection method are single-tree selection, where individual trees are removed from a range of diameter classes, and group selection, where small groups of less than two tree heights in diameter are periodically removed from throughout the stand (Table 4). Single-tree selection emulates small canopy gap formation from individual-tree mortality that occurs due to senescence, insects and disease, or wind, snow or ice damage. Group selection emulates small-scale disturbances caused by insects and disease, windthrow, and snow or ice damage that cause tree mortality in patches. Because single-tree selection produces continuous shaded conditions in the understory, this method is only suitable for regenerating shade-tolerant species such as balsam fir. Although balsam fir regeneration is not a typical management objective in Ontario, Groot *et al.* (2001) provide recommendations for regenerating this species using single-tree selection in good quality, windfirm, uneven-aged balsam fir stands.

Group selection openings can often provide enough understory light to promote the regeneration of both shade-tolerant and shade-intolerant species. Openings of 18 to 20 m in diameter provide enough direct light at ground level to allow aspen and white birch recruitment (Groot *et al.* 1997, Kneeshaw and Bergeron 1998). Lieffers *et al.* (1996) recommend that single-tree selection be applied to obtain an all-aged mainly coniferous stand in multi-storied, uneven-aged mixedwood coniferous stands that have a range of sizes of understory saplings. They also suggest that group selection be used to regenerate a mosaic of uneven-aged patches to a mixture of deciduous and coniferous species of different ages in single-storied mixedwood coniferous stands.

Although windthrow risk of residual stems is minimal for both variations of the selection method (Navratil 1995), these approaches involve substantial risk of damage to the site, the root systems and stems of residual trees, and to existing advance growth. Harvesting practices that are low-impact and minimize the total stand area affected are required for success (Fjeld and Granhus 1998, Granhus and Fjeld 2001).

Although the selection method has not been implemented in Ontario BMWs to date, uneven-aged silviculture appears to be applicable to peatland black spruce in northeastern Ontario (Groot 2002). Early studies on selection cutting in late successional uneven-aged spruce-fir BMWs in eastern Canada have shown the potential of this method to maintain this structure in these stand types (Croome 1970, Weetman and Algar 1976). However these studies also indicated that if relying on natural regeneration alone, successive selection cuts will produce a steady stand conversion from spruce to balsam fir. Harvey *et al.* (2002) recommend late summer or fall individual selection cutting favouring merchantable balsam fir over spruce to preferentially promote spruce in late successional spruce-fir-birch stands. Wedeles *et al.* (1995) suggest that if an increase in balsam fir does not meet management objectives, short cutting cycles with associated ground disturbance should be used to reduce balsam fir and encourage spruce. They also suggest underplanting spruce to increase the spruce component, in conjunction with alternative site preparation and tending treatments.

Enhanced Overstory Retention

Enhanced overstory retention is an element of the variable retention concept initially described by Franklin *et al.* (1997). In British Columbia, variable retention is being integrated into forest management practices in various ways (Mitchell and Beese 2002, Sougavinski and Doyon 2002, Beese *et al.* 2003). In Ontario BMW management, EOR can be implemented in conjunction with either the shelterwood or selection methods (OMNR 2003). This approach involves retaining part of the canopy that would normally be harvested to create snags and downed woody debris to meet biodiversity objectives. This approach differs from other traditional partial cutting approaches in that it is structure-based, where the regeneration of a new crop is secondary to biodiversity objectives. The retained structural elements remain on the cutblock either permanently or for a minimum of one complete rotation (Hunter and Seymour 1992, Franklin *et al.* 1997). Overstory retention requires determining which trees (species, individuals) should be retained, and at what level and distribution, to meet management objectives.

One of the economic impacts of applying EOR with any reproduction cutting method is reduced fibre yield. The continuous overstory will also reduce the growth of the regenerating stand (Franklin *et al.* 1997, Mitchell and Arnott 1995). This is true regardless of the shelterwood method variations used. Resulting stand development patterns will differ throughout the rotation due to continuous modification of the understory microclimate and regeneration will grow more slowly compared with the traditional approaches.

When EOR is applied with the selection method, a portion of the right side of the classical J-shaped diameter distribution is retained and mortality of some trees that would normally be harvested occurs. However, additional retention should not affect the growth response of the regeneration compared with the traditional selection approach, which already subjects regeneration to continuous shading.

Table 4. *Objectives, applicable harvest methods, and appropriate current stand conditions for selection management in boreal mixedwoods (from Lieffers* et al. *1996).*

OBJECTIVE	APPLICABLE HARVEST METHOD	CURRENT STAND CONDITION
Create or maintain an uneven-aged, softwood-dominated mixedwood stand	Single-tree selection	Multi-storied, uneven-aged softwood-dominated mixedwood stands that have a range of sizes of understory saplings
Create or maintain an uneven-aged, softwood-dominated or leading mixedwood stand.	Group selection	Single-storied, uneven-aged softwood-dominated mixedwood stands that can be a mosaic of small even-aged stands

Summary

Boreal mixedwood management incorporates the use of both traditional and non-traditional reproduction cutting and harvest methods. This note describes the traditional methods that are currently applied in Ontario's BMWs. As well, methods currently in use in other Ontario forest types that have not yet been applied in BMWs and several entirely new approaches that have not yet been applied anywhere in Ontario, are recommended.

Managed forests maintain the composition and structural features that exist in forests created by natural disturbance agents. The choice of a reproduction cutting and harvest method for a particular site relies on analysis of current site and stand conditions, desired forest species, environmental and socio-eonomic constraints, and available markets for resulting timber and wood products. Forest attributes controlled by the reproduction cutting and harvest method include species composition, amount of crown canopy closure, and the spatial and vertical distribution of remaining vegetation (Graham and Jain 1998).

Resource managers determine the level of emphasis on the retention and renewal of certain tree species to ensure the reproduction cutting and harvest methods meet forest management objectives. Factors such as initial species composition and stand structure directly affect the stages through which the forest will progress over time. What may work in one eco-region or eco-district may not work in another due to differences in macro-climatic features, growing season, topography, parental mineralogy, and natural disturbance regimes. Removal or retention of stand canopy, available biomass, and seed sources all contribute to the biological legacy that results from the manager's choice of reproduction cutting and harvest method.

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Notes
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Tending for Boreal Mixedwood Management in Ontario

by L.M. McKinnon*, W.D. Towill**, and C.L. Palmer**

> ***The boreal mixedwood management philosophy has necessitated some change in emphasis and modification to traditional tending practices.***

Introduction

In Ontario, tending refers to forest management operations carried out to improve the survival, growth, or quality of forest stands (adapted from OMNR 2004). These silvicultural practices channel resources such as light, water, and nutrients to direct stand development towards a future stand condition composed of target and acceptable species with a specific composition, structure, and growth rate (Wagner *et al*. 2001). Tending treatments can be applied prior to overstory harvest, immediately post-harvest, or following renewal (OMNR 2003). Application of appropriate tending treatments can be particularly critical to ensuring that boreal mixedwood management objectives are met (Hearnden *et al*. 1992, Lautenschlager and Sullivan 2002). To determine the influence of various tending treatments on desired future stand condition, it is essential to understand the factors that influence growth, development and dynamics of mixedwood stands. These sites are typically characterized by high intra- and interspecific competition, especially following overstory removal (e.g., Lieffers *et al*. 1993, Groot *et al*. 1997).

Where the objective is to promote a significant softwood component, tending methods, treatments, and techniques traditionally used for conifer plantation management may also be appropriate for boreal mixedwood management. However boreal mixedwood management may also require additional and sometimes unique tending approaches since it promotes (Lieffers and Beck 1994, MacDonald 1995, Lieffers *et al*. 1996, Greene *et al*. 2002):

- tree species mixtures and the concept of managing with succession (e.g., accepting a hardwood component on the site)[1]
- the use of partial canopy removal methods (partial cutting) and low impact silvicultural methods, and
- reliance on natural regeneration and advance growth

where ecologically appropriate and silviculturally feasible. To add to this silvicultural complexity, interest also exists in reducing herbicide use (MacDonald 2000) (through more selective

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[1] Tree species mixtures not required at all stages of succession.

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applications or through alternatives) and increasing the representation of conifers such as white spruce (*Picea glauca* (Moench) Voss) on boreal landscapes (Greene *et al*. 2002, Lautenschlager and Sullivan 2002).

The requirement for tending depends on the management objective as well as the type and degree of inter- and intraspecific competition. Target densities of both the hardwood and conifer component required to achieve the stand composition established in the management objectives must be defined prior to stand intervention.

Tending treatments should be applied at the appropriate time and intensity, recognizing that promoting tree species mixtures and maintaining long-term site productivity and biological diversity are inherent aspects of the boreal mixedwood management philosophy (MacDonald 1995). The goal or result of tending is never to completely eradicate any given species while enhancing the growth of desired components (MacDonald 1995, Lautenschlager and Sullivan 2002). Where a need for tending is identified, the tending treatments selected would ideally be those with the highest silvicultural efficacy and the least impact on other ecosystem components.

The purpose of this note is to review stand tending practices in the context of a boreal mixedwood management philosophy.

Tending Opportunities as Influenced by Stand Development

Tending methods applicable to boreal mixedwood management in Ontario can be distinguished based on their potential to achieve one or more primary management objectives and, in some cases, the stage of stand development (successional stage) to which they best apply (Table 1, OMNR 2003). Cleaning and juvenile spacing are tending methods that can be used to help favour crop trees at the stand initiation stage. Recruitment of crop trees to the main tree canopy can be further promoted at the stem exclusion (closed canopy) stage by liberation treatments. In contrast, thinning and pruning can be used at this stage to improve the growth and/or wood quality of crop trees that comprise the main tree canopy. Compositional treatment can be carried out at either the stand initiation or stem exclusion stages, whenever a change in tree species composition or working group is a primary objective.

Tending is often not required beyond the stem exclusion stage because the stand is already well established. At this stage, it is often more economical to simply harvest the stand than to conduct further tending treatments. An exception is cleaning, which can be applied at any stage of stand development (OMNR 2003). This non-traditional extension of

Table 1. *Principle tending objectives, associated tending methods, and applicability during the four stages of boreal mixedwood stand development (OMNR 2003). Shading identifies the stages of stand development where individual tending methods apply. Stages of stand development follow Chen and Popadiouk (2002).*

Tending		Stand Development Stage							
		Stand initiation		Stem inclusion		Canopy transition		Gap dynamics	
Objective(s)	Method	Early	Late	Early	Late	Early	Late	Early	Late
Removing vegetation or undesirable tree species that are close to or are overtopping crop trees	Cleaning	▨	▨	▨	▨	▨	▨	▨	▨
	Liberation			▨	▨				
Reducing stand density, with or without an objective of improving wood quality	Juvenile spacing (unmerchantable removal)		▨						
	Pre-commercial thinning (unmerchantable removal)			▨					
	Commercial thinning (merchantable removal)			▨	▨				
Changing species composition	Compositional treatment		▨	▨	▨				
Improving wood quality	Pruning			▨					

the use of cleaning to later stand development stages is necessary to accommodate the many scenarios in boreal mixedwood management that involve the promotion and protection of understory trees to form the next cohort (or canopy) in the post-harvest stand.

Tending Methods

Where tending is required to achieve the desired future stand condition, one or more of the methods, techniques, and strategies presented in this section may be considered.

Cleaning

In the context of boreal mixedwood management, 'cleaning' refers to chemical, manual, mechanical, or alternative treatments applied to free desired crop trees from ground vegetation or undesirable trees of similar age or size that overtop them or are likely to do so (OMNR 2003). The nature and abundance of competing vegetation are influenced by site quality, stand history and neighbouring stand composition, and stage of stand development (Greene and Johnson 1999, 2000, Nguyen-Xuan *et al*. 2000, Wagner *et al*. 2001, Chen and Popadiouk 2002, Wang and Su 2002). On fertile boreal mixedwood sites, aspen (*Populus* spp.), alder (*Alnus* spp.), mountain maple (*Acer spicatum* Lam.), beaked hazel (*Corylus cornuta* Marsh.), willow (*Salix* spp.), raspberry (*Rubus* spp.), sedges (*Carex* spp.), and grasses (e.g., *Calamagrostis canadensis L.* (Michx.) Beauv.) are often major competitors of spruce. For further consideration of species interactions and competitive potential, Buse and Baker (1991), Buse and Bell (1992), and Arnup *et al*. (1995) provide a more in-depth review of the literature.

Where intimate mixtures of hardwoods and softwoods are being promoted at the stand initiation stage, some cleaning of hardwood trees may be required to ensure that this component does not become so dominant that it threatens conifer survival and growth. Removal of ground vegetation may also be warranted wherever the distribution and amount of competition would otherwise prevent or unacceptably delay crop tree establishment, survival and early growth. This applies particularly to conifer crop trees (Lautenschlager and Sullivan 2002) but, on some boreal mixedwood sites, vegetative competition and other factors can also render desired hardwood regeneration difficult following overstory removal (Navratil *et al*. 1991). Although traditionally carried out at the stand initiation stage, cleaning can be applied at any stage of stand development, for example, to ensure survival and acceptable growth of existing advance growth or underplanted conifers at the late stem exclusion/early canopy transition stage.

A pre-harvest assessment (e.g., Bidwell *et al*. 1996) helps to predict potential competition problems and to plan vegetation control in advance. Potential competition problems can be predicted using knowledge of the vegetation potential of a site combined with past management experience with similar sites and stands (Wagner *et al*. 2001). For example, competition potential and the vigour of non-crop species on sites of differing edaphic quality can to some extent be inferred from knowledge of the autecology (particularly reproductive strategy) and frequency of occurrence of major competitors (Buse and Bell 1992, Arnup *et al*. 1995). Vegetation control that is applied early (within critical period) and reduces competition below a critical level (i.e., competition threshold) generally results in better long-term growth and yield than vegetation control applied more intensively in later years (Wood and Von Althen 1993, Wagner *et al*. 1999, Jobidon 2000, Wagner 2000).

Where competition between crop trees and ground vegetation or undesired trees becomes incompatible with management objectives, there is a need to identify this and select and apply an appropriate cleaning treatment. The requirement for cleaning is typically assessed using various competition thresholds or indices (Wagner *et al*. 2001). However, these assessment methods, as well as so-called "free-growing" criteria (e.g., OMNR *in prep*.a) have been developed mainly for conifer plantations and are likely inappropriate for evaluating competition under unique boreal mixedwood management scenarios. For example:

- boreal mixedwood management promotes reliance on natural regeneration (MacDonald 1995) but assessment of the need for cleaning in naturally regenerated stands may be rendered difficult by extended recruitment periods and heterogenous spacing; there is a higher likelihood that cleaning will be required when stands are regenerated from seed rather than from advance growth or planted stock (Wagner *et al*. 2001)
- traditional free-growing criteria cannot predict

the competitive effects of shade-intolerant hardwoods on light availability to conifers in stands where conifers and hardwoods are grown together in intimate mixtures (Lieffers *et al*. 2002)

To implement effective vegetation management for boreal mixedwoods, competition indices and regeneration standards should be developed based on mixedwood competition dynamics to predict both short- and long-term growth and yield of hardwoods and conifers in intimate mixtures. Such indices and standards should consider the optimum spatial arrangement of conifers and hardwoods to allow acceptable light levels for the growth of all crop trees (Comeau 2003a, Harper and Kabzems 2003). Examples of current and recent research on boreal mixedwood competition dynamics that may be used to develop competition indices and regeneration standards in Ontario include:

- research in northeastern Ontario and Alberta on the effect of vegetation control on the growth of white spruce and aspen in mixtures, where white spruce is planted at a relatively low density (400 stems/ha) and aspen regenerates naturally in the intervening areas (Pitt *et al.* 2003)
- development of models based on light availability (LITE, MIXLIGHT) to determine the optimum size of the hardwood-free zone to maximize spruce growth in various aspen-white spruce spatial mixtures in B.C. (Comeau 2001, 2003a; Stadt and Lieffers 2003)
- a long-term study initiated in 1991 by the Western Boreal Growth and Yield Association to examine the effects of residual aspen density following spacing on dynamics and yield of mixedwood stands (Comeau 2003b, Comeau *et al.* 2004)
- a long-term study of the effects of stand cleaning alternatives on stand dynamics, stand growth and yield, vegetation competition and treatment efficiency in aspen-white spruce mixedwoods in B.C. (Harper and Kabzems 2003)
- a comparison of various individual tree non-spatial and spatial competition indices for predicting diameter growth of trees in maturing boreal mixedwood stands in Alberta (Stadt *et al.* 2002)

In the absence of information for specific mixedwood scenarios, a general rule for ensuring long-term survival and eventual response to release of shade tolerant boreal conifers is to maintain >25% full sunlight at seedling or sapling height (Greene *et al*. 2002). For practical purposes, it is possible to relate light criteria to more easily measured stand attributes such as density or basal area (Comeau *et al*. 1998, 2003; Comeau 2001, 2003a; Lieffers *et al*. 2002, Comeau and Heineman 2003).

