Advancing Boreal Mixedwood Management in Ontario:

Proceedings of a Workshop

held at
Sault Ste. Marie, Ontario
on
October 17–19, 1995

Compilers

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Foreword

The management of boreal mixedwoods has become a topical issue in recent years, reflecting, perhaps, a growing recognition of their economic potential and their importance as providers of multiple forest values. Although changing market forces have undoubtedly stimulated interest in more proactive management of these cover types, much of the impetus for improved practices derives from the stated objectives of governments to adopt sustainable development as the principle for current and future forest management policies and practices.

In Ontario, boreal mixedwoods have long been a challenge for forest managers because of their complexity, their species composition, and the fact that they grow on some of the most fertile and productive sites in the boreal zone. In a conifer-dominated forest economy, the past lack of markets for hardwoods posed a major obstacle to creative mixedwood management. At the same time, the inherent fertility of mixedwood sites created major silvicultural problems, especially in terms of forest regeneration. Consequently, traditional approaches to the management of these forests have generally been simplistic—most commonly clear-cutting or selective cutting of the spruce component, followed by attempted conversion to conifers.

Some 10 years ago, the situation began to change. In the west, and later in Ontario, markets for aspen began to open up, thereby creating new opportunities for managing boreal mixedwoods. At the same time, social and environmental pressures began to be felt within the forestry community. Not only have traditional forest management practices come under attack, but fundamental concerns over forest use have emerged as well. The mixedwoods, especially, are attractive to a broad range of nontimber-oriented interest groups, who demand to have their interests accommodated in the development of forest management policies and strategies.

As a result of these forces, an entirely new forest management reality is emerging, one that will create both opportunities and headaches for the mixedwood manager. In this climate of change and broadened responsibility, many new, and different, questions are being posed. The need for integrated, multidisciplinary research has never been greater and extends well beyond traditional forest research into the more fundamental realm of ecosystem function and processes. Such research is essential if we are to acquire the knowledge and understanding needed to establish a strong ecological foundation for the future sustainable management of boreal mixedwood ecosystems.

The past three years have seen a proliferation of new research studies dealing with boreal mixedwood issues, many of them funded by the Northern Forestry Program of the Northern Ontario Development Agreement, the federal Green Plan, or Ontario's Sustainable Forestry Initiative. As this workshop demonstrated, much of this research focuses upon the relationships between forestry practices and ecosystem response. At first sight, many of the issues and topics being studied might appear remote from the problems that have to be dealt with in day-to-day forest management. However, it must be recognized that only through an understanding of these seemingly esoteric issues can we ever begin to practise ecosystem management.

This is not to infer that a massive shift to alternative silvicultural systems is being promoted or that there is no longer a need for traditional silvicultural research. Simply put, demands for ecosystem management have caught us with our pants down, so that we are ill-prepared to practise the "new forestry"! In truth, we have a large body of prior research to draw upon. In Ontario, both the Canadian Forest Service and the Ministry of Natural Resources have been involved in various aspects of boreal mixedwood research, albeit under different guises, for many years. A great deal of this research, some of it going back to the 1940s, has dealt with insect and disease problems (especially the spruce budworm), forest fire behavior, growth and yield, and innumerable silvicultural questions. The present challenge is to gain a better understanding of how boreal mixedwoods work.

The purpose of this workshop, then, was twofold: first, through the plenary papers, to summarize our current state of knowledge about the ecology of boreal mixedwoods and to discuss management philosophies for these cover types; and second, to present, through brief technical reports, miniworkshops, and posters, information on new research relevant to the future management of boreal mixedwoods. Many of this second group described research that was initiated relatively recently, so that only preliminary results could be presented. The workshop organizers considered it essential that this new research be brought to the attention of the practising forestry community at this time, both to show the breadth of the research now under way and to demonstrate the manner in which the research community is trying to provide the knowledge that will be needed to practise "new forestry" in the 21st century.

J.B. Scarratt
Canadian Forest Service–Sault Ste. Marie

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PLENARY SESSION I

Moderator

James J. Farrell

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The emergence of boreal mixedwood management in Ontario: background and prospects

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Abstract

A site-based definition of the Boreal Mixedwood Forest of Ontario is presented, and the rationale for proactive mixedwood management is outlined. Mixedwood forests are extensive and expanding, despite past attempts to maintain conifer monocultures. Mixed-species forests resist pests, improve biological diversity, and enhance ecological processes such as nutrient cycling. They are ideal candidates for integrated resource management, because they support multiple values. Market conditions, wood supply patterns, regeneration costs, and stand productivities provide economic advantages for mixedwood management. A history of neglect has produced degraded stands throughout much of the Boreal Mixedwood Forest of Ontario. However, a more favorable attitude toward promoting species mixtures has evolved during the last two decades. There is a promising future for boreal mixedwood management in Ontario, but the serious lack of information to support mixedwood policies and practices must be addressed.

Résumé

La présente communication définit la forêt mixte boréale de l'Ontario selon des critères stationnels et explique brièvement les raisons qui justifient sa gestion proactive. Cette forêt occupe un vaste territoire et est en expansion, malgré les tentatives passées de maintenir des monocultures de résineux. Pourtant, les peuplements renfermant plusieurs essences résistent bien aux ravageurs, contribuent à la biodiversité et favorisent certains processus écologiques, dont le cycle des éléments nutritifs. Ils se prêtent de façon idéale à la gestion intégrée des ressources, car ils répondent à des besoins multiples. De plus, étant donné les conditions du marché, les diverses tendances de l'approvisionnement en bois, les coûts de régénération et la productivité des peuplements mixtes, une telle gestion est avantageuse sur le plan économique. Malheureusement, cet aspect a été négligé dans le passé, ce qui a entraîné une dégradation des peuplements dans la plus grande partie de la forêt mixte boréale de l'Ontario. Depuis une vingtaine d'années, on assiste à l'émergence d'une attitude plus favorable à la mise en valeur de mélanges d'essences, et la gestion de la forêt mixte boréale semble avoir un avenir prometteur dans la province. Cependant, pour pouvoir mettre en place les politiques et les pratiques voulues, il faudra corriger de graves lacunes en matière d'information.

Introduction

The extent, persistence, productivity, and complexity of the Boreal Mixedwood Forest are recognized by all resource managers who have practised in northern Ontario. However, this forest was rarely managed for mixed-species crops. Traditional attitudes favored simple stand structures that produced large and predictable yields of conifer timber. The increasing focus on biological diversity and ecological processes has stimulated interest in managing for mixedwood forests. However, the policies, practices, and information bases in Ontario do not adequately support boreal mixedwood management.

This paper provides the background for some of these issues, which are addressed in more detail in subsequent presentations. The objectives are to propose some definitions, present the rationale for intentional mixedwood management, trace the evolution of mixedwood management in the province, and outline future prospects.

Boreal mixedwood sites, stands, and forests

Working definitions of boreal mixedwood sites, stands, and forests have been developed for Ontario (MacDonald and Weingartner 1995). The definitions are summarized below, and the characteristic mixedwood species in northern Ontario are listed in Tables 1 and 2.

A *boreal mixedwood site* is an area with climatic, topographic, and edaphic conditions that favor 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 midsucces-

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.

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.

sional stages, and balsam fir (*Abies balsamea* [L.] Mill.) in late successional stages. The successional pattern of mixedwood sites is a key component of the definition, and it should guide management prescriptions. The abundance, diversity, and relative position of component species at each successional stage depend on the disturbance type and predisturbance stand composition.

Disturbances on boreal mixedwood sites in Ontario create 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. Shade-intolerant pines (*Pinus* spp.) may become established with the early successional hardwoods. The diffuse canopy provides a suitable regeneration environment for midtolerant 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, as it tolerates the increasingly dense shade and establishes well on the undisturbed accumulations of litter and humus.

Spruce–fir cover types seldom endure as climax formations, because disturbances return them to an earlier successional stage. Wildfire and spruce budworm (*Choristoneura fumiferana* Clemens) are important disturbance types that have affected the structure and composition of many boreal mixedwood forests.

The use of characteristic site types provides a stable frame of reference for defining and managing these complex and dynamic forests. Boreal mixedwood sites typically have well-drained, fertile soils on midslope positions and exclude wet lowlands, dry sand plains, and shallow soils on bedrock outcrops (McClain 1981). Deep soils, medium to fine textures, and unrestricted drainage are essential elements of a mixedwood site.

Annual precipitation decreases steadily from east to west in Ontario (Minister of Supply and Services Canada 1982). Thus, 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.

A *boreal mixedwood stand* is a tree community on a boreal mixedwood site in which no single species exceeds 80% of the basal area. All of the defining and associated tree species (Tables 1 and 2) qualify as canopy components. The definition includes stands composed of two or more hardwood species or two or more conifer species, provided they are established on boreal mixedwood sites. The implication is that the stands are candidates for mixedwood management prescriptions because the underlying sites have the potential to increase their diversity of tree species in the future. Stand composition at any point in time depends on the successional stage, which is controlled by the disturbance type and availability of seed or vegetative propagules.

A boreal mixedwood *site* often supports a single predominant tree species at a given point in succession. 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 an understory of white spruce or balsam fir.

A *boreal mixedwood forest* is the aggregate of all boreal mixedwood sites in any distinct area. Specifically, the Boreal Mixedwood Forest of Ontario is the aggregate of all boreal mixedwood sites in the province. Boreal mixedwood forests may contain mixtures of several species within each stand or mosaics of small single-species stands.

The forest ecosystem classification (FEC) systems in northern Ontario identify approximately 30 boreal mixedwood Vegetation Types (Jones et al. 1983; Sims et al. 1989), which are comparable to boreal mixedwood stands as defined in this paper. The FEC Soil Types are simpler, more stable, and more relevant than the Vegetation Types 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.

The ambiguity of the term "boreal mixedwood" is avoided by combining it with "site," "stand," or "forest," depending on the context. Similar versions of the preceding definitions have been accepted for over 15 years in Ontario. These working definitions are intended to help practitioners understand the Boreal Mixedwood Forest better, as the basis for more pro-active management. Variations in the details of the definitions may be appropriate for local situations, but the central concepts of site capability and successional dynamics must be preserved. These concepts underpin the usefulness of the definitions for planning and implementing mixedwood silvicultural prescriptions.

Rationale for advancing boreal mixedwood management

Extent of the mixedwood resource

Estimates of the extent of the Boreal Mixedwood Forest range from 20% to 50% of Ontario's productive forest area (Armson 1988). A detailed inventory based on remotely sensed data has revealed that mixed-species forests account for 52% of the total dense forest in northeastern Ontario (Spectranalysis, Inc. 1994). These estimates are based on forest cover types, because no provincial inventory of mixedwood site types exists.

The area of mixedwood cover types in northern Ontario is increasing as harvesting operations remove conifers and create conditions that favor early successional species. Recent surveys have revealed that conifer stands are regenerating to mixedwood species, especially balsam fir and trembling aspen (Yang and Fry 1981; Hearnden et al. 1992). This trend persists, despite past attempts to establish conifer monocultures after harvesting. Efforts to constrain renewal costs by government and industry in Ontario are leading to a greater reliance on natural regeneration. This type of extensive silviculture promotes mixed-species stands (Navratil et al. 1991).

Ecological factors

Boreal mixedwood forests are ecologically resilient. The loss of a single component does not threaten the integrity of a species-rich ecosystem. Companion species differ in their limiting environmental factors, growth habits, and physiological processes, maximizing biological activity per unit area (Chan et al. 1988; Schuler and Smith 1988). Mixed stands are also more resistant than monocultures to damage by wind, sun, insects, and fungi (Bedell 1962; Navratil et al. 1991). Physical separation of susceptible species inhibits the spread of many biotic pests (Burkhart and Tham 1992).

Growing a mixture of species over time on each site is a common agricultural practice to maintain site productivity. Soil nutrient status can be similarly enhanced in forestry by promoting species mixtures. For example, hardwood tree litter improves soil properties in European mixedwood forests (Nyyssonen 1991; Patterson 1993). The high calcium content of birch leaves stimulates microbe activity and accelerates nutrient cycling. The soil-improving benefits of mixed stands have been recognized in western Canada (Navratil et al. 1991). In Ontario, the nutrient cycling capabilities of soil may deteriorate under conifers because of raw humus formation. Hardwoods such as white birch prevent this deterioration, and the best-quality conifers are often found in mixedwood stands (Bedell 1962). The development of impermeable iron pans under black spruce monocultures is minimized by growing black spruce in combination with hardwood species (Bedell 1962). Furthermore, nutrient replacement times following disturbances such as harvesting are more rapid in mixedwood stands than in spruce monocultures (Gordon 1983).

Although pure stands of some species are ecologically appropriate on the boreal landscape, public support for large-scale clear-cutting and extensive planting of single-species stands is declining (Brooks and Grant 1992). Silvicultural prescriptions should aim at building complexity into forest ecosystems to promote the conservation and cycling of energy, water, nutrients, and air (Burger 1994). The need for high yields of crop species must be balanced with the need to preserve the biological processes that support sustainable forestry. These objectives can often be achieved by planning for a diversity of species and structures in managed stands.

Multiple values

Many benefits can be realized from mixedwood management because of its emphasis on species mixtures and partial cutting. Aesthetically varied mixedwood landscapes provide opportunities for recreation and tourism, and the succession of vegetation protects watershed stability, ensures an even flow of crop trees to wood-processing industries, and supports many wildlife species. The habitat conditions for many species of birds and mammals are favored by the variety of successional stages typical of mixedwood forests (Boyle 1992). The diversity of flora and fauna also supports many aboriginal values, such as opportunities for hunting, fishing, trapping, and securing traditional medicinal plants.

The promotion of species diversity ensures adaptability to the changing needs of society (Schütz 1990). Unresolved debates about resource values, ecological processes, and future climatic conditions emphasize the need to manage for a wide range of future choices (Brooks and Grant 1992).

An integrated mixture of species is not always the most appropriate management goal for a mixedwood site. For example, habitat protection for some species of fauna requires the maintenance of extensive areas of homogeneous mature forest. In this case, operations would be planned to create diversity between larger elements of the mixedwood landscape mosaic.

Economic considerations

Commercial interest in mixedwood forests is increasing, because they represent an easily accessible source of high-quality fiber. Mixedwood sites are the most fertile and productive in the boreal region, and their proximity to mills results in lower delivered wood costs. Mixedwood management reduces market volatility for industry, because hardwoods and softwoods generate different products. The structures of many boreal mixedwood stands produce large trees that constitute an attractive source of sawlog and veneer material (Opper 1981). Mixedwood stands occur primarily on upland sites that can be harvested during the frost-free season. This provides a flexibility in harvest scheduling not available for lowland conifer stands, which must be harvested during the winter to minimize site damage. Furthermore, road construction on mixedwood sites is less difficult and costly than that in lowland conifer areas.

Deliberate utilization of all mixedwood species brings stands into production that would be uneconomical if operated only for the conifers. Advanced wood products technology permits a shift from managing one species to managing for maximum production from multiple species (Debyle 1991). Formerly unused mixedwood species such as trembling aspen and balsam fir represent a valuable wood supply. Aspen produces excellent pulp, hardboard, insulation board, particle board, and structural flakeboard (waferboard and oriented strand board). In Ontario, aspen utilization rose from 0.7 million cubic meters in 1976 to 2.7 million cubic meters in 1986 (Armson 1988). Balsam fir is the least preferred boreal mixedwood conifer in Ontario, although it is comparable to spruce in product quality. For example, fir pulp is superior to spruce pulp in some ways (Bedell 1962). The insect and disease susceptibility of fir could be reduced by applying management techniques suited to the silvics of the species, such as thinning young stands and lowering the rotation age.

Softwood shortages can be partly offset by modified harvesting and thinning to release conifer understories in mixedwood stands. Boreal mixedwood stands are well suited to natural regeneration, which is less expensive than artificial regeneration of conifers. Conifer plantation establishment on mixedwood sites in Alberta can cost $1000 per hectare, and two-thirds of the plantations are reverting to mixedwood or hardwood stands (Brace and Bella 1988). The economics of tending are also shifting in favor of mixedwood stands. As the commercial value of aspen rises, it becomes increasingly difficult to justify the use of herbicides to maximize conifer yields (Beck 1988).

Some mixed stands have higher yields than monocultures of a component species. For example, mature mixedwood stands in north-central Ontario produce about 268 m^3/ha, compared with 188 m^3/ha for average black spruce stands (Opper 1981). In Europe, a birch component can improve the growth and yield of conifer stands (Tham 1988; Nyyssonen 1991). The mixed-species effect is most pronounced for vertically stratified mixtures (Burkhart and Tham 1992).

Evolution of boreal mixedwood management in Ontario

The exploitation of Ontario's forests began in the early 1800s, with the extraction of white pine square timbers for navy masts (MacKay 1985). The southern portion of the Boreal Mixedwood Forest was affected by this high-grading. The pulp and paper industry expanded in the early 1900s, but the low value of pulpwood prevented intensive management, and mixedwood stands were usually bypassed in favor of pure black spruce. Although the concept of sustained yield was promoted as the demand for timber accelerated after World War II, the best mixedwood stands were high-graded for spruce sawlogs without any management strategy. Selective conifer extraction was designed for economic efficiency of harvesting, with no thought for protecting understory regeneration. Skid trails were designed to access the conifers economically, not to minimize damage to the site and residual trees. If the residual vegetation provided useful wildlife habitat, it was by accident rather than by design, because the maintenance of other resource values was not an important issue until the 1980s.

Selective tree removal was appropriate during the era of horse-logging and the subsequent chain saw operations. Productivity and safety considerations in modern forestry operations have led to the advent of mechanized harvesters that perform most efficiently in clearcuts. No equipment has been designed specifically for modified harvesting in the complex structures of boreal mixedwood forests.

The first complete inventory of the boreal forest revealed a lack of conifer regeneration and a large proportion of degraded stands (MacKay 1985). Scarification, planting, and herbicide spraying were widely prescribed in an attempt to increase conifer production, but this approach failed on many mixedwood sites. Forest management agreements were initiated in 1980 between government and industry, with the objective of moving from forest administration to forest management. However, the need for intentional mixedwood management was not accepted in Ontario until the late 1980s, when the value of biological diversity, nontimber uses, and ecological processes began to be expressed in forest policy and practice. The futility of attempting to convert boreal mixedwood sites to conifers is now widely recognized, but there are still few instances in Ontario of deliberate management for mixed-species crops.

The commercial timber market has determined the level of utilization and management of the Boreal Mixedwood Forest. Where no market for aspen, birch, and fir existed, companies ignored mixedwood stands. This neglect perpetuated unregulated stand conditions that created obstacles for harvesting and silvicultural operations. As the demand for hardwoods has accelerated during the past decade, active management of mixedwood forests has become more economically feasible. More complete utilization of mixedwood stands allows the costs of road building and silvicultural operations to be covered.

As in the rest of Canada, Ontario has progressed through the exploitive, administrative, and ecologically based forestry paradigms into the most recent stage, known as the social forestry paradigm (Kimmins 1995). The emerging paradigm addresses such issues as biodiversity, old-growth conditions, site disturbance, aesthetic appeal, and spiritual values. It advocates mixtures of conifers and hardwoods and emphasizes the importance of ecosystem integrity and natural successional processes. This provides a more effective framework for proactive mixedwood management than did the preceding paradigms.

Ontario has no tradition of intentional management for boreal mixedwood forests. However, recent legislation reveals a philosophical shift toward sustainable forestry practices that promote biological diversity. This trend closely parallels the developments in other jurisdictions, notably western Canada, the province of Quebec, and northern Europe. The changing attitudes of policymakers and practitioners are facilitating the acceptance of proactive mixedwood management in Ontario.

The future of mixedwood management

Issues and initiatives

The public is demanding that all forest values be respected by actively planning for diversity. This philosophy is compatible with proactive mixedwood management, which is encouraging, because public attitudes increasingly determine the direction of Ontario forest policy and practice. The need to maintain ecological processes and conserve biological diversity is now accepted policy (Ontario Forest Policy Panel 1993). Forest practices that emulate natural disturbances and landscape patterns and minimize ecological impacts are sought. Mixedwood management supports these policies and practices.

In Ontario, the responsibility for funding and conducting silvicultural operations is being transferred to industry. The resulting focus on cost reduction will favor increased use of natural regeneration. This could be a positive development for mixedwood management, which emphasizes harvesting, site preparation, and tending techniques that promote natural regeneration.

The Ontario government introduced its *Crown Forest Sustainability Act* in late 1994. This initiative supports mixedwood management indirectly by emphasizing silvicultural systems that promote biological diversity and multiple resource values.

The environmental assessment for timber management in Ontario examined all aspects of forest policy and operations in the Ontario Ministry of Natural Resources (Koven and Martel 1994). The Ontario government is legally bound to implement 115 terms and conditions arising from this investigation. Many of the terms address mixedwood issues, such as the effects of management practices on biodiversity, ecosystem processes, and nontimber values. The Ministry of Natural Resources is ordered to produce a mixedwood silvicultural guide to be used in the timber management planning process. The guide will present the most current knowledge in a concise, updatable format for practitioners. It will draw on experience in other jurisdictions and information from past field trials and current large-scale research and demonstration projects in the province.

Opportunities for advancement

The rising demand for previously unused species is creating an unprecedented opportunity for deliberate mixedwood management. However, most forest companies in northern Ontario use only softwoods or hardwoods. When harvesting a preferred species in mixedwood stands, associated species are often damaged. If protection of the residual species is prescribed, the harvesting operation is slower and more expensive. Apart from market-driven wood exchanges between companies, mechanisms to resolve these operational concerns are not well developed. The forest industry must diversify its range of products and adapt its woodlands operations to promote naturally productive mixtures of species. Mixedwood management emphasizes partial cutting and low-impact silviculture, which can help to secure sales in ecologically sensitive markets.

Traditionally, boreal mixedwood stands were utilized in Ontario only if they contained many large conifers. As utilization patterns broaden to include more species and smaller sizes, it becomes economically feasible to bring more mixedwood stands under management. Utilization patterns are important, because harvesting represents the main forest management tool. If stands are not utilized, then there is no opportunity to manipulate them to benefit timber and nontimber values.

Balsam fir and trembling aspen are replacing spruce on many mixedwood sites in northern Ontario (Yang and Fry 1981). Management strategies must recognize the ecological importance and commercial potential of these species and avoid large-scale conversions to spruce monocultures. Midrotation tending and modified harvesting and site preparation will be required to maintain productive densities and reduce the susceptibility of fir and aspen to insect and disease losses.

Mixedwood prescriptions should specify the stand structures and species compositions desired at critical points in the rotation and indicate the silvicultural systems required to achieve these stand conditions. However, the low unit value of the tree species in northern Ontario limits the amount of intensive silviculture that can be conducted. This emphasizes the need to combine harvesting and silviculture, adopting modified cutting techniques that protect residual trees and promote natural regeneration. The refinement of these harvesting techniques represents one of the greatest opportunities for advancing mixedwood forestry and obtaining industry cooperation. It will be a challenge to develop harvesting practices that meet both timber and nontimber objectives.

Ontario has a limited information base to assist resource managers in formulating boreal mixedwood prescriptions. Partial-cutting systems designed to maintain productive mixedwood stands over several rotations have been developed in Alberta (Brace Forest Services 1992). However, these systems cannot be applied in the complex mixedwood forests of northern Ontario without extensive testing and modification. The unique autecology of each component mixedwood species must be considered to design effective silvicultural prescriptions.

The equipment used in Ontario for harvesting, skidding, site preparation, and thinning is generally inappropriate for mixedwood management. Machines should be produced specifically for the mixedwood forest environment, combining strength and maneuverability. Much of the machinery is designed in foreign countries, where terrain and stand structures are different. For example, Scandinavian equipment designed for partial cutting is generally too light to handle the large-diameter aspen in northern Ontario mixedwood stands. Furthermore, the operators must be trained to minimize damage to the site and residual trees, while maintaining commercially acceptable productivity.

On many boreal mixedwood sites in Ontario, natural succession has produced deteriorating stands of aspen, birch, and jack pine (*Pinus banksiana* Lamb.), with dense thickets of balsam fir and shrubs in canopy gaps. The lack of mineral soil exposure prevents the establishment of spruce seedlings. Low-quality stands with poor stocking and undesirable species mixtures have often resulted after commercial clear-cutting or high-grading for spruce and pine. Although these degraded stands may provide wildlife habitat or recreational opportunities, a concentrated program of silvicultural rehabilitation is required to regain their timber production potential.

A preoccupation with regeneration in Ontario during the past 25 years has resulted in some lost opportunities for increasing the value of existing stands. For example, thinning young aspen stands enhances vigor and shortens rotation lengths. In boreal mixedwood stands, this early release can enrich the coniferous component and maintain the value of the stands for wildlife habitat (Weingartner 1991). Balsam fir and jack pine are other mixedwood species that may require precommercial thinning. Although thinning is often neglected in Ontario, it is one element of an entire rotation management system that must be applied to achieve regulated, productive, and healthy mixedwood forests.

Major disturbances on mixedwood sites initiate successional trajectories that can be directed, but not successfully resisted. Thus, mixedwood management should control the timing, intensity, and distribution of disturbances to produce a mosaic of species and stands supporting multiple resource values. Regulated mixedwood forests with predictable wood yields can be achieved through a system of harvesting, regeneration, and tending designed to promote a sequence of successional stages. Blocks of variable successional stages on the landscape would facilitate economic harvesting and silvicultural operations, ensure sustainable supplies of wood to mills, and maintain a diversity of wildlife habitat and recreational opportunities.

The management of boreal mixedwood forests is complicated by differences in the rotation ages of the component species, ranging from 50 years for aspen and birch to 70 years for jack pine and 90 years for spruce (Armson 1988). Balsam fir should be harvested before age 45 to avoid large losses from decay and spruce budworm infestation. Thus, the growth rates of individual species must be acknowledged by planning for multiple harvest entries.

Harvesting and silvicultural operations that imitate natural disturbances must be encouraged to maintain the character and productivity of the Boreal Mixedwood Forest. Herbicides should be used sparingly in mixedwood management, supplementing manual and mechanical control of hardwoods when conifer enrichment is prescribed. However, the use of prescribed burning should be expanded, because the Boreal Mixedwood Forest is a fire-dependent ecosystem (Alexander and Euler 1981). Controlled fire could assist the rehabilitation of unproductive mixedwood stands, reduce undesirable species in naturally regenerated mixedwood stands, and prepare the site for the establishment of natural spruce regeneration. It has been recommended as the best site preparation technique on boreal mixedwood sites (Jovic 1981).

Most mixedwood stands arise from natural regeneration, but productive mixtures of species can be established artificially. Successful mixtures combine faster-growing shade-intolerant species above slower-growing tolerant species. Underplanting a midrotation aspen stand with spruce could be used to maintain stocking of desirable conifers. Planting patterns should facilitate the protection of the conifer understory during subsequent removal of the aspen overstory.

Research and development needs

Mixedwood management in Ontario will be successful to the degree that a proactive mixedwood attitude is adopted by policymakers and effective management techniques are implemented by resource managers. Thus, the development and transfer of applied knowledge must be pursued without delay.

Mixedwood stakeholders in Ontario judged the following areas to be the most important regarding the need for new knowledge (Weingartner and MacDonald 1994): modified harvesting, natural regeneration, ecosystem structure and function, ecological impacts of forestry practices, species utilization, stand rehabilitation, yield prediction, and decision support systems. Applied ecology and silviculture were higher research and development priorities than physiology, genetics, forest protection, or wood science, in the context of mixedwood forestry. Respondents considered fish and wildlife habitat management to be the most important discipline to link with mixedwood silviculture.

The extent of the mixedwood resource in Ontario is underestimated, because inventories do not include understory species. There is a need for detailed classification and mapping of boreal mixedwood soils and vegetation to assist resource managers in developing site-specific mixedwood prescriptions. Important groundwork for this information base has been completed through the FEC systems in northern Ontario (Jones et al. 1983; Sims et al. 1989). The site classifications must be supplemented with knowledge about vegetation dynamics, as a basis for mixedwood regeneration standards.

Mixedwood management is hindered by a lack of information on specific silvicultural techniques (Navratil et al. 1991). The impacts of mixedwood silvicultural treatments on wildlife habitat and other non-timber values must be investigated more extensively. Planners also need to know how modified harvesting to optimize wildlife habitat affects timber productivity and wood flow. This highlights the need for large-scale forest manipulations in controlled studies. As the demand for trembling aspen, white birch, and balsam fir accelerates in Ontario, more research initiatives must include these species.

There is an urgent need for predictive tools to assist mixedwood resource managers (Burkhart and Tham 1992). Models of growth and yield for mixed-species stands are essential for making sound management decisions. The variety of possible species mixtures, coupled with the range of environmental conditions under which mixtures might be grown, necessitates a modeling approach. Models supporting ecosystem-based silviculture require information on the structure and natural development of mixed forests.

The complexity of mixedwood forests requires considerable skill to manage stands and predict outcomes. Thus, training courses, applied workshops, and demonstration areas must be planned to encourage researchers, resource managers, and equipment operators to exchange information regularly. Considerable training is required to develop equipment operators with new technical expertise combining economic productivity and conservation ethics. Respect for natural diversity and adaptation to successional tendencies must be emphasized, because these attitudes have not been prominent in traditional forestry operations. It is a positive sign for mixedwood management that some Ontario companies have invested in cut-to-length harvesting and forwarding systems designed for partial cutting with reduced impacts on the site and residual stand.

Conclusions and recommendations

Some lingering negative attitudes toward boreal mixedwood management may be the legacy of a history of neglect and exploitation. However, the perception of the Boreal Mixedwood Forest has changed dramatically during the past two decades. The ecological advantages of mixedwood management are now widely accepted. The economic justification supplied by recent market developments has made intentional mixedwood management an attractive option for many forest companies. The diversity and productivity of mixedwood forests ideally qualify them for the integrated resource management approach that is widely sought in modern forest practices. Broad support for mixedwood management is anticipated, because its softer approach is acceptable to an environmentally aware society.

Management of the Ontario Boreal Mixedwood Forest can be advanced by defining this forest in terms of site characteristics and adapting management to its successional tendencies. An inventory of boreal mixedwood sites should be undertaken, including overstory canopies, understory vegetation types, and soil features. Ecologically sensitive, economically viable silvicultural options must be designed for each mixedwood site type, and regeneration standards must be revised to account for mixed-species crops.

Incentives and training programs are required to encourage forest companies to protect conifer understories, residual overstories, and soil stability when operating in mixedwood stands. The level of midrotation silviculture, such as controlling stand density and quality, should be increased. The costs of such operations should be balanced against the accelerated increment of residual trees and the reduced regeneration costs associated with mixedwood management. The inherent capacity of mixedwood forests to produce a wide range of resource values could be improved through interdisciplinary linkages and geographic information system technology.

Accelerated mixedwood management must be underpinned by applied research focused on high-priority information gaps. The transition to more proactive mixedwood management must be facilitated by carefully targeted demonstration and education programs.

The opportunities for sustainable supplies of multiple resource values from Ontario's Boreal Mixedwood Forest are only beginning to be realized. However, the magnitude and urgency of the challenges will require the coordinated effort of resource managers, forest companies, federal and provincial research agencies, universities, and all stakeholder organizations.

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Ontario's boreal mixedwood forest: distribution, extent, and importance[1]

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Abstract

Boreal mixedwoods occur throughout northern Ontario, north of a line that extends roughly from Kenora through Thunder Bay and Wawa to New Liskeard. Mixedwoods containing one or more boreal species also occur on a wide range of sites within the ecozone transition between the Boreal and Great Lakes–St. Lawrence forests, although many of these stands differ fundamentally in their ecology and dynamics. Boreal mixedwoods are estimated to comprise some 15.8 million hectares, representing 53% of the productive forest within the boreal zone. The amount of land with soil and site conditions that could support good growth of the five principal mixedwood species is likewise substantial, according to estimates derived from previous inventories, such as the Ontario Land Inventory and prime land classifications. The creation of an ecosystem-based inventory system incorporating elements of Ontario's ecological land classification hierarchy is urgently required for the management of mixedwoods at both the stand and forest level.

Mixedwoods are excellent for multiple or integrated uses. They have an increasing value for fiber and wood products; they furnish key habitat, as well as forage and browse components for many of Ontario's wildlife species; they provide superb watershed protection; and they have aesthetic appeal. Their temporal, spatial, compositional, and structural diversity contribute to both stand- and landscape-level diversity. The productivity of boreal mixedwood sites and the resilient nature of these ecosystems favor integrated ecosystem management in the boreal landscape.

Résumé

La forêt mixte boréale est présente dans tout le nord de l'Ontario, c'est-à-dire essentiellement au nord d'une ligne reliant les villes de Kenora, Thunder Bay, Wawa et New Liskeard. Il existe également des peuplements mixtes renfermant une ou plusieurs essences boréales dans une vaste gamme de stations situées dans la zone de transition entre la forêt boréale et la forêt des Grands Lacs et du Saint-Laurent, mais bon nombre de ces peuplements ont une écologie et une dynamique fondamentalement différentes. On estime que la forêt mixte boréale occupe environ 15,8 millions d'hectares, ce qui représente 53 % de la forêt productive de la zone boréale. De même, selon des estimations fondées sur des relevés antérieurs (Ontario Land Inventory, classifications visant les terres de grande valeur, etc.), les terres présentant des sols et des facteurs stationnels propices à une croissance vigoureuse des cinq essences principales de la forêt mixte occupent une proportion importante du territoire ontarien. La gestion de la forêt mixte boréale, dans son ensemble et à l'échelle des peuplements, nécessite de toute urgence un système d'inventaire qui soit axé sur les écosystèmes et intègre les catégories de la classification écologique des terres de l'Ontario.

La forêt mixte convient parfaitement à une exploitation polyvalente ou intégrée : elle a une valeur de plus en plus grande comme source de fibre et de produits du bois; elle procure des habitats essentiels ainsi que brout et fourrage à de nombreuses espèces de la faune ontarienne; elle assure une protection de grande qualité aux bassins-versants; elle a un grand attrait esthétique. Très variée dans le temps, dans l'espace et sur les plans taxonomique et structurel, elle contribue à la fois à la diversité des peuplements et à celle des paysages. Enfin, la productivité des peuplements mixtes et leur capacité de se rétablir en cas de perturbation favorisent une gestion intégrée de ces écosystèmes dans la zone boréale.

[1] Paper not available.

Boreal mixedwoods in Ontario: defining the resource in relation to climate and soil/site

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Abstract

Boreal mixedwoods are very common and widespread in northern Ontario. However, their exact definition remains something of an enigma. Depending upon the definition chosen, boreal mixedwoods may be considered in different contexts. Existing definitions range considerably, from a broadly defined cover type complex to more detailed concepts, which are based on either a set of field-keyed forest ecosystem (i.e., vegetation + soil) attributes or an integrated set of biotic and abiotic conditions that together favor mixedwood development. Additionally, when the geographic and ecological range is narrowed so that a "local" set of boreal mixedwoods is considered, the context is again different.

Some definitions of boreal mixedwoods in northern Ontario are considered further in this paper. Based upon an evaluation of the network of forest ecosystem classification plots in northern Ontario, boreal mixedwoods are quantitatively described in terms of some associated climate and soil/site features. Results demonstrate that there are data and methodologies currently available for better describing the boreal mixedwood resource in Ontario—but we first need to better define that resource. Some recommendations to accomplish this are made.

Résumé

La forêt mixte boréale, pourtant omniprésente dans le nord de l'Ontario, se prête mal à une définition précise. En effet, selon le point de vue adopté, on pourra la considérer comme un type forestier à caractère général ou y voir une notion plus restreinte définie soit par une série de critères écologiques (végétation et sol) reconnaissables sur le terrain, soit par un ensemble intégré de facteurs biotiques et abiotiques favorisant l'apparition d'une forêt mixte. De plus, si on limite le cadre géographique et écologique de cette définition de manière à n'envisager qu'un ensemble «local» de peuplements mixtes, on obtient un tout autre point de vue.

Nous examinons en détail certaines des définitions de la forêt mixte boréale pour le nord de l'Ontario. À partir d'une évaluation du réseau de parcelles servant à la classification des écosystèmes forestiers de cette région, nous décrivons la forêt mixte boréale quantitativement, selon certaines critères climatiques, édaphiques et stationnels. Nos résultats montrent que les données et les méthodologies actuellement disponibles permettraient de mieux décrire la forêt mixte boréale ontarienne, à condition que la définition de cette ressource soit d'abord précisée. Nous présentons quelques recommandations à cet égard.

Introduction

Fifteen years ago, during the opening session of a "Boreal Mixedwood Symposium" held in Thunder Bay, Ontario, Mr. Fred Robinson remarked, "What's in a name? . . . in the definition [of boreal mixedwood forest], we must be very clear about what we include and what we exclude, so that we are all talking about the same thing. It avoids a lot of confusion" (Robinson 1981). Despite his admonishment, the term "boreal mixedwoods" has continued to cause confusion, and it continues to remain without a widely accepted working definition—despite attempts by a number of authors to deal comprehensively with this condition (e.g., see Pierpoint 1981; Kabzems et al. 1986; Davidson et al. 1988; Mueggler 1988; Corns 1989; MacDonald and Weingartner 1995; McCarthy et al. 1995; MacDonald, these proceedings).

Some things have changed considerably in Ontario in the years since that earlier gathering devoted to the biology and management of boreal mixedwoods. Foremost among these changes—and a situation already highlighted by earlier authors in these proceedings—is a fast-growing commercial pressure on the boreal mixedwood resource in Ontario. Considerable efforts in scientific research over the intervening years have also helped by providing a greater ecological understanding of boreal mixedwoods (e.g., Corns 1989; Navratil and Chapman 1991; Wedeles et al. 1995).

It is not appropriate to manage the boreal mixedwood resource "by default"! The concept that boreal mixedwoods are "good" and easy to produce and that the constituent tree species can grow anywhere is not a valid approach to managing these ecosystems. In fact, mixedwoods are complex and dynamic ecosystems. At the local level, they are associated with characteristic regimes of nutrient cycling, soil/water movement, carbon allocation, vegetation competition and succession, subsurface soil/root interactions, and other soil/site relations. At a landscape level, boreal mixedwoods dynamically interact with an additional range of abiotic and biotic conditions, including patterns and vectors of disease and insect infestation, forest fire, mesoscaled climatic factors, patterns of surficial deposits and bedrock types, and landscape-level successional responses to forest harvesting and treatment regimes (Thorpe 1992; Sims et al. 1995). At all levels of resolution, issues of biodiversity conservation and ecologically sustainable management need to be addressed. Being cognizant of such processes and learning to relate these—within an ecosystem context—to planning and operational management are the appropriate ways to manage boreal mixedwoods in the future.

As a consequence of this growing awareness and improved understanding of the boreal mixedwood resource in Ontario, there should be a clear and concise definition emerging as to what a boreal mixedwood is; however, there continues to be confusion and debate. Definitions of boreal mixedwoods are varied and enigmatic, even to the point where they are not always boreal, nor are they necessarily mixedwoods at any particular given point in their successional cycle (MacDonald and Weingartner 1995; MacDonald, these proceedings). Despite the ecological soundness of this concept, it may be that this more inclusive definition creates additional anxiety for field foresters who are looking for simple, effective solutions for the management of boreal mixedwoods. One thing is certain: the resource, however you define it, is large, diverse, complex, amorphous, and variable (McClain 1981; Davidson et al. 1988).

The objective of this paper is to consider some definitions of boreal mixedwoods in northern Ontario in terms of some broad climatic and soil/site characteristics. To accomplish this, we will first parameterize some boreal mixedwood "definitions" that are currently in use in northern Ontario. Then, using summaries from forest ecosystem classification (FEC)-related field surveys (Jones et al. 1983; Merchant et al. 1989; Sims et al. 1989; McCarthy et al. 1995) and incorporating some new techniques that permit the interpolation of climate surfaces and other data to biological survey locations, we will summarize and compare selected climate and soil/site data.

General extent of the boreal mixedwood resource in Ontario

Mixed conifer–deciduous forest stands occur as a regular element throughout the circumpolar boreal forest (Hare and Ritchie 1972; Larsen 1980; Shugart et al. 1992). Within the Boreal Forest Region in Ontario (cf. Rowe 1972), the interaction of climate, landform, soils, fire, pests, and human disturbance has resulted in a varied and constantly changing mix of forested landscapes. Mixedwood forests are widespread throughout Ontario's boreal forest and include various admixtures of trembling aspen (*Populus tremuloides* Michx.), white birch (*Betula papyrifera* Marsh.), balsam poplar (*Populus balsamifera* L.), black spruce (*Picea mariana* [Mill.] B.S.P.), white spruce (*Picea glauca* [Moench] Voss), balsam fir (*Abies balsamea* [L.] Mill.), and jack pine (*Pinus banksiana* Lamb.) (Pierpoint 1981; Davidson et al. 1988; MacDonald and Weingartner 1995).

The southern boundary of boreal mixedwoods in Ontario is not as clearly accepted as the southern boundary of the Boreal Forest Region in the province. Throughout most of the Great Lakes–St. Lawrence Forest Region (cf. Rowe 1972) in the northwestern part of the province and in a broad band of several hundred kilometers south of the boreal forest in the northeastern part of the province, boreal mixedwood forests very similar to those within the Boreal Forest Region are frequently encountered. The commercial distribution in Ontario of aspen, one of the characteristic tree species components of the Boreal Mixedwood Forest, extends considerably south of the Boreal Forest Region; aspen is also relatively widespread and abundant throughout its commercial range in Ontario.

In other words, whereas the "boreal" in boreal mixedwoods reflects a general affinity of this condition with the Boreal Forest Region in Ontario, it is generally accepted that boreal mixedwood components may also be frequently encountered some distance to the south of this region. It is also clear, however, that some geographic areas, landform features, and soil conditions have more of a propensity to support boreal mixedwood forests than others (e.g., see Figure 1; also McClain 1981).

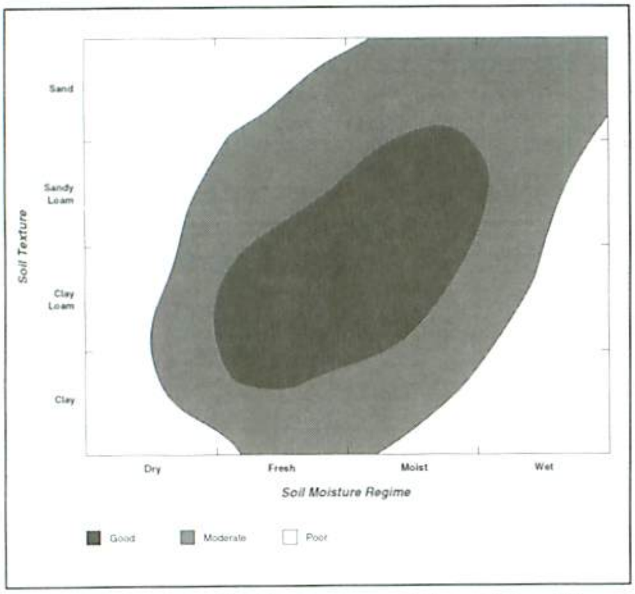

Figure 1. A generalized treatment of the relationship of soil moisture regime and broad classes of soil texture to good (dark), moderate (gray), and poor (white) categories of growth by trembling aspen.

Source: Steneker (1976).

Parameterization of some definitions of boreal mixedwoods

The typical concept of a boreal mixedwood includes a hardwood–conifer mixed forest with multitiered aspen, birch, and conifer components and perhaps a multitiered canopy with a white spruce and/or balsam fir subordinate. Within the canopy, a well-developed shrub and herb layer occurs, and there is a characteristic pattern of light diffusion to the forest floor that is reflected in a patchwork of ground layer vegetation species. The ground flora typically includes a rich and herb-rich mixture of species (e.g., bush-honeysuckle *Diervilla lonicera* Mill., large-leaved aster *Aster macrophyllus* L., blue bead lily *Clintonia borealis*, and others), often with a moist mat of feathermoss. Soils most frequently associated with boreal mixedwood forests are described as deep and well-drained, with a fresh soil moisture regime (SMR) (Steneker 1976; Kabzems et al. 1986; Davidson et al. 1988).

In reality, boreal mixedwoods may be found in association with a wide range of soil/site conditions. Moreover, a hardwood stand with a significant and up-and-coming second conifer canopy may become a mixed stand within the space of a few years; if we are basing the definition of boreal mixedwoods on a more permanent ecological basis that includes the propensity of the soil to support mixedwood conditions, then this may well be considered as a mixedwood. Likewise, consider a mixedwood canopy where the fir component has succumbed to spruce budworm (*Choristoneura fumiferana* Clemens)—does this mean it is technically no longer a mixedwood? Perhaps it would be more acceptable to accept these conditions as merely a different successional stage within a boreal mixedwood ecosystem's chronosequence.

The five working boreal mixedwood definitions adopted here are outlined briefly below.

Group 1 (1157 FEC plots)

This definition attempts to include a complex system of biotic and abiotic conditions that together favor mixedwood development and includes successional stages or following disturbance regimes where the characteristic mix of overstory species may not be present or intact. This definition is based upon all possible conditions (e.g., all vegetation conditions and a wide range of SMR conditions, from moderately dry [SMR 0] to very moist [up to SMR 6]) that are known to support a mixture of aspen/conifer (balsam fir, black spruce, white spruce, and/or jack pine) in the geographic region selected. This is the broadest definition of the five, indicating the widest range of conditions that may support mixedwoods at some point in the successional cycle, not necessarily just at the current time of sampling. To manage the boreal mixedwood condition suitably, perhaps such a broad definition is desirable, in particular if the full range of boreal mixedwood conditions is to be considered in developing effective management regimes for the constituent species.

Group 2 (498 FEC plots)

This definition consists of a set of field-keyed forest ecosystem (i.e., vegetation + soil) attributes and is based upon a mix of criteria for the geographic region selected. First, the very dry (SMR θ) and wet (SMR 7, 8, and 9; organic soils) soil moisture conditions were excluded. Then those stands where some of the typical overstory elements were present were included; the rule set selected any plots where aspen was "present," i.e., occurred with 2% or more cover within an FEC plot *and* where any of balsam fir, black spruce, white spruce, or jack pine were also present as a stand component. This is a more encompassing definition (although not as broad as Group 1), which favors the concept of a boreal mixedwood as including a mixture of characteristic soil and vegetation components and which, because of the aspen component, may have a predisposition, through suckering and seed-fall, to develop, postharvest, into an aspen-dominated mixedwood forest.

Group 3 (291 FEC plots)

This definition is the closest of the five to a "characteristic" cover-type concept of a boreal mixedwood. In this instance, we used the following criteria to define the condition: within the FEC plot network, plots were included in this group if they had aspen occurring as a major forest cover component in the overstory, i.e., 20–70% cover class as a ratio of the total percent forest cover in a stand. In addition, any (or all) of the following conifer species also had to be present in the overstory: balsam fir, black spruce, white spruce, or jack pine. This definition was designed to emulate the generally held concept of boreal mixedwood as a forest cover-type "working group" or a mappable Forest Resources Inventory (FRI) photointerpretation-based polygon.

Groups 4 and 5 (58 and 30 FEC plots, respectively)

These last two definitions are more restrictive, in terms of both what vegetation and soil conditions would qualify for inclusion and a much narrower geographic range (i.e., only those plots occurring within northwestern Ontario). Based upon the definitions for Vegetation Types and Soil Types (Sims et al. 1989), two different mixedwood groupings were selected: Group 4 consists of V18 FEC plots (i.e., jack pine mixedwood/feathermoss) on coarse loamy/sandy soils (i.e., S1, S2, S3, SS5, and SS6), and Group 5 consists of V9 (trembling aspen mixedwood) on fresh fine loamy soils (i.e., S5, S6, S9, S10, SS7, SS8). Groups 4 and 5 are specific V-Type/S-Type combinations that represent stands that have a specific mixture of mixedwood canopy cover conditions in association with some specific ranges of forest soil textures and SMRs.

Methods

The data base

The FEC plot network in Ontario (McLean and Uhlig 1987; Uhlig and Baker 1994; Sims et al. 1995) provides an important basis for developing some basic understandings of boreal mixedwood ecosystems. The approximate geographic extent of the data set is from a northern boundary of 51.5°N latitude southwards to the Canada/USA border and east–west from the Quebec border to the Manitoba border. The data include tallies of vegetation, soils, physical site, and forest stand descriptors of height, age, and density. Province-wide, the FEC data set is composed of approximately 6000 georeferenced sample plots, of which about 4200 are forested plots; more than half of these support conifer–hardwood mixtures.

For the current analyses, subsets of the FEC plot network from across northern Ontario were selected, based upon the definitions for the five groups. All of northwestern Ontario and a broad band up to about 100 km in width in the northeastern half of the province were included in defining the geographic extent of samples. Further analyses were then undertaken as described below.

Analyses of the FEC data

Climate

An approach has been recently developed to interpolate accurately climate surfaces to point-of-survey locations in the province; this interpolation procedure makes use of a new high-resolution digital elevation model for Ontario, long-term monthly meteorological data from approximately 470 recording stations, and proprietary software from the Australian National University. The approach is described elsewhere (Mackey and Sims 1994; Mackey et al. 1994[1,2]; McKenney et al. 1995); the technique allows the generation of a complete suite of estimated climate variables with error values for a given FEC site, as if there were a long-term recording station on that spot, based upon the existing network of meteorological data maintained by the Atmospheric Environment Service of Environment Canada. For the current study, this approach was applied successively to each group of boreal mixedwood FEC plots to obtain long-term means and standard deviations for the following selected climate variables: annual mean temperature, mean July temperature, mean January temperature, annual mean precipitation, temperature of the hottest quarter (i.e., June, July, and August), precipitation of the hottest quarter, growing season length, and growing degree days during the growing season.

In addition, we undertook a spatial analysis of climatic data for Group 3 using the bioclimatic analysis method described by Mackey and Sims (1994), McKenney et al. (1995), and Mackey et al.[3] The approach defines climatic envelopes for a given set of FEC plots, using a suite of 16 climate surfaces (including all those reported on in this paper for boreal mixedwood definitions), and matches the climatic values upon a 1-km grid of a province-wide digital elevation model (Mackey et al. 1994). The geographic information

[1] Mackey, B.G.; McKenney, D.W.; Yin-Qian, Y.; McMahon, J.P.; Hutchinson, M.F. Site regions revisited: a climate analysis of Hills' site regions for the province of Ontario using a parametric method. Can. J. For. Res. (In press.)

[2] Mackey, B.G.; McKenney, D.W.; Grott, U.; Sims, R.A. A bioclimatic analysis of trees and selected understory plants in Ontario. (In prep.)

[3] Ibid.

system (GIS)-based analysis provides a potential climatic domain map as output. Grid points whose climatic parameters lie within the upper and lower limits of the plot network's climatic profile represent the overall potential climate domain; however, by selecting the 5–95 and 10–90 percentiles, it is also possible to identify, respectively, "intermediate" and "core areas" of the climate domain (McKenney et al. 1995).

Soil/site

The existing FEC plot data bases are maintained as computer files and include a large number of soil/site variables that were field measured. For the current investigation, the following variables were selected and subsequently summarized according to the five groupings: position on slope (crest, upper, mid-, and lower slope, depressions, and flat), forest humus form (mull, moder, mor, and peatymor; as per descriptions in Sims and Baldwin[4]), soil drainage, and soil moisture regime (classes as defined by Ontario Institute of Pedology 1985), as well as field-measured depths, where they occurred, to bedrock and soil carbonates. Field estimates of the primary modes of deposition were also made during the FEC surveys, based upon the local topography and characteristics observed during the excavation of a soil pit (Ontario Institute of Pedology 1985). For each of the groupings of FEC plots defined in this investigation, we summarized modes of deposition according to the following classes: morainal and morainal tills/rock, glaciolacustrine and lacustrine, glaciofluvial and fluvial, colluvium, and other deposits (aeolian, organic, etc.).

Results

An examination of the geographic distribution of boreal mixedwoods, using the definitions for Group 1, 2, or 3, shows that they were widely distributed in the province, both within and in a broad band south of the Boreal Forest Region. There was some trend for Group 3 plots to generally be affiliated with more southerly positions than either Group 1 or 2. Group 4 and 5 plots were more restricted geographically in their distribution, occurring in the northwestern portion of the province only.

Climate data, obtained using the interpolation procedure, are summarized for the five groups in Table 1. Mean group values for annual temperatures ranged between 0.27°C and 1.23°C, precipitation means for the warmest quarter ranged between about 254 and 273 mm, and average growing season length ranged between 172 and 177 days. Growing degree day (GDD) values at FEC plots ranged upward of 1600, a figure that falls well above the 1300 isoline that was used to approximate the southern limit of the Boreal Forest Region in west-central Canada (Singh and Wheaton 1991). In general, variations among the five groups were small, in particular among Groups 1, 2, and 3. Group 1 showed some climate values that can be attributed to this grouping's generally more northerly affinity—for example, it was associated with the lowest GDD values of the three groups. For several climate parameters, some notable variations occurred when Groups 4 and 5 were examined in relation to the other groupings (Table 1). Group 4, composed of jack pine mixedwoods on drier, coarse-textured soils, was associated with considerably lower temperature and GDD mean values, in part because these plots were geographically more northwesterly and hence more continental; Group 5, on the other hand, the aspen mixedwood on fine-textured soils, had the highest mean GDD value and the lowest precipitation values.