Cleaning in boreal mixedwood stands can be accomplished using chemical (herbicide), manual, and mechanical treatments, or various vegetation management alternatives including animal grazing, mulching, cover cropping or the application of biological control agents (Table 2) applied alone or in combination. The comparative merits of these cleaning treatments, as well as descriptions of the various techniques and tools available for applying each treatment, are detailed in *Vegetation Management Alternatives Program* (VMAP) technical notes (Myketa *et al*. 1995, McLaughlan *et al*. 1996a,b, Foster 1998, Harvey *et al*. 1998), and other Ontario-specific (Wagner *et al*. 2001, OMNR 2003) and additional (Fraser *et al*. 2001) sources. The choice of a particular treatment or treatment combination, should include consideration of whether or not subsequent treatment(s) will be required.

Cleaning treatments should be chosen to preferentially remove competitive species without damaging the desired crop tree species or permanently eliminating competitors. Important considerations include:

- the relative susceptibility of crop trees and competitors to individual chemical, manual, and mechanical treatments (McLaughlan et al. 1996a, OMNR 2003)
- the relative proximity of crop tree species and competitors, including the spatial arrangement of tree species in intimate versus patchy mixtures
- the potential effects on both the competitive plant community and associated wildlife habitat

Broadcast aerial chemical cleaning is the most common, effective, and inexpensive method currently available to promote the establishment of boreal conifers (Wagner *et al.* 2001). However, where mixtures of hardwoods and softwoods are being promoted, particularly in partial canopy removal scenarios, adequate protection of desirable tree species requires that more emphasis be placed on the use of ground equipment and band/patch or directed spot chemical spraying or other even more selective techniques directed at individual or group tree release. Although herbicides may reduce plant diversity (e.g. Newmaster *et al.* 1999), they are considered to have

Table 2. *Selected cleaning treatments for boreal mixedwood management in Ontario (Bell et al. 1995, Dumas et al. 1995, Myketa et al. 1995, McLaughlan et al. 1996 b, Foster 1998, Harvey et al. 1998, Bell et al. 1999, OMNR 2003).*

Treatment	Technique	Mode of action	Target vegetation	Application	Comments
Chemical (herbicide)	Glyphosate	· foliar-absorbed · inhibits protein synthesis	· controls most annual, perennial, and woody species, including perennial grasses, sedges, aspen, and birch · spruce, fir, and pine sensitive only when actively growing · eastern white cedar and eastern hemlock sensitive at all times during the growing season	· aerial or ground applications · injection or stump treatment of individual woody plants	· apply as a post-emergence treatment when target vegetation is actively growing or in early autumn before a killing frost · if crop trees are conifers, apply after conifers have set bud and hardened off · ineffective control of the soil seedbank because of rapid adsorption to soil particles
	2,4-D(amine and ester forms)	· foliar-absorbed · collects in meristematic tissues and causes abnormal growth; affects cell division, respiration, and food reserves	· controls many broadleaf plants and woody species including aspen and birch · ineffective against balsam poplar, grasses, sedges · conifers sensitive only when actively growing	· ester forms applied by air or ground, and used for injection, basal, or stump treatment of individual woody plants · amine forms used for injection or stump treatment of individual woody plants	· apply as a post-emergence treatment when target vegetation is actively growing and desired trees are dormant (hardened off) · some target species resprout, possibly requiring repeated treatment · amine (salt) forms may leach in sandy soils · highly volatile forms are not recommended for use around susceptible crop areas
	Hexazinone	· soil-active · inhibits photosynthesis	· controls a broad spectrum of annual, perennial, and woody plants, including grasses and sedges · conifers resistant, with exception of jack pine	· ground applications · soil treatment of individual woody plants	· apply as a pre- or post-emergence treatment early-spring and mid-summer during the period of maximum foliage development · not to be used on coarse sandy soils due to rapid leaching · not to be used on frozen ground
	Simazine	· soil-active · inhibits photosynthesis, causes chlorosis and dehydration	· controls annual grasses, sedges, and broadleaf plants · ineffective against plants with root systems extending below the depth of simazine movement and those that resprout	· ground applications	· broadcast or selective · apply before vegetation emergence in spring or before freezing in autumn
	Triclopyr	· foliar-absorbed · collects in meristematic tissues · mode of action unclear, but appears similar to 2,4-D (interfering with cell division, growth)	· controls many woody, annual, and perennial broadleaf plants, including aspen, birch · ineffective against most grasses	· aerial or ground applications · basal or stump treatment of individual woody plants	· broadcast or selective · apply as a post-emergence treatment when target vegetation is actively growing, or to woody species in the dormant season

Table 2. Continued

Treatment	Technique	Mode of action	Target vegetation	Application	Comments
Brushing	Manual	· severs woody vegetation	· controls woody species (shrubs and hardwood trees including aspen and birch) · not very effective for grasses and herbs	· shears, Sandviks, machetes, brush hooks, axes, hoes	· selective · apply during the active growing season when root carbohydrate reserves of suckering or sprouting competitors are lowest · cut aspen in June/July at 50–75 cm height to reduce aspen regeneration and cut in autumn at 25 cm height to promote aspen regeneration · cut white birch and other root collar sprouting species such as mountain maple and pin cherry at ≤10 cm to reduce subsequent sprouting · short-term control of competition generally requires subsequent or supplemental treatments · expensive · labour intensive
	Motor-manual	· severs woody vegetation	· controls woody species (shrubs and hardwood trees including aspen and birch) · ineffective for grasses and herbs	· brush saws and chain saws · brush saws can be used for stems ≤15 cm diameter · chain saws better suited for stems ≥16 cm diameter	· see above
	Mechanical	· severs/pulverizes woody vegetation	· controls woody species (shrubs and hardwood trees including aspen and birch) · effective for grasses and herbs	· mechanical brush cutters with vertical- or horizontal-shaft cutting heads · mowers	· mowers and horizontal-shaft brush cutters allow for either selective or broadcast removal of stems · apply during the active growing season when root carbohydrate reserves of suckering or sprouting competitors are lowest · cut aspen in June/July at 50–75 cm height to reduce aspen regeneration and cut in autumn at 25 cm height to promote aspen regeneration · cut white birch and other root collar sprouting species such as mountain maple and pin cherry at ≤10 cm to reduce subsequent sprouting · short-term control of competition generally requires subsequent or supplemental treatments
Girdling	Manual	· removes bark and cambial layer	· controls large (> 15 cm diameter) woody vegetation	· motorized or non-motorized girdling hand tools	· ensure girdling wound is wide enough not to reconnect · conduct in mid-late spring to minimize resprouting · full control delayed several years · expensive · labour intensive

Table 2. Continued

Treatment	Technique	Mode of action	Target vegetation	Application	Comments
Trampling/ binding	Manual	· trample or binding of shrubs	· control of mountain maple stems	· trample stems with feet · bind stems together with rope	· selective · experimental technique that appears to be effective for prevention of basal resprouting [a] · no experience with this technique in boreal Ontario · expensive · labour intensive
Grazing	Sheep [b]	· clips/defoliates vegetation	· sheep will graze many species, but prefer trembling aspen, white birch, mountain ash, mountain maple, pin cherry, raspberry, bluejoint grass, fireweed	· graze sheep early in stand development at the time when target vegetation is most palatable	· broadcast · sheep will graze most herbs, grasses, and low shrubs, while leaving spruce and taller (> 1.5 m) aspen/birch unharmed · most effective when conducted early in the growing season · multiple treatments per year usually needed for effective control · requires even topography and effective supervision of sheep [c] · limited experience with this technique in boreal Ontario
Cover cropping	Non-woody agricultural crops	· outcompetes non-crop vegetation	· displaces all competing vegetation	· sow crops prior to establishment of regeneration	· broadcast · biodiversity issues due to establishment of non-native vegetation · limited experience with this technique in boreal Ontario · difficulty in establishing in boreal Ontario [d]
Mulching	Mulch mats	· smothers and inhibits vegetation	· control of herbaceous and other low-growing woody vegetation · poor control of larger shrubs and hardwood trees	· biodegradable mulch mats placed around crop tree seedlings before herbaceous vegetation is established	· selective · an effective alternative to herbicides to control herbaceous and low-growing woody vegetation · expensive: high cost may limit use to select high-value stands
Biological control	*Chondrostereum purpureum* (native fungal pathogen) [e]	· invades damaged tissue and kills host vascular tissue	· effective on stump and root sprouting hardwoods and shrubs, including birch, aspen, speckled alder, pin cherry	· stump treatment or hack-and-squirt	· highly selective · limited experience with this technique in boreal Ontario · differences in susceptibility between aspen and birch may be useful to promote aspen · control of aspen sprouting does not appear to differ by season of application · expensive: high cost may limit use to select high-value stands

a. Aubin and Messier 1999, Kneeshaw *et al.* 1999

b. Sheep must be treated prophylactically to reduce risk of disease transmission to wild cervids (e.g., moose, caribou).

c Fraser *et al.* 2001

d. Wagner *et al.* 2001

e. The development of other native fungi and bacterial pathogens that can be used as biocontrol agents in forestry is an area of active research in Canada (e.g., progress on the development of biological control agents for Canada blue-joint grass is reported by Macey and Winder 2001).

acceptable overall effects on ecosystem structure and function in boreal forests when applied as directed (Lautenschlager and Sullivan 2002). However, public opposition to chemical cleaning methods is common (Wagner *et al.* 2001). The use of alternative cleaning methods can help to alleviate this concern. Alternative techniques such as sheep grazing, mulching, and the use of the biological control agent *Chondrostereum purpureum* have shown potential as cleaning methods in boreal Ontario and B.C. (Pickering and Richard 1993, Strobl 1993, 1994, Foster 1998, Harper *et al.* 1999, Pitt *et al.* 1999, Fraser *et al.* 2001, Macey and Winder 2001). However, sheep grazing has specific requirements that must be met to ensure effective vegetation control (Table 2). While *Chondrostereum purpureum* and mulch mats are very effective selective cleaning methods, the high cost of these techniques may limit their use to high-value stands.

Some cleaning techniques and strategies that can be used to help create different spatial arrangements of hardwoods and softwoods include (Bell *et al.* 1995, MacDonald 2000, BCMoF 2000, Comeau 2003b, Harper and Kabzems 2003):

- creating alternating bands/strips (patches) of hardwoods and conifers ("green striping") by modifying ground or aerial herbicide applications (flight patterns, application precision) (OMNR 2003)
- creating a "hardwood-free zone" within a prescribed radius of individual or clusters of conifers by the removal of hardwoods using manual or chemical means
- promoting a mosaic of patches of pure conifer and hardwood mixedwoods by concentrating chemical, mechanical or manual cleaning of hardwoods only in conifer patches (but conifers must be located carefully relative to edges of hardwood patches to ensure adequate light availability)
- promoting intimate mixtures of hardwoods and conifers using mechanical brushing to uniformly cut ("mow") hardwoods above a conifer crop of uniform height (Ehrentraut and Branter 1990), so as to slow hardwood growth and increase light availability to conifers
- promoting intimate mixtures of hardwoods and conifers using vehicle (ground)-mounted airblast sprayers (Desrochers and Dunnigan 1991) to chemically target understory vegetation without harming susceptible hardwoods that are either co-dominant or in a super-canopy position to the regenerating cohort
- promoting intimate mixtures of hardwoods and conifers using directed herbicide applications, manual or motor-manual brushing tools, and/or girdling to selectively remove undesirable hardwood stems and/or other competitors without harming conifer regeneration by:
  - applying herbicides to selected hardwood stumps during harvesting operations (Desrochers *et al.* 1998), or spot spraying glyphosate post-harvest to reduce hardwood tree densities (MacDonald 2000[2])
  - applying herbicides into woody stems using the "hack and squirt" method (cutting the bark with an axe or knife and then applying herbicide to the exposed cambial layer) to reduce hardwood competition
  - selectively injecting herbicides into woody stems to reduce hardwood competition
  - applying spot applications of soil active herbicides to reduce hardwood tree densities and grass competition (Bell *et al.* 1995)
  - using selective manual or motor-manual cutting or girdling to reduce hardwood competition (Ehrentraut and Branter 1990, Bell *et al.* 1999)

Spacing and Thinning

Tree and stand growth on any given site can be controlled by manipulating species composition and/or by managing stand density. Species composition can be controlled by compositional treatment (discussed in detail below), while juvenile spacing, pre-commercial thinning, and/or commercial thinning can be used to influence density. For the purposes of boreal mixedwood management in Ontario, these tending methods have been distinguished as follows (OMNR 2003):

- *Juvenile spacing:* the reduction in canopy tree density at the stand initiation stage (it may not be possible to target small inferior trees for removal if dominance has not yet been expressed)
- *Pre-commercial thinning:* the reduction in stand density during the early stem exclusion stage,

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[2] Multiple applications may be required on clearcut boreal mixedwood sites, but one application may suffice where these sites are partially cut to about 50% removal and underplanted with conifers (MacDonald 2000).

after crown closure has occurred but before stems are merchantable; small, inferior trees are targeted for removal when possible based on the thinning technique

Juvenile spacing and pre-commercial thinning are similar, except that juvenile spacing is done during the stand initiation stage before crown closure occurs. Juvenile spacing is carried out whenever it is apparent that thinning will be required following crown closure but the forest manager does not wish to wait.

- *Commercial thinning:* the reduction in stem density in well stocked stands during the stem exclusion stage, but only when a portion of the stems removed have reached merchantable size and will potentially earn a positive financial return

As "density management" (i.e., manipulating the number and arrangement of stems per hectare) methods, the primary objective of spacing and thinning is to accelerate the diameter growth of residual trees (and perhaps improve stem form and quality), thereby controlling stand growth and future stand structure (OMNR 1997, 2003, 2004). In Ontario, spacing and thinning treatments are not used to change stand species composition (which can be achieved by compositional treatment as described below). Spacing and thinning treatments also are not associated with regeneration objectives, even though they could potentially promote mixedwood stand conditions by increasing understory light levels enough to provide conditions suitable for conifer ingress (Rice *et al*. 2001), the release of natural advance growth (MacDonald 1995), and increased growth of underplanted stock (Weingartner 1995). Instead, where regeneration is the objective, partial overstory removal treatments should be classified as shelterwood (partial) harvests (OMNR 2003).

Techniques used for juvenile spacing, pre-commercial thinning, and commercial thinning include the use of manual or motor-manual tools, mechanical brush cutters, chemical stem injections, basal bark chemical treatments, and mechanical felling equipment (Table 3). In some cases, more than one technique may be combined. For example, manual thinning can be applied in untreated strips left by mechanical strip thinning to increase individual residual tree growth (e.g., St. Amour 2000). Although the intention of pre-commercial thinning is the preferential removal of small, inferior stems, this approach is only possible with selective manual, motor-manual, or chemical methods. Mechanical strip thinning does not allow the preferential selection of individual trees.