There is a general expectation that boreal mixedwoods will occur more frequently on upper slope or crest positions, on deep, well-drained, fresh soils, and results for the five groupings generally confirm this notion (Tables 2 and 3, Figure 2). Groups 1–4 were primarily associated with crest, upper, and mid-slope positions, but Group 5 included a larger component of plots that were located on mid-, lower, or toe slopes or in depressions (Table 2). Mor humus forms, which are widespread throughout the boreal forests of northern Ontario (Sims and Baldwin[5]), are the most predominant humus form associated with all five definitions of boreal mixedwoods; Group 4, which included plots assigned on the basis of an extensive feathermoss cover, showed the highest correlation (100%) with mor humus forms (Table 2). As well, higher percentages of mulls and moders were associated with the generally richer site conditions of Group 5 mixedwoods, compared with the other four groups. Data for Groups 1, 2, and 3 on the mean depth to bedrock or carbonates further confirm that boreal mixedwoods occur predominantly on deeper (>1 m) soils and that when carbonates are encountered within the profile, they are also in deeper positions (Table 2).

Similar soil drainage conditions occurred in Groups 1, 2, and 3; Group 4 was primarily associated with rapidly drained soils, whereas most Group 5 plots were associated with well to moderately well drained soils. In terms of soil moisture regime, Groups 1–3 demonstrated similar patterns, whereas Group 4 showed a

[4] Sims, R.A.; Baldwin, K.A. Classification of forest humus forms in northwestern Ontario. Can. For. Serv., Sault Ste. Marie, ON. North. Ont. Dev. Agreement NODA/NFP Tech. Rep. (In press.)

[5] Ibid.

Table 1. Comparison of selected climate parameters for five different definitions of boreal mixedwoods in northern Ontario.

Climate parameter	Group 1 – suitable SMR conditions, 0 < SMR < 7 (n = 1157)	Group 2 – >2% aspen and >2% conifer component (n = 498)	Group 3 – 20–70% aspen cover, as a % of total tree cover (n = 291)	Group 4 – jack pine mixedwood on coarse loamy/ sandy soils (n = 59)	Group 5 – aspen mixedwood on fresh fine loamy soils (n = 30)
Annual mean temperature (°C)	1.11 ± 0.94	1.21 ± 0.94	1.23 ± 0.78	0.27 ± 0.91	1.14 ± 0.83
Mean temperature, July (°C)	17.91 ± 0.95	17.95 ± 0.99	17.94 ± 1.04	17.82 ± 0.90	18.05 ± 1.28
Mean temperature, January (°C)	−18.55 ± 1.63	−18.51 ± 1.34	−18.47 ± 1.25	−20.38 ± 1.29	−18.82 ± 1.03
Annual mean precipitation (mm)	788.53 ± 81.08	775.57 ± 78.60	772.17 ± 77.48	727.07 ± 38.73	704.48 ± 54.98
Temperature, hottest quarter (°C)	16.23 ± 0.89	16.28 ± 0.93	16.28 ± 0.96	16.01 ± 0.87	16.37 ± 1.19
Precipitation, hottest quarter (mm)	265.27 ± 15.87	268.28 ± 16.97	267.85 ± 17.09	272.81 ± 13.67	253.68 ± 20.72
Growing season length (days)	176.00 ± 5.84	176.65 ± 5.61	176.76 ± 5.47	172.34 ± 5.53	177.17 ± 6.27
Growing degree days (>5°C during the growing season)	1365.49 ± 139.63	1377.23 ± 44.58	1377.99 ± 146.19	1304.41 ± 132.92	1389.07 ± 179.56

Table 2. Comparison of some selected soil/site parameters for five different definitions of boreal mixedwoods in northern Ontario.

Soil/site parameter	Group 1	Group 2	Group 3	Group 4	Group 5
Position on slope[a] (%)	Crest/flat 37.3 Upper 24.9 Mid 21.6 Low/toe/depr 16.3	Crest/flat 31.6 Upper 26.3 Mid 24.3 Low/toe/depr 17.8	Crest/flat 31.7 Upper 29.7 Mid 22.9 Low/toe/depr 15.7	Crest/flat 32.2 Upper 35.6 Mid 20.3 Low/toe/depr 11.9	Crest/flat 40.0 Upper 13.3 Mid 26.7 Low/toe/depr 20.0
Humus form (%)	Mull 5.2 Moder 27.5 Mor 62.4 Peatymor 5.0	Mull 6.7 Moder 31.5 Mor 60.1 Peatymor 1.7	Mull 8.2 Moder 33.1 Mor 55.9 Peatymor 2.9	Mull 0 Moder 0 Mor 100 Peatymor 0	Mull 13.3 Moder 26.7 Mor 60.0 Peatymor 0
Soil drainage[b] (%)	VR–R 30.4 W–modW 35.3 Imp–VP 34.3	VR–R 26.1 W–modW 43.5 Imp–VP 30.4	VR–R 25.3 W–modW 43.9 Imp–VP 30.9	VR–R 72.9 W–modW 25.4 Imp–VP 1.7	VR–R 0 W–modW 83.3 Imp–VP 16.7
Depth to bedrock (cm)	165.33 ± 62.82	172.83 ± 54.49	174.52 ± 54.21	n/a[c]	n/a
Depth to carbonates (cm)	116.74 ± 89.05	105.36 ± 92.09	103.13 ± 91.52	n/a	n/a

[a] Low = lower; depr = depression.
[b] Soil drainage classes are VR–R — very rapid to rapid; W–modW — well to moderately well; Imp–VP — imperfect to very poor.
[c] Data not available.

Table 3. Comparison of dominant modes of deposition for five different definitions of boreal mixedwoods in northern Ontario.

Dominant mode of deposition[a]	% of total				
	Group 1	Group 2	Group 3	Group 4	Group 5
Morainal and till over bedrock	47.4	56.3	53.8	33.9	16.7
Glaciolacustrine and lacustrine	18.0	20.3	24.1	3.3	70.0
Glaciofluvial and fluvial	31.9	23.4	22.2	61.0	6.7
Colluvial	0	0	0	1.7	6.7
Other deposits (aeolian, organic, etc.)	2.7	0	0	0	0

[a] Naming conventions follow Sims and Baldwin (1991).

shift toward somewhat drier conditions, and Group 5 showed a much stronger affinity to fresh soil moisture conditions (Figure 2).

In general, boreal mixedwoods in northern Ontario are most frequently associated with morainal conditions, according to summaries associated with Groups 1, 2, and 3 (Table 3). In contrast to the first three definitions, Group 4 was more frequently encountered on glaciofluvial and fluvial soils, whereas Group 5 was most frequently affiliated with lacustrine parent materials (Table 3).

The spatial analysis of climatic data for Group 3 defined climatic envelopes by matching values upon a 1-km grid of a province-wide digital elevation model (Mackey et al. 1994). The potential climatic domain map for Group 3 (Figure 3) showed, based upon the 291 FEC plots included in the analyses, that the general climatic distribution for boreal mixedwoods, using this definition, ranged throughout the Boreal Forest Region, but also south of the Boreal Forest Region, especially in northwestern Ontario. The "core areas" (cf. McKenney et al. 1995) for Group 3 were generally located just west of Lake Superior and north of the U.S. border, and adjacent to the Quebec border in northeastern Ontario. Sections of eastern Ontario north of Lake Huron and east of Lake Superior were excluded because of the low coverage of points in this area, and this same condition occurred in the Quetico Park area and extreme corner of northwestern Ontario south of Kenora. The inclusion of additional points from some of these areas could have changed this distribution somewhat. Although not perfect, results shown in Figure 3 indicate that prediction of the distribution of boreal mixedwoods primarily on the basis of climate variables is a feasible approach. Future use of this approach, in particular with additional FEC or other point survey data, may help to refine considerably our understanding of boreal mixedwoods in terms of vegetation/climate patterns. It should also assist considerably in the development of improved understanding of climate's relations to growth and yield factors, successional responses to disturbance, and other mixedwood dynamics.

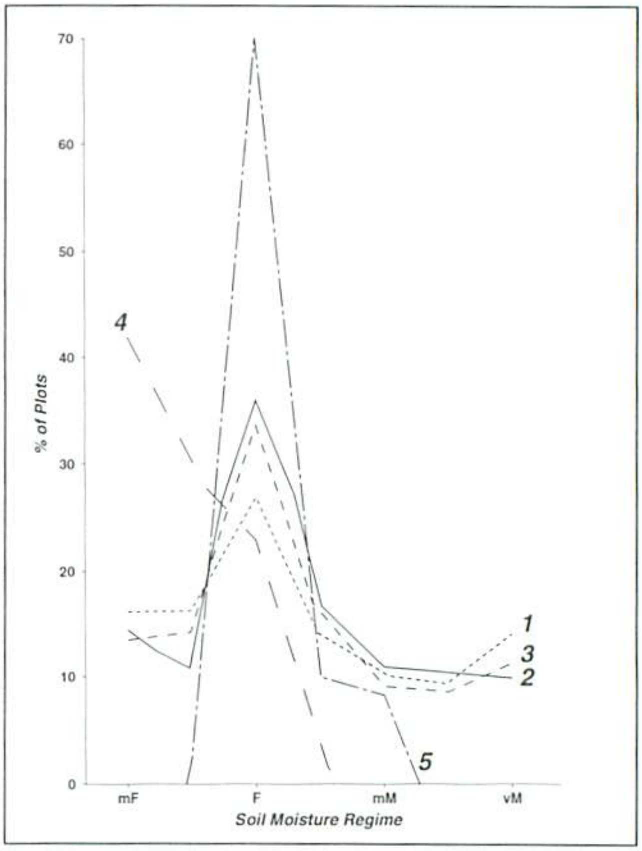

Figure 2. Mean values for soil moisture regime classes (mF — moderately fresh, F — fresh, mM — moderately moist, vM — very moist; after Sims et al. 1989) compared for the five groups (1, 2, 3, 4, 5) of boreal mixedwoods; sample sizes for groups are as shown in Table 1.

Discussion

Results of this investigation indicate that there is a need to be clear about what boreal mixedwoods are—each of the five definitions examined yielded slightly different results when ancillary climate and soil/site

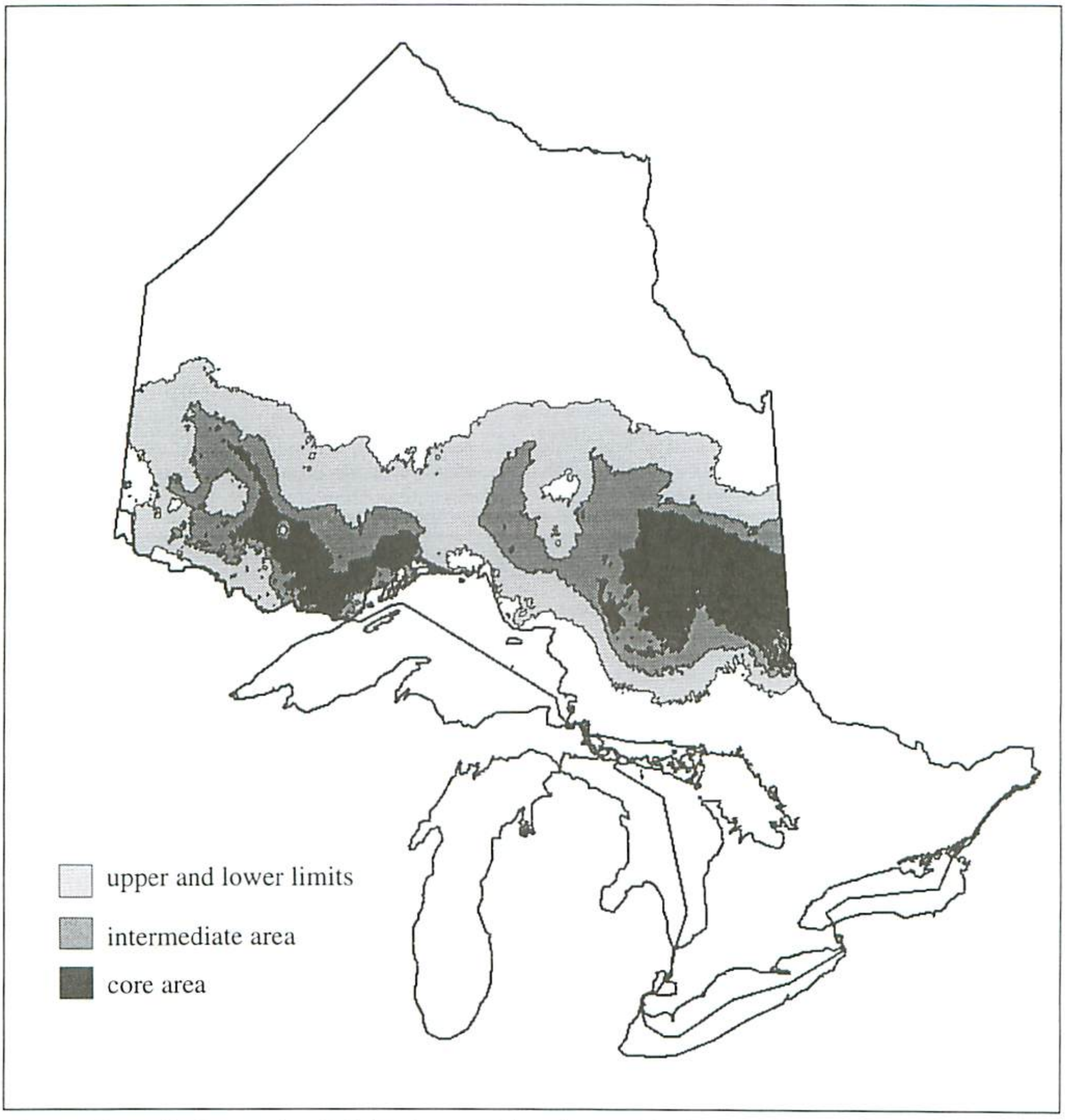

Figure 3. Biomap for Group 3 (n = 291) showing a spatial prediction of the climatic domain for boreal mixedwoods in northern Ontario.

characteristics were summarized. Perhaps our limited ability to manage boreal mixedwoods effectively in the past has been in part due to such varying definitions. It becomes particularly critical when we attempt to fit complex resource management concepts like biodiversity conservation and sustainability into this framework. Boreal mixedwoods in northern Ontario appear well adapted to a variety of climate and soil/site regimes. This condition may help to explain their wide geographic distribution.

In redefining boreal mixedwood management in an ecosystem-based management framework, there is a very good argument to start with a broader definition rather than the more restrictive cover-type one, or even the vegetation + soils based definition. This is because boreal mixedwoods are a component of a set of dynamics and successional patterns, and the occurrence or nonoccurrence on a given site of the characteristic cover conditions is, in itself, not necessarily relevant.

We currently have most of the "tools" needed to develop a more comprehensive scientific understanding of the boreal mixedwood resource in Ontario. The current provincial program of ecological land classification (ELC) is developing more precise, quantitatively based descriptions of forests and forestland within Ontario, at local and landscape levels (Uhlig and Baker 1994). In addition, ongoing research is addressing ELC–forest inventory linkages and ELC integration with GIS technologies. There are current activities under way to restructure and update provincial silvicultural guides in order to better address the range of boreal mixedwood conditions that exist in Ontario. Moreover, there are approaches that will be available in the near future that will further assist with the ecosystem-based management of boreal mixedwoods; these include decision support tools for the integration and monitoring of cumulative impacts at landscape levels through the use of ELC approaches and complementary frameworks, such as explicit linkages to models of wood supply, growth and yield prediction, and wildlife habitat projection and the application of spatially defined indices of biological diversity.

Depending upon the definition chosen, boreal mixedwoods clearly represent different things botanically, climatically, ecologically, and abiotically. The kinds of questions that are being asked about boreal mixedwood management in Ontario are becoming increasingly complex and include such issues as the "storability" of aspen (i.e., the probability of deferral of harvesting to later age-classes without a significant increase in mortality) on sites; best practices for the delineation and prioritization of harvest blocks within existing mixedwood stands within a local area, and at a broader scale; the selection of site-specific postharvest treatments to encourage boreal mixedwood or other successional pathways; and field practices to maintain wildlife habitat and address measures of biological diversity (in particular because some boreal mixedwoods are relatively rich and diverse sites). Such questions must be addressed using more exact and ecologically sound criteria and principles.

Conclusions

This paper has considered some definitions of boreal mixedwoods in northern Ontario in terms of broad climatic and soil/site characteristics. Five boreal mixedwood "definitions" currently in use in northern Ontario were parameterized and examined. Using summaries from FEC-related field surveys and incorporating some new techniques that permit the interpolation of climate surfaces and other data to biological survey locations, selected climate and soil/site data were summarized. Managers, field foresters, and scientists need to be more specific in their approach and clearer in their description of which boreal mixedwood paradigm they are using: the "cover-type boreal mixedwood," "potential boreal mixedwood," "incipient boreal mixedwood," or some more precise stand-level definition. Although there are both data bases and suitable methodologies currently available for better describing the boreal mixedwood resource in Ontario, the first step is consistency in applying existing terminology.

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The role of disturbance in boreal mixedwood forests of Ontario

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Abstract

Boreal mixedwood forests in Ontario are affected by a number of disturbance agents, the most important of which are fire and spruce budworm *(Choristoneura fumiferana* Clemens*)*. The objectives of this paper are to describe the disturbance regimes prevalent in boreal mixedwoods, emphasizing the roles of fire and budworm; to summarize the life history characteristics of mixedwood species; and to use the "vital attributes" approach as a framework for predicting the impacts of disturbance in boreal mixedwood stands. In addition, the similarities and differences between timber harvesting and fire are discussed. Finally, the concepts of "climax" and "old growth" are examined in the context of boreal mixedwood ecosystems.

Résumé

La forêt mixte boréale de l'Ontario est touchée par plusieurs sources de perturbation, les plus importantes étant le feu et la tordeuse des bourgeons de l'épinette (*Choristoneura fumiferana* Clemens). Dans la présente communication, nous décrivons les régimes de perturbation les plus fréquents dans la forêt mixte boréale, en mettant l'accent sur les rôles respectifs du feu et de la tordeuse. Nous résumons ensuite les caractéristiques du cycle vital des essences présentes, puis nous utilisons ces caractéristiques pour prévoir l'incidence de la perturbation sur les peuplements. Nous traitons enfin des ressemblances et différences qui existent entre la récolte du bois et le feu, puis examinons les notions de «climax» et de «vieux peuplement» du point de vue des écosystèmes de la forêt mixte boréale.

Introduction

Boreal mixedwood ecosystems comprise approximately half of the productive forestland in Ontario (McClain 1981). They occur under a wide range of site conditions, and each stand is the result of a complex and unique history of disturbance. It is extremely difficult to generalize about successional relationships in boreal mixedwood stands owing to the interactions among site factors and disturbance history. Several authors have presented summaries of successional replacement sequences for mixedwood stands (Alexander and Euler 1981; Day and Harvey 1981; Yang and Fry 1981; Bergeron and Dubuc 1989), and no attempt will be made to repeat that information here. Rather, the objective of this paper is to present a conceptual framework that can be used to predict the impacts of disturbance on mixedwood stands and their subsequent development, given information about the life history characteristics of important species in the stands of interest.

There are several definitions of boreal mixedwoods, and other authors at this workshop have discussed this in depth (e.g., MacDonald, these proceedings). For the purposes of this paper, the species considered to be characteristic of boreal mixedwood stands are listed in Table 1.

These species occur in various proportions, depending on site and soil conditions, disturbance history, and stage in stand development. Mixedwood stands generally occupy soils of moderate to high fertility that are moderately to well drained and relatively deep (McClain 1981; Sims and Uhlig, these proceedings).

Disturbance agents

Fire

Much of the species composition and stand structure characteristic of mixedwood stands are the result of disturbance. Fire and spruce budworm (*Choristoneura fumiferana* Clemens) infestations are the most important disturbance agents in mixedwoods, with additional impacts from other pest species and from abiotic sources (windthrow, ice storms, etc.). Ontario lies at the midpoint of the range of the spruce budworm, with severity of infestations increasing toward the Maritime provinces (Blais 1985). In contrast, fire occurrence increases to the west of Ontario, so that northern Ontario lies at the intersection of spruce budworm out-

Table 1. Common name, scientific name, and species abbreviations used in the text.

Common name	Scientific name	Species abbreviation
Trembling aspen	*Populus tremuloides* Michx.	Pot
White birch	*Betula papyrifera* Marsh.	Bw
Jack pine	*Pinus banksiana* Lamb.	Pj
Black spruce	*Picea mariana* (Mill.) B.S.P.	Sb
White spruce	*Picea glauca* (Moench) Voss	Sw
Balsam fir	*Abies balsamea* (L.) Mill.	Bf

Source: Nomenclature from Sims et al. (1990).

breaks and high levels of fire disturbance—and therefore at the point of maximum interaction between the two. Fire can be characterized by its frequency or return interval, its type and severity, and its size. These factors are collectively known as the *fire regime* (Heinselman 1981) and describe the main features of the fire environment in which species have evolved.

Table 2 shows a range of estimated fire return intervals for northern Ontario and northern Minnesota. It is important to recognize that these are average values and have a large degree of uncertainty associated with them. Note also that these values are not for boreal mixedwood stands *per se* but represent estimates among a variety of boreal and near-boreal forest communities. The overall average of the values in Table 2 is 64 years, relatively similar to the value of 75 years suggested by Day and Harvey (1981).

Fire type and severity are other important aspects of the fire regime. Fire type refers to the location of flaming combustion and is categorized as a surface, crown, or ground fire. Fire severity refers to the ecological impact of the fire. Surface fires are generally the least severe, burning in loose litter on the forest floor. Crown fires burn continuously in the forest canopy and release the greatest amount of heat energy because of the rapid rates of spread and large amounts of biomass consumed. However, ground fires often have the greatest ecological impact. Ground fires occur under strong drought conditions and burn deeply into the organic layer. Root systems are damaged or destroyed, soil organic matter and nutrients are often completely removed, and propagules in the seed bank are consumed. Fuels and weather interact to determine which fire type occurs, and most large fire events comprise a mixture of the three types. In general, the higher the proportion of hardwood species in a stand, the less likely a crown fire is to occur. This is due to relatively high moisture retention in hardwood foliage, lower amounts of flammable resins and oils, and the discontinuous nature of hardwood crowns (Chandler et al. 1983). This suggests that stands with a high proportion of trembling aspen (*Populus tremuloides* Michx.) and white birch (*Betula papyrifera* Marsh.) may experience mostly surface fires, whereas conifer-dominated stands will often support crown fires.

Table 2. Fire return intervals reported for northern Ontario and northern Minnesota.

Fire return interval (years)	Location
20	NW Ontario
50–100	NW Ontario
65	Northern Minnesota
78	Quetico Park, NW Ontario
30–135	Clay Belt, NE Ontario

Source: Heinselman (1981); Ward and Tithecott (1993).

Finally, fire size is also a factor in describing the fire regime. Mixedwood stands contain varying proportions of hardwoods and conifers. Because of the differences in fire behavior among these fuel types, the amount of hardwood and conifer will have a strong influence on the nature of the fire. In stands with a large conifer component, crown fires can develop, and fire openings can be quite large. In stands with a hardwood canopy, crown fires are less likely, and fire size may remain relatively small. Size of opening created is particularly important in determining the ability of different species to recolonize an area. Large fire openings will be easily repopulated by wind-disseminated seed, whereas large-seeded species may not reach the interior. However, most large fire areas include islands of unburned vegetation, which will act as reservoirs of seed and increase the rate of recovery (Eberhart and Woodard 1987); this is particularly true of mixedwood stands, owing to the mixture of species. Dispersal of seed by animals will depend on how the animals respond to the fire event. The size of opening created also determines the pattern of the forest mosaic at the landscape level.

Whereas the fire regime describes the general characteristics of fire impacts, individual species interact with fire in a number of ways. Noble and Slatyer (1980) identified a number of species characteristics or "vital attributes" important to understanding and predicting

Table 3. Summary of vital attributes (*sensu* Noble and Slatyer 1980) for important boreal mixedwood species.

Species	Availability of propagules	Conditions for establishment	Age at reproductive maturity (years)	Life span (years)	Time to extinction of propagules (years)
Trembling aspen	Vegetative reproduction from rhizomes; seed dispersal	Intolerant	20	120	120
White birch	Seed dispersal; sprouting from root collar when <40 years old	Intolerant	40	130	Infinite (?)
Jack pine	Serotinous cones—seed storage in canopy; adults resistant to low-severity fires	Intolerant	10	120	150
Black spruce	Semiserotinous cones—seed storage in canopy	Semitolerant	40	200	250
White spruce	Seed dispersed from undisturbed areas	Tolerant	30	200	Infinite (?)
Balsam fir	Seed dispersed from undisturbed areas	Tolerant	20	200	Infinite (?)

Source: Data from Fowells (1965); Sims et al. (1990); Bell (1991).

species' responses to fire. These vital attributes provide a convenient way of summarizing the adaptations of species to disturbance and can be extended to any species in the context of many different disturbance types. The vital attributes identified by Noble and Slatyer (1980) that apply to mixedwood species are as follows:

1. Method of arrival or persistence of the species at the site during and after the disturbance:
   - D, dispersed seed from outside of the disturbed area
   - V, vegetative regeneration
   - G, seed stored in a canopy seed bank
2. Ability to establish and grow to maturity in the developing community (tolerance):
   - T, tolerant of shade
   - I, intolerant of shade
3. Time taken for the species to reach critical life stages:
   - m, reproductive maturity
   - l, life span
   - e, point at which propagules are extinct.

Table 3 summarizes the vital attributes for important boreal mixedwood species.

Budworm

Spruce budworm is the other major disturbance agent in boreal mixedwood stands. Budworm affects only coniferous species, in the order balsam fir (*Abies balsamea* [L.] Mill.) > white spruce (*Picea glauca* [Moench] Voss) > black spruce (*Picea mariana* [Mill.] B.S.P.) > pines (*Pinus* spp.) (MacLean 1990). Impacts of budworm infestation in mixedwood stands include changes in species composition and stand structure resulting from differential mortality; changes in reproductive capability as a result of budworm predation on female flowers; changes in live:dead biomass ratios due to mortality and consequent effects on fire behavior; and changes in rates of biomass decomposition and nutrient cycling (Blais 1985; Stocks 1987; MacLean 1990).

Stand susceptibility to budworm involves a number of factors and is not completely understood. The most important factors appear to be the occurrence of early summer drought and a high proportion of contiguous mature balsam fir (>50 years old). In Ontario, summer drought conditions are relatively common, so the limiting factor is probably the proportion of balsam fir in the stand (Blais 1968). In areas of Ontario where balsam fir is an important stand component, budworm outbreaks have been severe; these include areas near Sioux Lookout, the western shore of Lake Nipigon, and the Algoma region (Blais 1983). The frequency of budworm infestation is hard to quantify owing to the small sample sizes and difficulty in determining past outbreaks. Blais (1983) reported that outbreaks in northwestern Ontario occurred on a 93-year cycle, based on analysis of tree ring data. However, his sample period was about 250 years and included data for only three outbreaks. His analysis for the Algoma region indicated a similar frequency prior to European settlement but revealed an increase in frequency following the advent of timber harvesting. Blais (1983) attributed this increase to harvesting practices that favored removal of pine and spruce, thus increasing the proportion of balsam fir.

In general, the effect of spruce budworm on stand composition is to reduce the proportion of balsam fir in the canopy, thereby increasing the proportion of spruce, pine, and hardwoods. Understory and seedling balsam fir are less susceptible to the budworm, so canopy trees are killed but may be replaced by younger recruits. However, as the younger trees reach the canopy, they will also be attacked, so that the pool of canopy replacing balsam fir may become exhausted if the infestation is of long duration. Conversely, canopy white spruce and black spruce suffer less direct mortality, but the female flowers of these species are attacked by the budworm during severe infestations. These species are then unable to form cones and fail to reproduce (Blais 1985). The relative impacts of budworm on the regeneration of these species will determine the postbudworm stand composition. This is further discussed with regard to old-growth stands below.

Gap dynamics

A third disturbance agent not often considered in mixedwood ecology is gap formation. This refers to openings in the canopy caused by the fall of one or a few trees. This mechanism is most important in the periods between major fire and budworm events. In mixedwood stands, the predisposing factors leading to gap formation are mortality caused by budworm or some other insect or disease, combined with a strong wind. The entire tree may fall at ground level, or, in the case of dead trees, the stem may break off some distance above the ground. Frelich and Reich (1995) identified what they refer to as the "demographic transition" in mixedwood forests of northern Minnesota. This refers to the change in stand structure as an even-aged postfire stand begins to break up at about age 100. Wind, insects, and disease kill individual trees, which fall, creating openings in the canopy 10–30 m across. The formation of these gaps has several effects on subsequent stand development and response to further disturbance. The canopy opening allows the release of shade-tolerant species growing in the understory, especially balsam fir and white spruce. In addition, these gaps provide opportunities for the establishment of early successional species, especially white birch. As gaps are continually formed across the forest landscape, a heterogeneous mosaic emerges, made up of many small stands of varying ages and successional stages. This process produces a forest structure much different from the relatively even-aged stands created by large fire events. These uneven-aged stands each respond somewhat differently to local disturbance events, further accentuating the patchiness of the landscape. Eventually, however, a catastrophic fire will eliminate many small stands, and an even-aged forest will become reestablished. In summary, the mixedwood landscape is a mixture of large and small stands, all resulting from some combination of large-scale fire events and local gap formation.

Fire and budworm

The interaction of fire and budworm outbreaks must be considered in order to understand fully the role of these disturbance agents in boreal mixedwood forests (Furyaev et al. 1983). The coniferous component of the mixedwood fuel complex is modified by the spruce budworm. Depending on the frequency and severity of the outbreak, fuel modification by budworm includes changes to the vertical and horizontal arrangement of the fuel bed, changes to the chemistry and moisture relationships of the fuel particles, and changes to the depth and moisture content of the forest floor. As these factors change, fire behavior is affected. The general effect of budworm is to increase the amounts of dead and down fuel, thus increasing the severity of the fire (Figure 1). The majority of budworm-caused tree mortality occurs within the first five years of the initial outbreak (Blum and MacLean 1984) and will affect fire occurrence and severity for an additional 10–15 years following the outbreak (Stocks 1987). The Canadian Fire Behavior Prediction System, a component of the Canadian Forest Fire Danger Rating System, includes several fuel types that allow the prediction of fire behavior in budworm-killed mixedwood stands (Forestry Canada Fire Danger Group 1992). Fire behavior is largely determined by the proportion of hardwood and coniferous species and the proportion of dead balsam fir in the stand (Figure 2). Specific aspects of fire behavior and impacts, such as surface fuel consumption, rate of spread, likelihood of crown fire development, and rate of increase in fire area, are available from this model. In addition, ecological impacts on the tree canopy can be predicted from heat output (fire intensity), which is strongly related to degree of crown scorch (Van Wagner 1973). Although

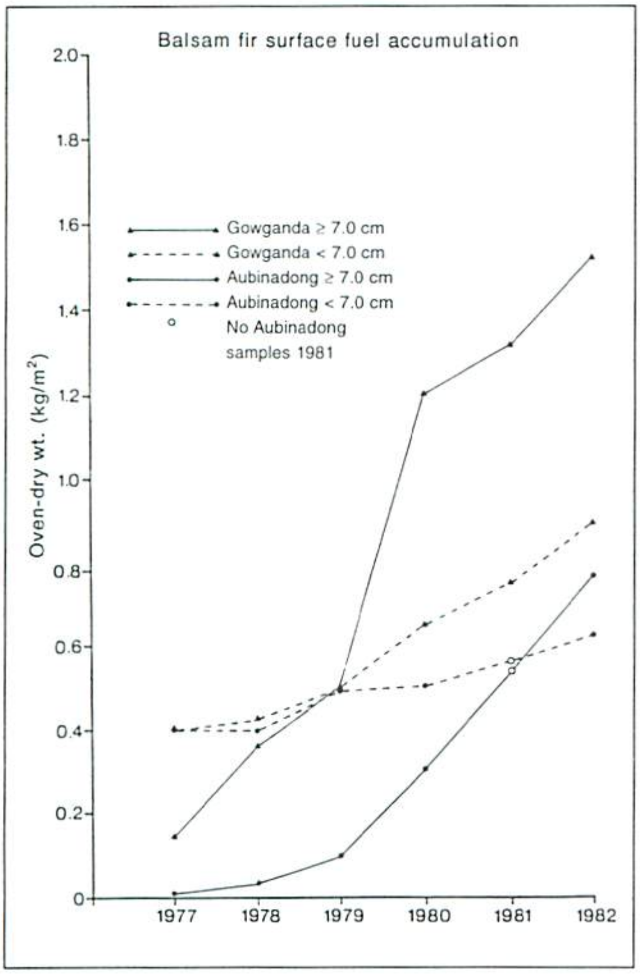

Figure 1. Balsam fir surface fuel accumulation at two sites (Gowganda and Aubinadong) in northeastern Ontario following maximum fir mortality in 1977–1978.

Source: Stocks (1985).

these aspects of fire behavior have not yet been related to ecological impacts in a comprehensive way, the elements are in place with which to begin modeling these relationships. A project with this goal has been established by the Canadian Forest Service and is in the early stages.[1]

Predicting successional patterns in boreal mixedwoods

Prediction of successional pathways following disturbance in mixedwood requires knowledge of both species autecology and specific characteristics of the disturbance. Figure 3 shows the life stage characteristics for mixedwood species using the classification from Noble and Slatyer (1980). The diagram shows that the

[1] L. Duchesne, Canadian Forest Service, personal communication, October 1995.

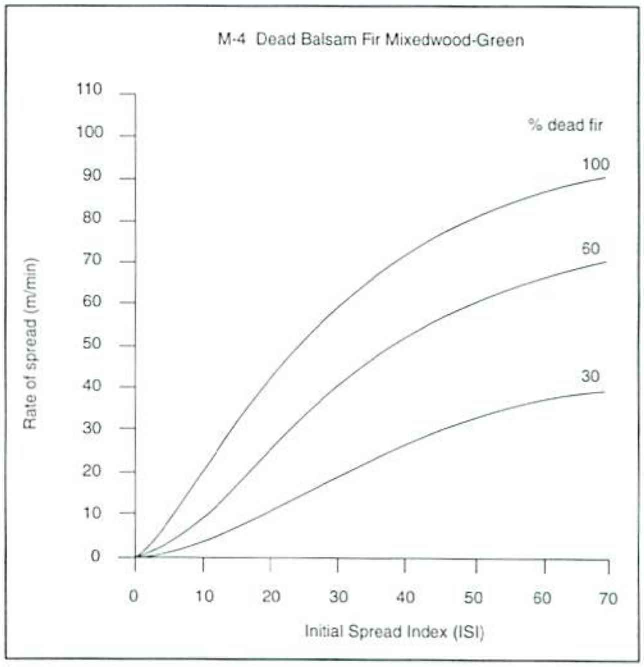

Figure 2. Relationship between proportion of dead balsam fir, rate of spread, and Initial Spread Index for the Dead Balsam Fir Mixedwood–Green fuel type in the Canadian Fire Behavior Prediction System.

Source: Forestry Canada Fire Danger Group (1992).

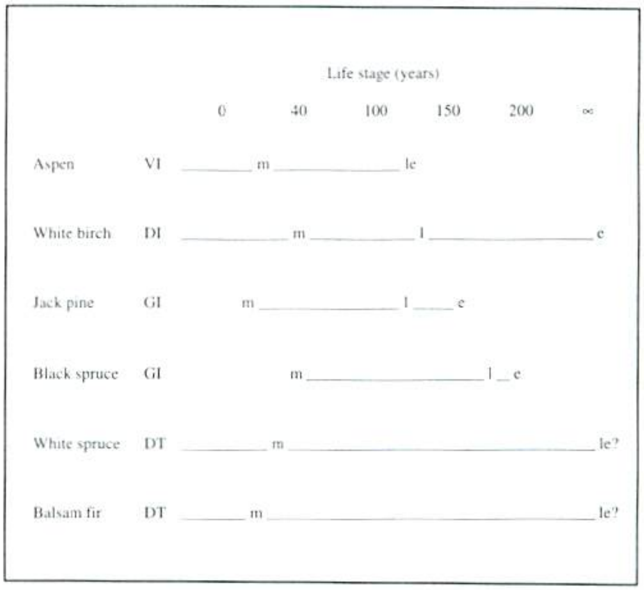

Figure 3. Summary of life stage characteristics for mixedwood species using the classification from Noble and Slatyer (1980). See text for definition of terms.

impact of fire on a given species varies depending on the life history stage in which it occurs. For example, reproduction in aspen is possible before an individual is sexually mature, as aspen can reproduce through resprouting. In contrast, jack pine (*Pinus banksiana* Lamb.) has no propagules available before it is sexually

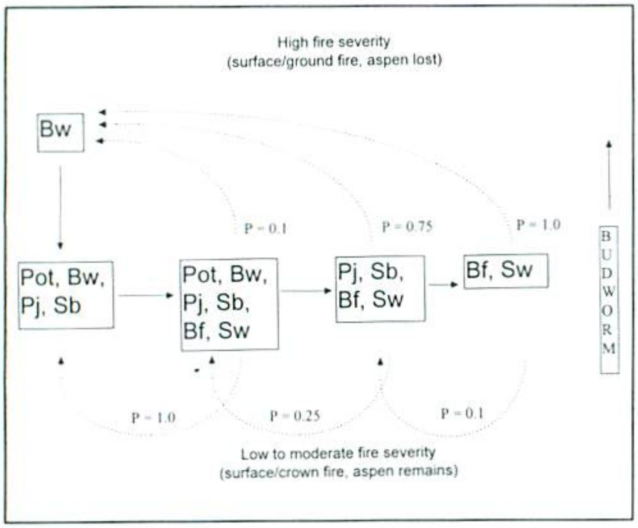

Figure 4. Example of multiple successional pathways for a hypothetical mixedwood stand following various levels of fire severity and budworm attack. "P" indicates estimated likelihood of pathway developing.

mature and therefore would become locally extinct if a fire killed all individuals before this point in its development. These characteristics, in combination with knowledge of fire impacts, can be used to determine potential successional pathways. There are multiple successional pathways for any given mixedwood stand, each depending on the severity of the fire and the point in the species' life span at which disturbance occurs. Figure 4 shows an example of the multiple successional pathways for a single stand, displayed in graphical format. In general, low- to moderate-severity fires change species composition little, providing regeneration opportunities for species already in the stand. As succession proceeds, the hardwood component decreases and fire severity and size increase owing to the more uniform and flammable conifer canopy. Budworm infestation will increase the fire severity and may also increase the likelihood of crown fire. As the stand ages and severe crown fires become more likely, the postfire stand may become dominated by birch owing to birch's ability to colonize large areas with wind-disseminated seed. The later stages are unlikely because of the relatively short fire interval in mixedwood ecosystems. In the absence of disturbance, balsam fir and white spruce will probably be dominant owing to their shade tolerance. General trends in change of stand conditions with time are given in Table 4.

Table 4. Trends in fire-related stand conditions over time.

Increasing biomass accumulation
Increasing conifer component
Increasing fire size
Increasing fire severity
Increasing probability of crown fire
Increasing homogeneity of fuels
Increasing energy storage, released in fire

Comparing harvesting and fire

Recent management and policy initiatives in Ontario direct resource management agencies and forest industry to develop resource management systems that emulate natural disturbance. For example, the new *Crown Forest Sustainability Act* (CFSA) in Ontario is based on the premise that the long-term health and vigor of Ontario's forests require the use of "forest practices that, within the limits of silvicultural requirements, emulate natural disturbances and landscape patterns, while minimizing adverse effects on plant life, animal life, water, soil, air and social and economic values, including recreational values and heritage values" (CFSA 1994:3–4). However, the extent to which harvesting is able to emulate fire is poorly understood. Recent research by the Ontario Ministry of Natural Resources has begun to reveal some of the ways in which these disturbance agents differ across a range of spatial scales. Johnston and Elliott (1996)[2] recently investigated a mixedwood stand north of Thunder Bay containing sites that had been burned in a wildfire, harvested and then burned in the same wildfire, or harvested only. They found that herbaceous species composition, species diversity, and soil characteristics all differed among the sites and that sites that experienced either fire only or harvesting and fire were more similar to each other than they were to the site that had been harvested only. Gluck and Rempel (1996) found that spatial patterns created by wildfire and harvesting were different at the landscape scale as measured by the shape, size, and interspersion of vegetation patches. In general, these results suggest that fire and harvesting are different at local and landscape scales and that these disturbances produce ecosystems that are different in both structure and function.

The concepts of "climax" and "old growth" in boreal mixedwoods

Old-growth or climax boreal mixedwood forests are probably rare in Ontario if a fire return interval of 75–100 years is accepted. In addition, mixedwood species are not long-lived in comparison to such species as red pine (*Pinus resinosa* Ait.) or white pine (*Pinus strobus* L.). Balsam fir is unlikely to survive

[2] See also Johnston, M.H. A comparison of fire and harvesting impacts on soil–vegetation relationships in a black spruce mixedwood ecosystem in northwestern Ontario (In review.)

beyond about 120–150 years, whereas white spruce may live to 200 years (Sims et al. 1990). However, if a stand does not experience fire, tolerant balsam fir and white spruce are the most likely stand constituents. If the stand is attacked by spruce budworm, mature fir will be killed, and white spruce will either be killed or fail to regenerate. Fir seedlings in the understory may survive, perpetuating the fir component. If white spruce is not able to reproduce, the final stand composition would be balsam fir mixed with tolerant shrub such as beaked hazel (*Corylus cornuta* Marsh.) and mountain maple (*Acer spicatum* Lam.) (Day and Harvey 1981). If budworm did not eliminate white spruce regeneration, white spruce would also be a component in the stand. Ghent et al. (1957) examined the understory composition of several mixedwood stands in northern Ontario and Quebec and speculated about the ultimate stand composition following budworm attack in the absence of fire. They concluded that it was not possible to generalize about the relative importance of spruce and fir in the postbudworm stand; stands in Quebec would move toward spruce dominance, whereas stands in Ontario would experience an increase in the fir component. Day and Harvey (1981) suggested that an old-growth mixedwood stand would contain a few widely spaced pioneers with a dense understory of balsam fir and hardwood shrubs. However, they commented that such a condition would be rare given the short fire return interval in mixedwood stands. Gordon (1985) presented data from a number of spruce–fir stands in north-central Ontario that had been affected by budworm. He concluded that the budworm's preference for mature balsam fir, and especially its impact on flowers, would reduce or prevent the regeneration of fir, allowing spruce to maintain a presence in or even dominate the postbudworm stand. In summary, some mixture of balsam fir and white spruce will probably form the climax stand, but little is known of these stands because the condition is so rare.

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Boreal mixedwoods as wildlife habitat: observations, questions, and concerns

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Abstract

Boreal mixedwoods provide important habitat at one or more successional stages for the majority of vertebrates that occur in the boreal forest. Many of these species, however, also require other forest types in equal or greater proportions. There are also some species that do not occur in mixedwoods. Consequently, we must manage boreal mixedwoods as part of the habitat mosaic at various spatial scales, as required by this diverse set of wildlife species. The trend toward conversion of conifer stands to mixedwoods raises a number of questions and concerns about the future availability of habitat to ensure the diversity of wildlife species in the boreal forest.

Résumé

À un ou plusieurs stades de sa succession, la forêt mixte boréale fournit des habitats importants à la majorité des vertébrés de la forêt boréale. Cependant, un grand nombre de ces espèces ont également besoin d'autres types forestiers, dans une proportion égale ou supérieure, tandis que d'autres espèces ne sont jamais présentes dans les peuplements mixtes. Par conséquent, il faudra gérer la forêt mixte boréale à titre de composante de la mosaïque d'habitats présents à diverses échelles spatiales, afin de répondre aux besoins d'une faune diversifiée. La tendance à convertir les peuplements de conifères en peuplements mixtes soulève un certain nombre de questions et de préoccupations quant à la disponibilité future des habitats nécessaires au maintien de la diversité faunique de la forêt boréale.

Introduction

Recent interest in improving our knowledge and management of boreal mixedwoods (MacDonald and Weingartner 1994) is consistent with the goal of maintaining biodiversity and managing for the sustainability of all resource values in Ontario (Ontario Forest Policy Panel 1993; *Crown Forest Sustainability Act* 1994). The term "biodiversity" is a concept meaning the variety of life (Noss 1990); however, to manage in a manner that maintains biodiversity, we must ground the concept in more pragmatic and visible attributes. Wildlife, especially vertebrates, are a visible attribute. The recent interest in boreal mixedwoods was prompted by the evidence for increasing conversion of pure coniferous types to mixedwoods and a decline of conifers, especially both species of spruce, in the second-growth boreal forest as a result of past forest management practices (Hearnden et al. 1992). Although our wildlife data sources are not ideal, we must at least begin to explore what the consequences of these changes mean for wildlife habitat in the boreal forest and then incorporate this imperfect knowledge into management policy regarding rates of timber harvest and allocation of future timber supplies.

We will provide some perspective about the relative importance of wildlife to boreal mixedwoods using a compilation of current information on habitat associations in the boreal forest to explore what we believe are some appropriate questions about wildlife and boreal forest types. Using this information base and other sources, we will then address some questions concerning the potential consequences to wildlife of long-term changes in the supply of boreal forest types and successional stages.

What is wildlife habitat?

Habitats of high quality are those that provide for successful survival and reproduction over long periods, as compared with lower-quality habitats (Morrison et al. 1992). Historically, this conceptual definition was adequate when biologists were concerned primarily with single-species management, but it is inadequate when we must consider how to provide habitat for all species. Furthermore, this definition does not provide a functional understanding of how animals actually select and occupy habitat.

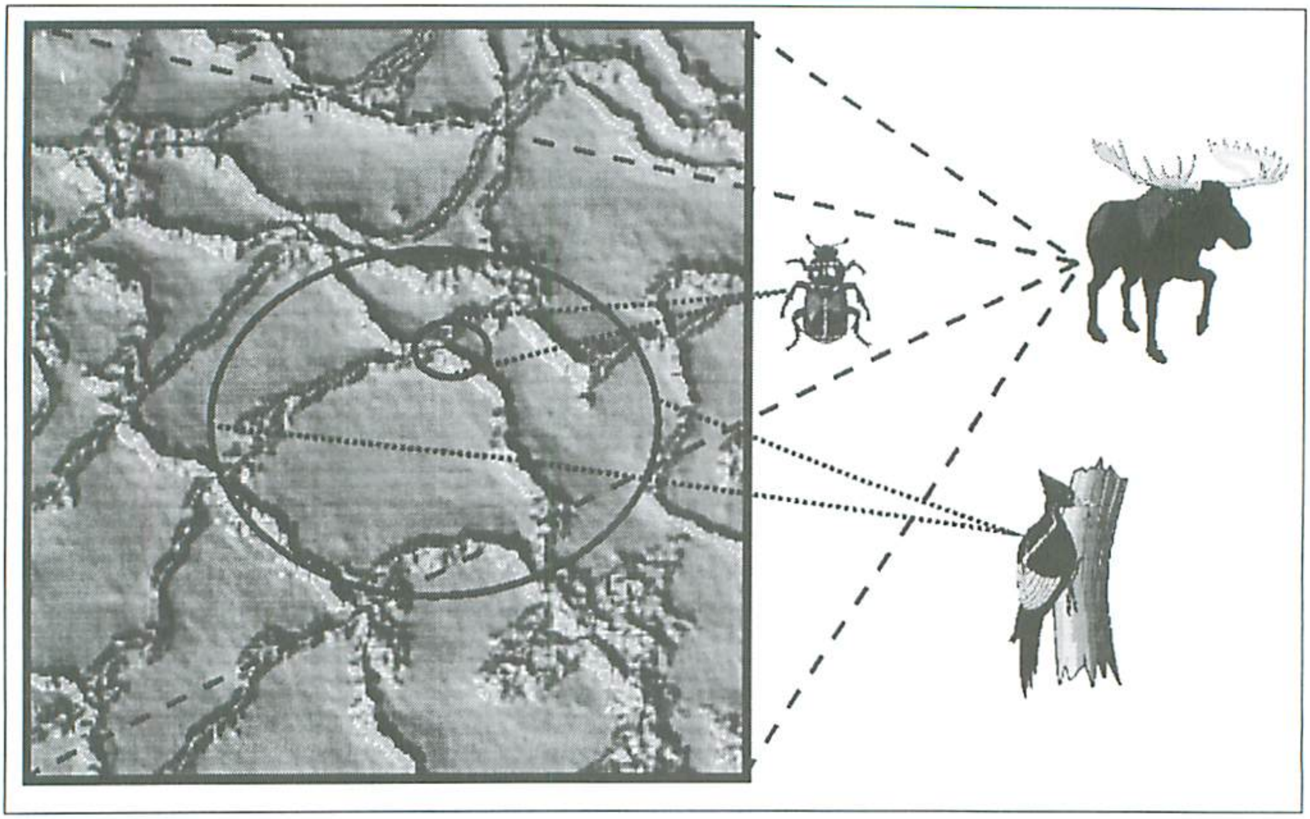

Figure 1. The concept of wildlife habitat from the animal's perspective of scale and patch mosaics. Three animal sizes use habitat patches of different scales relative to their body size. The square patch boundary of the moose and the elliptical patch boundaries of the woodpecker and the beetle are used simply to illustrate the point that, although we observe patches on the landscape, there is no reason to expect that any species "sees or uses" the same boundaries.

A considerable amount of research has been devoted to describing and testing habitat selection over the past 20 years (Morrison et al. 1992). This work has resulted in acceptance of the concept of habitat selection as a hierarchical process whereby an animal, because of evolutionary factors, is constrained to a particular geographic area. Within this geographic area, the animal then makes choices on the basis of which habitat patch will provide appropriate food and cover (Hutto 1985). Within this habitat patch, the animal will then choose a particular site for feeding, resting, breeding, etc. This hierarchical concept of habitat selection, in combination with the development of landscape ecology, has provided a functional view of habitat (from an animal's perspective).

Biologists now generally agree that habitat should be defined from an animal's perspective as a landscape containing a mosaic of habitat patches, within which there is a particular patch or a combination of patches that is preferred by one or more species (Dunning et al. 1992). The preference of a species for a patch or patches can only be defined relative to that species and the spatial scale over which the daily, seasonal activity of that species normally occurs (Wiens 1976) (i.e., a moose and a mouse view their respective habitats over very different scales). Furthermore, within any given patch type at a particular scale, the patch can be divided into even smaller patches, each one of these smaller patches can be divided into another set of smaller patches, and so on.

Because we as foresters and biologists are familiar with forest inventory data that are classified on the basis of our perception of a forest stand, we usually think of a habitat patch as a stand. However, there is no *a priori* reason to choose the stand as a patch. It is unlikely that any species recognizes its particular preferred habitat patch as a forest stand (Figure 1). We need to think about habitat not only in terms of the spatial mosaic of habitat patches but also in terms of the temporal mosaic of patch types such as successional stages. By accepting the definition of a scale-specific, spatial mosaic of wildlife habitat, we must consider boreal mixedwood sites as parts of a larger mosaic of sites of other boreal types and therefore as a nested set of patches within a boreal mosaic, spatially and temporally.

Ideally, to examine the importance of mixedwoods as wildlife habitat, we would analyze the spatial arrangement of this type relative to other types at scales specific for a variety of species. As home range size is scaled to body weight (Harestad and Bunnell 1979), we could scale body weight to the appropriate scale of patch mosaics of mixedwoods and other types to determine the appropriate habitat patch sizes for various ranges of body sizes. If we then also had some reasonable estimates of relative abundance among species at various scales, we could define habitat patches for various body sizes of species relative to the mosaic of patches containing varying amounts of boreal mixedwoods and other boreal types such as pure jack pine (*Pinus banksiana* Lamb.), pure black spruce (*Picea mariana* [Mill.] B.S.P.), pure deciduous, wetlands, riparian areas, etc. Although, at present, we do have spatially explicit mosaics of patches from forest inventory data and satellite imagery (Pala 1994), we do not have corresponding relative abundance estimates for wildlife at a variety of scales and patch mosaics.

The spatial configuration of habitat supply is critical. Unfortunately, we do not have large-scale spatial models for habitat supply in Ontario, although we are beginning to develop them. Currently, nonspatial habitat supply models have been developed for a few species only and specifically for planning at the forest management unit level in Ontario: American marten (*Martes americana*) and red-shouldered hawk (*Buteo lineatus*) by Naylor et al. (1994a,b). Both nonspatial and spatial models are being developed for forest songbirds in Ontario (Welsh and Venier[1]) and for other species in Central and Northeast Administrative Regions.[2]

Wildlife and boreal forest types: methods and assumptions

The definition of "mixedwoods" (MacDonald and Weingartner 1994) is different from that normally used by biologists to classify forest habitats (Baker 1988; Baker and Euler 1989). Biologists use the term mixedwoods to describe a forest stand composed of codominant deciduous and coniferous species. This same concept of mixedwoods was recently used in an audit of forest regeneration in the boreal forest (Hearnden et al. 1992). We have used the boreal mixedwoods definition rather than the biologists' definition. The definition can be made more precise by the use of a classification system, such as the forest ecosystem classification (FEC) system (Jones et al. 1983; Sims et al. 1989).

In Northeast Region (D'Eon and Watt 1994) and Central Region (Bellhouse and Naylor[3]), wildlife biologists have created habitat matrices that relate FEC types to wildlife species habitat preferences. These relationships are not ideal, because they use site-level interpretations from the literature with only limited empirical data. However, these sources represent the only comprehensive source of information for all species and the current scale of forest classification. Furthermore, the site-based definition provides a similar scale of comparison to the boreal mixedwood definition. Models of forest songbirds in relation to FEC site types are currently being developed (Welsh and Venier[4]). When these models are developed, we will be able to quantify the relationships of forest songbirds to boreal forest FEC types more precisely.