Given that boreal mixedwood management promotes the use of natural regeneration wherever appropriate (MacDonald 1995), spacing and/or thinning treatments may be desirable on sites that have regenerated naturally to unacceptably high densities. Positive growth responses (diameter and merchantable volume) due to pre-commercial thinning of black spruce are well documented (Newton and Charlebois 2004). In Ontario, spacing or pre-commercial thinning of spruce has not historically been carried out in naturally established upland boreal mixedwoods since these stands are seldom overstocked. Pre-commercial thinning of overstocked balsam fir stands has also not typically been conducted in Ontario, although this practice is common in naturally regenerated balsam fir stands in

Table 3. *Spacing, thinning, liberation, and compositional treatment techniques (Bell* et al. *1995, Harvey* et al. *1998, Meek 2000).*

Tending method	Techniques
Juvenile spacing , pre-commercial thinning, liberation, compositional treatment	· manual tools and motor-manual tools (brush and chain saws) for felling or girdling · mechanical brush cutters for strip thinning · chemical (herbicide) stem injections and basal bark treatments for killing individual stems

Commercial thinning, liberation, compositional treatment	· manual, motor-manual, or mechanical tools and equipment for strategies such as:
	  · cut-to-length with manual felling
	  · fully mechanized cut-to-length
	  · tree-length or full-tree system with manual felling
	  · fully mechanized full-tree system

many parts of eastern North America (Ruel *et al.* 2003). Juvenile spacing and/or pre-commercial thinning may be justified for aspen and birch, which often regenerate at high densities (Brais *et al.* 2004, Simard *et al.* 2004), to improve the yield of large diameter trees or to increase crop tree value (OMNR 2003). However pre-commercial thinning of these species should be limited to the best sites. Pre-commercial thinning of aspen is uneconomical if fibre production is the goal, since self-thinning is sufficient to meet this objective, but it can be an effective practice to increase product value and shorten rotations for sawlog production (Peterson and Peterson 1992, Rice *et al.* 2001). Pre-commercial thinning studies in juvenile birch stands in B.C. indicate that a positive growth response combined with acceptable stem quality and site utilization are possible (Wang *et al.* 1995, Simard *et al.* 2004). While experience with pre-commercial thinning of aspen and birch is limited in Ontario, suggestions for these practices are detailed in OMNR (2003).

Experience with commercial thinning also is limited in Ontario and warrants further research. Commercial thinning of aspen has shown positive results in Quebec (Doucet 2000) and Minnesota (David *et al.* 2001). Similarly, commercial thinning has been shown to increase diameter growth of white spruce in Ontario (e.g., Berry 1974) and white birch in Alaska (Graham 1998). Results for commercial thinning of black spruce and balsam fir in Quebec (Weetman *et al.* 1980, Lussier 2001) and Ontario (Van Schip *et al.* 1990) have been mixed. Results will vary with site and stand conditions. The best diameter growth responses are expected when commercial thinning is conducted on high quality sites in fully stocked, vigorous, immature stands with a history of density regulation (planted or previously spaced or pre-commercially thinned).

The optimal spacing/thinning treatment depends on management objectives. For even-aged stands, density management diagrams can provide general guidance on decisions related to density regulation, particularly when used in conjunction with local site index curves (Jack and Long 1996). Stand density management diagrams (SDMDs) are average stand-level models that describe the relationship between stand density and mean or average tree size, and identify conditions associated with crown closure and density-dependent mortality or “self-thinning”. However, these diagrams only apply where spacing or thinning treatments approximate the natural self-thinning process (i.e., for thinning from below), and different diagrams may be needed for natural and managed stands (Newton and Weetman 1993). In Ontario, SDMDs are available for some pure or nearly pure (softwood- or hardwood-dominated), even-aged stands of boreal mixedwood tree species (Table 4). Similar diagrams have also been developed for these species in other jurisdictions, either singly (e.g., Farnden 1996, Newton and Weetman 1993, 1994, Newton 1997) or in mixture with other species (Smith 1996, Sturtevant *et al.* 1998). However, SDMDs developed in other jurisdictions must be evaluated for their applicability over broader geographic areas (Jack and Long 1996). Effective density regulation to meet objectives in stands containing mixtures of conifers and hardwoods in Ontario will require the refinement of local mixed species SDMDs.

In addition to effects on growth and yield, other considerations when planning spacing and thinning operations may include (OMNR 1997, 2003):

- Protecting existing advance growth that is part of the desired future stand condition during thinning, even though thinning has no associated regeneration objective
- Ensuring vigour of remaining stand and long-term sustainable harvest
  - thinning should not promote unacceptable insect and disease damage (e.g., Pitt *et al.* 2001), excessive blowdown of residual trees (Navratil 1997), or excessive damage to residual stems
    - windthrow risk can be reduced by retaining the more windfirm individuals; potentially windfirm trees can be identified using the slenderness coefficient, with low height/dbh ratios indicating higher resistance to windthrow (Navratil 1995)
- Maintaining future wood quality and product value
  - a tradeoff can occur between increased growth and increased stem taper and branchiness (Smith *et al.* 1997, Peterson *et al.* 1997)
  - thinning aspen is not required if the objective is fibre production (Peterson and Peterson 1992, Rice *et al.* 2001).
  - spacing or thinning of birch coppice clumps may be necessary to improve stem quality

***Table 4**. Availability of stand density management diagrams (SDMDs) for the five defining and selected associated boreal mixedwood tree species. These are primarily from Ontario data sources but for some species additional long-term data sets from neighbouring provinces are included.*

Species	Stand Type	Published SDMDs	Computerized SDMDs
Defining species			
Trembling aspen	Natural Managed	Woods *et al.* *in prep.* (draft) —-	OMNR *in prep.* b (draft) —-
White birch	Natural Managed	—- —-	—- —-
White spruce	Natural Managed	—- Woods *et al.* *in prep.* (draft)	—- OMNR *in prep.* b (draft)
Black spruce	Natural Managed	Smith 1996 Newton 1998, 2003; see also Newton and Weetman 1994	OMNR *in prep.* b (draft) Based on Newton 1998: ftp://ftp.glfc.cfs.nrcan.gc.ca/pnewton/outgoing/ (SDMDMIG.EXE) Based on Newton 2003: ftp://ftp.glfc.cfs.nrcan.gc.ca/pnewton/outgoing/ (SDMDSP.ZIP) OMNR *in prep.* (draft)
Balsam fir	Natural Managed	Penner *et al.* 2004 —-	OMNR *in prep.* b (draft) —-
Associated species			
Jack pine	Natural Managed Natural and mangaged combined	Smith 1996 —- Archibald and Bowling 1995	OMNR *in prep.* b (draft) OMNR *in prep.* b (draft) —-
White pine	Natural Managed	Smith and Woods 1997 —-	OMNR *in prep.* b (draft) OMNR *in prep.* b (draft)
Red pine	Natural Managed	—- Smith and Woods 1997	OMNR *in prep.* b (draft) OMNR *in prep.* b (draft)

- Modifying stand structure for non-timber uses (e.g., wildlife habitat, recreation)
  - wildlife habitat can be manipulated through stand density management (e.g., Sturtevant *et al.* 1996)
- Maintaining genetic variation
  - genetic differences among aspen clones appears to be responsible for much of the variation in thinning response (Penner *et al.* 2001)

Liberation

Liberation refers to the release of seedlings or saplings, at the stem exclusion stage of stand development, from distinctly older, merchantable or unmerchantable, overtopping trees (OMNR 2003). Liberation should occur when crop trees are large enough to withstand the development of any competition that could be stimulated by the treatment (Smith *et al.* 1997). This silvicultural treatment differs from removal cuttings for seed-tree and shelterwood methods or two-stage harvesting in that the older trees being targeted for removal must not have been intentionally left behind for seed, shelter, or to facilitate growth (Smith *et al.* 1997).

Techniques used for liberation (i.e., the cutting, girdling, or chemical treatment of overtopping trees) are the same as those used for removing trees during thinning operations (Table 3). Manual girdling (in spring after leaf flush and during the period of active growth) and stem injection of herbicides (e.g., glyphosate or 2,4-D applied in late summer or autumn) may be particularly effective for limiting damage to the younger, overtopped crop trees that are to be released.

Compositional Treatment

Compositional treatment is a term newly introduced in Ontario to describe a stand tending operation that selectively removes one or more species from the overstory so as to effect a change from one stand composition type (overstory tree species composition) to another to meet management objectives (OMNR 2003). Compositional treatment can be carried out at the stand initiation and stem exclusion stages of stand development, although it is not usually considered until late during the stand initiation stage after tree recruitment has slowed. The species composition of the overstory can be altered by cutting, girdling, or applying herbicide to selected overstory tree species using any aforementioned cleaning or spacing/thinning technique appropriate to the species and size of trees being removed (merchantable or unmerchantable) (Table 3). The use of a compositional treatment requires that site occupancy be maintained (OMNR 2003).

In the context of boreal mixedwood management, it is generally not valid to apply a compositional treatment to convert a mixedwood stand to a pure-species future stand condition (OMNR 2003)[3]. However, the possible impacts of shifts in tree species composition on future stand health must be considered. Conversion of a mixedwood stand to one with a larger component of balsam fir may, for example, be inappropriate during spruce budworm outbreaks. When compositional treatment is conducted during the stem exclusion stage, consideration must also be given to windthrow risk, which can be increased by the removal of only a portion of the canopy.

Pruning

Pruning is the removal of lower branches from standing live trees by natural or artificial means (NRC 1995). Pruning occurs naturally in dense stands, but in low density stands (including thinned stands) trees tend to develop large persistent lower branches (Smith *et al*. 1997). Because the knots associated with persistent branches reduce wood quality, artificial pruning may be desirable when a high-value end product is required (e.g., veneer logs). Pruning for this purpose is best done in conjunction with thinning regimes that maintain diameter growth, because rapid growth is generally required to produce enough clear wood to render the pruning operation economically viable. Suitable pruning tools include various hand or power saws, clubs, clippers, and axes (Smith *et al*. 1997).

Little artificial pruning of trees in boreal Ontario has occurred. However, general principles for pruning that integrate economics will likely apply (Smith *et al*. 1997). Interim guidance may be obtained from the silviculture guide for Ontario's Great Lakes-St. Lawrence forests (OMNR 1998). As a component of boreal mixedwood management, pruning may be particularly beneficial to produce birch sawlogs (Towill 2000).

Proactive Management: Reducing the Need for Tending

Although competing vegetation is often not desirable, its presence can sometimes be beneficial. For example, maintaining a component of hardwood trees and other vegetation can help to moderate microclimate and provide protection (against frost, dessication) that improves the establishment of certain species, particularly white spruce (Groot and Carlson 1996, Carlson and Groot 1997, Groot *et al*. 1997). Even when the presence of competing vegetation is undesirable or when improved stand growth and quality are desired, the need for tending may be reduced by using specific management options including:

- selecting the type and timing of harvesting and site preparation methods (where applicable) so that these physical disturbances do not needlessly promote the reproduction of potential competitors (Wagner *et al*. 2001, Sutton and Weldon 2003)
- using partial canopy removal methods to suppress post-harvest development of undesirable hardwoods and certain ground vegetation species[4] (Lieffers and Stadt 1994, Groot *et al*. 1997, MacDonald 2000, Prévost and Pothier 2003)
- promoting the use of natural and artificial (e.g., underplanting) advance conifer growth, that will have a competitive height advantage over most competing species following disturbance (Stewart *et al*. 2000, Greene *et al*. 2002)
- avoiding planting delays and associated competing vegetation problems (especially from grass) (Ehrentraut and Branter 1990, Wagner *et al*. 2001)
- selecting competitive nursery stock (such as large or nutrient-loaded seedlings) where planted stock

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[3] Mixtures of tree species are believed to be more stable and to exhibit greater disease resistance than pure-species stands (e.g., Navratil *et al*. 1991). A pure-species condition can, however, be acceptable in the early stages of mixedwood stand development (e.g., spruce ingress may eventually convert a pure aspen stand into a mixedwood stand condition). Pure stands are those where a single species comprises >80% by basal area (MacDonald 1995).

is to be used on sites with high vegetation competition potential (e.g., Lieffers and Beck 1994, Malik and Timmer 1996, Stewart *et al.* 2000, Imo and Timmer 2001)

- accepting a hardwood tree component on boreal mixedwood sites that previously supported a hardwood component (MacDonald 1995) as this may be easier than trying to establish pure or softwood-dominated stands
- accepting natural self-thinning of stands instead of applying spacing and/or thinning treatments where it is recognized that early stand dynamics can contribute to the desired future stand condition and satisfy management objectives (e.g., Rice *et al*. 2001)
- creating stand conditions (horizontal and vertical distribution of crop tree stems) that promote lower branch mortality at a young age and natural self-pruning (until a desired length of branch-free bole is achieved), rather than scheduling artificial pruning as a tending treatment (Smith *et al*. 1997)

Summary

The boreal mixedwood management philosophy has necessitated some change in emphasis and modification to traditional tending practices. Principle among these changes are (1) a shift from reliance on broadcast chemical tending methods to use of more selective or directed methods, (2) the introduction of several unique tending approaches to address the promotion of hardwood and conifer mixtures, and (3) the use of a variety of management options that may reduce or eliminate the need for tending. Tending methods and techniques suitable for boreal mixedwood management are not lacking. Rather, what is lacking in some cases is knowledge about the appropriate type, timing, and intensity of treatments relative to the diversity of mixedwood site and stand conditions encountered throughout boreal Ontario. Future research will help to refine tending practices for boreal mixedwood site and stand conditions.

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[4] On fertile boreal mixedwood sites, some level of cleaning will still be required since the suppression of competing vegetation due to partial canopy retention alone will not be adequate (MacDonald and Thompson 2003, MacDonald *et al.* 2004).

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Disease Considerations in Unmanaged Boreal Mixedwood Forests of Ontario

by S. Greifenhagen[1]

> *Boreal mixedwood forests present unique conditions that can influence disease prevalence, spread, and severity...*

Introduction

In its broadest sense, disease is defined as any abnormality in the structure or function of a plant (Manion 1991). Traditionally, the definition of plant disease is restricted to damage caused by biotic factors including fungi, bacteria, viruses, and parasitic plants, and abiotic factors such as frost, drought, or nutrient deficiencies. Biotic tree diseases are the result of interactions between the host, the pathogen, and the environment over time (Figure 1). For example, environmental factors such as soil moisture influence not only the vigour of the host tree but also affect the viability and virulence of the pathogen. In many cases, disease is not caused by any one factor; rather, it is the result of complex interactions between biotic and abiotic agents (Schoeneweiss 1981).

Boreal mixedwood forests present unique conditions that can influence disease prevalence, spread, and severity. Defining features of the boreal mixedwood forest (MacDonald and Weingartner 1995), including the mix of tree species and soil moisture, nutrition, and texture, can increase or decrease the susceptibility of individual trees or stands to specific diseases.