Table 1 is the basis for our evaluation of wildlife distribution by habitat. It is a comparison of the boreal mixedwood definition and FEC-based descriptions in the habitat matrix of D'Eon and Watt (1994). This "translation" is the basis of habitat interpretation for mixedwoods used later in this paper. To make this comparison (Table 1), we used the FEC Clay Belt manual (Jones et al. 1983), which provides average dominant tree species composition for each FEC site type. This procedure has some problems but is useful for this assessment. The single-species types have a single dominant species (greater than 20%). Clearly, some site types do not fit the definition well. Site type 3, for example, has a fairly significant conifer component, although no one conifer species reaches the 20% level. In this table, we have interpreted the "boreal mixedwood" stand definition ("no single species exceeds 80% of the basal area") to mean two or more species on a site requiring separate silvicultural prescriptions. For example, in site type 9, white spruce (*Picea glauca* [Moench] Voss) and black spruce are regarded as a single dominant. In site type 10, balsam poplar (*Populus balsamifera* L.) and trembling aspen (*Populus tremuloides* Michx.) are regarded as a single dominant.

[1] Welsh, D.A.; Venier, L. A descriptive model of boreal forest songbird habitat using generic ecosystem classification. Can. Wildl. Serv., Ottawa, ON. (In prep.)

[2] B. Naylor and B. Watt, Northeast Region Science and Technology, Ontario Ministry of Natural Resources, North Bay, ON, personal communication.

[3] Bellhouse, T.; Naylor, B. Habitat suitability matrix for central Ontario. Ont. Min. Nat. Resour., Cent. Ont. Technol. Dev. Unit. (In prep.)

[4] Welsh, D.A.; Venier, L. A descriptive model of boreal forest songbird habitat using generic ecosystem classification. Can. Wildl. Serv., Ottawa, ON. (In prep.)

Table 1. Comparison of mixedwood definition with FEC site descriptions.

Site type description/ number[a]		Boreal mixedwood definition	Site characteristics (dominant type: soil texture/moisture/ drainage)	FEC Clay Belt dominant tree % composition (subdominants in parentheses)
Very shallow soil	1	Single species	Variable/dry/rapid	Sb 80
Jack pine/coarse soil	2	Single species	Sandy/dry/rapid	Pj 89
Mixedwood	3	Single species	Sandy/fresh/moderately well	Po 46 (Sb 18 Pj 17)
Jack pine/black spruce	4	Mixed[b]	Sandy/moderately moist/imperfect	Sb 65 Pj 33
Black spruce	5	Single species	Fine loam/moderately moist/ imperfect	Sb 89
Aspen/spruce mixedwood	6	Mixed	Fine loam, clay/very fresh/ moderately well	Sb 27 Po 25 B 22 (Sw 16)
Hardwood	7	Mixed	Clay/very fresh/moderately well	Po 41 B 20 (Sb 19 Sw 11)
Black spruce/ feathermoss sphagnum	8	Single species	Fine loam/moist/poor	Sb 99
Conifer/moist soil	9	Single species	Fine loam/moist/poor	Sb 43 Sw 23 (Ce 18 B 14)
Hardwood/moist soil	10	Single species	Fine loam/moist/imperfect	Pob 37 Pot 34
Black spruce/ labrador tea	11	Single species	Organic/moderately well/very poor	Sb 96
Black spruce/alder	12	Single species	Organic/moderately well/very poor	Sb 81
Conifer/alder	13	Mixed[b]	Organic/moderately well/very poor	Sb 50 Ce 32
Black spruce/ leatherleaf	14	Single species	Organic/well/very poor	Sb 82
Tolerant hardwood mixedwood	15	Mixed[b]	Sand to silt loam/fresh/not available	Not available
Sugar maple/ yellow birch	16	Single species	Silt sand to silt loam/fresh/ not available	Not available

[a] From Jones et al. (1983); D'Eon and Watt (1994).

[b] In our interpretation, this type does meet the stand definition of boreal mixedwood but does not fit the site characteristics; consequently, these "mixed" stands were not included in some of the mixedwood evaluations in the paper.

Source: Jones et al. (1983).

Wildlife and boreal mixedwoods: questions and answers

There are several questions that are related to the importance of boreal mixedwoods and other forest types and the consequences of future change:

1. How many species use mixedwoods compared with pure spruce, poplar, and jack pine?
2. How many species prefer particular age-classes of mixedwoods and single-species types?
3. What are the long-term implications to wildlife of an increase in boreal mixedwoods and a decline in conifer forest types, as suggested by Hearnden et al. (1992)?
4. What are the consequences for keystone species?

With apologies, for now (see "Keystone species," below), to the thousands of invertebrate species in the boreal forest, in this discussion we use the word "wildlife" to refer to all of the free-living vertebrate species in Ontario's boreal forest. We believe they number 153 species (D'Eon and Watt 1994). These species have available, as shown in Table 1, 16 types of forested area (forest units), each of which has five age-classes: initial, regenerating, young, mature, and old. Based on expert opinion, the matrix indicates whether, for each species, a habitat is preferred, is marginal, or is rarely or never used. We used only preferred habitat units for our analysis.

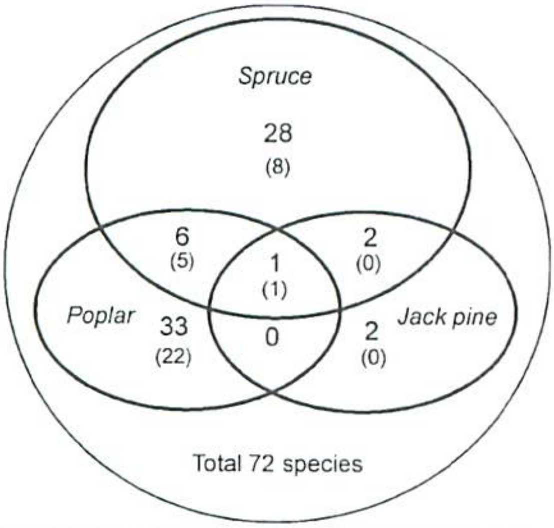

Figure 2. Distribution of species preferences for four boreal forest types. Each circle represents the number of species that have a preference for spruce, jack pine, or poplar habitat. The number located where the circles overlap means those species prefer both types. The center area represents species that use all three. The number in parentheses is the number of species in the group that also use boreal mixedwood types.

1. How many species use mixedwoods compared with pure spruce, poplar, and jack pine?

To illustrate the distribution of species among habitat types, we reduced the number of habitat types, because the relationship of FEC site types with the mixedwood definition is imprecise at present. We can use the six "pure" habitat types to demonstrate the distribution of wildlife species among the types, without stretching the definitions too much. Also, these six types have been used to forecast wood supply for Northeast Region; therefore, we can use these forecasts to predict future wildlife habitat trends. Of the 16 types that are in the Northeast Region matrix (D'Eon and Watt 1994), we used the four spruce types (FEC site types 5, 8, 11, 12) and one jack pine type (FEC site type 2) with greater than 80% single dominant tree species. We also used the poplar type (FEC site type 10) that is close to the criterion for a single-species deciduous type. For the mixedwood type, we used FEC site types 6 and 7, as these most closely matched the mixedwood definition for both soil and vegetation composition. For all four types, mixed, spruce, poplar, and jack pine, we collated wildlife species preferences for each from D'Eon and Watt (1994) and for combinations of all four types.

The distribution of wildlife species among the four forest types is shown in Figure 2. At the top of the figure, the number 28 in the "spruce" circle means that of the 72 species in this analysis, 28 prefer spruce and not poplar or jack pine (because we excluded some FEC types in this analysis and used only "preferred" habitat, the number is less than 153). The number shown in parentheses—in the case of spruce, 8—means that of the 28 species that prefer spruce, 8 also prefer mixedwood types. The distribution of species among the four types provides an indication of the importance of pure spruce or poplar stands. The low number of species that prefer exclusively jack pine is not a fair representation of its importance, as many species will use it, although they do not prefer it. In the area of overlap between circles is the number of species that prefer either type over other boreal forest types. Between spruce and poplar, the number of common species, 6, is relatively low compared with the number of exclusive species. This further underlines the importance of those pure types.

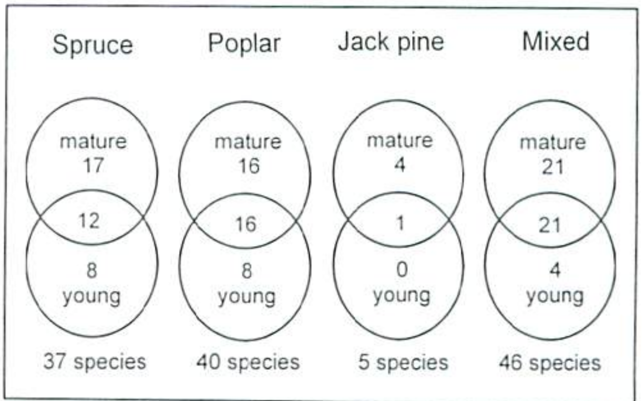

Figure 3. The distribution between young (initial, regeneration, and young stages) and mature (mature and old stages) age-classes within each of four boreal forest types. Each pair of circles depicts the number of species that prefer young, mature, or (in the overlap area) either age-class. The species in one type are not exclusive to that type. In other words, the 17 species in mature spruce do not use only mature spruce.

2. How many species prefer particular age-classes of mixedwoods and single-species types?

The distribution between young and mature/old age-classes within each of the four types is shown in Figure 3. Please note that the number of species in any one type might also prefer another type—i.e., the number of species shown for each in Figure 3 is not exclusive to that type. For example, the 37 species that prefer the spruce type are not exclusive to spruce. The numbers mean that of the 37 species found in spruce, 17 are found in the mature/old classes and 8 in the younger classes. Table 2 provides a list of species that prefer only mature/old habitat types. Note that some species on this list will use younger types, but they

Table 2. Species that prefer *only* mature habitat types of spruce, poplar, jack pine, or mixedwood.

Species	Spruce	Poplar	Jack pine	Mixedwood
Cooper's hawk (*Accipiter cooperii*)		X		
Broad-winged hawk (*Buteo platypterus*)	X			
Red-tailed hawk (*Buteo jamaicensis*)	X	X	X	X
Great horned owl (*Bubo virginianus*)	X	X		
Barred owl (*Strix varia*)	X	X		
Great gray owl (*Strix nebulosa*)		X		
Boreal owl (*Aegolius funereus*)	X			X
Northern saw-whet owl (*Aegolius acadicus*)		X		X
Yellow-bellied sapsucker (*Sphyrapicus varius*)		X		X
Downy woodpecker (*Picoides pubescens*)				X
Hairy woodpecker (*Picoides villosus*)				X
Three-toed woodpecker (*Picoides tridactylus*)	X			X
Black-backed woodpecker (*Picoides arcticus*)	X	X		X
Pileated woodpecker (*Dryocopus pileatus*)	X			X
Olive-sided flycatcher (*Contopus borealis*)	X			
Least flycatcher (*Empidonax minimus*)	X	X		X
Gray jay (*Periosoreus canadensis*)	X			
Blue jay (*Cyanocitta cristata*)	X			X
Black-capped chickadee (*Parus atricapillus*)	X	X		X
Boreal chickadee (*Parus hudsonicus*)	X			
Red-breasted nuthatch (*Sitta canadensis*)		X		X
Brown creeper (*Certhia americana*)		X		X
Golden-crowned kinglet (*Regulus satrapa*)	X			X
Cape May warbler (*Dendroica tigrina*)		X		X
Bay breasted warbler (*Dendroica castanea*)	X	X		X
Ovenbird (*Seirus aurocapillus*)	X			
White-winged crossbill (*Loxia leucoptera*)	X			
Pine siskin (*Carduelis pinus*)				X
Northern short-tailed shrew (*Blarina brevicauda*)		X		X
Woodland caribou (*Rangifer tarandus*)		X		
Red squirrel (*Tamiasciurus hudsonicus*)	X			
Southern red-backed vole (*Clethrionomys gapperi*)	X			X
Heather vole (*Phenacomys intermedius*)	X	X		
Black bear (*Ursus americanus*)				X
American marten (*Martes americana*)	X			X
Fisher (*Martes pennanti*)				X

prefer mature/old types. The conclusion is that there is a group of species that require older forest types. The implication of this dependency is discussed below.

Long-term management implications and concerns

3. *What are the long-term implications to wildlife of an increase in boreal mixedwoods and a decline in conifer forest types, as suggested by Hearnden et al. (1992)?*

To explore this question, we used the Strategic Forest Management Model (SFMM) (Davis 1995) to try to foresee the amount of change that could occur over the long term. We are using as the basis for input the analysis that was completed for Northeast Region by B. Callaghan[5] during the preparation of the Forest Resource Assessment Policy (FRAP 1994).

[5] B. Callaghan, Callaghan and Associates, Richards Landing, ON, personal communication.

We have made predictions of the future trajectory for the three pure types only. We did not make a prediction for the mixedwood type, for two reasons. First, at the operational level, the meaning of boreal mixedwood is still not established. Although Callaghan's analysis included a type that could be boreal mixedwood, it was not clear that his definition was consistent with the definition used here. Secondly, and most importantly, it was not clear to us what the appropriate parameters are for modeling mixedwoods. In Callaghan's analysis, he assumes either basic or, in some cases, intensive silvicultural prescriptions. Consequently, mixedwoods will tend to decline, because they will be managed for either poplar or spruce types. However, this prediction might be too optimistic. Instead, mixedwood management could become a widespread activity, because it can be done with less cost as a part of extensive forest management. Given this uncertainty, it is difficult to forecast trends for mixedwoods, especially as part of a preliminary analysis of wildlife habitat trends. In any event, because, collectively, all the wildlife species that prefer mixedwoods also prefer the pure types, the trajectories of the mature pure types provide a picture of the future trends in habitat supply for these species.

Figure 4 presents the predicted trajectory of the change in area of mature/old age-classes for each of the three pure types. The mature and old age-classes of all three types are forecast to decline significantly over the next 40 years, particularly for spruce, starting this decade. This forecast is consistent with management toward a "normal" forest, which is the current forest policy direction. The SFMM model outcome depicted in Figure 4 is based on maximizing timber harvest levels, with few environmental and social constraints. Given the political and economic climate in the province, this is a reasonable scenario for the foreseeable future. From a timber perspective, the forecast is attainable and possibly sustainable. However, from a wildlife (biodiversity) perspective, is it sustainable?

Given our lack of understanding of the importance of older age-classes of these types, especially spruce, to those wildlife species that we know prefer old spruce, there is considerable uncertainty as to the future for these species. Although, as indicated in Table 2, most species in the mature spruce type also prefer mixedwoods, we do not know how viable metapopulations in mixedwoods compare with those in spruce, especially the projected spatial fragmentation of mature spruce types over Northeast Region. A spatially explicit model is not needed to predict a problem for the spatial distribution of spruce with such a low percentage (13% in 2055; Figure 4) on the landscape of Northeast Region. Moreover, we should not base future conservation risks

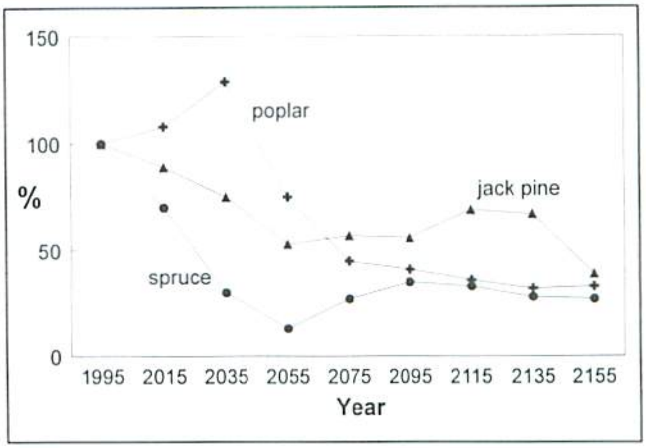

Figure 4. Forecast of the change in area (ha) that mature and old age-classes of spruce, poplar, and jack pine will undergo in Northeast Region. Species listed in Table 2 are likely to decline if these trajectories become reality.

on an untested hypothesis. We should be avoiding risks rather than improving our chance of failure.

On the one hand, at our most optimistic, one might speculate that these species could use other types, and therefore there might not be a problem. On the other hand, with our most conservative view, we might speculate that all species that prefer old age-classes will be in trouble. Given our track record in other cases of overexploitation of resources, North Atlantic cod being the most current, conservation should win out. Regardless, we cannot wait for 40 years to find out if we committed a Type I error (finding a significant effect when there really is not one) or, especially, a Type II error (not finding a significant effect when there really is one). We must more rigorously investigate the potential impacts and be willing to change forest management policy accordingly.

In a survey of forest regeneration in Ontario, Hearnden et al. (1992) concluded that the black spruce component in the boreal forest was being substantially reduced in the new forest. These results have been confirmed independently by Carleton and MacLellan (1994) in Northeast Region. This decline is a result of the regeneration of hardwoods on the better sites and poor success in black spruce regeneration owing to competition from hardwoods. On these sites, black spruce is becoming a minor component. The greatest challenge to a boreal mixedwoods program is to improve the black spruce component on these sites. It is unclear to us whether management objectives consistent with the definition of boreal mixedwoods will achieve a greater black spruce component. The definition assumes a succession from hardwoods to spruce. If, in fact, this is the normal pattern of succession in the new forest, then a management objective of increasing spruce content could be achieved. However, if, as Hearnden et al. (1992) suggested, the competition of hardwoods is preventing the establishment of spruce, then such a management objective cannot be achieved. One could suggest that Hearnden et al. (1992) are basing their conclusions on only a relatively short period (15 years) and that eventually spruce will increase in these stands. The only means of getting a truer picture of the successional trajectory is to compare the new postlogged forest with a new postfire forest. In other words, is the variation in successful regeneration of spruce as variable in the new forest as in the fire-origin forest? Based on Carleton and MacLellan's (1994) results of comparing fire-origin stands to harvested stands, successional patterns are not the same. We might have difficulty in conclusively answering this question, because the fire-suppressed forest that then burns might have a trajectory different from that of the normal fire-disturbed forest. Noneheless, we must compare both the plant and wildlife dynamics between managed and naturally disturbed forest if we are to sustain even current levels of biodiversity eventually.

Although the word biodiversity has become a modern buzzword for resource managers, bureaucrats, and politicians, it remains problematic as to how we should manage for biodiversity. Biodiversity includes structure, composition, and function of ecosystems from regional landscapes to genes (Noss 1990). In natural systems, biodiversity is maintained through maintenance of complexity at these scales. Naturally disturbed systems have many random events that dictate the structure and function of vegetation and wildlife at multiple scales (McCarthy and Burgman 1995), as well as genetic material (Gordon 1994). These random events create complexity, which we simplify through timber management and other human uses (Holling 1992; Gordon 1994).

Managing for biodiversity in the boreal forest will require us to emulate the complexity of naturally disturbed systems as legislated by the *Crown Forest Sustainability Act* (1994). Although a research program has been proposed to acquire new knowledge about how to improve our management of forest wildlife habitat to meet this legislated requirement (Other Wildlife Working Group 1995), it has not been fully implemented.

Keystone species: a management concern

4. What are the consequences for keystone species?

Mixedwood forests, like all forests, contain a number of keystone species. A keystone species is a species whose loss or removal would have cascading effects on other species or processes within the ecosystem.

Wildlife are usually portrayed as being dependent on the physical structure, species composition, and productivity of plant communities, almost as if wildlife are "welfare dependants" of the forest. Wildlife are often portrayed as the most obvious "victims" of forest harvesting. However, it is now becoming obvious that the forest is dependent on particular wildlife for its physical structure, species composition, and productivity.

Forest songbirds are recognized as being necessary for the growth and productivity of forests. Although, until recently, the most well-known example was the well-documented controlling influence of forest songbirds on spruce budworm (*Choristoneura fumiferana* Clemens) (Holling 1988), it is now known that forest songbirds are necessary for normal forest function in southern temperate forests (Marquis and Whelan 1994). Songbirds represent this keystone effect of a cascading top-down influence on many ecosystem processes essential for a healthy forest.

Although it is likely that most keystone species have not been identified (Krebs 1985), because many are soil invertebrates, several species or guilds of keystone species are well-known (in Ontario forest types, in addition to songbirds and wolves), including ants, earthworms (*Lumbricus* sp.), woodpeckers, and beavers (*Castor canadensis*). Each of the species or guilds affects forest development, forest decline, plant distribution, and the occurrence of various other vertebrate or invertebrate species. Another well-documented keystone species is the northern flying squirrel (*Glaucomys sabrinus*), which plays a critical role in nutrient exchange in northern forests (Maser 1990). All of these species require certain habitat structures associated with specific ages of forests. In the case of earthworms and ants, these species may be found in any age-class of forest but do best in richer organic soils with high moisture content and a good duff development, and some species of ants require fallen logs, stumps, or dead standing trees. Beavers and woodpeckers require mid to late successional forests. Some woodpeckers, such as downy (*Picoides pubescens*) and hairy (*P. villosus*) woodpeckers, are most common in mixed forests and are found regularly in selectively harvested stands, but others, such as black-backed woodpeckers (*P. arcticus*), are found predominantly in older conifer forests, especially with dead standing trees. The largest woodpecker, the pileated woodpecker (*Dryocopus pileatus*), requires large trees for nesting (Evans and Conner 1979; Renken and Wiggers 1993) and carpenter ants (*Camponotus* spp.) as an important source of food. The management concern is that with a reduction in conifer forests, a reduction in forest age, the altering of mixed-forest communities through reduction of spruce and increase in balsam fir (*Abies balsamea* [L.] Mill.), and soil compaction, habitat for keystone species can be reduced, resulting in effects within forest systems far beyond the reduction in populations of a single species—including possible effects on ecosystem processes, such as the growth and yield of trees. Many of these species are the same ones listed in Table 2 and are species that might be negatively impacted by the predicted future small area of mature spruce in Northeast Region.

As an example, consider woodpeckers in a mature or old-growth pine forest. As these forests age, the density of snags and decadent trees increases, thereby improving the quality of habitat for pileated and black-backed woodpeckers that search such trees for insect prey and dig cavities for breeding. Cavities are then used by numerous other species for resting, for breeding, or as escape habitat from predators or severe weather, including boreal (*Parus hudsonicus*) and black-capped (*P. atricapillus*) chickadees, brown creepers (*Certhia americana*), boreal owls (*Aegolius funereus*), northern saw-whet owls (*A. acadicus*), northern flying squirrels (*Glaucomys sabrinuss*), red squirrels (*Tamiasciurus hudsonicus*), red bats (*Lasiurus borealis*), hoary bats (*L. cinerius*), long-eared bats (*Myotis septentrionalis*), little brown bats (*M. lucifugus*), eastern pipistrelles (*Pipistrellus subflavus*), small-footed bats (*Myotis leibii*), and silver-haired bats (*Lasionycteris noctivagans*). Several of the species of bats breed in communal tree cavities and feed in adjacent areas. The tree cavities cannot be located in open logged stands to be used by the secondary suite of species, because all these species prefer older, closed-canopy forests as habitat. Data from Newfoundland[6] clearly indicate that habitat features (standing dead trees of sufficient size) are lacking for black-backed woodpeckers in second-growth balsam fir forests as late as 60 years postharvest. We are not suggesting that populations of all of these species are declining in Ontario, because we have no direct evidence for that. However, we use this example to point out that if we do not manage forests in consideration of keystone species, then populations of many species can be affected because of the direct and strong interrelationships among them.

Forest ants provide a second example of a species for which the keystone effects are not only on other species, but on ecosystem processes as well. Puntilla et al. (1994) and Holldobler and Wilson (1990) provide reviews of the ecosystem processes enhanced by ants: dispersal of certain plants (including fungi), pollination, nutrient cycling, soil mixing and aeration, and decomposition of dead wood. Ants may also affect the distribution and abundance of other ants and other ground-dwelling arthropods, certain canopy arthropods, including spruce budworm (Sanders 1964), and some vertebrates (e.g., pileated woodpeckers). Isolation of species through logging practices could alter colonization rates and species composition in regenerating forests, and thus the ecosystem processes within those forests (Puntilla et al. 1994). In Ontario, ant community structure differs in white pine (*Pinus strobus* L.) forests between northwestern and eastern areas of the province (Thompson et al. 1995). However, little is known about local community assemblage processes or how these may be affected by logging, including the broad-scale effects of loss of older forest stands. There appear to be no old-growth specialist ant species (Puntilla et al. 1994; Thompson et al. 1995), and community assembly appears to be primarily affected by obstacles to dispersal, history, and the resultant competition among species mixes. Loss of ecosystems, altered ecosystem states, and pattern of cutting different from natural processes may be affecting community assembly in ants at the landscape scale, which could have consequences for ecosystem processes because of the key roles that these species play.

From the landscape perspective, if timber management alters the relative contribution of ecosystem types within a landscape, then the persistence of communities may be affected. Isolated populations can readily become extinct, as has been well-documented in populations of forest birds (e.g., Askins and Phillbrick 1987; Angelstam 1992). A major difficulty for managers trying to make informed decisions for a number of important species is inadequate knowledge of parameters for dispersal of organisms. Small species generally have a lower capability to disperse than larger species. So, for small keystone species, such as ants, patches from which to colonize new habitats (postlogging) must be located close to the new habitats as they become suitable if community assembly processes are to occur in an uninterrupted fashion.

Conclusions

We have discussed the importance of boreal mixedwoods and other types to wildlife and touched upon the importance of wildlife to the boreal forest, and we have moved from the historical single-species view of wildlife and habitat. This change is a reflection of not only a societal concern for biodiversity but our own self-interest as harvesters of timber.

[6] I. Thompson, Petawawa National Forestry Institute, Chalk River, ON, and M. Setterington, Memorial University of Newfoundland, St. John's, NF, unpublished data.

In the analysis of the relationship of wildlife and boreal forest types presented here, the obvious lesson is that if we wish to maintain the boreal forest as habitat for wildlife, we will need to manage the whole boreal ecosystem. Doing this properly will necessitate the assessment of many ecosystem attributes. Given the evidence that wildlife are necessary for the survival and productivity of the forest, it is essential that the boreal forest be managed so that wildlife are explicitly considered in predictions of the future trends of all measurable ecosystem attributes. From a forest manager's perspective, this means that to reduce future input costs, it will be increasingly important to manage explicitly for all boreal wildlife in addition to the trees and plants of immediate economic value. Therefore, because of the importance of conifer types such as black and white spruce to wildlife and its apparent decline, the greatest challenge to the boreal mixedwoods program for sustaining the boreal forest (both plants and animals) will be to maintain spruce from site to landscape scales.

As resource managers, we often purport to be conducting scientific management; however, if that is to be the case, we must accept that we need to evaluate our management methods critically to determine whether they are achieving societal goals. In this case, it means managing in a way that sustains the boreal forest ecosystem at all spatial and temporal scales. Harvesting of the boreal forest over the past 50 years should be thought of as at least somewhat like inventing or developing a new widget. In the world of inventing new widgets, there are as many failures as successes. In our case, we are not just developing a new widget, we are manipulating an ecosystem. Because of its complexity, we should proceed with the attitude that our management for sustaining the boreal forest will fail until demonstrated otherwise.

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PLENARY SESSION II

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Changing philosophies and management for boreal mixedwood

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Abstract

Forest management philosophy and silvicultural practice change at a slow pace. Apparent changes are mainly the result of changes in technology and not philosophy. Implementation of the concept of ecosystem management and the results of social and legislative reaction to ecological activism are beginning to effect changes in forest management and silvicultural practice. Managing the Boreal Mixedwood Forest for mixedwood is being accepted across northern Ontario as a result of increased markets for previously underutilized hardwood species, principally trembling aspen (*Populus tremuloides* Michx.), and industrial responsibility for regeneration. However, greater philosophical and technological changes are required before the goal of sustainable development is attained.

Résumé

Les philosophies de gestion forestière et les pratiques sylvicoles mettent du temps à évoluer. Les changements perceptibles sont principalement dus au progrès technologique et non à l'adoption d'une nouvelle philosophie. Il n'en reste pas moins que la mise en oeuvre de la gestion écosystémique et les conséquences de la réaction sociale et législative au militantisme écologiste commencent à modifier les pratiques de la gestion forestière et de la sylviculture. Dans le nord de l'Ontario, on commence à accepter de gérer la forêt mixte boréale de manière à mettre en valeur les peuplements mixtes, étant donné la demande plus grande pour certains feuillus autrefois sous-utilisés, principalement le peuplier faux-tremble (*Populus tremuloides* Michx.), et la responsabilité de l'industrie en matière de régénération. Il faudra toutefois des changements philosophiques et technologiques plus profonds pour que l'objectif de développement durable puisse être atteint.

Introduction

In 1979, the Spruce–Fir–Aspen Forest Research Committee of the Canada–Ontario Joint Forestry Research Committee coined the name Boreal Mixedwood Forest and produced the report *Forest management and research needs in the Boreal Mixedwood Forest of Ontario.*[1] A little more than a year later, the Boreal Mixedwood Symposium was held on September 16–18, 1980, in Thunder Bay. In the 15 years since the symposium, the forest management agenda has changed as a result of the Class Environmental Assessment (Koven and Martel 1994), Comprehensive Forest Policy Framework for Ontario (Ontario Forest Policy Panel 1993), National Forest Strategy, and *Crown Forest Sustainability Act.* The momentum for this change is the result of a local to worldwide recognition that forests are important for the health and well-being of the human species and functioning of the biosphere.

The Comprehensive Forest Policy Framework for Ontario introduces the idea of a "new forest culture" and defines culture as "the total of ideas, beliefs, values, and knowledge that underpins social action." The Comprehensive Forest Policy Framework for Ontario identifies four basic components that summarize societal values and beliefs: a broad definition of forests, forest sustainability, community and resource use sustainability, and adaptive ecosystem management. The concepts of sustainability and ecosystem management are affecting, and will continue to affect, the way the Boreal Mixedwood Forest is viewed and how forest management is practised. This paper presents some issues, values, and ideas within the context of sustainability and ecosystem management that are influencing and will influence the development of forest management and silvicultural practice within the Boreal Mixedwood Forest.

Ecosystem

The biotic communities within the Boreal Mixedwood Forest are the result of an evolutionary process following glacial recession in which climate, soil, biotic and

[1] Weingartner, D.H.; Basham, J.T., eds. 1979. Forest management and research needs in the Boreal Mixedwood Forest of Ontario. Unpublished file report prepared by the Spruce–Fir–Aspen Forest Research Committee, Canada–Ontario Joint Forest Research Committee. 90 p.

abiotic disturbance, and the migration of plant and animal species combined to form the forest present today. As we begin to manage the Boreal Mixedwood Forest on an ecosystem basis, we need to define our perspective of this ecosystem and our role in its functioning. Botkin (1990) suggests an organic view in which we accept the changes and complexities of the ecosystem and recognize that we are part of the system. Within this perspective, we influence the forest ecosystem and take responsibility for the changes we bring about.

Within our culture, an industrialized consumer society, we have become alienated to the metaphysical or spiritual aspects of the natural world and life (Berry 1990; Drengson 1994). This metaphysical perspective or communion with nature can be equated with a recognition and respect for life. Without this perspective, management decisions tend to be made expeditiously without considering the long-term consequences; as a result, the tree becomes a mere commodity and the ecosystem a warehouse. Ecosystem management and sustainability are tied to a recognition that trees and other organisms are living entities, rather than lifeless inanimate objects, and that they perform functions of greater significance than the utilitarian, by maintaining life processes. Without this perspective and realization, we are unlikely to accept responsibility for our actions, and the ecosystem will become dysfunctional.

Diversity

The Boreal Mixedwood Forest functions by accumulating solar energy and redirecting this energy conservatively before it is dissipated (entropy). The diverse assemblage of green plants provides the structural diversity to maximize collection of solar radiation and provides habitat and nourishment for a variety of consumers (animals, nonphotosynthetic plants, fungi, and bacteria). Individually and collectively, the consumers provide benefits to the producers and other consumers by recycling the accumulated biomass (the associated organic compounds and nutrients) and by physically modifying the habitat (light, atmosphere, and soil conditions). Habitat change results in a succession of species communities within the ecosystem.

What is unique about the Boreal Mixedwood Forest is the assemblages of plants and animals that occur on mixedwood sites during the various successional stages. In a complex system like the Boreal Mixedwood Forest, there is a redundancy of life-forms to fill voids as individual species are displaced, and as a result there are many successional pathways for the system. There are general successional pathways that the Boreal Mixedwood Forest tends to follow during various stages of development. Even with general successional trends, the interaction of changing climate, developing soils, varying disturbance regimes, and the migration of plant and animal species, the biotic community on a mixedwood site may never again resemble that which previously existed; therefore, the Boreal Mixedwood Forest is an open-ended system.

In a degraded system or system of naturally low diversity, the restricted variety of life-forms limits the successional pathways for the system. In a system of low diversity, loss of individual species may result in major impacts, because of the limited alternatives available to compensate for the perturbation. Even with a diversity of species, the effect of human activity on the system and its components must be carefully considered (Ontario Forest Policy Panel 1993).

The two most important aspects of diversity in the Boreal Mixedwood Forest are species diversity and genetic diversity. Species diversity provides the forest with the primary resilience to withstand natural and anthropocentric disturbance. Genetic diversity provides the species with the adaptive capacity required to survive changing environmental and synecological conditions. Gene pool maintenance has been identified as an important component of biodiversity (Ontario Forest Policy Panel 1993; Hammond 1994; Maser 1994; Noss 1994).

The genetic resources of the Boreal Mixedwood Forest are unique and require some level of protection that has yet to be determined. The intolerant hardwoods (trembling aspen [*Populus tremuloides* Michx.] and white birch [*Betula papyrifera* Marsh.]) may not require as much protection as a result of their propensity to regenerate vegetatively. Vegetative reproduction, however, is a relatively static genetic state and limits new genetic material to mutations. In this regard, white birch may be in a better position than aspen, as it tends to seed-in more frequently. Current aspen clones may have existed for thousands of years and seem to have fared well; however, if climatic change develops as rapidly and to the extent projected by some climatologists, these genotypes may not be capable of providing the required timber and nontimber resources without genetic recombination. The conifer component of the Boreal Mixedwood Forest typically regenerates by means of seed. Black spruce (*Picea mariana* [Mill.] B.S.P.) and balsam fir (*Abies balsamea* [L.] Mill.) would appear to be relatively safe. The semiserotinous cones of black spruce provide a means for maintaining the native gene pool on site following harvest, and balsam fir seeds-in naturally on most sites without assistance (see Yang and Fry 1981). White spruce (*Picea glauca* [Moench.] Voss), on the other hand, requires more care. In the 1979 report,[2] it was suggested that high-grading represents a negative form of phenotypic selection in which succeeding generations become poorer. Maintenance of the white spruce gene pool appeared to be somewhat safe owing to the range of white spruce in Ontario; however, local genetic resources could be lost in areas where utilization is intensive. Two methods were suggested to maintain the genetic diversity of white spruce: 1) collect seed before harvest for planting stock to be returned to the site; and 2) use the white spruce seed tree system (Lyon and Robinson 1977) for regeneration. However, it was cautioned that the number and phenotypic characteristics of the seed trees required for successful regeneration and gene pool conservation were unknown.

In addition to traditional silvicultural operations, the introduction of foreign genetic material into the Boreal Mixedwood Forest could have negative impacts on native gene pools. Hybrid trees have the potential to become integrated into the landscape by seeding-in or breeding with native species. Hybrids may have adverse effects on ecosystem processes and stability over the long term by introducing new pests or pathogens or by disrupting the nutrient cycling process. Currently, a policy committee is preparing a gene conservation strategy policy statement to deal with this issue.

The impact of traditional silvicultural operations on the gene pool of understory species has not been studied, but it would appear that frequently occurring species (generalists) that have both sexual and asexual modes of reproduction and relatively nonspecific site requirements are safe. Infrequently occurring species (specialists) that have complex reproduction strategies or specialized habitats may not be safe. The introduction of plants for stabilization of logging roads or skid trails, both native living outside the range of the Boreal Mixedwood Forest and exotic, potentially could displace native species if they are aggressive colonizers. Currently, there is no policy addressing this issue.

Over 80 species of songbirds utilize the Boreal Mixedwood Forest (Welsh 1988) during various successional stages of forest development. Habitat maintenance or protection across all successional stages is generally important for sustaining songbirds and other species of wildlife. Habitats important during specific phases of the life cycle for some species or habitats of cryptic species are not obvious and can be easily damaged or destroyed during forest operations. The species involved and the location of the habitat must be identified prior to implementing operations to protect them. In addition to existence value, these species may have commercial, recreational, or other values. As an example, brook trout (*Salvelinus fontinalis* Mitchill) young-of-the-year utilize very small streams (<1 m wide x <25 cm deep) hundreds of meters from the primary habitat for protection for short intervals to periods of several years; only one-quarter of these small streams are indicated on maps of 1:20 000 scale (Ontario Ministry of Natural Resources 1993). Streams of this size may be easily overlooked in forest operations and may be clogged with logging slash or have their flows disrupted by heavy equipment. In addition to habitat value, these small streams help to maintain the temperature in the primary habitat into which they discharge.

Landscape

The landscape is the scale at which the Boreal Mixedwood Forest exists, occupying 45–50% of the productive forestland in northern Ontario (McClain 1981), and it is visible as a mosaic of stands of diverse composition. The Boreal Mixedwood Forest exists not in isolation but as an integral component of other local and continental ecosystems. As seasonal habitat for Neotropical birds, the Boreal Mixedwood Forest is directly united with ecosystems much farther to the south. Allen and Hoekstra (1994) suggest that the scale for managing the landscape is variable depending on what is to be sustained. For a forest, it may be a scale of tens of thousands of hectares, or 10 hectares for a specific organism. Salwasser and Pfister (1994) suggest that ecosystem management at the landscape level requires cooperation. Depending on what is being managed and the scale of the landscape, it may require cooperation across geographic or political boundaries.

Geographic information systems and management models are available and being improved to aid in planning management activity at a variety of scales (see Davis 1992). It must be remembered that models are constructs that simulate reality. The assumptions incorporated in the models are value judgments on the resources and processes that influence the output. Whether a model is accurate or not may not be of ultimate importance. What is important is the outcome of the management decisions on the landscape. As the Boreal Mixedwood Forest develops, the successional direction of the ecosystem is dependent upon random influences (sometimes catastrophic) that cannot be accounted for by models; because of this, there is a need to monitor the forest organisms considered of value for ecosystem and economic sustainability.

[2] Ibid.

Forest management

Historically, forest management in Ontario was synonymous with timber management. Economically, the spruce stock in northern Ontario was the main focus of industry, and only limited market interest existed for balsam fir and intolerant hardwoods (principally trembling aspen). Harvesting tended to be high-grading of the spruce stock and/or hardwood veneer logs in mixedwood stands. There were some exceptions, where all species except white birch were utilized.

The regeneration audit (Hearnden et al. 1992) revealed that following harvest, the percentages of mixedwood and hardwood cover types have increased at the expense of spruce and mixed softwood cover types, and the report suggests that the loss of conifer dominance is not reasonable. There may be significant economic and ecological reasons for maintaining conifers in the boreal forest. However, in long-term management planning, the successional trends of mixedwood sites must be recognized and taken into account. Within the dynamics of the Boreal Mixedwood Forest, each site is unique, both spatially and temporally. The ability of the site to produce a given level of a specific physical resource changes as the system migrates down various successional pathways. Left alone, a mixedwood site may again produce a similar level of a specific physical resource, but the successional time scale may be measured in centuries rather than years. With careful and thoughtful planning and investment in silvicultural activities, it may be possible to direct the successional pathway of a stand to obtain the desired physical resource.

Silviculture within the Boreal Mixedwood Forest has been traditionally limited to attempts to regenerate pure spruce, followed by weeding (mostly chemical release, some manual release) during the establishment period. Once established or free to grow, the stand was left to develop unaided. Survey results suggested that the cost of regeneration limited the funds available for other treatments (Weingartner and MacDonald 1994).

Silvicultural systems that consider the development of stand throughout the rotation are needed. Stand interventions at various times can be applied to modify species composition, influence the rotation age, maintain wind firmness, produce advanced regeneration, stabilize wood flow, enhance structural and species diversity and aesthetics, or provide wildlife habitat. It may be argued that funds for these treatments are still not available; however, with the increased development and use of careful logging techniques to protect advanced regeneration, funds should be available for other treatments that may result in future ecological or economic savings or improved production (qualitative or quantitative).

Sustainability

The National Forest Strategy, Class Environmental Assessment (Koven and Martel 1994), Direction '90s (Ontario Ministry of Natural Resources 1991), Comprehensive Forest Policy Framework for Ontario, and *Crown Forest Sustainability Act* bring forward in a cataloged or legalistic manner summaries of general societal ideals, values, and beliefs about the importance, use, and maintenance of forest ecosystems. The main propositions expressed are the ideas of sustainability and sustainable development.

Sustainability as expressed in the Comprehensive Forest Policy Framework for Ontario, "forests are forever," is straightforward and easily grasped. Sustainable development, on the other hand, remains a vague concept even after reading Direction '90s and the Comprehensive Forest Policy Framework for Ontario. Two concepts from ecological economics that are helpful in understanding sustainable development are economic growth and economic development. Economic growth relates to increased throughput (i.e., increased resource consumption), and economic development relates to increased product quality (Daly 1991, cited in Wetzel and Wetzel 1995). "What is being sustained in sustainable development is a level, not a rate of growth, of physical resource use. What is being developed is the qualitative capacity to convert that constant level of physical resource use into improved services for satisfying wants" (Daly 1991, cited in Wetzel and Wetzel 1995). Economic growth is an impetus for resource use, but there is a limit that must not be exceeded if economic stability and well-being are to be maintained over the long term. The economic carrying capacity is the point beyond which continued economic growth will exceed sustainable resource production and result in declining economic well-being. In this situation, promoting continued economic growth only intensifies the decline in economic well-being. The only effective remedy is a reduction in the size of the economy (Wetzel and Wetzel 1995).

The Forest Resource Assessment Policy will replace the Timber Production Policy of 1972. The "interim" version released in September 1995 addresses components of the ecosystem in addition to timber production, specifies the requirements for the assessment, and provides for a minimum projection period of at least 150 years. The policy also provides an audit function to assure that the forest is sustained and should prevent exceeding the economic carrying capacity. For the communities of northern Ontario, the Boreal Mixedwood Forest is the most important ecosystem for maintaining economic sustainability, because it occurs on the sites having the greatest production potential and represents a significant proportion of the landscape.

Education

Lifelong learning as a means of nonformal education has been promoted for as long as I can remember. Learning is the first step in the education process and represents the acquisition of basic concepts and facts, or knowledge. The Ontario Advanced Forestry Program, conferences like this one, professional and scientific journals, and publications by the Canadian Forest Service, Ontario Ministry of Natural Resources, and USDA Forest Service all provide opportunities for learning. The second step in the education process is an internal synthesis of knowledge that results in understanding. Without understanding, knowledge is of little value. Understanding enables us to apply knowledge to different situations that are encountered. It is everyone's responsibility to increase their knowledge and understanding of ecosystem function and processes, forest management, and silvicultural techniques applicable to the Boreal Mixedwood Forest. An additional responsibility is to transfer this knowledge to those with whom we associate and to any others who may have an effect on the forest.

Ontario's component of the National Forest Strategy identified the certification of silviculture and forest workers as a need (NFSC-OS 1993). The Ontario component of the strategy identified the technological aspects of a worker's career that were required to meet health and safety standards and production capabilities: "To enable the workforce to contribute fully to sustainable forest management and enhanced economic opportunities" (NFSC-OS 1993). The *Crown Forest Sustainability Act* has provisions for setting the minimum qualifications to be specified in the Forest Operations and Silviculture Manual. It is essential and cannot be overemphasized that woods workers need a basic biological understanding of the functioning of the Boreal Mixedwood Forest as an ecosystem, because it is the woods workers who carry out the physical operations within the forest and thereby directly modify the ecosystem. Woods workers are in the best position to prevent thoughtless physical or biological damage to the ecosystem during operations.

Summary and conclusions

Sustainability and adaptive ecosystem management are the current terms used to describe the human perspective on forest use and interaction with forest ecosystems. At the surface, the concepts of sustainability and adaptive ecosystem management may not appear to be significantly different from the concepts of multiple-use or integrated resource management. On a philosophical level, these concepts represent a change from a more utilitarian perspective, to one where the utilitarian aspect is secondary to the life processes of the forest.

To implement ecosystem management for sustainability in the Boreal Mixedwood Forest, five areas must be given increased recognition and consideration. First, the conservation of species and genetic diversity is central to maintaining the Boreal Mixedwood Forest. Second, the Boreal Mixedwood Forest is an open and dynamic system, thereby limiting the physical resources available in time and space and the capacity for economic growth. Third, silvicultural systems that consider stand development over the entire rotation and successional pathways are needed. Fourth, greater cooperation in planning among a broader group of forest users is required. Fifth, there must be increased knowledge and understanding of the biology and ecology of the Boreal Mixedwood Forest by all those involved with management and operations.

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Management tools and strategies: forest operations

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Abstract

"Alternative" forest operations aimed at boreal mixedwood stands can be grouped into five broad categories:

- strip-cutting techniques to promote regeneration in the removed strips;
- removal of most of the aspen (*Populus tremuloides* Michx.), white birch (*Betula papyrifera* Marsh.), and balsam fir (*Abies balsamea* [L.] Mill.) component of the stand, leaving the remaining softwoods, usually spruce (*Picea* spp.);
- removal of the majority of the overstory while protecting advance regeneration and any trees that may be left;
- harvesting of small, irregular-shaped patches (e.g., 0.1–0.5 ha in size) to promote regeneration of stands too susceptible to windthrow and snow damage, or which are of poor quality; and
- selection thinning operations in 30- to 50-year-old stands to utilize volumes that would be lost to mortality, concentrate growth on the remaining trees, and make the remaining stand more wind firm and resistant to snow damage.

Natural regeneration is usually relied on when harvesting in boreal mixedwood stands using alternative harvesting systems. Light site preparation techniques, however, combined with some planting, should result in adequate regeneration with a broad species mix. Some of the equipment and techniques that can be used in alternative harvesting systems in boreal mixedwoods are outlined. The specific requirements for the equipment and operational constraints are presented, and the limitations of some of the current equipment discussed.

Résumé

Les opérations forestières visant les peuplements boréaux mixtes peuvent être groupées en cinq grandes catégories :

- Techniques de coupe par bandes pour favoriser la régénération des bandes coupées;
- Enlèvement de la plupart des éléments constituants d'un peuplement de peupliers-faux-tremble (*Populus tremuloides* Michx.), de bouleaux (*Betula* spp.) et de sapins baumiers (*Abies balsamea* [L.] Mill.) laissant au sol les espèces résineuses, ordinairement de l'épinette (*Picea* spp.);
- Enlèvement de la plus grande partie de l'étage dominant tout en protégeant la régénération préétablie ainsi que les arbres résiduels;
- Coupe par bouquets de forme irrégulière (e.g., d'une superficie de 0,1–0,5 ha) afin de favoriser la régénération des peuplements qui sont soit trop sensibles aux chablis et aux dommages causés par la neige, soit de qualité inférieure; et
- Opérations d'éclaircies par jardinage dans les peuplements de 30 à 50 ans afin d'utiliser la matière ligneuse qui serait perdue par suite de mortalité; concentrer la croissance au niveau des arbres residuels et voir à ce que le reste du peuplement devienne plus résistant au vent et aux dommages causés par la neige.

Ce communiqué met en relief quelques unes des techniques, des systèmes ainsi que l'équipement disponsible dans les opérations forestières «alternatives» au niveau des peuplements boréaux mixtes. On y discute des considérations d'exploitation, des exigences dans la planification et des limitations de quelques unes des pièces d'équipements standards actuels. Il y est aussi question des besoins de ces équipements, de mesures visant à minimiser les dommages subits par les arbres résiduels et par la station, ainsi que des conditions préalables de succès dans les coupes partielles à l'intérieur des peuplements boréaux mixtes.

Introduction

"Alternative" forest operations aimed at boreal mixedwood stands can be grouped into five broad categories:

- strip-cutting techniques to promote regeneration in the removed strips;
- removal of most of the aspen (*Populus tremuloides* Michx.), white birch (*Betula papyrifera* Marsh.), and balsam fir (*Abies balsamea* [L.] Mill.) component of the stand, leaving the remaining softwoods, usually spruce (*Picea* spp.);
- removal of the majority of the overstory while protecting advance regeneration and any trees that may be left;
- harvesting of small, irregular-shaped patches (e.g., 0.1–0.5 ha in size) to promote regeneration of stands too susceptible to windthrow and snow damage, or which are of poor quality; and

- selection thinning operations in 30- to 50-year-old stands to utilize volumes that would be lost to mortality, concentrate growth on the remaining trees, and make the remaining stand more wind firm and resistant to snow damage.

This paper outlines some of the techniques, systems, and equipment available for "alternative" harvesting in boreal mixedwood stands. The operational considerations and requirements in planning are discussed, as well as limitations of some of the "standard" current equipment. Requirements for equipment, minimal damage to residual trees and site, and prerequisites for success when partial cutting in boreal mixedwood stands are also presented.

Operating techniques

There is a wide range of techniques in which conventional full-tree harvesting systems have been adapted to partial cutting in boreal mixedwoods. Most of these techniques strive to remove most of the aspen, birch, and balsam fir component, while favoring the remaining softwoods (usually spruce). Cutting generally occurs as one pass over the entire cut area, two- or three-pass strip cutting, or progressive strip cutting, starting on the leeward side of the stand. The cut and leave strips can have varying widths, and there can be edge areas where some selection cutting can occur. Navratil et al. (1994) present good descriptions of the many techniques available. Similar operating techniques using full-tree, tree-length, or cut-to-length (CTL) systems can be used when harvesting areas as outlined above and when protecting the advance regeneration.

Shelterwood cutting and selection thinning can also be employed. In general, CTL systems employing forwarders for off-road transport are recommended. A CTL operation would normally have 4-m-wide machine trails, at a spacing of 20–30 m, with ghost trails within the leave corridors, if required. Motor-manual CTL logging, with a small-size skidder or forwarder, is also applicable.

When a stand is opened up and is too susceptible to windthrow or snow damage or is of poor quality or low volume, small (e.g., 0.1–0.5 ha), irregular-shaped patch cuts may be required. In this situation, CTL systems employing forwarders are the most suited. This is due to the widespread nature of the patches, small size of patches, long off-road transport distances, and the need for minimal roadside landings.

Harvesting systems

Full-tree method

With the full-tree method, full trees (tree bole with branches and top intact) are delivered to roadside for processing. A typical system employs feller-bunchers, grapple skidders, roadside delimbers, and slashers. Full-tree logging is well developed and is the major logging method used in Ontario.

However, full-tree systems have been developed mainly for clear-cutting. When used in partial- or small patch cutting situations, full-tree logging has the following disadvantages:

- large roadside landings;
- removal of limbs and tops from site, resulting in removal of nutrients from the stump area and concentrations of debris at roadside;
- wide cut corridors;
- excessive damage to residuals (10–20% damage to residuals is not uncommon), especially along corridors;
- limited skidding distance (usually limited to a maximum of 300 m); and
- considerable off-road vehicle traffic concentrated near the roadside landings.

Although there are some exceptions, feller-bunchers have been designed to work in clearcuts, generally in a zone in front of the machine. A minimum cut strip width of 8 m is usually required. However, this depends on the feller-buncher employed and is influenced by the operating procedure:

- the operator generally crowds the right side of the strip because the boom causes a blind spot;
- width of the machine (about 3 m or more);
- tail swing (0–3 m);
- area required to bunch wood; and
- maximum and minimum working reach (generally, maximum 6–7 m and minimum 3–5 m).

Tree-length method

With the tree-length method, tree boles without branches and tops are delivered to roadside. The tree lengths may be slashed at roadside or delivered directly to the mill. Some typical tree-length systems are as follows:

- conventional cut and skid, with motor-manual felling, limbing and topping, cable skidding, and possibly roadside slashing;
- feller-buncher, in-stand delimbing with a stroke delimber, grapple skidding, and possibly roadside slashing; and

- one-grip harvester and cable or grapple skidder.

Of the above systems, the feller-buncher/in-stand stroke delimbing system is not possible in partial-cutting situations where large standing residuals are left. This is because the delimber's boom will strike residual trees. Otherwise, the tree-length method is applicable to corridor and small patch cutting.

When compared with full-tree systems, tree-length systems generally result in more or less the same amount of damage to residual trees, require slightly smaller roadside landings, and result in the tops and branches being left in the stump area. However, as the boles are skidded along the ground, they pick up more dirt.

Cut-to-length method

With the CTL method, bucked pulpwood and logs are delivered to roadside. Generally, all of the processing occurs at the stump. A typical system includes a one-grip harvester and forwarder or motor-manual felling, limbing, and bucking, with off-road transport by forwarder or small skidder. Current mechanized CTL systems have been designed specifically for widely dispersed small patch and partial-cutting situations (e.g., Finnish/Swedish conditions). When used properly, CTL systems can result in minimal residual stand damage. For example, in Finland, the maximum damage allowed to residuals is 2%, although in practice forest owners are demanding 0% damage. Damage levels of 10–20% to residuals and large landings typical to full-tree systems are not tolerated.