Diseases affect trees of all ages, although their impact can vary considerably, depending on the life stage of the tree. Foliar diseases such as needle rusts can result in growth loss and even death of seedlings

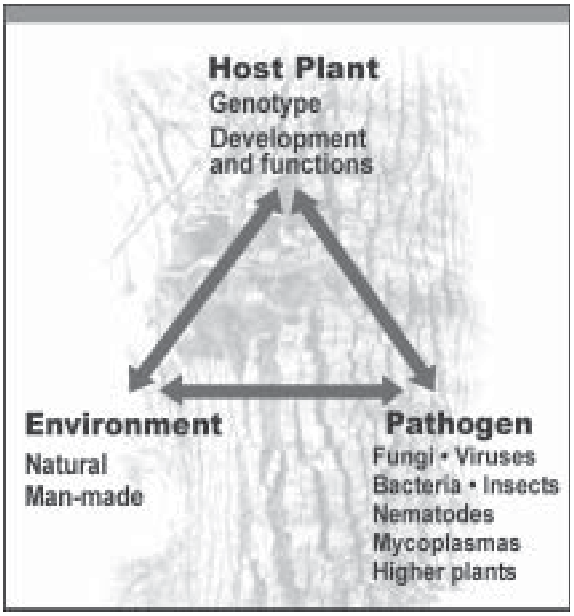

Figure 1. *The disease triangle: host, environment, and pathogen interact over time causing biotic disease (from Manion 1991).*

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Ontario

and saplings, whereas damage to mature trees is often negligible. The impact of stem decay, on the other hand, increases as stands mature. Foliar diseases that depend on specific weather conditions or alternate hosts to reach damaging levels are examples of diseases causing sporadic damage. In comparison, root diseases and stem decays are examples of persistent diseases in natural forests that usually progress slowly over time.

Diseases are often considered to be destructive agents in the forest, because they reduce growth and tree quality, cause decay and deformation, predispose trees to windfall or other pests, and can cause mortality (Riley 1955). Diseases, combined with insect pests, cause greater timber losses than any other damaging agent, and thus have the greatest impact on the productivity of Ontario's forests (Gross et al. 1992, Haack and Byler 1993). However, diseases also play a vital role in many fundamental biological processes that occur in forests. Many of the fungi that cause disease contribute to the cycling and recycling of carbon and nutrients, help to maintain soil fertility, and contribute to forest diversity (Manion 1991). By removing less fit and overmature trees, diseases act as natural thinning agents, thereby promoting succession and increasing overall fitness of forests and stands (Burdon 1991). Diseases and their hosts have developed a balanced relationship that benefits the survival of both the host and the pathogen. However, interventions by man or the introduction of exotic pests can quickly destroy this balance to favour the pathogen.

Trees have the ability to ward off disease through their natural defense mechanisms. Introducing stress (defined as any environmental factor capable of inducing a potentially injurious strain in living organisms [Schoeneweiss 1978]) into the host-pathogen relationship can shift the balance in favour of the disease. Stress can cause changes in physiological processes; energy redirected to basic survival functions is no longer available to maintain the tree's natural defense systems that protect against disease infection and spread (Hale and Orcutt 1987). Two of the most common stresses predisposing trees to disease in boreal mixedwood forests are moisture stress and defoliation (Schoeneweiss 1981). Defoliation stress can increase susceptibility to stem and root decay fungi by reducing the tree's ability to compartmentalize, or "wall off" the infected wood (Shortle and Ostrofsky 1983, Shigo 1979). Other stresses include frost, competition, and tree wounding (Whitney and Dumas 1994, McLaughlin and Dumas 1996). Even non-aggressive pathogens can become damaging if the host is in a stressed condition.

Natural disturbances, such as insect defoliation and fire, play a role in disease development and impact. Fire scars are primary entry points for decay fungi (Basham 1991). Wildfires may also increase the root disease potential of a site. Dead trees and stumps remaining after a fire provide a large food base for these largely saprophytic fungi. The fungi are thereby maintained on the site while the new stand develops. However, hot fires can also kill root-rotting fungi that grow in shallow soil and on root surfaces (Whitney and Dumas 1994). These fire-disease relationships are not yet clearly understood.

Major Diseases of Boreal Mixedwood Species

Although literally hundreds of organisms can cause disease in trees, only a few of them significantly affect growth and survival on a stand basis. Important diseases (Table 1) of the main boreal mixedwood tree species (as defined by MacDonald and Weingartner 1995) are described in detail in the following sections.

Root Diseases

Root rot fungi are endemic to the boreal forest, causing decay in the roots, butt, and stem of living trees. All of the defining boreal mixedwood tree species and their associates are susceptible (Table 1). Root diseases result in the loss of sound wood, either through tree mortality, reduced increment, windthrow, butt cull, or some combination (Whitney 1988). Trees with 60% or more of the root wood decayed or stained are prone to windfall and may be killed outright if decay continues to the sapwood (Whitney 1989). Infection takes place at or below ground level, and lateral roots usually die first. As much as 40% of a tree's root system may be killed by root rotting fungi before aboveground symptoms become apparent. These symptoms include dead branches in the lower crown, needle necrosis, and decreased growth. Finally, when the majority of the root system is decayed, only a few living branches may remain on the tree, or the entire tree may be dead (Figure 2) (Whitney 1988). In very young

Table 1. *Important diseases affecting the main boreal mixedwood tree species (X = common host, o = occasional host).*

	Balsam Fir	Black Spruce	White Spruce	Aspen	White Birch	Jack Pine
Root disease						
Armillaria ostoyae	X	X	X	X	X	X
Armillaria sinapina	o		o	X	o	o
Tomentosus root rot	o	X	X			o
Stem decay						
Phellinus tremulae				X		
Phellinus pini	X	X	X			X
Stereum sanguinolentum	X					
Fomitopsis pinicola	X	X	X	X	X	X
Hypoxylon canker				X	o	
Western gall rust						X
Spruce needle rust		X	X			
Aspen leaf and shoot blight				X		

stands, all of the foliage may die at once. Root diseases produce sporophores, or mushrooms, that grow at or near the base of infected trees. The decayed wood in the roots and butt becomes soft and discoloured, and the mycelium produced by some of these fungi is visible in the wood and under the bark of infected trees.

Armillaria is the most common root disease in the world (Kile et al. 1991) and the most common chronic disease problem in Ontario, infecting all boreal mixedwood tree species. This disease comprises a complex of *Armillaria* species, of which *A. ostoyae* (Romagn.) Herink.(a decayer of conifers and hardwoods) is the most common and destructive in boreal mixedwood forests (Dumas 1988). These fungi infect the root system of the host, but also grow into the sapwood at the root collar, effectively girdling and killing the tree. Trees may be killed singly, in small groups, or scattered throughout a stand (Whitney 1988). Of the conifers, balsam fir (*Abies balsamea* (L.) Mill) is most susceptible to this disease, followed by black spruce (*Picea mariana* Mill. [BSP]), and then white spruce (*Picea glauca* [Moench] Voss). Merchantable volume losses of 30% (balsam fir), 22% (black spruce), and 15% (white spruce) were caused by Armillaria root disease in pure and mixed stands surveyed in Ontario (Whitney 1989). Volume loss estimates for jack pine (*Pinus banksiana* Lamb.) do not exist (Mallet and Volney 1990). The addition of disease-caused growth losses to these figures would substantially increase merchantable volume losses. Boreal mixedwood stands with a high component of balsam fir may be greatly affected by Armillaria root disease at a relatively young age, as tree death and windfall occur at less than 70 years of age with this species. Spruce budworm (*Choristoneura fumiferana* Clemens) outbreaks may also increase the susceptibility of such stands to Armillaria root disease. Because of its saprophytic role, *A. ostoyae* readily colonizes balsam fir that has been killed by budworm defoliation. In mixedwood stands, these dead trees act as disease reservoirs and the risk of significant disease losses in the spruce component of the stand, which may also be experiencing some defoliation stress, increases. The relationship between defoliation stress and disease, however, remains unclear: does infection by the root disease determine the extent to which trees are damaged following insect defoliation, or does the defoliation predispose trees to attack by root pathogens (Mallet and Volney 1990, Parks et al. 1994)?

Site conditions influence the incidence and severity of Armillaria root disease (Singh 1983). For black spruce, fresh sites, which are typical of boreal mixedwoods (soil moisture regime 1-3), have a greater incidence of Armillaria root disease than moist or wet sites (soil moisture regime 5-7)

(Whitney 1995). Soil moisture has a similar, but less pronounced effect, on the susceptibility of white spruce and balsam fir. Similarly, soil texture can influence the host's susceptibility to root disease, probably because of its influence on soil moisture holding capacity. For conifers, infection is higher on sandy than silty soils. In black spruce plantations, the relationships between Armillaria infection and FEC type have been studied (Wiensczyk 1995); similar studies have not occurred on mixedwood sites.

Regeneration method can also affect the incidence of Armillaria root disease. For example, suckers commonly sprout from the stumps of dead, mature trembling aspen (*Populus tremuloides* Michx.). These stumps are usually well colonized by Armillaria species, (*A. ostoyae and A. sinapina*) and suckers become infected by direct contact with the stump (Stanoz and Patton 1987).

Tomentosus root rot, caused by the fungus *Inonotus tomentosus* (Fr) Teng, is most common in mature black and white spruce, although most conifers are susceptible to some degree. The fungus grows through the roots towards the stem, eventually killing the tree by girdling its base (Whitney 1994). This disease is mainly spread through direct root contact; the fungus grows from a diseased root into a healthy one if they are touching one another. Thus, diseased trees tend to be grouped. In mixed stands, especially those with a high component of aspen, which is virtually resistant to Tomentosus, direct root contact between spruce occurs less frequently, thereby restricting spread of the disease. Although Tomentosus root rot occurs on a wide range of sites in boreal mixedwoods, it is most prevalent on soils with low nutrient and moisture holding capacity (Whitney 1994), and on shallow soils, where rooting depth is limited (VanGroenewoud and Whitney 1994).

Stem Decay

Wood decay organisms, including fungi and bacteria, break down the cell walls of trees. Depending on the type of decay produced, the resulting weakened wood cannot be used when manufacturing products such as lumber, pulp, and paper.

Decay in living trees usually increases with tree age; overmature trees almost always contain some decay. Principal entry points for decay fungi are stem wounds such as frost cracks, forked crowns, fire scars, and large branch stubs (Basham 1991). As trees age and lose vigour, the prevalence of entry points increases and thus the extent of internal decay also increases. In the boreal mixedwood forest, decay increases with tree age for all species except black spruce. Other factors that influence the incidence of stem decay include tree species, site conditions, geographic region, cover type, and stand history (Basham 1991).

Of the major boreal mixedwood tree species, aspen is the most susceptible to stem decay. Although trembling aspen is prone to infection by many decay fungi, the most destructive is *Phellinus tremulae* Bondartsev, also called the false tinder conk (Basham 1993). Hoof-shaped sporophores on the stems of living trees are an indication of advanced internal decay (Hiratsuka and Loman 1984) (Figure 3). Although decay is rare in aspen less than 40 years old, at least 20-25% of the merchantable stem volume is decayed in trees over 100 years old (Basham 1993). Susceptibility to decay may be influenced by clonal variation (Wall 1971). Because aspen grows as a mosaic of small clonal groups (averaging 0.12 ha) (Kemperman 1977), relationships between decay and stand-level factors such as site, or age, may be confounded by clonal influences (Basham 1993). In general, aspen decay increases marginally on dry sites (moisture regime < 2), and with tree age (Weingartner and Basham 1985).

Incidence of decay is much lower in white birch (*Betula papyrifera* Marsh.) than in aspen, with less than 5% of merchantable stem volume decayed on average by age 100 (Basham 1991). *Phellinus*

Figure 2. Phellinus tremulae conks indicate extensive internal decay of aspen.

igniarius (L.:Fr.) Quel. is the main causal agent of decay in white birch. A reddish-brown stain (called red heart), that is triggered by the enzymes of non-decay fungi, often affects white birch by age 50. Although red heart has little effect on hardness or strength, the wood tends to check and crack more than clear wood (Campbell and Davidson 1941).

Of the boreal mixedwood conifers, balsam fir has the highest incidence of stem decay, averaging over 10% of merchantable volume in trees over 80 years of age (Basham 1991). *Stereum sanguinolentum* (Albertini & Schwein.:Fr.) Fr. is the main causal organism of decay in balsam fir. The decay is more extensive on well-drained upland sites than on wet, lowland sites. However, the net impact of decay may not reflect this relationship because the increased growth rate of trees on upland sites compensates for the greater cull losses (Spaulding and Hansbrough 1944). Increased incidence of decay has also been observed in balsam fir growing in mixedwood forests compared to pure conifer forests (Heimburger and McCallum 1940); once again, increased decay is usually offset by better tree growth in mixedwood forests (Lavalee 1986).

Black spruce is the most decay-resistant of the defining boreal mixedwood species. On average, only 3% of gross merchantable volume is decayed on an individual tree basis (Basham 1991). A strong relationship exists between soil moisture and decay incidence in black spruce: as moisture decreases, decay incidence increases (Basham 1991). However, as with balsam fir, the higher volume per tree on well-drained soils typical of boreal mixedwood sites more than compensates for decay losses (Morawski et al. 1958). Similar trends are expected for white spruce, however current data are insufficient. For jack pine, decay is strongly influenced by soil depth and tree age. Jack pine growing on shallow sites may experience cull rates of more than 20% of gross total volume by 120 years of age, whereas decay levels averaged only 5% of gross total volume for trees growing on deep mineral soils (Woods and Miller 1998).

Hypoxylon Canker

Hypoxylon canker, caused by the fungus *Entoleuca mammata* (Wahlenberg:Fr.) J.D. Rogers and Y.-M. Ju, is one of the most damaging diseases of aspen throughout North America (Manion and Griffin 1986). Annual stand losses have been estimated at 1-2% for tree mortality and 30% reduced net growth for surviving trees (Anderson 1964). In Ontario, Hypoxylon canker causes a loss of more than 2 million cubic metres of aspen annually (Gross et al. 1992). Cankers caused by the disease girdle and kill trees outright, or increase susceptibility to windthrow by weakening the stem at the point of the canker (Figure 3). Disease-caused mortality is greatest in young saplings and small trees where cankers develop on the main stem (Perala 1984). Although canker incidence may be higher in older trees, the majority of these cankers are located on branches within the crown, and do not cause tree mortality (Falk et al. 1989).

Although site factors, such as site quality and moisture, and wounding agents, such as insects and woodpeckers, may influence the incidence of Hypoxylon canker, substantial clonal variation in resistance to the disease may mask such relationships (Copony and Barnes 1974, Ostry and Anderson 1995). Stand density also appears to influence disease incidence. Fully stocked stands often have lower rates of Hypoxylon than open stands (Bruck and Manion 1980). Unfortunately, a critical component of the Hypoxylon disease cycle (i.e., its mode of infection) remains unknown. Without knowledge of how the disease infects its host trees, information about any of these influencing factors remains purely observational (Manion and Griffin 1986).

Stem Rusts

Figure 3. *Aspen stems with hypoxylon cankers typically break off at the infection site.*

A number of stem rusts infect jack pine in Ontario's boreal forests, including western gall rust (*Endocronartium harknesii* (J.P. Moore) y. Hirats.), Commandra blister rust (*Cronartium comandrae* Peck), and sweet fern blister rust (*Cronartium comptoniae* Arthur). Of these, western gall rust has the greatest impact, particularly on trees less than 10 years of age (Davis and Meyer 1997). In northwestern Ontario, an average of 15% of trees surveyed in young jack pine stands were infected with western gall rust (Juzwik and Chong 1990). Jack pine in northeastern Ontario were less affected. Galls that form on the branches and main stem can kill young trees and severely deform older trees (Myren 1994). Because western gall rust infections are spread by spores from pine tree to pine tree, infection levels should be less in mixedwood stands than in pure jack pine stands.

Foliar Diseases

Foliar diseases occur in stands of all ages, however their effect is usually greatest in young stands. Small trees can ill afford to lose any foliage, and higher humidity levels often found near the ground are conducive to spread and infection by many of these fungi.

Spruce needle rust, caused by the fungi *Chrysomyxa ledi* (Alb. & Schwein.) de Bary var. *ledi* and *C. ledicola* Lagerh., infects and kills current year needles of white and black spruce (Myren 1994). Although seldom resulting in mortality, severe outbreaks can reduce growth in stands where the alternate host, labrador tea (*Ledum groenlandicum* Oeder), is abundant (Meyer and Davis 1997). Infection seldom occurs in successive years.