Owing to the larger load size of forwarders (10 m^3 vs. 2–2.5 m^3), the maximum off-road operating distance is much farther than with skidders (600 m vs. 300 m). As a result, a CTL system employing a forwarder requires less road (8.6 m/ha vs. 17.2 m/ha) and can be efficiently used when cutting small patches widely dispersed over the terrain. As no processing occurs at roadside, and as bucked logs and pulpwood are of short length and can be piled high, the CTL method requires minimal roadside landings. As a result, more area can be left in a partially cut condition, and site impacts are reduced. As the wood is carried and cut inventory levels are low, wood quality is also maintained.

Specially designed one-grip harvesters can fell trees in front of and on both sides of the machine. Generally, the maximum reach for a one-grip harvester is about 10 m, and it can fell trees directly beside the machine. Thus, the operating zone is much larger than for a feller-buncher. Because of its design, the harvester can work in a 20-m-wide swath through the stand, while traveling on one 4-m-wide trail. Usually the trees are limbed in front of the harvester, thus forming a brush mat on which both the harvester and forwarder can travel.

If the machine trail spacing is greater than 20 m, a ghost trail through the leave corridor is generally required. The ghost trail is about 3 m wide, and the harvester fells and directs the fall of the trees toward the machine trail. The harvester then returns down the machine trail, grabbing the tops of the trees, and processes them. When employing a small-size one-grip harvester and a 20-m machine trail spacing, the harvester can work within the stand from a ghost trail and pile the wood at the side of the machine trail.

The most appropriate operating techniques depend on the age of the stand, tree size, and the spacing between the residual trees.

Considerations/requirements

Economics

One of the most important factors to consider when choosing the most appropriate operating technique and system is economics. For a one-grip harvester and forwarder operation to be economically feasible, the following are generally required:

- removal of more than 50 m^3/ha;
- reasonably priced equipment;
- minimum operation of two shifts per day;
- minimum production greater than 30 000 m^3/year, but preferably greater than 40 000 m^3/year; and
- the realization that partial cutting costs more than clear-cutting, and this has to be offset by lower stumpage fees or higher millgate prices.

Stand condition

When choosing the most appropriate operating technique and system, the stand condition must be considered. This includes the ability of the remaining trees to respond to the opening up of the stand (e.g., amount of live crown) and their susceptibility to windthrow or snow damage. Also, the presence of rot and insects and the quality of the remaining trees are important. There is no point in thinning or partially cutting stands that have little or declining value or have low potential for future growth.

In addition to volumes removed per hectare, off-road transport distances, and harvesting area size, stand conditions that affect the harvesting operations also need to be considered. Among others, these factors include:

- size of the trees removed and retained;
- species removed and retained;
- branchiness of the trees;
- presence of undergrowth;
- ground conditions/terrain class; and
- amount of dead and unmerchantable trees.

Equipment design

In partial-cutting situations, equipment use should result in minimal residual tree and site impact. The equipment should be narrow (<3 m), have low ground pressure (maximum 6–7 psi), and have low-impact running gear (rubber tires or low track grousers).

Visibility from the cab should be excellent. In many cases, the visibility from conventional feller-bunchers is limited to the right or left, depending on the location of the cab, boom, and engine cowling. As individual trees are selected in partial-cutting situations, good visibility of the crown is also necessary. This requires a skylight or a large sloping front window on the cab.

On a fully operational scale, logging must also occur at night. This is especially true during winter, when the daylight period is short. This requires good diffuse lighting systems that light up the entire surrounding forest to allow good visibility and selection of trees.

The harvesting machines must have a wide operating zone in front and to the sides. This allows for minimal machine trails, machine movement within the stand, and stand damage. It also allows the harvester to reach trees from various positions along the machine trail. Working from both sides of the machine trail results in more time spent harvesting trees than moving within the stand.

Because most feller-bunchers and some excavators equipped with harvester heads pick the tree up to move it closer to the machine, they must be equipped with a counterweight or be specially designed (e.g., Timbco T420 and John Deere JD653E). This counterweight, or overhang in many cases, on the feller-buncher can result in a tail swing in excess of 3 m (i.e., rear of feller-buncher extends over tracks when turned 90 degrees). When operating in partial-cutting situations, this is an important factor in regard to damage to residuals and cut strip width.

In partial-cutting situations, the protection of advance regeneration is often a priority. In these situations, the use of continuous saw heads should be discouraged. This is because whenever the head is moved toward a tree to be cut, any advance regeneration in its path will also be cut.

Stand damage

Damage levels to residuals of 10–20% typical of full-tree operations are not acceptable. As mentioned above, the maximum allowed in Finland is 2%, and the norm is to strive for 0% damage. This also includes minimal damage to the roots and soil and minimal alteration of surface or subsurface water flow.

Good planning and layout are prerequisites for minimizing stand damage. The layout must be done with the partial cutting in mind (i.e., typical clear-cutting layout does not work). A minimum of machine trails should be ribboned in the stand (i.e., 20-m spacing at least). The trail width should be kept to 4 m, except on curves, where it should be increased to 5 m. The machine trails should have no sharp curves and should be in loops or have turnarounds. All machine trails should run straight up or down hills (maximum side slope 10%) and around obstacles and soft spots.

Proper operating technique and equipment selection are also critical. For example, some general rules to follow are:

- use CTL systems;
- avoid full-tree systems;
- use small, narrow, low ground pressure machines with long-reach capability;
- preferably use rubber-tired machines;
- if tracked machines are used, use low grousers;
- limb the trees in front of the harvester to form a brush mat;
- use bumper trees to absorb most damage where necessary; and
- do not bring in excessively large equipment to handle a few large trees; get out with a chain saw to take care of them.

In addition to proper planning, layout, and selection of equipment, choosing the correct season to operate in is also important. Preferably, partial-cutting operations in boreal mixedwood stands should occur during the winter. This is because boreal mixedwood stands are generally found on fine soils (i.e., clays, silts, or loams) that are susceptible to compaction and rutting when wet and unfrozen. Also, spruce and aspen are very susceptible to attack from root-rotting pathogens, owing to their fine surface root systems, which are easily damaged by vehicle traffic on unfrozen fine soils. Also, bark adhesion to the wood is highest during winter.

Perhaps the most important component for minimizing damage in partial cuts is the operator. For partial-cutting operations, it is imperative that highly skilled and motivated operators are chosen. These operators must be trained in both the operation of the machine and the basics of forestry. They must have general knowledge in silviculture, ecology, and mensuration. To make the operations profitable, it is the operator who must select the trees and ensure the correct basal area is maintained in the stand. Good supervision is also required to monitor the harvesting production results and damage to residuals and site and to give feedback to the operators.

Prerequisites for success

The following prerequisites are required to ensure success in "alternative" or partial-cutting operations in boreal mixedwood stands:

- proper selection of harvesting method, equipment, system, and technique to meet the conditions;
- good planning, layout, and control;
- good operator training and commitment;
- good planner/supervisor training and commitment;
- company management commitment; and
- government commitment.

No single harvesting method or system is a panacea for all situations. Feller-buncher-based, full-tree systems may be required in certain situations, whereas the CTL systems may be more applicable in others. The key to choosing the right system in most situations is knowing the operating conditions and good planning. The requirement for good training of operators, supervisors, and planners involved in partial-cutting situations cannot be stressed enough.

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Implications of new legislation and policy changes for boreal mixedwood management in Ontario[1]

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Abstract

During the last 10 years, the forestry community has given increased attention to the mixedwood component of the boreal forest. As is often the case, local management initiatives involving on-the-ground actions have preceded the availability of formalized policy and legislation. In recent years, there have been many developments in legislation and policy that recognize the importance of all aspects of Ontario's forests, including the boreal mixedwood component. Legislative changes include the development of the *Crown Forest Sustainability Act* and the release of the Environmental Assessment Board's decision regarding the Class Environmental Assessment for Timber Management on Crown Lands in Ontario. Recent policy developments include a policy framework for sustainable forests, the preparation of a new silvicultural guide, and a series of *Boreal Mixedwood Notes.* The new legislation, policy documents, and technical manual provide support for advancing boreal mixedwood management in Ontario.

Résumé

Depuis une dizaine d'années, les forestiers accordent de plus en plus d'importance aux peuplements mixtes de la forêt boréale. Comme il arrive souvent, des mesures de gestion locales ont été mises en oeuvre avant d'être encadrées par une législation et des politiques en bonne et due forme. Cependant, au cours des dernières années, l'importance de tous les aspects de la forêt ontarienne, y compris la forêt mixte boréale, a été reconnue dans le cadre de nombreux changements touchant les lois et les politiques. Les changements de nature législative comprennent l'élaboration de la *Loi sur la durabilité des forêts de la Couronne* et la publication d'une décision de Commission des évaluations environnementales sur l'Évaluation environnementale de portée générale en ce qui concerne la gestion des forêts de la Couronne ontariennes. Les changements touchant les politiques comprennent l'élaboration d'une politique-cadre sur la durabilité des forêts et d'un nouveau guide de sylviculture ainsi que la publication de la série *Boreal Mixedwood Notes.* Tous ces changements vont dans le sens d'une meilleure gestion de la forêt mixte boréale de l'Ontario.

[1] Paper not available.

Boreal mixedwoods—an industrial perspective

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Abstract

Progress in mixedwood management to date has focused on silvicultural techniques and scientific advancements for individual site prescriptions, based on stand by stand management. However, the management of mixedwood forests necessitates forest-level planning with specific objectives and targets embodied in the strategies. Improvements in computer modeling, crop planning, and growth and yield data are needed to address this level of planning. The future of mixedwood management is bright, but the utilization of low-grade birch (*Betula* spp.) must be gradually phased in as industrial markets develop over the next decade.

Résumé

Les progrès réalisés jusqu'à présent en ce qui concerne la gestion des forêts mixtes ont porté sur les techniques sylvicoles et les progrès scientifiques applicables à chaque station, selon un mode de gestion axé sur les peuplements. La gestion des forêts mixtes nécessite pourtant une planification à l'échelle de forêts complètes, avec des objectifs et des cibles précis intégrés aux stratégies. Pour pouvoir effectuer ce type de planification, il faudra améliorer la modélisation par ordinateur, la planification des récoltes et la qualité des données de croissance et de rendement. L'avenir de la gestion des forêts mixtes est prometteur, mais l'exploitation du bouleau (*Betula* spp.) de qualité inférieure devra être introduite graduellement au cours de la prochaine décennie, à mesure que les marchés industriels le permettront.

Introduction

I have been asked to give an industrial perspective of boreal mixedwood management. This industrial viewpoint will not be Ontario Ministry of Natural Resources or Canadian Forest Service bashing. Rather, I would like to take this opportunity to highlight a few of the economic realities and challenges of industrial silviculture.

E.B. Eddy Forest Products Ltd. is a major user of both trembling aspen (*Populus tremuloides* Michx.) and white birch (*Betula papyrifera* Marsh.). This fiber, along with a mix of tolerant hardwoods, is used to produce pulp for blending into specialized, high-value paper products. We currently use 640 000 m^3 of hardwood fiber per year. A further expansion of 162 000 m^3 of white birch and tolerant hardwoods is scheduled for 1998, and we are planning for a major expansion around the turn of the century.

Our company has developed the manufacturing processes and marketing strategy to reflect the available wood supply. The company currently manages three sustainable forest licences (SFLs), and we are negotiating cooperative SFLs on four other units. In addition, the company purchases fiber from Crown management units in both the Boreal and Great Lakes–St. Lawrence forest regions.

Demand and supply

A serious problem at this time is that the current supply of white birch pulpwood significantly exceeds the industrial demand. Yet we firmly believe that the hardwood component of the mixedwood forest will be used over the next 5–10 years. The wood supply is sustainable, and industry will develop the manufacturing capacity to reflect the timber supply.

A demand for the softwood component of these mixedwood stands will always be present. The softwood timber is critical to the viability of the saw milling, veneer, and pulp sectors. The wood supply is sustainable, provided the silvicultural strategies and prescriptions ensure the renewal and management of the softwood component.

The tendency to a soft forestry regime of natural regeneration and an aversion to tending will be a disaster to the sustainability of the softwood resource. The Hearnden et al. (1992) regeneration audit revealed that the stocking of young stands is acceptable, but that the species composition is shifting toward mixedwood and hardwood stands in many areas.

The forests will be green, but are we allowing the softwood species composition to be eroded? The broader definition of forest sustainability includes community stability and industrial viability within an adaptive ecosystem-oriented approach to forest management. The gradual erosion of the softwood component is not consistent with a philosophy of sustainability. Foresters have focused on individual stand prescriptions, and we have developed good site preparation techniques. However, it appears that we have not placed sufficient attention on the balance of the hardwoods and softwoods in the future.

Many may criticize industry for an old-school timber attitude, yet most biologists will acknowledge that timber harvest planning has the most significant effect on habitat management. Industry supports the position that all forest values must be respected from the initial stages of forest planning, and management must be based on credible information. The challenge is to identify and plan for the nonindustrial values of biodiversity, wildlife habitat, old growth, and others, such as endangered species. However, it must be management by direction. The indiscriminate withdrawal of timber from the industrial land base violates the basis of sustainability. The tensions and conflicts can be lessened by building the values into the planning process.

The emphasis on planning will guide the management of the Boreal Mixedwood Forest. We may need more softwood components for wildlife strategies in some areas and more hardwood in others, but boreal mixedwood management must be planned so that the harvest and regeneration programs can be integrated and effective.

Silvicultural performance

The most significant accomplishment in Ontario's forest management in the last 15 years has been the establishment of the Forest Renewal Trust Fund and the Forestry Futures Trust Fund. These guaranteed funding techniques will ensure that there is sufficient money for silvicultural operations. They will allow foresters to "walk the talk." It is one thing to promise good silviculture in a management plan; it is another thing to do the job.

We are all aware of examples of softwood plantations that were choked because of the lack of money for tending. Also, the trend toward natural regeneration because of purely economic constraints has resulted in an erosion of the softwood sustainability. The trust fund system will now resolve these problems.

The challenge of silvicultural responsibility has been accepted by industry. The new SFLs have specific planning and silvicultural responsibilities. Industry is paying into the trust funds and special purpose accounts and is aggressively pursuing new SFLs. It is marrying the responsibility and financing of silviculture. This is a win–win formula for forestry in Ontario.

Challenges

Now that the silvicultural financing is resolved, the next step is to ensure forest-level planning to guide stand prescriptions. This will require more attention to:

- forest-level modeling;
- crop planning;
- silvicultural growth and yield projections; and
- inventory data.

Ontario desperately needs a land use strategy to guide the resolution of conflicting demands for forest resources. One of the components of a land use strategy must be the Forest Resource Assessment Policy, to identify the range of industrial opportunities and silvicultural investments.

The quality of mixedwood silviculture in individual stands is meaningless unless we know what we are aiming for at the forest level. A stand may look reasonable, but is it contributing to the forest-level objective?

I believe that we, as industry and government foresters, have made significant strides in mixedwood silviculture. You have heard and seen examples from the research community. Let me now share some highlights and directions that we at E.B. Eddy Forest Products Ltd. have witnessed in silviculture.

Messages

As you have seen, we have developed good stand management techniques. The next challenge is to plan and develop silviculture on a forest-level landscape. I would like to leave you with three messages:

1. *Be site specific.* Please remember that one size does not fit all. Prescriptions for jack pine (*Pinus banksiana* Lamb.) and white spruce (*Picea glauca* [Moench] Voss) are very different.

2. *Remember the boreal ecosystem.* The selection strategies for the Great Lakes–St. Lawrence Forest Region are not appropriate for the Boreal Forest Region. The public love for tree marking and the anti-clear-cutting pressures should not undermine the silvics and ecology of the boreal forest.

3. *Marketability is near.* Industry is expanding to reflect the sustainable forest that is available, but this will take 5–10 years for the birch pulpwood component of the boreal forest. The industrial demand and utilization of poplar should not be a problem; however, the pressure to demand that all birch pulpwood be used now is not reasonable. A restriction on harvest will simply aggravate the softwood timber shortages and future crop planning.

Conclusion

As government and industrial foresters, we are moving in the right direction. The stand prescriptions, silvicultural techniques, and financial assurances have been secured. The next challenge is the design of forest-level planning for the Boreal Mixedwood Forest.

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TECHNICAL SESSION I(A): UNDERSTANDING DIVERSE MIXEDWOOD ECOSYSTEMS

Moderator

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A multithematic spatial data base for managing boreal mixedwood forests of Ontario

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Abstract

Mixedwood forests must be managed as a multiuser renewable resource, as an integral component in a landscape, and on a sustained basis. Large-scale spatial data are crucial for this approach. We describe a comprehensive spatial data base assembled by the Forest Landscape Ecology Program, which is suited for managing boreal mixedwood forests of Ontario. Forest land cover, historical forest harvests, historical forest fires, surficial geology and substrate, topography, and climate are basic components of the data base. These data permit the use of new tools such as geographic information systems for increased spatial accuracy in decision making. They also present an opportunity for forest managers to link the multiscale facets of forestry practice explicitly: policy development, strategic planning, and silvicultural operations.

Résumé

La forêt mixte boréale est une ressource renouvelable à utilisateurs multiples, qui doit être gérée de façon durable, à titre de partie intégrante du paysage. Les données spatiales à grande échelle revêtent à cet égard une importance cruciale. Nous décrivons la base de données spatiales du Programme d'écologie des paysages forestiers, qui convient à la gestion de la forêt mixte boréale de l'Ontario. Les principaux éléments de cette base de données intégrée sont le type forestier, l'exploitation forestière passée, l'historique des incendies de forêt, le substrat rocheux, les dépôts superficiels, la topographie et le climat. Grâce à ces données, les gestionnaires pourront utiliser de nouveaux outils, comme les systèmes d'information géographique, pour mieux cibler spatialement leurs décisions. Ils pourront aussi créer des liens explicites entre les divers aspects de la pratique forestière, à toutes les échelles : élaboration des politiques, planification stratégique, travaux sylvicoles.

Introduction

Perceptions of boreal mixedwood (BMW) forest vary from polycultures of different tree species at smaller spatial scales to mosaics composed of patches of different forest stands at larger spatial scales. The former perception of BMW forest is used in silvicultural manipulation (establishment to harvest) of forest stands. On the other hand, the latter view is relevant to the "big picture issues," such as conserving biodiversity, establishing corridors, and strategic planning for woodsheds or watersheds. Neither view is right or wrong; instead, both are complementary approaches to managing a forest resource on multiple scales. BMW forest mosaic in a landscape is dynamic: it is a spatial geometry that shifts in time owing to ontogenic (e.g., stand conversion due to aging) and allogenic (e.g., stand replacement due to fires) changes. The nature of this shift and its causal factors are fundamental to policy and strategic plan development. Because of the differences in spatial and temporal scales, extrapolation of conventional species/site-oriented information is not adequate to understand and manage BMW forest landscapes.

The multithematic spatial data base

The Forest Landscape Ecology Program (FLEP) of the Ontario Forest Research Institute developed, compiled, and acquired a series of spatial data bases to support the Ontario old-growth forest policy formulation (Perera and Baldwin 1994). Several features are common to these data. They are spatially explicit (georeferenced), cover most of northern Ontario, and are coarse in resolution. In addition, these data exist in a geographic information system (GIS) medium (in SPANS™ quad tree raster format) and, thus, are easily accessible. Three major groups of the spatial data comprise the FLEP multithematic spatial data base. The first group contains the primary land attributes that provide information on the structure and composition of the forest landscape. The second group of data includes the various sources of landscape change. The third group is composed of templates that are used to subdivide the province of Ontario either ecologically or administratively.

Primary land attributes

The data layers that comprise the first group are forest land cover, bioclimate, surficial geology, soils, and topography (Table 1).

Forest land cover

The forest land cover data layer was derived from a supervised image analysis of the Landsat Thematic Mapper (TM) data. The temporal range of these images is from 1987 to 1991, and they contain nine general classes, which include two dense mixedwood forest types: mixed forest with >50% coniferous species and mixed forest with >50% deciduous forest species (Table 1). Further methodological details of land cover classification can be found in Spectranalysis (e.g., Spectranalysis Inc. 1993).

Bioclimate

We use the Ontario climate surface produced by Watson and MacIver,[1] based on Ontario climate stations. The spatial resolution of these data is 1 km^2. The bioclimate parameters derived from these data include mean periodic (day, month) temperature, degree days, frost-free period, precipitation, and water deficit.

Surficial geology

We developed a digital atlas for surficial geology of Ontario (Perera et al. 1996). It combined all the information published to date by various authors into a provincially comprehensive classification (Table 1), which eliminated locally specific terminology and classes. However, it also retained the original classification schemes (e.g., Chapman and Putnam 1984). These data were integrated at 1:500 000 map scale.

Soils

Our data base on soils is based on the digital Ontario Land Inventory, which provides information on several pedological parameters, such as soil texture and carbonates. This data base was digitized at 1:250 000 map scale.

Topography

The digital terrain data layer was developed by Spectranalysis Inc.,[2] based on the U.S. Defence Mapping Agency Digital Terrain Elevation Data. These data exist at a horizontal resolution of 1 ha and a vertical resolution of 10 m. The major derivatives of the terrain data include slope, aspect, and elevation.

1 Watson, B.G.; MacIver, D.C. 1995. Bioclimate mapping of Ontario. Environ. Can., Toronto, ON. Mimeo.

2 Spectranalysis Inc. 1994. The generation of elevation, slope and aspect data for the Great Lakes–St. Lawrence study area of the OFRI spatial forest database project. Mimeo.

Sources of landscape change

The major direct causes of landscape change in northern Ontario include forest fire, forest harvest, and anthropogenic intrusions through increased infrastructure development and road access.

Forest fire

The occurrence of forest fires in Ontario during the last 70 years was assembled into a digital data base from various sources, such as previously published maps (e.g., Donnelly and Harrington 1978), Ontario Ministry of Natural Resources [OMNR] fire data, and Landsat TM data from 1973 to 1990. This data set exists in a readily useable digital form (Perera and Bae[3]). It describes the size (larger than 200 ha), spatial characteristics, geographic location, and time (by year) of all fires in northern Ontario from 1920 to 1994.

Forest harvest

Our information base on forest harvest includes the large clearcuts (200+ ha) in northern Ontario from 1950 to 1990. These data contain the spatial characteristics of the harvest polygons (e.g., size, shape, edge, substrate, geographic location) and time of the forest harvest (by decade). The source of forest harvest data is a supervised classification of Landsat TM imagery from 1973 to 1990.

Anthropogenic intrusions

The forested landscape of northern Ontario is not affected by direct anthropogenic intrusions as much as that of southern Ontario. However, development activities (e.g., settlements, mining, and agriculture) are common in certain parts of the north. In addition, expansion of the access road network poses the potential for increased development and other anthropogenic influences. We extracted information on developed areas and the road network, including secondary logging roads, from Landsat imagery through a supervised analysis.

Spatial templates

Ontario can be divided into subunits based on administrative boundaries (e.g., OMNR regions, districts, and areas), ecological information (e.g., ecological land classifications), geography (e.g., watersheds), or simple cartography (e.g., Ontario Base Maps). Our spatial data base contains a variety of such templates to provide different context based on the questions discussed below.

3 Perera, A.H.; Bae, R.E. A digital forest fire atlas for Ontario 1920–1994. Ont. For. Res. Inst. For. Fragmentation Biodiversity Proj. Tech. Rep. Ser. No. 23. (In press.)

Table 1. Primary land attributes of the FLEP spatial data base.

Data layer	Forest land cover	Bioclimate	Surficial geology	Soils	Topography
Classes	Water Coniferous forest Mixed coniferous forest Mixed forest (mainly deciduous) Deciduous forest Cut/fire disturbances within last 40 years Poorly vegetated area Wetland Developed area	Mean temperature (2 categories) Growing season (3 categories) Probability of frost Degree days (9 categories) Water deficit (2 categories) Precipitation	Bedrock Ground moraine End moraine Esker Outwash deposits Lacustrine deposits Beach and aeolian deposits Organic deposits Limestone and shale plains Escarpment Miscellaneous (eskers, dunes, drumlins, and beach ridges)	Soil texture Soil carbonates Soil depth Soil moisture Parent material Organic cover Organic depth Bedrock	Elevation Slope Aspect
Coverage	OMNR Area of Undertaking	Provincial	Provincial	Partial in the Area of Undertaking	OMNR Area of Undertaking
Spatial resolution	1 ha	1 km^2	1:500 000	1:250 000	1 ha
Major sources	Landsat TM	Ontario climate stations	Zonal Geology Maps	Ontario Land Inventory	U.S. Defence Mapping Agency

Potential uses of the data base

Many large-scale questions related to BMW forest in Ontario can be answered by this spatial data base, by using the various data layers described above singly or in many overlay combinations. These questions range from forest policy and strategic planning needs to gaps in research and information. The spatial data base will also provide an opportunity to examine larger-scale issues related to BMW forest in Ontario, to supplement hitherto focus on site-scale issues (e.g., MacDonald and Weingartner 1994a).

Where is BMW forest?

The definition of BMW forest in Ontario (MacDonald and Weingartner 1994b) includes species, site, and disturbance components. Using this definition, a comprehensive assessment of BMW forest can be done. The potential queries include extent and distribution of BMW forest on various ecological (e.g., Hills' site regions), administrative (OMNR), or geographic (e.g., watersheds) templates. In addition, the BMW definition itself can be revisited by using spatially specific information on soils, terrain, geology, climate, disturbances, and land cover. Subsequently, spatially explicit predictive models of potential occurrence of BMW forest could also be developed.

What are the spatial characteristics of BMW forest?

Information on sizes and shapes of BMW forest patches is important to landscape ecological issues such as forest interior availability, habitat supply, and fragmentation. The spatial arrangement of the BMW forest patches in a landscape can be examined through their nearest-neighbor distances, degree of isolation from each other, similarity to their neighbors, and degree of existing connectivity among them. This information is important to answer questions about dispersal and movement of seeds and organisms, developing and managing corridors, and spread of disturbances such as forest fire and pest epidemics.

How can BMW forest be managed sustainably?

Numerous questions around the goal of sustainable management of BMW forest could be answered by this spatial data base. These range from relatively simple questions (e.g., how much BMW forest is there in different forest management units?) to complex questions (e.g., what is the optimal extent and spatial arrangement of BMW forest patches in a given landscape?). Contextual information—such as the origin of existing BMW stands; the current extent of BMW forest protected in provincial parks, national parks, and other nonmanaged areas; the current degree of access to BMW forest patches; and the spatial distribution of BMW forest based on various forest policy scenarios—is essential to develop strategies toward forest sustainability.

Conclusion

The strength of this multithematic data base lie in its consistency across vast spatial extents, geographic comprehensiveness, and spatial explicitness. However, it will not be appropriate to anticipate the fine degree of information accuracy (e.g., species and microsite details, short-term vegetation cycles) that many silviculturists and foresters are accustomed to, locally. Potential for misuse of these large-scale data can be avoided by careful scaling of the BMW forest issues *a priori*.