Aspen leaf and shoot blight, caused by the fungus *Venturia macularis* (Fr.:Fr.) E. Muller & Arx, is one of the most important diseases affecting aspen regeneration (Peterson and Peterson 1992). Up to 100% infection is common in aspen stands throughout the boreal forest; stems damaged by this disease then become new infection sites for decay agents (Gross and Basham 1981). The disease kills leaves and shoots of young aspen, especially the leader (Anderson and Anderson 1980), resulting in the typical shepherd's crook appearance. Leaf blight rarely affects aspen taller than 7 metres (Gross and Basham 1981).

Conclusions

The focus on forest-disease interactions has shifted from simply pest-related timber losses to a more holistic consideration of pathogen effects on forest health (USDA 1993). The presence of disease does not indicate an 'unhealthy' forest; balanced systems have evolved that allow survival of both the pathogen and its host trees.

Our knowledge of tree diseases is far from complete. More information is needed to understand the interactions among diseases and other natural forest disturbances such as fire and insect outbreaks. The effect of combined stresses on a tree's ability to ward off infection has not been studied extensively. Disease impact data were often collected from pure stands so loss figures may or may not be accurate for boreal mixedwood stands. Intervention in the form of harvesting, silviculture, and fire prevention can 'unbalance' the pathogen-host relationship. Knowledge of the role that diseases play in natural systems, and how man's activities affect these roles is essential for effective management of boreal mixedwood forests.

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FOREST HEALTH

Managing Disease in Boreal Mixedwood Stands

by J. A. McLaughlin[1]

> *Although our understanding of disease behaviour in unmanaged ecosystems is far from complete, even less is known about the effects of management activities on disease...*

Introduction

The ecology of pathogens in boreal forests undisturbed by human interventions is complex and only partially understood. Seeds and cones, foliage, shoots, stems, and roots are all subject to parasitism by a wide range of pathogenic microorganisms, especially fungi. Disease occurrence and effects are the result of the dynamic interaction of the pathogen, host, and site/environmental factors, also referred to as the disease triangle (Figure 1). Variations in any of these factors can produce significantly different disease conditions.

Pathogen strains often vary in their aggressiveness, as do hosts in their resistance to the pathogens, either because of genetic variation or their developmental stage. Site and environmental factors are extremely important. For example, the dynamic balance that exists between pathogens and hosts (the result of thousands of years of co-existence) can be tipped in favour of the pathogen or the host by environmental conditions such as moisture or temperature fluctuations that produce or alleviate stress and its associated physiological changes in the hosts, or that result in changes in the pathogen population level. The association of drought stress and increased Armillaria root disease illustrates the sensitivity of this balance. Drought reduces the levels of complex carbohydrates (e.g., sucrose) and increases the simple carbohydrates (e.g., glucose) in the root bark and cambial zone of the host. Armillaria is a glucose fungus (Garroway 1974); it uses glucose for increased growth and to overcome the tree's chemical defences (e.g., phenols) (Wargo 1984).

A Changing Forest

Although our understanding of disease behaviour in unmanaged ecosystems is far from complete, even less is known about the effects of management activities on disease. Forest management practices such as harvesting, regeneration, and fire suppression can greatly affect each of the factors in the disease triangle, resulting in new disease behaviour on a site. A fundamental management effect is an increase in the amount of area of forests identified as boreal

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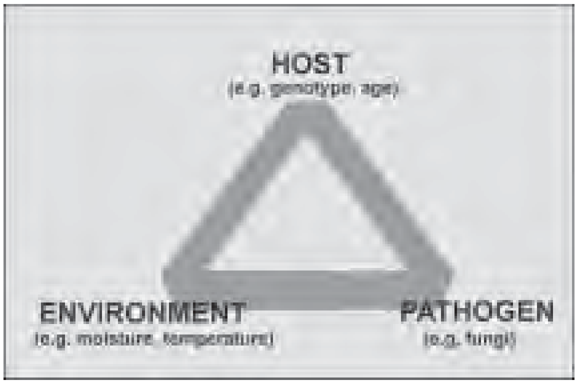

Figure 1. *The disease triangle (from Manion 1991).*

mixedwood. A study conducted by Hearnden *et al.* (1992) determined that the composition of the boreal forest of Ontario is changing (Table 1). The proportion of boreal forest characterized as boreal mixedwoods increased by 5% between 1970 and 1985. During this period, the spruce (*Picea* spp.) cover type and mixed softwoods decreased, while jack pine (*Pinus banksiana* Lamb.) and the hardwood cover type increased. The balsam fir (*Abies balsamea* (L) Mill.) component also increased, probably largely due to exclusion of fire. These changes likely reflect the different conditions for forest renewal that result from harvesting activities as compared to natural disturbances.

Implications for disease incidence

These fundamental changes in the species mix of the boreal forest will naturally be reflected in the incidence of diseases related to the particular host species. For example, as the proportion of aspen (*Populus tremuloides* Michx.) increases, the incidence of Hypoxylon canker [caused by *Entoleuca mammata* (= *Hypoxylon mammatum* (Wahl.) Mill.)] will increasingly be an issue. However, many disease concerns associated with boreal mixedwood management relate to the effects of the silvicultural and stand-tending systems used in these stands. Partial-cut systems have the greatest pathological impact. The main concerns are increases in:

- root disease losses, especially through Armillaria root disease [primarily by *Armillaria ostoyae* (Romagn.) Herink and *A. sinapina* Bérubé & Dessureault (Dumas 1988)], which is found across northern Ontario (Whitney 1988) and has greatest impact in the northwest (Whitney 1995),
- blowdown of residuals,
- mortality of trembling aspen from Hypoxylon canker,
- pre-existing stem decay in potential crop trees (especially aspen),
- development of stem decay in residuals resulting from wounds suffered during harvesting operations.

Management approach

Successful management of disease in the boreal mixedwood requires a proactive, ecological approach. Protection strategies such as application of fungicides, appropriate in nurseries or greenhouses, do not have a role in stand or forest disease management.

An understanding of the biology and ecology of pathogens, their hosts, and the environmental factors that influence them is essential. For example, the timing and appropriateness of interventions should be considered in light of factors such as host condition (e.g., recent insect defoliation), site (e.g., susceptibility to water deficit), and the amount of inoculum present (e.g., root disease). Thus, the disease triangle can be used as a conceptual tool for predicting outcomes of silvicultural practices; that is, measures can be taken to address host susceptibility, environmental factors, or the amount of inoculum on the site.

In some cases, especially on prime sites, corrective interventions may be effective; for example, reducing root disease inoculum or inoculum potential (i.e., the energy of growth available for infection of a host, at the surface of the host organ to be infected; Garrett 1956) through aggressive site preparation that removes

Table 1. *Changes in cover type between 1970 and 1985 in Ontario's boreal forest (from Hearnden et al 1992).*

Cover type	1970	1985
Boreal mixedwood	36%	41%
Mixed softwoods	29%	21%
Spruce	18%	4%
Jack pine	10%	15%
Mixed hardwoods	6%	19%

stumps and residual root systems or at least breaks soil contact with the stumps/root systems.

To provide the information needed to identify alternate management choices and predict possible outcomes, a pre-harvest site assessment is required.

How Mixedwood Silvicultural Practices Affect Disease Occurrence and Impact

Common practices

Partial cutting and low-impact silviculture are emphasized in boreal mixedwood management (MacDonald 1996). Methods include partial cuts with different levels and patterns of canopy removal (e.g., commercial thinning, patch cuts), careful logging to protect advanced regeneration, underplanting, and pre-commercial release and thinning. In addition, these forests are protected from loss to fire. These practices all affect succession patterns and thus disease.

Effects on stand characteristics and disease

Succession and stand composition

Ontario's boreal mixedwood forests are generated by disturbances, especially fire (Day and Harvey 1981), but also by insects, disease, windthrow, and harvesting activities. These disturbances can be large scale (e.g., fire) or small scale (e.g., root disease) and recur at various frequencies. Succession is greatly influenced by the intensity and periodicity of disturbances. Intense disturbance (e.g., hot fire) usually promotes the dominance of early successional species such as trembling aspen and white birch (*Betula papyrifera* Marsh.). Less intense disturbance will often release more shade-tolerant species (e.g., balsam fir) in the understory, thus accelerating succession towards these species.

Typical boreal mixedwood management practices can result in stands dominated by late-successional species through partial cutting (Leblanc 1996), exclusion of fire (Day and Harvey 1981), and regeneration choices (e.g., suppression of aspen in favour of spruce). These stands, especially if they have much balsam fir, tend to be more susceptible to Armillaria root disease (Hagle and Goheen 1987, Byler *et al.* 1990, Whitney 1989, Whitney and Dumas 1994), stem decay, and spruce budworm damage. All the boreal mixedwood and associated species are susceptible to Armillaria root disease, but jack pine appears to be the least susceptible conifer, followed by white spruce [*Picea glauca* (Moench) Voss] and black spruce [*Picea mariana* (Mill.) B.S.P.], with balsam fir being highly susceptible (Whitney 1989).

Buildup of Armillaria inoculum

Armillaria root disease is the most damaging root disease of both conifer and broadleaf hosts in Ontario, resulting in losses through mortality, reduced increment, windthrow, and butt cull. Most boreal mixedwood stands are infected to some extent. Partial cuts and shorter rotations (e.g., for aspen) can increase Armillaria inoculum and disease losses (Stanosz and Patton 1987a,b).

In many stands selected for management, the Armillaria inoculum level is already high due to mortality of the balsam fir understory, which often has been heavily attacked by spruce budworm and is already infected with Armillaria. The dead fir provides an excellent food base on which the Armillaria lives saprophytically. Roots of adjacent healthy trees that contact the infected balsam fir roots may also become infected, as may those penetrated by rhizomorphs extending from infected roots and stumps. Infected balsam fir stumps and root systems can remain sources of inoculum for many years. Likewise, the stumps and root systems of other species removed during partial cutting can add to the pathogen's food base and become potent sources of new infections for many years. This buildup of inoculum can negatively affect the success of regeneration, both natural and planted.

Seed tree and advance regeneration quality

Successful regeneration from seed trees or advance regeneration depends on their health and quality. Seed tree residuals and advance regeneration experience numerous stresses before they can adjust to their new environment, including logging damage to roots and bole, windthrow, and sudden soil moisture and temperature changes. They are also subject to increased threat of Armillaria infection and mortality. For example, in a wound study associated with the Black Sturgeon Boreal mixedwood research project, 42 of 100 wounded residual white and black spruce were dead within 2 years of the partial cut (McLaughlin and Dumas 1996); after 5 years 70 had died (McLaughlin, unpub. data). Advance regeneration damaged by felling or extraction is less likely to become healthy, decay-free crop trees.

Site preparation, pre-commercial release, and thinning

Regeneration quality

Methods of site preparation, pre-commercial release, and thinning can affect the quality and survival of residuals. For example, on sites where white spruce is the preferred crop species, aspen originating from root suckers may pose a competition threat during establishment. Mechanical or chemical site preparation is often used to control suckers. Basham studied the effect of surviving chemical (1982a) and mechanical (1982b) site preparation on the stem quality of suckers. Suckers that survived severe damage from herbicide (2,4-D; 2,4,5-T) were considered to have the same potential to produce good-quality crop trees as unsprayed saplings, but suckers wounded by scarification had a higher risk of developing into poor-quality crop trees with more stem and root rot.

Root disease

The effect of pre-commercial thinning on the incidence of Armillaria root disease is unclear. Armillaria colonizes stumps and root systems of thinned trees, and this increased food base increases inoculum potential, which is the ability of the pathogen to successfully infect its hosts. However, thinning can also increase the vigour of the residuals, which may increase resistance to disease. Studies from western North America have produced contradictory results. In studies of pre-commercial thinning in a ponderosa pine stand, and in stands composed of Douglas-fir, hemlock, and true firs (Filip et al. 1989; Filip and Goheen 1995), pre-commercial thinning did not increase mortality by Armillaria root disease. Much of the disease resistance was attributed to enhanced tree vigour due to thinning. Conversely, in a study of thinned 16- to 23-year-old Douglas-fir plantations, the largest and fastest growing trees, as well as less vigorous trees, became infected and died (Rosso and Hansen 1998). The authors concluded that tree vigour was not a factor. Anecdotal evidence from British Columbia suggests that pre-commercial thinning results in higher mortality in the interior but not on the coast. The effect of pre-commercial thinning on the incidence of Armillaria root disease in Ontario's boreal mixedwood forests has not been studied.

Canker and stem decay

Thinning dense aspen regeneration to shorten rotation to merchantable size is an appealing silvicultural option in light of the expected sharp increase in demand for aspen fibre (OMNR 1996). Several studies have shown that diameter growth of thinned trees exceeds that of unthinned controls (e.g., Anderson and Anderson 1968, Lux 1998). However, Hypoxylon canker infection and subsequent mortality was higher in thinned stands (Anderson 1964, Anderson and Anderson 1968, Lux 1998), possibly due to increased air flow (and thus spore dispersal) and creation of suitable habitat for insects such as the poplar-gall saperda (*Saperda inornata* Say) or cicada (*Magicicada septendecim* L.). These insects create wounds that are associated with Hypoxylon infections (Anderson *et al.* 1979, Ostry and Anderson 1983).

Opening the stands also results in increased branchiness, thus providing more entry points for the most destructive aspen pest, the wood decay fungus *Phellinus tremulae* (Bond.) Bond. & Boriss., which infects stems primarily through branch stubs 1.5 cm or more in diameter (Basham 1993).

Commercial thinning and other multi-stage harvesting

The main pathological concerns related to commercial thinning and other multi-stage harvesting are pre-existing and subsequent decay in residuals, growth and mortality losses to root disease, and windthrow. If timber values are paramount, trees already infected with stem decay fungi are poor candidates as residuals. For example, aspen quality lessens rapidly after 50-60 years of age, due primarily to the fungus Phellinus tremulae, which causes 75-80% of advanced aspen stem decay in Ontario (Basham 1993). This decay fungus, although not generally a serious problem in trees under age 30, is more damaging to older trees (Basham 1993).

Logging wounds serve as entry points for wood decay fungi (Whitney 1979, 1991) and can reduce tree survival (McLaughlin and Dumas 1996). Wounded trees are more susceptible to Armillaria root disease, which can become more aggressive after the cut as the pathogen colonizes the stumps and root systems of cut trees and uses this substrate as an energy source. Tomentosus root rot may be introduced into thinned stands through spore infections of butt and root wounds on spruce (Whitney 1966, Lewis and Hansen 1991).

Finally, the windthrow hazard for residuals will be high in the years immediately following stand opening. Many trees, especially shallow-rooted spruces, may be lost, especially those that have disease-weakened root systems (McLaughlin and Dumas 1996).

Disease Incidence and Hazard Assessment

Although most prophylactic or curative methods are impractical for dealing with diseases in boreal mixedwoods, potential losses can be reduced through timely site assessment.

Choosing the assessment method

Generic hazard assessment methods can be developed; for example, stand composition and soil information can be used to identify disease hazard for certain tree species and diseases. In British Columbia, hazard rating is related to site classification using the province's biogeoclimatic ecosystem classification; future work in Ontario should aim to develop similar forest ecosystem classification-based hazard-rating tables for hosts and pathogens.

Surveys to inventory and assess the behaviour of resident diseases provide a site-specific assessment of disease hazard. For example, susceptibility to Hypoxylon canker on aspen has been found to vary somewhat among clones (Enebak *et al.* 1996), thus assessing the incidence and impact of Hypoxylon canker on the clones present could contribute to decisions about managing the aspen on the site. Likewise, assessing the amount of pre-existing stem decay in aspen or spruce could provide a basis for evaluating which species to favour under a partial-cut scenario. Finally, stratifying the site based on the presence of active root disease centres could direct choices of species and/or site preparation methods.

Timing the assessment

The current type and level of disease as well as the probable effects of management activities on pathogens, hosts, or site environment can be assessed prior to any activities. At the pre-harvest stage, assessing the current level of disease in the existing stand can reveal what may be expected in the future stand, especially if the same species or species mix will be reestablished. For example, regenerating conifers on a conifer-dominated site that shows signs of severe root disease will probably suffer heavy losses during the juvenile stage.

Disease and other stress levels and possible outcomes of interventions can also be assessed at the pre-treatment stage (e.g., before commercial thinning). For example, following an outbreak of spruce budworm or drought, conifer residuals will be more susceptible to root disease from Armillaria and Tomentosus. Waiting until the trees have recovered from the stress event before carrying out the treatment could help to minimize losses.

Management Considerations

Although a disease-free stand is neither possible nor desirable, some steps can be taken to reduce losses and avoid unpleasant surprises.

Root Disease

- Conduct a pre-harvest assessment to identify, map, and quantify of infection.

- On sites moderately to highly infected with Armillaria root disease, favour early seral species such as jack pine and aspen.
- Expect some root disease mortality associated with stand entry, and allow for it in calculations of volume growth after thinning.
- Do not manage for spruce in Tomentosus root rot centres (Whitney 2000).
- Reduce the balsam fir component, especially in the understory where it is particularly vulnerable to budworm and Armillaria attack and thus contributes to the inoculum level.
- Plant seedlings at least 1 m away from stumps and large roots (Chavez *et al.* 1980).

Blowdown of Residuals

Be aware of the risks of thinning and other partial cuts, and take into consideration that:

- Stands are particularly vulnerable to blowdown in years immediately after thinning (Persson 1969), and
- Blowdown will be worse on shallow soil sites and with shallow-rooting species, especially if residuals have diseased root systems (Whitney 1989).

Hypoxylon Canker on Aspen

- Assess prevalence of cankers on existing mature trees before deciding to promote regeneration of these clones.
- If considering whether to thin juvenile aspen stands, remember that although results are mixed (Manion and Griffin 1986), several studies found higher infection levels in more open stands (Day and Strong 1959, Anderson 1964, Lux 1998).

Pre-existing Stem Decay

- Assess stem decay (especially in aspen) before making management decisions (e.g., species mix, products, rotation age).
- Remove trees with signs (e.g., conks) or symptoms (e.g., wounds, cavities) of decay during partial cut (unless also managing for wildlife habitat, in which case these signs and symptoms indicate trees useful for nesting sites for cavity dwellers).
- Realize that more open-grown trees will retain branches longer, thus increasing risk of infection by heart rot fungi, especially in aspen.

Wounding of Residual Trees

Take appropriate measures to minimize damage to residual trees, as identified in numerous studies of partial cutting operations (e.g., Rice 1994), i.e.:

- Match equipment size with tree size; equipment that is larger or smaller than necessary results in more damage to site and residuals.
- Plan the cut well, identifying skid trails, felling direction, and bump trees in advance.
- Whenever possible avoid conducting operations in the spring when boles, roots, and soil are easily damaged.
- Train operators in partial cutting methods.
- Ensure that operators understand the objectives and standards of the operation.
- Supervise the operation continuously.

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boreal mixedwood Notes

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Considerations for Integrated Pest Management in Boreal Mixedwoods

by D. Schroeder*

> *The potential for reduced pest damage as a result of BMW management may offer significant economic benefits to the timber industry...*

Introduction

Integrated pest management (IPM) incorporates biological and ecological principles into pest management strategies. In forestry, IPM approaches combine research, specific pest control measures, and forest management techniques aimed at mitigating damage, as well as fostering increased awareness of relevant information related to forest pest management among resource managers. The intent is to enable resource managers to limit pest damage to acceptable levels through prescriptions that are based on sound ecological and economic factors. IPM typically focuses on single pest/host species interactions, emphasizing protection of commercial timber and non-timber values while minimizing negative effects on natural ecological processes.

The management of boreal mixedwood (BMW) forests forms a component of Ontario's sustainable forestry approach. BMW stand management supports overstory replacement patterns that occur naturally (MacDonald 1995). Following overstory-destroying events such as fire, pest disturbances can influence these stand replacement dynamics (Arnup 1998; Towill *et al.*, in prep.). These disturbances may be welcome where wildlife habitat and other values are the management focus. However, these pest disturbances can reduce the economic viability of the timber industry. This note presents some considerations for applying IPM approaches to managing Ontario's BMW forests.

A specific IPM policy for forests is not currently in place. However, the management policy developed during the last major spruce budworm (*Choristoneura fumiferana*) outbreak is an example of an IPM approach (T. Scarr, OMNR, *pers. comm.*). The strategy is:

1) Short term:

- Protect stands that are scheduled for harvest from mortality (using pesticides)
- Accelerate harvest of highly susceptible stands
- Redirect planned harvest to stands that may be affected

2) Long term:

- Detect and monitor pest populations, especially outbreaks
- Convert susceptible stands (mainly balsam fir (*Abies balsamea* (L.) Mill.) to other conifers
- Shorten rotation ages
- Evaluate effects of existing pest management approaches

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- Educate resource managers and stakeholders about significant pests (e.g., ecology, dynamics, management)
- Foster cooperation among government agencies developing protection strategies and conducting ongoing research

Vulnerability: A species' ability to withstand attack by an insect or disease.

Example: Black spruce is less vulnerable to spruce budworm than balsam fir.

Susceptibility: The likelihood that a species will be attacked by an insect or disease.

Example: Balsam fir is more susceptible to Armillaria root disease than black spruce.

Management Strategies

The strategies for spruce budworm combine reactive and proactive tactics. A reasonable long-term goal for IPM is to reduce dependence on reactive strategies to reduce both pest management costs and potentially negative ecological consequences. Historically, active pest management in boreal Ontario has largely been reactive – pests were managed only after an unacceptable damage threshold had been exceeded (Howse and Sippel 1974, Howse 1995).

Conversely, proactive techniques such as those suggested by Régnière *et al.* 2001 (e.g., eliminating outbreak epicentres using insecticides and avoiding large pure balsam fir stands) may allow resource managers to anticipate and plan for pest infestations before damage exceeds acceptable thresholds. These techniques might also be used to maintain pest damage at acceptable endemic levels.

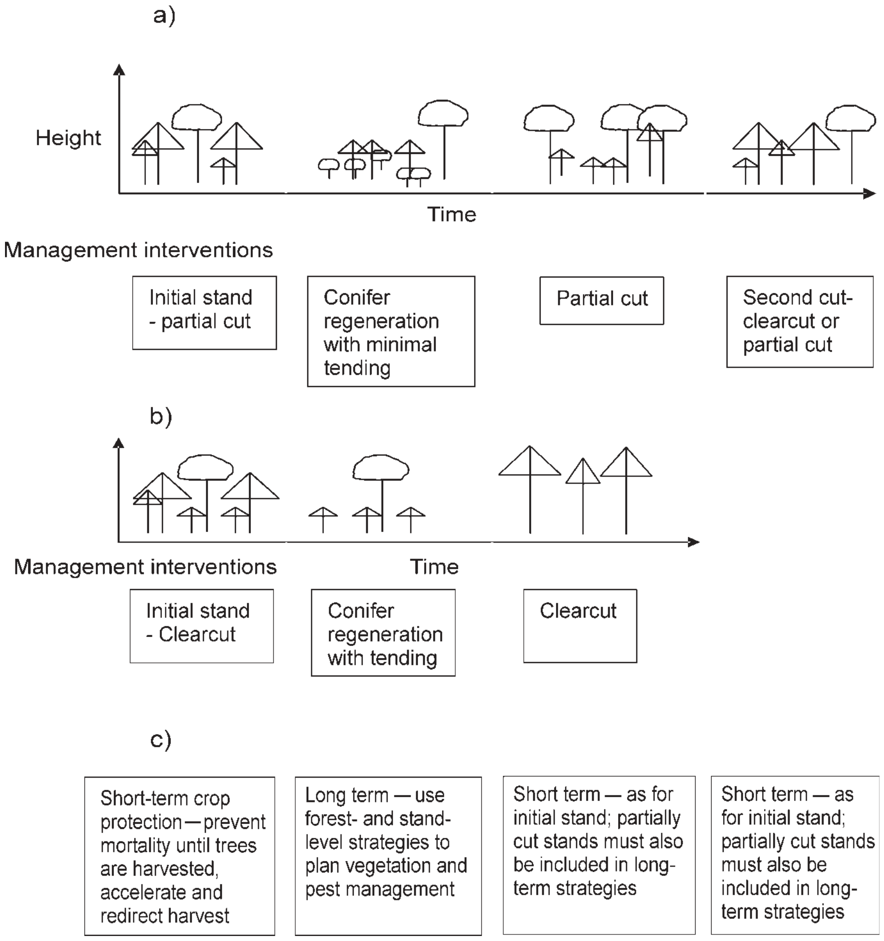
Forest Age and Composition

One objective of BMW management is to allow natural succession patterns to occur. As a result, BMW stands typically support mixed species with abundance varying throughout their evolution, and are managed at longer rotations, or even continuously relative to traditional clearcut cycles. Therefore, pest management strategies in BMWs are planned over different time frames than those used for single-species stands (Figure 1). However within this temporal framework, resource managers still need to consider the age and physiology of each species since older trees are more vulnerable to pest attack than younger, more vigorous trees. For example, to minimize pathogen damage, it is recommended that aspen (*Populus tremuloides* (Michx.)) be harvested before age 60 (McLaughlin 2003); however, older aspen provide critical wildlife habitat so these conflicting objectives need to be balanced.

Species composition variability inherent to BMW stands may benefit pest mitigation efforts. Logically, a mixedwood stand contains fewer host species for a given pest relative to a single-species stand, but more hosts for a wider diversity of pests as well as pest parasitoids (organisms that attack pests). However, as long as the damage by any given pest remains below acceptable damage thresholds, then a diversity of pests is of less concern than an abundant pest within a single-species stand. Proof of this concept was provided by Su *et al.* (1996) in a study of spruce budworm outbreak intensity and severity in New Brunswick. They found that outbreaks were shorter and less damaging in mixedwoods with 40% or more hardwood content. What is only now being determined for boreal forests is the optimal mixture of species needed for maximum protection. Similar results are not yet available for Ontario, nor for other pests.

Some pests, especially fungi, are not species specific. A well-known example is *Armillaria ostoyae*, a root rot fungus that will attack any boreal tree species. However, not all BMW species are equally susceptible; therefore, managing composition can help reduce this pest's overall impact. For example, balsam fir is more susceptible to *A. ostoyae* than white spruce (*Picea glauca* (Moench) Voss) or black spruce (*Picea mariana* (Mill.) B.S.P.) (J. McLaughlin, OMNR, pers. comm.) indicating that resource managers might want to control fir abundance on their limits. Appendix I provides a brief list of BMW species – pest interactions; other BMW notes on pests and diseases also provide more specific information (see Greifenhagen 2003; McLaughlin 2003).

Given its status as a favoured insect and pathogen host, and its relative importance as a commercial species in Ontario, prescriptions for mature balsam fir need to be developed for commercially important BMW stands. Related questions include:



Short-term crop protection—prevent mortality until trees are harvested, accelerate and redirect harvest	Long term — use forest- and stand-level strategies to plan vegetation and pest management	Short term — as for initial stand; partially cut stands must also be included in long-term strategies	Short term — as for initial stand; partially cut stands must also be included in long-term strategies

Figure 1. *A generalized comparison of BMW management (a), single-species management (b), and associated short- and long-term IPM decisions (c).*

- How much balsam fir needs to be removed before spruce budworm outbreaks are affected, if in fact there is a relationship?
- Is it more economical to do prescribed burns to control balsam fir compared to other methods – given potential losses expected if balsam fir is allowed to proliferate?
- How much balsam fir should be maintained to meet wildlife habitat and other ecological requirements?

Forest mosaics

MacLean (1996) provides a good example of the importance of forest-wide pest management approaches. He suggests that past management of spruce budworm in New Brunswick spruce-fir forests (i.e., susceptible species were kept alive, becoming more abundant over time, thereby increasing potential damage across large regions) led to subsequent outbreak severity that might have been minimized had multiple management techniques been used historically. Key forest-level pest management considerations are:

- *Vulnerability and susceptibility of vegetation across landscapes*: Species composition and age class might be managed to mitigate broad-scale damage through reduced pest damage in existing stands and decreased risk to future plantations. The abundance and structure of BMW stands across forests will obviously affect this.
- *Interaction among pests and other disturbances*: The best known example is the interaction between spruce budworm epidemics and subsequent fire hazard. The extent of balsam fir mortality will directly affect forest-wide protection.
- *Current pest levels and potential outbreaks within*

and beyond the management area in question: Pests don't care about forest management unit boundaries so forest planners will benefit from coordinating broad-scale, long-term IPM strategies with neighbouring SFL holders. Candau *et al.* (1998) determined that spatiotemporal patterns of spruce budworm outbreaks indicate Ontario could be divided into 3 defoliation zones. Outbreaks appear to begin in the east and then move to the central and western zones.

- *Historical outbreaks:* Some pest outbreaks are cyclical (e.g., Scarr *et al.* 2001). Forest managers can assume that serious pest epidemics of the past will be repeated (not necessarily in the same location) and plan accordingly.

One potential area for applying IPM at forest levels is to use BMW stands to shield valuable conifer plantations from severe pest damage. This idea is supported by the findings of Capuccino *et al.* (1998) who observed that balsam fir mortality near Lac Duparquet, Quebec, was lower within patches surrounded by deciduous forest compared to that of balsam fir within conifer forests. They suggested that increased diversity may enhance parasitoid habitat diversity and mitigate outbreak severity.

Disturbances change the spatial patterns of stands in the landscape, which may in turn affect pest outbreaks. In studies of forest tent caterpillar (*Malacosoma disstria*) outbreaks, Roland (1993) and Roland and Taylor (1997) found that forest fragmentation (edge between forest cover and cleared land) affected outbreak duration. They speculated that fragmented forests had a negative effect on parasitoid wasps, resulting in less tent caterpillar parasitism occurring there than in contiguous forests.

An invaluable data source has enabled these kinds of studies. The forest insect and disease surveys conducted by the Canadian Forest Service since the 1930s provide valuable historical data on spatial and cyclical pest damage patterns. These data illustrate the importance of long-term data collection as a tool to support the evolution of IPM from reactive to proactive techniques.

Anticipating Forest Pest Problems

The ability to anticipate pest problems is key to proactive IPM strategies. The best example for boreal forests is spruce budworm, where vulnerability and control measures have been intensively researched (e.g., MacLean 1980, Blais and Archambault 1982, Schmitt *et al.* 1984) and used to develop a spatially based spruce budworm decision-support (DSS) tool (MacLean and Porter 1995). The DSS uses a geographic information system to rank current and future forest stands for spruce budworm vulnerability. The DSS allows forest planners to evaluate various scenarios for spruce budworm management, including the feasibility of using BMWs to shield conifer stands from damage associated with major outbreaks. This would be especially useful before embarking on expensive silvicultural prescriptions without knowing the potential gains or risks.

An important part of anticipating pest problems is to avoid treatments that may solve one problem but create others. An example is the use of thinning to mitigate spruce budworm damage (Régnière *et al.* 2001). The idea is that thinning enhances tree vigour and resistance to budworm damage. Unfortunately, sawflies may benefit from environmental changes following thinning and damage the remaining spruce (T. Scarr, pers. comm.[1]). As well, thinned stands contain stumps that serve as entry points for diseases that may be just as or more damaging than the existing insect problem (McLaughlin 2003).

Economics of Integrated Pest Management

BMW management has been shown to be a viable option for forestry in northeastern Ontario (MacDonald 2000, Schroeder 2003) even though these studies did not consider the potential for BMWs to mitigate pest damage. If BMWs can be shown to reduce pest losses by even a small amount, then the economic value of BMW management could be very significant, especially given the extent of BMWs across Ontario (OMNR 2001).

Some factors that may limit present economic analysis of BMW/IPM management scenarios are:

- Losses due to pests are well documented at broad scales (Gross *et al.* 1992) but are difficult to translate into yield models for mixedwood stands

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- Economics of BMW management objectives have not been well documented. However, economic analyses such as those discussed by McKenney *et al*. (1997) and Schroeder (2003) can be used to construct cost-benefit scenarios for different BMW-IPM strategies

Interactions among pests and silvicultural prescriptions are starting to be understood, but more work is needed especially for the purpose of setting parameters for growth and yield models and landscape disturbance models

Summary

Integrated pest management strategies typically focus on individual pests and treatments emphasize protection of species attacked by a given pest (e.g., Howse 1981, Volney and Mallett 1998). However, in forestry, integrated pest management might be more effective if the focus were shifted to crop species (T. Hopkin, Can. For. Serv., pers. comm.) or stands of species. As well, the consequences of species-specific pest management prescriptions must be considered carefully – if applied in isolation, a solution to one problem may create other more severe problems. For example, in the absence of other management interventions direct controls may allow host species to proliferate, thereby delaying or even exacerbating the problem.

Integrated pest management approaches are shifting from reactive to proactive, presenting new opportunities for forest managers to limit associated crop damage. However, application of these techniques should be coordinated among forest managers. The effects of proactive steps taken within a single management unit may be ineffective against pests that cause damage across larger areas (e.g., decreasing balsam fir abundance in one management unit but not the adjacent ones will not be as successful as decreasing it in all of them).

The following prescriptions have potential for successfully applying integrated pest management in BMWs [see also notes on pathogens (Greifenhagen 2003, McLaughlin 2003)]:

- Harvest commercial aspen before age 60 to prevent losses to pathogens
- Regenerate sites infected with Tomentosus root rot (Whitney 2000) to non-spruce species
- Maintain a substantial hardwood component to reduce spruce budworm damage
- Minimize balsam fir (a favourite of insects and diseases alike) abundance to reduce overall losses, keeping in mind that this must occur not just on one site but forest-wide
- Place conifer plantations strategically within mixedwood mosaics to reduce spruce budworm damage

Integrating these techniques and applying them in the field will require careful use of forest management planning models (to anticipate problems) and ongoing monitoring to assess effectiveness. However, the potential for reduced pest damage through boreal mixedwood management may offer significant economic benefits to the timber industry. This should encourage forest managers and researchers to implement and continue developing proactive integrated pest management approaches for boreal mixedwood forests.

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Appendix 1. Brief summary of major pests of boreal mixedwood forests.

Pest	Host species	Potential damage Pure stands	 Mixedwood	Interaction with other pests	Management options	Potential effect on mixedwood trajectory
Spruce budworm	Balsam fir	Severe – all ages - highest on xeric and hydric sites (Dupont et al. 1991)	Mixedwood stands (>40% hardwood) in New Brunswick had less damage than spruce-fir stands (Su	Dead trees serve as inoculum for root rot, especially Armillaria (J. Mclaughlin, OMNR, pers. comm.); see also note on disease management	– Remove from stand by herbicide, site prep, tending	Balsam fir regenerates under its own
	Black spruce	Little mortality, growth reduction- Lowland spruce are least susceptible (G. Howse, Can. For. Serv., pers. comm.)			– Remove balsam fir – Use B.t.	Balsam fir and black spruce can regenerate under spruce canopy
	White spruce	Mortality occurs if outbreak			– As for black spruce	White spruce may be lost from stand without additional disturbance/ intervention – stand composition becomes dominated by shrubs and balsam fir
Forest tent caterpillar	Trembling aspen, balsam poplar	– All ages, sites, and mixtures are equally susceptible – Mortality can occur after repeated, heavy defoliation, and is higher on nutrient poor sites – Roland (1993) has suggested that outbreak duration		Weakened aspen suffer more attack by poplar wood borer (*Sperda calcarata*) and *Hypoxylon* *Armillaria* is a concern in areas	– Use B.t. – Schedule crop plans and harvesting with anticipated	Defoliation allows increased conifer growth and decreases time of conifer
Armillaria	All Ontario boreal species – endemic across boreal region	Lowland black spruce (moist – wet sites) have lower incidence compared to fresh sites (typical mixedwood)	Balsam fir most susceptible; high fir mortality (spruce budworm) can result in increased Armillaria abundance within	Any agent causing disease or mortality provides inoculum for *Armillaria* and an opportunity for the disease to spread; relationship between spruce budworm and *Armillaria* is	– Control balsam fir abundance – Stump and root removal, and push felling has been done in British Columbia to lower inoculum abundance – Thinning, herbicide applications, and mechanical site preparation can increase inoculum abundance	Infected trees are susceptible to blow down resulting in gap openings Large gaps may allow regeneration by
Tomentosus	All conifers; most common in black and white spruce	Diseased trees tend to be grouped due to root	Mixed stands, esp. with abundant aspen reduce root contact	Logically, weakened trees are more vulnerable to other	– Do not regenerate spruce on infected sites, or at least allow abundant aspen on spruce plantations – Stands are good candidates for	Infected trees are susceptible to blow down resulting in openings Large gaps may allow regeneration by
Phellinus tremulae	Trembling aspen	Composition does not appear to influence		As above	– Harvest aspen before 60 years – Old aspen with stem rot are very important to wildlife; therefore, some aspen should be left to grow beyond 60 years – see BMW notes on habitat	Mortality and blowdown provide
Hypoxylon	Trembling aspen	Not known if composition affects hypoxylon		As above	– Harvest aspen before age 60 – Precommercial thinning does not appear to influence *hypoxylon* (Pitt et al.	Logically a high incidence of *hypoxylon* in young stands will result in canopy openings and potential for accelerated

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Economics of Boreal Mixedwood Management

by D. Schroeder*

> *Comparing the economics and outcomes of management scenarios can help resource managers and stakeholders to make cost-effective forest management decisions...*

Introduction

Boreal mixedwood (BMW) sites cover approximately 45% of Ontario's managed boreal forest (Towill 1996) and are among the most productive in that region. However, past management practices and underutilization of some species have resulted in many degraded mixedwood stands in northern Ontario (MacDonald 1995). Foresters are now being encouraged to manage mixedwood sites to ensure that ecological processes follow natural patterns.

Managing mixedwood stands to meet ecological goals as well as the needs of forest users requires careful forest-level planning and may require techniques that are new to resource managers in Ontario. Without being able to assess potential benefits or costs, managers may be reluctant to try these new techniques. Comparing the outcomes of management scenarios and their economics (McKenney 2000) can help resource managers and stakeholders make cost-effective forest management decisions.

This report discusses the forest-level economics of BMW management and presents case studies of the economics of forest-level and silvicultural management options.

Forest-level economic analysis background

At the forest level, resource managers are faced with the following tasks:

- Maintaining present and future wood supply at reasonable cost
- Ensuring access to a sustainable supply of non-timber forest products and uses
- Ensuring ecological objectives (e.g., maintaining wildlife habitat) are met

Developing complex, economically optimal management scenarios is beyond the scope of this note. However, a top-down approach using existing spatial data that first considers the coarse scale and then addresses finer scales, can help to identify areas of potential conflicts or synergies in resource use. This approach is also advocated for identifying some wildlife habitat types (OMNR 1998). Among the considerations required to conduct a forest-wide economic analysis are (a) existing forest policy, (b) optimal timber growth site identification [prime land], (c) non-timber forest values, and (d) forest disturbance regimes. Some examples of these considerations are briefly described below:

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- *Policy*: Ontario's forest policy objectives are to ensure ecologically and economically sound resource use (OMNR 1999). Hence, timber harvesting and other activities may be subject to policies and guidelines that give specific directions meant to sustain resources. In some areas, for example, timber may not be harvested using the most economically viable methods because of alternate directions in management guidelines that are based on ecological rationale. Ontario's forest management guidelines focus on modifying timber harvesting in areas that are considered ecologically or socially important, including BMW sites. Areas where enhanced forest productivity approaches can be applied in Ontario have yet to be formalized.
- *Prime land* (most economically viable prime sites): Prime sites are areas with the best conditions for tree growth regardless of location. Identifying prime sites and prime land is important for prioritizing areas to be managed and choosing those with potential for more intensive practices. Balancing the amount of land allocated to extensive versus intensive management will affect wood and habitat supply across forests. A spatial tool (OLIPIS) developed by Elkie *et al.* (2000) uses a GIS query tool to identify prime sites following the concept of prime site identification developed by OMNR in the 1980s (Greenwood 1986). Prime lands identified in OLIPIS are those prime sites with optimal transportation and silviculture costs.
- *Non-timber forest values*: Comparing non-timber values of all forest components to timber values is difficult for individual stands (Klemperer 1996). However, at coarse scales, spatial patterns of forest cover are important to diversity, and especially wildlife habitat (Hunter 1990). For example, small, isolated mixedwood stands adjacent to primary haul roads may have relatively less wildlife habitat value than larger stands that are further removed from roads. However, proximity to access may make these roadside sites attractive for intensive mixedwood management, which will also add aesthetic value to the road's viewshed. Non-timber values such as recreation and cultural heritage areas are identified spatially through provincial and local land-use plans, spatial databases of forest values, and forest management plans.
- *Natural disturbances:* Risk of disturbance to a forest area must be considered in order to factor potential protection costs into economic analyses. For example, mixedwood stands can reduce insect-caused losses compared to pure conifer stands (Su et al. 1996). Therefore, after including pest management costs (assuming insect or pathogen control will be necessary), the net value of a pure conifer stand may not differ greatly from a mixedwood stand that did not warrant treatment. Mixedwoods are known to be less vulnerable to fire than pure coniferous stands (Kafka *et al.* 2001); therefore strategically located mixedwood stands may act as fire buffers for more intensively managed plantations. The economic value of using fire resistant stands as buffers has not yet been quantified, but is being given serious consideration by forest protection agencies (Hirsch *et al.* 2001).

Forest management teams can begin to objectively balance these considerations by analyzing spatially overlapping layers of ecological, growth potential, and policy data.

Forest-level case study analysis

The Black Sturgeon Forest, near Thunder Bay, Ontario, is used here as an example to demonstrate a top-down approach to forest-level economic analysis. The forest was divided into sub-units based on stand characteristics and spatial factors, and wood supply was analyzed using the Strategic Forest Management

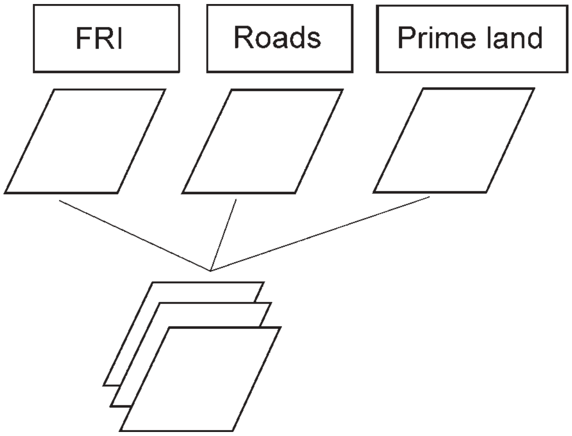

Figure 1. *Process of creating sub-units for SFMM analysis using spatial data layers.*

Model (SFMM) (Davis 1999). Since comparing complex forest models and management scenarios is beyond the scope of this note, SFMM configurations were kept simple to allow relative comparisons among management scenarios.

Sub-unit definition

1) Spatially based Forest Resource Inventory (FRI)[1] forest sub-units were created for use in SFMM by querying GIS layers describing the Black Sturgeon Forest (Figure 1). Stands were classified into sub-units (SU) described by:

- Good access (any stand within 200 m of a primary or secondary road) and potential mixedwood
- Good access and prime mixedwood (OLIPIS – best aspen sites assumed to be best mixedwood as well)
- Poor access and potential marten habitat (conifer working group > 80 yrs)
- Good access and potential marten habitat
- Other

2) The FRI data was processed in SFMMTool (Watkins and Davis 1999) using Plonski's yield curves (1981) and loaded into SFMM. Because the emphasis here is a relative comparison among management techniques, Plonski's curves were considered acceptable and used in place of intensive management yield curves.

3) Wood supply generated by SFMM was used to compare the following management scenarios:

- Scenario 1: Basic forest management on all site types, including mixedwoods, using clearcut harvesting. Potential marten habitat excluded from harvest.
- Scenario 2: Option for partial harvesting on mixedwood sites with good access.
- Scenario 3: As for Scenario 2, with partial harvest area extended to include potential marten stands.

For this example, the SFMM configuration was set as follows:

- Succession towards black spruce
- Northwestern Ontario forest units (SFMMTool)
- No natural disturbance (done to simplify model)
- Silviculture costs based on Forestry Futures data
- No clearcutting in *poor access and potential marten areas* sub-unit. Unharvested stock in this sub-unit was set to 100% but partial harvesting allowed

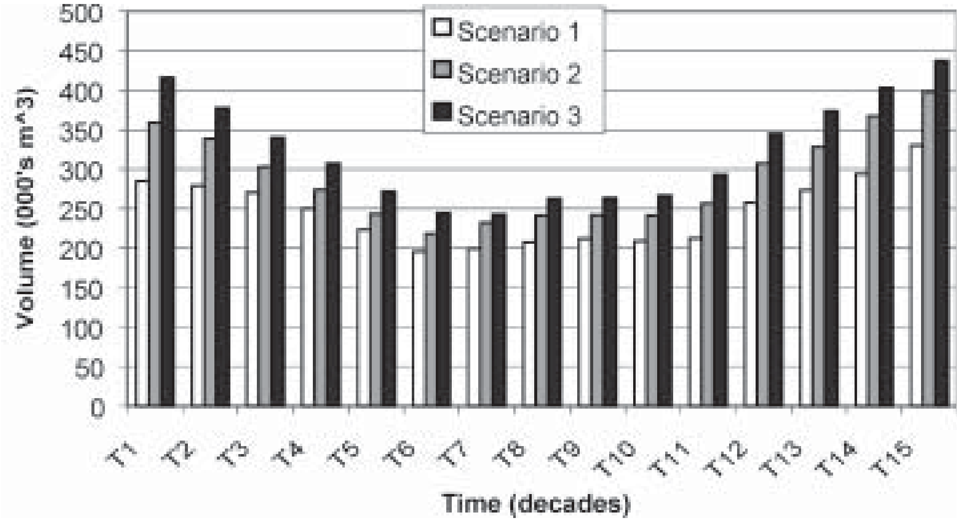

Figure 2. *Harvest volume for possible management scenarios: (1) clearcut excluding marten habitat, (2) partial harvest with good access, (3) as for (2) but harvesting extended to potential marten habitat.*

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[1] The FRI classifies a landbase into broad physical components such as productive forest, non-productive forest, non-forested land and water. Within forest stands, information is provided about forest resources such as interpretations of tree species composition, stand age, stand height, stocking level and site productivity class (OMNR 1996).

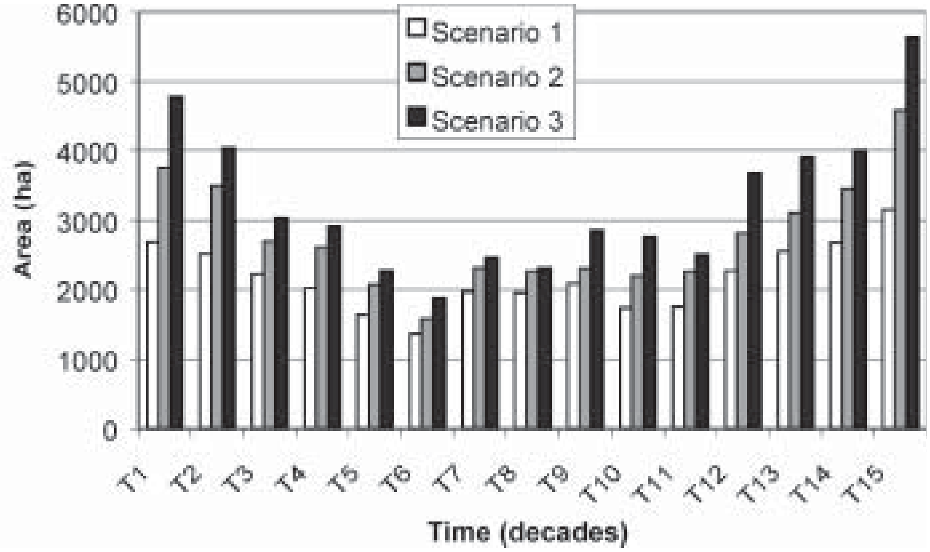

Figure 3. *Available harvest area for the management scenarios described in Figure 2.*

- Post-partial cutting forest condition was set to younger age classes to emphasize potential for enhancing understory conifers; e.g., 65-year-old mixed hardwood to 15-year-old conifer mixedwood. Assumed that partially harvested stands result in conifer regeneration
- Harvest flow limit of ± 10%
- Management scenario: optimize timber value; timber value assumed as: conifer = \$42 per m^3, aspen = \$20 per m^3, other = \$12 per m^3 (L. Gravelines, pers. comm.[1])

Results and discussion

The forest area of each sub-unit is given in Table 1. Volume harvested was highest in the scenario that allowed the most partial cutting (Scenario 3) and lowest in the clearcut only area (Scenario 1) (Figure 2). Volume was expected to increase with partial cutting (Scenario 1 vs. Scenario 2) because future forest classes of partially harvested stands were older (15 to 25 years depending on age of initial stand), which decreased the time to the next harvest. A more complex study could include prime land for spruce and pine (classed as *other* in this exercise), which may result in greater yield for Scenario 1. Scenario 3 illustrates additional volume that may be available in areas where clearcutting is otherwise excluded.

Increased area harvested in Scenarios 2 and 3 suggests that access costs will increase with partial cutting (Figure 3). However, the total area harvested using partial cutting will be less because of repeated harvesting of the same stands before a rotation cycle is completed. Access costs for repeated entry should be minimal compared to establishing and maintaining new roads – especially if partial harvest stands are located near long-term access roads. Since partial cutting operations have been shown to be economically viable in northeastern Ontario (MacDonald 2000), this approach may be of interest to the timber industry.

It was not the purpose of this exercise to demonstrate the absolute economic effects of partial harvesting – only, its potential effects — therefore these results should not be taken out of context! The forest-level analysis demonstrated that partial

Table 1. *Forest area in each sub-unit type in the Black Sturgeon Forest.*

Sub-unit	Available forest area (ha)
Good access and potential mixedwood sites	16 349
Good access and prime mixedwood sites	61 386
Poor access and potential marten habitat	35 156
Good access and potential marten habitat	5 968
Other	315 516
Total	434 375

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[1] Forest Economist (retired), OMNR, Sault Ste. Marie, ON

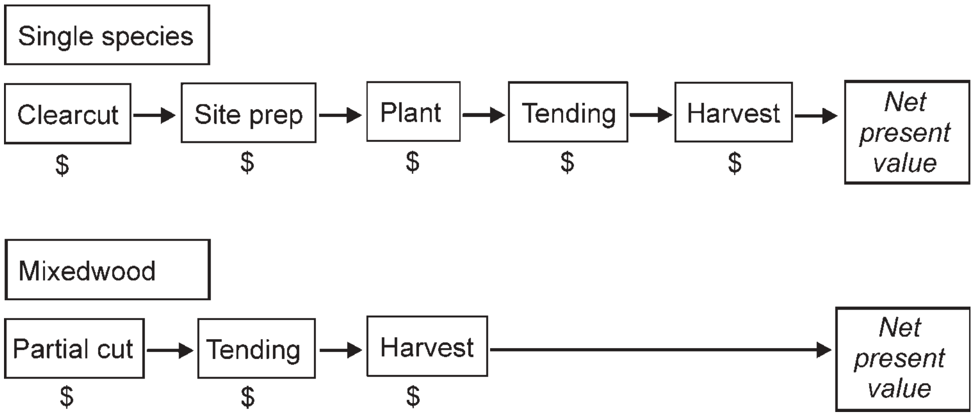

Figure 4. *Types of costs incurred in a single species management approach compared to a mixedwood approach. Future costs are discounted over time to calculate net present value.*

harvesting might increase wood supply with minimal associated cost increases. Potential to increase wood supply through partial cutting must be tested using more detailed models and better data to reduce the uncertainty associated with assumptions used here.

Silvicultural system case study analysis

Mixedwoods can be managed using traditional techniques based on clearcut systems and non-traditional techniques such as partial cutting (Wedeles *et al.* 1995). However, experience with new systems is limited in the boreal region of Ontario and examples of crop planning with financial analyses are limited to pure species stands (Ghebremichael *et al.* 1996, Willcocks *et al.* 1997). Figure 4 illustrates a simplified flow chart for comparing a single crop rotation with a mixedwood rotation.

Financial calculations and valuation

- Net present value (NPV) was calculated for an infinite time series, using a discount rate of 4%. The NPV indicates the expected effect of a project and is calculated as the present value of the project's cash inflows minus the present value of the project's cash outflows (Figure 4). Actual formulae, an explanation of their use, and examples of associated financial calculations are available in Davis and Johnson (1987), Williams (1995), Ghebremichael *et al.* (1996), Willcocks *et al.* (1997), and Nautiyal *et al.* (2001).
- Timber valuation is not straightforward in economic analyses of publicly owned forests. A common approach is to use the value of wood delivered to the mill gate; however, Willcocks *et al.* (1997) used final processed wood values as a measure of value to the Ontario public. Differences in valuation significantly influence financial calculations (see examples below), emphasizing that any conclusions made based on financial analyses should be made within the proper context.
- Price volatility makes estimating real price increases for timber risky. However, Ghebremichael *et al.* (1996) provide an example of real price increases for conifer fibre products that significantly affects NPV.

Costs were compared for the following silvicultural systems:

1) Extensive management
- 60-year rotation
- Assumed natural regeneration to deciduous forest

2) Clearcut I
- 90-year rotation
- Site preparation
- Planting conifers
- Single tending treatment – assumed that a single tending does not permanently remove all hardwoods so a mixedwood forest results

3) Clearcut II
- 90-year rotation
- Site preparation

- Aerial seeding
- Assumed this system unlikely to work for aspen-spruce mixedwoods, but included it for the sake of comparison

4) Two-coupe harvesting
- Partial cut aspen at 30 years
- Clearcut spruce at 90 years

5) Partial harvesting
- Partial cut aspen at 30 years (volume for deciduous stands)
- Partial cut aspen and spruce at 60 years (volume for deciduous stands)
- Final harvest spruce at 100 years (volume for conifer stands)

6) Underplanting spruce prior to harvesting
- Starting with bare land – allow natural aspen regeneration
- Underplant spruce at 70 years
- Clearcut aspen at 90 years (volume for deciduous stands)
- Harvest spruce at 140 years (volume for conifer stands)

Additional information:

- Data from Evert (1975) was used for growth and yield estimates (Appendix I)
- A harvesting cost of \$14 per m^3 for clearcutting (Garner 1989) was used to standardize the comparisons. Partial cutting costs were estimated by adding the productivity difference (MacDonald 2000) between clearcutting and partial harvesting for a cost of \$17.75 per m^3. Since this was a relative comparison, harvesting costs were standardized, but they will vary based on, for example, site conditions, season, weather, and equipment availability
- Timber prices used here were identical to the forest-level case study described above

Results of comparison

As expected, NPV was highest for the extensively managed system (Figure 5). Management cost was highest for those systems that included site preparation, planting, and tending at the beginning of each rotation (Figure 5). Interestingly, underplanting spruce resulted in a much higher NPV than all other systems except extensive because of the delay in planting costs. If the assumed conifer yield was underestimated for this example, then this approach may enhance future conifer harvest volumes

This exercise compared basic silvicultural systems that could be used in BMW management. Factors such as renewal costs, rotation period, timber price, and discount rate all influence NPV to make silvicultural investment seem attractive or unattractive. As an example, sensitivity to conifer price was compared for four systems (Figure. 6). Advanced underplanting of

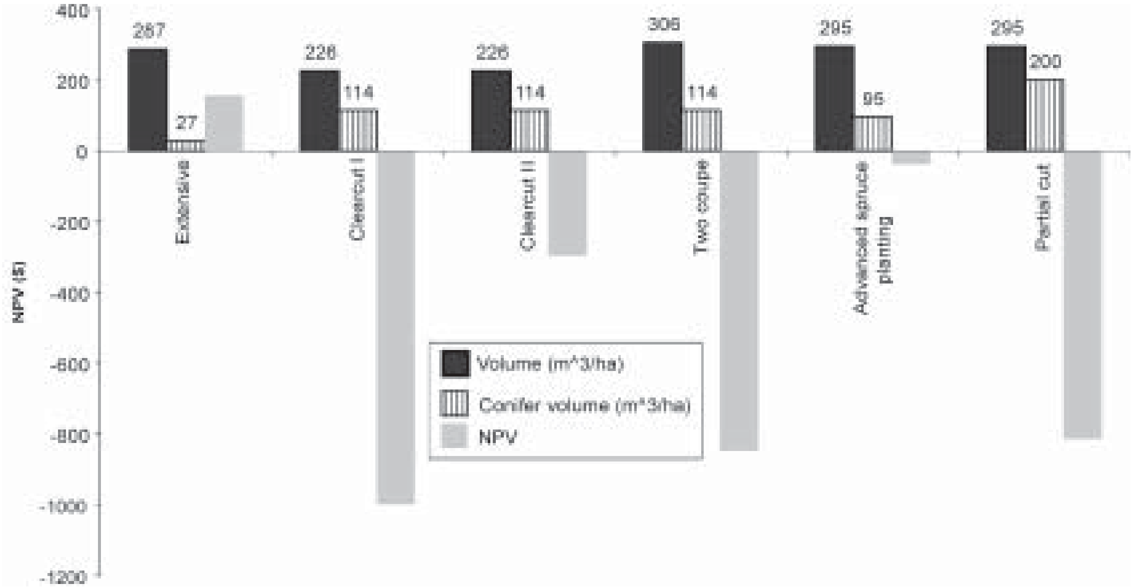

Figure 5. *Net present value relative to wood volume for 6 silvicultural systems in the case study analysis.*

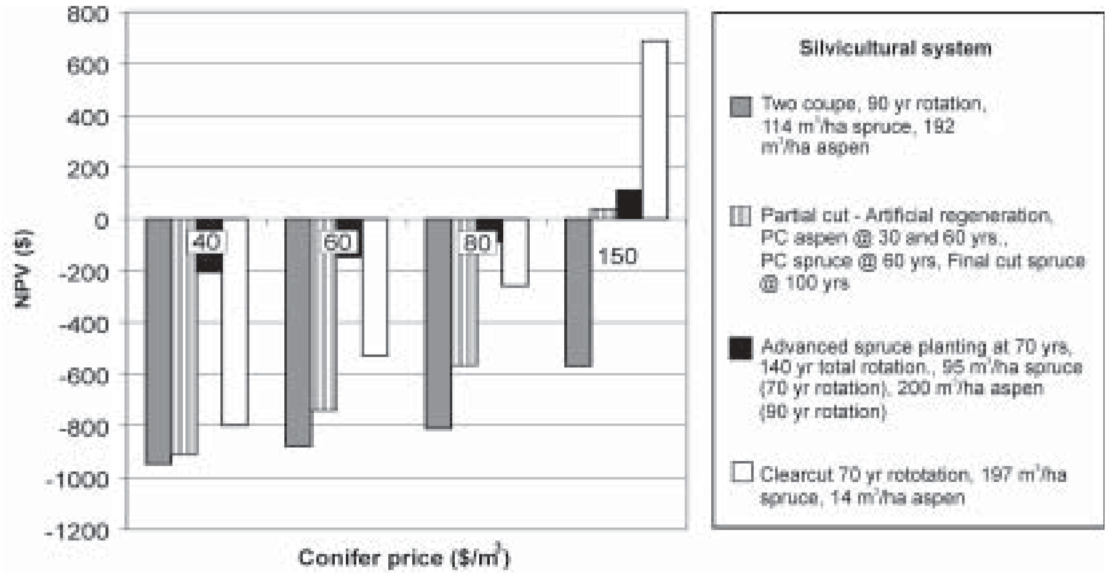

Figure 6. *Price sensitivity of 4 silvicultural systems based on conifer prices of 40, 60, 80, and 150 m^3.*

spruce was least affected because of the low conifer volume, whereas clearcutting with conifer regeneration was most affected (see Ghebremichael *et al.* 1996 for more examples).

Conclusions

- Planning teams can efficiently analyze wood supply under different management scenarios by stratifying forests into spatial sub-units based on policies and management objectives linked to non-timber values and prime sites for BMWs and other forest types.
- At a forest level, long-rotation BMW management prescriptions are being encouraged as an important part of sustainable ecosystem management. Using partial harvesting techniques on these sites may allow cost-effective harvesting that would otherwise not be viable.
- Delaying silviculture investments increases NPV, thus favouring BMW management techniques that take advantage of natural regeneration and mid-rotation harvesting. This may reduce time between treatment and harvest thereby providing greater returns.
- Current inventory methods (e.g., FRI) and growth and yield knowledge limit our capacity to undertake accurate stand-level economic analyses but our results indicate that techniques such as underplanting appear to be economically feasible for BMW site management. Quantitative information about natural conifer regeneration is limited, but once available will help to improve the accuracy of economic analyses.
- The future value of wood and the market demand for products cannot be predicted with certainty so economic analyses will always consist of a relative assessment of alternative scenarios.
- Foresters need a better understanding of the relationship between harvesting activities and the production of timber and non-timber values to accurately assess the economics of boreal mixedwood management scenarios.

To reduce costs, enhance wood supply, and sustain non-timber values first consider these questions:

- Given the gains that can be made from exploiting natural regeneration and advanced understories, are the silvicultural systems being used the best available alternative?
- Can expanded boreal mixedwood management enhance wood supply and contribute to net present value?
- Are prime sites on the management unit being used effectively for timber or other values?

Comprehensive surveys of advanced regeneration are needed to help answer these questions and would likely pay for themselves by helping to optimize investment in future timber harvests.

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Appendix

Table 1. *Yield (m³/ha) data from North Central Ontario[1] (Kimberley Clark and American Can Compa-*

Age (years) n=347	Mixed softwood		Mixedwood		Hardwood	
	Softwood	Hardwood	Softwood	Hardwood	Softwood	Hardwood
30	11.21	1.07	15.70	15.70	3.36	84.11
40	34.20	3.25	38.97	32.80	11.77	162.60
50	61.12	5.16	61.12	49.34	20.19	218.67
60	93.64	7.40	79.62	65.60	27.47	258.76
70	128.40	9.59	95.60	81.58	34.20	290.44
80	164.85	11.94	107.37	97.28	37.57	314.83
90	197.37	13.91	113.82	112.14	38.69	332.50
100	222.04	15.31	118.30	124.76	39.81	343.15
110	241.10	16.43	120.55	134.57	40.93	347.07
120	253.44	17.16	121.67	140.74	42.05	350.44

[1] Minimum tree diameter considered was 10 cm

Table 2. *Costs and timing of silvicultural activities used for stand-level economic analysis (from Garner 1989).*

Activity	Years after harvest	Cost ($/ha)
Mechanical site preparation	0	300
Planting (including stock)	0	700
Tending	5	100
Tending	7	0
PCT	12	400
Aerial seeding	0	100
Tending - partial cut system	4	150
Planting - understory		800
Logging		14 ($/m³)