The current focus of BMW forest research is primarily at site scale (e.g., MacDonald and Weingartner 1994a,b). That information will not be adequate to provide answers to contextual questions pertinent to forest policy and planning issues. A landscape-scale approach to research and information development in BMW forest in Ontario can answer many questions on biodiversity conservation and sustainable management of the BMW forest resource of Ontario. It will complement the many ongoing research and development activities at site scale. The FLEP spatial data base can provide a good nucleus for such an effort. Our attempt to describe the potential uses of the data base is hardly exhaustive or systematic. A more thorough examination of BMW forest landscape issues should be accomplished by a multidisciplinary team comprising expertise in silviculture, wildlife management, landscape ecology, GIS, forest policy, and many other facets of sustainable forest management. Our recommendation is 1) to assemble such a team under the leadership of mixedwood forest scientists and 2) to develop a comprehensive research and information development project. Such an effort will answer many large-scale questions surrounding sustainable management of BMW forest in Ontario.

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Spruce budworm and forest dynamics in a boreal mixedwood stand

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Abstract

We describe and summarize a study of the population ecology of a spruce budworm (*Choristoneura fumiferana* Clemens) outbreak in a boreal mixedwood stand near Black Sturgeon Lake, Ontario. The purpose of the study is to estimate rates of change in the abundance of spruce budworm throughout the outbreak and to relate these changes in abundance to ecological processes.

After more than 10 years of defoliation, there is significant yet differential mortality among susceptible trees. Losses have been greatest among codominant balsam fir (*Abies balsamea* [L.] Mill.), intermediate for white spruce (*Picea glauca* [Moench] Voss), and lowest for black spruce (*Picea mariana* [Mill.] B.S.P.). Nonsusceptible species such as trembling aspen (*Populus tremuloides* Michx.) now dominate the canopy. As gaps have opened in the stand, a diverse herbaceous layer has developed, as well as advance regeneration of balsam fir. Influence of mixedwood structure on budworm dynamics and of budworm on mixedwood dynamics is discussed.

Résumé

Nous avons étudié, du point de vue de l'écologie des populations, une infestation de tordeuse des bourgeons de l'épinette (*Choristoneura fumiferana* Clemens) survenue dans un peuplement mixte de la forêt boréale, près du lac Black Sturgeon, en Ontario. L'étude visait à estimer le taux de variation caractérisant l'abondance du ravageur dans l'ensemble du secteur infesté et à relier les changements d'abondance à des processus écologiques.

Après plus de dix années de défoliation, on constate encore chez les arbres sensibles un taux de mortalité appréciable, qui varie cependant selon les essences : le taux était le plus élevé chez le sapin baumier (*Abies balsamea* [L.] Mill.) en position de codominance, moins élevé dans le cas de l'épinette blanche (*Picea glauca* [Moench] Voss) et le plus faible chez l'épinette noire (*Picea mariana* [Mill.] B.S.P.). Des essences non vulnérables, comme le peuplier faux-tremble (*Populus tremuloides* Michx.), dominent aujourd'hui l'étage supérieur. De plus, comme l'infestation a créé des ouvertures dans le peuplement, le sol est maintenant couvert d'une strate herbacée diversifiée et d'une régénération préexistante de sapin baumier. Nous décrivons l'incidence de la structure des peuplements mixtes sur la dynamique des populations de tordeuse ainsi que l'incidence de la tordeuse sur la dynamique de ces peuplements.

Introduction

The spruce budworm (*Choristoneura fumiferana* Clemens) is a natural and recurring disturbance in boreal forests. Populations of the spruce budworm oscillate over a 35- to 45-year period. Severe outbreaks are associated with mature forest stands with a substantial fir/spruce component. These outbreak events may last more than 10 years, causing extensive loss of vulnerable trees. The ecological nature and impact of these outbreaks deserve consideration when managing boreal mixedwood stands.

Research on the population dynamics of the spruce budworm has an extensive history in the Canadian Forest Service. Although this work has contributed significantly to modern concepts and methods in animal population dynamics (e.g., Morris 1963; Royama 1984), the ecological relationships between the dynamics of the insect and that of the forest it inhabits remain poorly understood. This paper describes a study of the population ecology of a spruce budworm outbreak in a boreal mixedwood stand near Black Sturgeon Lake, Ontario. We first summarize the life history and ecology of the spruce budworm and describe the Black Sturgeon Lake habitat. An overview of the objectives, methods, and results of our research is provided to give a flavor of the entomological work being carried out. We then discuss the ecological impact of this spruce budworm outbreak and pose questions that we consider key to the management of boreal mixedwood stands susceptible to the spruce budworm.

Life history and population ecology of the spruce budworm

The life history and ecology of the spruce budworm are best understood in the context of its close association with its principal host trees: balsam fir (*Abies balsamea* [L.] Mill.), white spruce (*Picea glauca* [Moench] Voss), and, to a lesser extent, red (*Picea rubens* Sarg.) and black (*Picea mariana* [Mill.] B.S.P.) spruce. The geographic range of the spruce budworm coincides completely with that of these tree species. Damaging outbreaks can and do occur anywhere within the range.

The spruce budworm completes one generation per year, and the insect spends its entire life cycle on the host tree. Female moths lay eggs on foliage in midsummer. Hatching budworms do not feed but seek sheltered locations under bark scales, where they hibernate. The budworms emerge the following spring and enter expanding buds of the host trees. The buds of tree species that flush relatively early in the season, such as balsam fir and white spruce, are easily colonized, whereas later-flushing species such as black spruce do not readily support budworms in these early stages. Larvae feed almost exclusively on current-year foliage. In severe infestations, budworms will feed on older foliage, even though it is less nutritious. As with the early feeding stages, however, their capability of exploiting old foliage differs with tree species. Previous years' foliage of balsam fir is readily consumed, but feeding on older foliage of spruces reduces the survival and size of the budworms. Pupation also occurs on the host tree, and moths emerge to mate and lay eggs within a few weeks of pupation. Moths are capable of long-distance dispersal and may distribute eggs over a large area. A recent and comprehensive review of budworm biology by Sanders (1991) is recommended.

Our current working hypothesis on the population dynamics of spruce budworm is that outbreaks occur in forest stands with an abundance of susceptible foliage—i.e., stands composed of a significant quantity of mature fir or spruce—and a relatively low number of natural enemies. The high foliage volumes and low natural mortality result in good survival of feeding larvae. High insect densities and severe defoliation follow. After several years of defoliation, reduced foliage volume in the forest leads to a gradual decline in the budworm populations, even though the intensity of the infestation and defoliation on surviving trees may remain severe. The altered canopy and gaps created by dying trees also change forest structure by encouraging greater density and diversity of herbaceous plants. These plants support a greater density of insect herbivores, which, in turn, support more natural enemies. It is the increase in these natural enemies that contributes most directly to sudden collapses of budworm outbreaks. Migration of moths is not considered a primary cause of these basic dynamics, but dispersal of moths probably acts to synchronize many local infestations and creates the phenomenon of extensive and persistent outbreaks.

Black Sturgeon Lake

The Black Sturgeon Lake study area is located 45 km from the northwestern shore of Lake Superior (49°18'N, 88°52'W, 260 m altitude). It is in the Superior Boreal Forest Region (B9) of Rowe (1972). A detailed site description is given by Lethiecq and Régnière (1988), based on measurements made in 1985. The stand originated from a salvage cutover following a spruce budworm outbreak occurring in the area between 1942 and 1950. At the beginning of the current outbreak, Lethiecq and Régnière (1988) described the stand as a closed 42-year-old balsam fir, trembling aspen (*Populus tremuloides* Michx.), and white spruce stand with a basal area of 42 m^2/ha, 44% of which was balsam fir and 12% each of white and black spruce.

Population studies of the spruce budworm

Population monitoring at some level has continued at Black Sturgeon Lake since the late 1940s. Evidence of the current outbreak was first detected in the area in 1980. Defoliation has remained severe (i.e., >50% of foliage removed) since 1984. Detailed studies have been carried out annually since 1982. The objectives of these studies are 1) to estimate rates of change in the stage-specific abundance of spruce budworm throughout the outbreak and 2) to relate these changes in abundance to ecological processes such as changes in fecundity and natural mortality. Our aim is to develop a predictive understanding of factors determining outbreak dynamics and to integrate this understanding with long-term forest management planning.

The basic methodology of the study is to census budworm populations repeatedly throughout their developmental stages. At each sample date, demographics of the population are determined. Collected insects are placed in individual rearing chambers and reared until eclosion of moths or death of the insects. Autopsies are carried out on dead insects to determine cause of death, usually a parasitoid or pathogen. Fecundity of individual surviving moths is also determined. From these basic data, life table statistics can be compiled. In support of this work, processes of particular importance such as parasitism and dispersal are examined.

Table 1. Summary of principal natural enemies (parasitoids and fungal pathogens) reared from spruce budworm collected near Black Sturgeon Lake in 1989 and 1995.

	1989			1995		
	No.	Mortality (%) to		No.	Mortality (%) to	
Natural enemies	of genera	small larvae	large larvae–pupae	of genera	small larvae	large larvae–pupae
Parasitoids	15	19	15	16	30	42
Fungi	8	2	4	>4[a]	7	10

[a] Determination of number of genera of fungal pathogens in 1995 incomplete at time of writing.

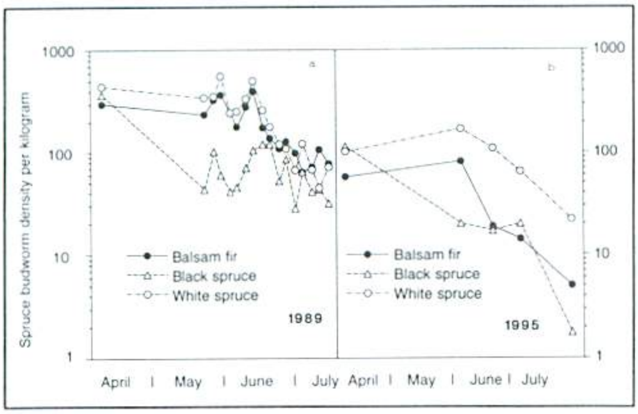

Figure 1. (a) A plot of spruce budworm density throughout the 1989 season on three tree species; (b) the same plot for the 1995 season.

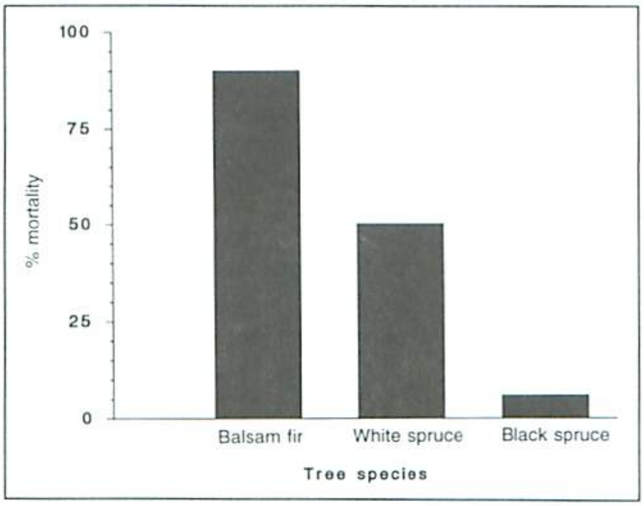

Figure 2. Mortality, by species, of codominant sample trees at Black Sturgeon Lake measured in 1995.

The results of a typical year's census midway through the current outbreak (1989) is shown in Figure 1a. Note that the density of overwintering budworm was comparable on all three tree species but dropped during the early feeding stages on black spruce. This was due to the difficulty that newly emerged spruce budworm experienced in establishing feeding sites in dormant buds of black spruce. Subsequent survival of budworms on all tree species for the rest of 1989 was high. Although there were diverse parasitoid and pathogen guilds attacking the budworm, their apparent impact was relatively low (Table 1).

By 1995, the situation had changed. Most of the spruce budworm population was now concentrated on white spruce, and the survivorship of larval stages overall was poor (Figure 1b). Both fungal pathogens and parasitoids appeared to be having a greater relative impact on the population, particularly in the late-larval and pupal stages (Table 1). The increase in relative abundance of parasitoids in 1995 was the result of at least two simultaneous factors. First, the absolute density of spruce budworm (number of budworms per hectare) in the stand has been declining in recent years as host trees die and are lost as a resource. At the same time, the absolute density of parasitoids has remained relatively unchanged and perhaps even increased. The reason for this is that the important parasitoids involved in this system are generalists and require alternative hosts to maintain their populations. The density and diversity of these alternative hosts have been increasing as the stand itself diversifies through reduction in the basal area of dominant conifer species and an increase in the herbaceous layer. The overall result was an accelerated decline in spruce budworm density in the stand. We expect that the outbreak at Black Sturgeon Lake is finally coming to an end.

Impact

The ultimate decline in spruce budworm density is inextricably linked to changes in the boreal mixedwood stand at Black Sturgeon Lake. The budworm has had a profound impact on the physiognomy of the stand. In 1995, we censused all codominant conifer species that had been used as sample trees during the study. All trees were alive when the current study was established in the early 1980s. As of 1995, 90% of the balsam fir, 50% of the white spruce, and 6% of the black spruce are now dead (Figure 2). From an industrial forestry perspective, this represents a catastrophic loss of basal area. From a forest ecology perspective, however, these numbers represent an interesting pattern of change in a boreal mixedwood stand. Mortality of susceptible trees in the stand has been differential, with most codominant balsam fir present in 1984 now dead, but half of the white spruce and most of the black spruce surviving. Nonsusceptible species such as trembling aspen now dominate the canopy. As gaps open in the stand, a diverse herbaceous layer has developed, as well as advance regeneration of balsam fir. Thus, we have a natural conversion from a mixedwood stand with a dominant, mature balsam fir element and substantial white and black spruce components to a mixedwood stand dominated by trembling aspen, relict white spruce, and largely unchanged black spruce elements. There has been a major shift to younger age-classes of balsam fir in the advance regeneration.

Implications for management of boreal mixedwoods

Our intensive study of a spruce budworm outbreak at Black Sturgeon Lake raises several questions pertinent to the relationship between budworm and forest dynamics and the management of boreal mixedwood forest stands. From the entomological perspective, we are interested in how stand composition affects budworm population dynamics. As conifer species differ in their susceptibility and vulnerability to budworm infestations, the particular mix of species may alter the behavior of the budworm population. The association of nonhost plant species may also have a complex influence, not only because their presence reduces the absolute availability of the budworm's resource, but also because these plant species support different insect faunas—these include alternative hosts for the predators, parasitoids, and pathogens, which, in turn, ultimately play such an important role in the dynamics of the spruce budworm.

From the forestry perspective, it would be useful to know to what extent the structure of boreal mixedwood stands affects their hazard to spruce budworm. Is, for example, susceptibility simply a function of total foliage volume or basal area of all principal hosts, or does the particular distribution of that basal area over a mix of host tree species modify the susceptibility of the stand? Similarly, does the structure of mixedwoods alter vulnerability of stands by, for example, permitting outbreaks to last longer in mixedwood stands than in more homogeneous forests? The impact of infestations in pure balsam fir stands can be dramatic and cataclysmic, with rapid and complete destruction of the once-dominant tree cover. When more resilient spruces are mixed with the balsam fir, outbreaks may be extended, with consequently greater impacts on normally less vulnerable species, such as red and black spruce and even jack pine (*Pinus banksiana* Lamb.). On the other hand, greater total plant diversity in mixedwoods may support a greater density of natural enemies of the spruce budworm, which may hasten a collapse of the outbreak. In that case, there would be less extensive tree mortality, and recovery of trees would be rapid. In terms of forest productivity, the results of these scenarios could be equally complex. If one is primarily managing for fiber, all species may be valued and the economic damage threshold low. In the case of increased vulnerability, one might want to manage for short rotations to minimize budworm hazard. If, on the other hand, one is managing for a specific value such as white or black spruce, budworm infestations might be regarded as a natural silvicultural treatment, removing vulnerable overstory represented by fast-growing balsam fir and releasing spruce. If one is managing for nontimber values, entirely different decisions may need to be made, depending on the anticipated impact of the outbreak. These decisions will be supported only by some predictive capability of budworm and forest dynamics.

Boreal mixedwood stands represent a complex habitat for the spruce budworm. Integrated research on interactions between the dynamics of the budworm and the dynamics of mixedwood stands will undoubtedly provide greater insight to both systems.

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Boreal forest succession: an intensive study of a mixedwood chronosequence

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Abstract

In order to understand the community structure of boreal forests better, it is necessary to examine forest stands in various stages of postdisturbance succession. Studying the effects of disturbance on forest vegetation is required to adequately predict the impact of natural and anthropogenic change to the forested ecosystem. An intensive vegetation succession field study was conducted in 18 northern Ontario mixedwood stands. Field sampling included measuring tree and shrub density, plant species composition at 15 height strata, and the abundance of forest floor vegetation types. Results provide a detailed description of the forest community along the successional chronosequence and indicate that age, residual conifer density, and shrub development alone are not controlling conifer regeneration of these stands. To adequately predict the postdisturbance vegetation composition of these stands, extensive data are needed on the predisturbance vegetation composition of the stand, time since disturbance, type of disturbance, intensity of disturbance, and shrub development. Until these data are available for a wide range of forest stands, one cannot predict postdisturbance vegetation composition of forests.

Résumé

Pour mieux comprendre la structure des communautés de la forêt boréale, il faut examiner les peuplements aux divers stades de succession qui font suite à une perturbation. Une telle étude des effets de la perturbation sur la végétation forestière est essentielle à la prévision adéquate de l'impact des changements naturels et anthropiques sur l'écosystème forestier. Nous avons donc entrepris une étude intensive de la succession végétale dans 18 peuplements mixtes du nord de l'Ontario. Sur le terrain, nous avons mesuré la densité des arbres et des arbustes, noté la composition des espèces de plantes pour 15 couches de hauteur et évalué l'abondance des divers types de végétation de sous-bois. Nous avons ainsi obtenu une description détaillée de la communauté végétale pour toute la chronoséquence et pu établir que l'âge, la densité des conifères résiduels et l'importance de la strate arbustive ne sont pas les seuls facteurs qui déterminent la régénération des conifères dans ces peuplements. En effet, pour pouvoir prédire de manière satisfaisante la composition végétative qu'aurait un tel peuplement après une perturbation, il faut disposer de données détaillées sur la composition végétative du peuplement avant la perturbation, sur le temps écoulé depuis celle-ci, sur la nature et l'intensité de la perturbation et sur l'importance de la strate arbustive. Tant que ces données ne seront pas disponibles pour une vaste gamme de peuplements, il sera impossible de prédire la composition végétative qu'aurait un peuplement donné après une perturbation.

Introduction

Succession is a key ecological process in natural ecosystems. It was first documented in the late 1600s and has since received considerable attention in the fields of ecology and forestry. Even though there is not yet consensus on the exact role of succession in ecological communities, ecologists generally agree that succession plays a key role in the distribution and abundance of species in the environment.

Boreal forests are ecologically important; they comprise the largest forest region in Ontario and are the main resource for the valuable pulp and paper industry. Knowledge of the secondary succession of boreal forests is needed to assess properly the effects of management practices on these ecosystems. In particular, increased knowledge on how plant species composition and regeneration patterns change following natural and anthropogenic disturbances and how these patterns develop through time is needed.

When discussing boreal forest succession, two of its main aspects must be considered. First, boreal forest succession is distinct from temperate forest succession, in that plant species diversity is lower in the boreal zone and boreal succession primarily involves changes in species abundance through time, as opposed to species replacement. Secondly, fire suppression combined with increased forest harvesting has resulted in a switch from wildfire to tree removal as the major form of disturbance in the boreal region. Prior to the 1920s, fires were large, and all but small pockets of forest frequently burned (Heinselman 1978; Ward and Tithecott

1993), resulting in similar-aged stands in a mixed-age forest. Intensively managed areas of the boreal forest usually experience only small fires now. Large tracts of boreal forest in the most accessible areas have been removed, and stands that normally would have burned continue to age. In addition, fire-disturbed conifer stands tend to reestablish following fire, whereas clear-cut conifer stands do not (Carleton and MacLellan 1994). In general, forest harvesting and fire suppression have led to the transformation of conifer-dominated forest to hardwood/mixedwood forest (Samoil 1988).

In summary, the following fundamental questions need to be answered: 1) What is the vegetation composition of postdisturbance forest stands? and 2) What are the relative effects of predisturbance vegetation composition, age since disturbance, type of disturbance, and intensity of disturbance on the vegetation composition of postdisturbance forest stands? Without this information, one cannot properly predict or assess the effects of forestry management practices on forest ecosystem functions and processes. No one study can realistically yield definitive answers to these fundamental questions. Our study, at the very least, is an attempt to answer these questions for mixedwood stands and to determine the additional work needed to develop generally applicable solutions. This study uses a chronosequence to provide a snapshot view of naturally regenerating forest stands in different successional stages.

Methods

Twelve harvested stands ranging in age from 0 to 33 years and six postfire stands ranging in age from 56 to 199 years were used for the study. The study was done during the summers of 1979 through 1983 and included both forest bird abundance and vegetation data. The first two years of vegetation data represent a successional chronosequence and are the focus of this paper. The study area was located northwest of Manitouwadge, Ontario (49°25′N, 85°47′W), in the American Can of Canada Limited timber limits (now owned by Buchanan Forest Products), in Ecozone 96, Ecoregion Abitibi Plains.

The vegetation data sets collected provide an intensive description of the 18 forest stands. Included are shrub and tree density data, species composition of vegetation profile (across height strata), and forest floor cover data. This paper focuses on the shrub and tree data only. For information about additional data, see Twolan-Strutt and Welsh.[1] The shrub and tree density data were collected by using a corrected-point-distance nearest-neighbor tree sampling technique. Sampling was done separately for three size-classes of trees—saplings (<2.5 cm diameter at breast height [dbh]), small trees (2.5–10.0 cm dbh), and large trees (>10.0 cm dbh)—and shrubs. A 9-ha (90 000-m^2) plot was established in each stand, and data were systematically collected along parallel lines within the plot. Tree and shrub densities and associated probable limits of error were estimated for all tree size-classes and shrubs at the scale of stand and species.

Data were summarized for all saplings, small trees, and large trees at the levels of conifer/deciduous and species. Tree volume tables for northeastern Ontario (Maurer 1993) and Forest Resources Inventory (OMNR 1974) data were used to develop criteria to separate tree data into residual and regeneration data. Simple linear regression was then used to test for an effect of conifer residual growth (density of conifers >10 cm dbh in cut stands) on regeneration (the sum of sapling and small tree density in cut stands). Similar analyses were done to test for an effect of shrub development (shrub density in all stands) on regeneration (the sum of sapling and small tree density in all stands).

Results and discussion

The results included in this paper are only a subset of results for the entire study. For other results, refer to Twolan-Strutt and Welsh.[2] The densities of saplings, small trees, and large trees are shown in Figure 1. Overall trends for saplings, small trees, and large trees support general successional trends. For instance, for all three size-classes of trees, deciduous cover dominated in the younger stands and coniferous cover in the older stands. As well, deciduous growth is dominant at peak density for each size-class, with peak density occurring at an increasing age range as tree size-class increases (i.e., 5–8 years for saplings [Figure 1a], 18–26 years for small trees [Figure 1b], and 23–56 years for large trees [Figure 1c]). This is consistent with previous findings, in that conifer species are generally shade tolerant, have conservative growth rates that permit them to establish under existing canopy across a range of fertility levels, and can persist until time of release. Conifer species like black spruce (*Picea mariana* [Mill.] B.S.P.) do not establish well when the forest floor has a buildup of leaf litter. They also do not establish well in shrub-dominated stands for a number of reasons, including the suppression of seedlings by competition from shrubs, poor seed rain, destruction of advance

[1] Twolan-Strutt, L.; Welsh, D.A. Boreal forest succession: an intensive study of a mixedwood chronosequence. Nat. Resour. Can., Can. For. Serv.–Sault Ste. Marie, Sault Ste. Marie, ON. NODA/NFP Tech. Rep. (In prep.)

[2] Ibid.

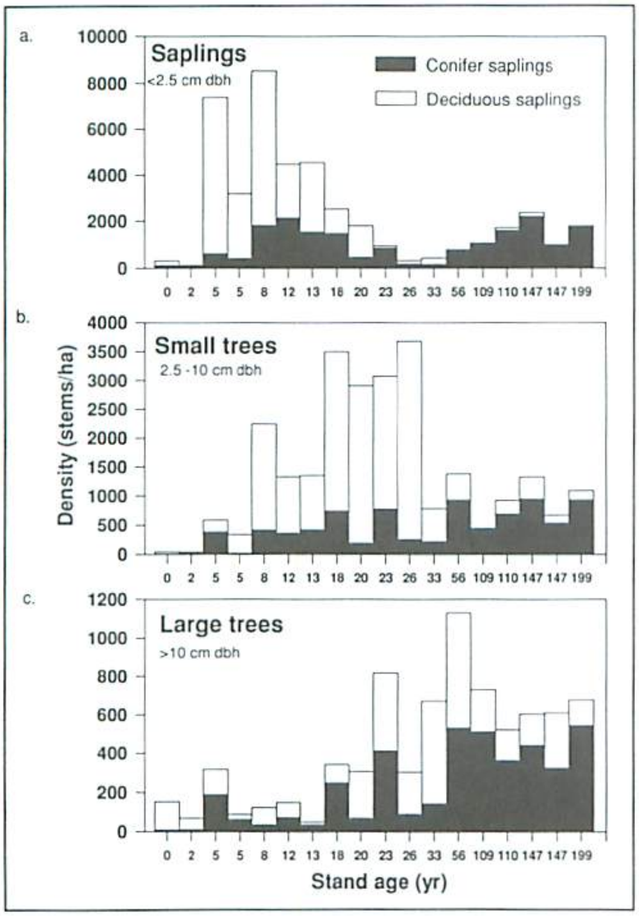

Figure 1. Density of three size-classes of conifers and deciduous trees across 18 stands.

growth, and unsuitable seedbed conditions. In contrast, deciduous trees like trembling aspen (*Populus tremuloides* Michx.) are early successional species and establish very well on disturbed sites with ample light. They develop strongly from existing roots and proliferate when sapling roots are damaged during harvesting. Deciduous trees tend to decrease in older stands because they are less shade tolerant than conifers and have shorter life spans.

Also important is that the density of large and small conifers did not show the same trend as the density of conifer saplings. This indicates that the density of conifers left in the stands after cutting is not controlling conifer regeneration, as one might expect. Furthermore, low levels of conifer saplings in the 20- to 33-year-old cut stands may be due to competitive effects of shrubs and deciduous trees on the growth and survivorship of conifer saplings. The low abundance levels of conifer saplings and small trees in the older cut stands (Figure 1) are unlikely to lead to high conifer levels as cut stands age further. Therefore, cutting these mixedwood stands may be shifting their composition toward deciduous/shrub-dominated stands.

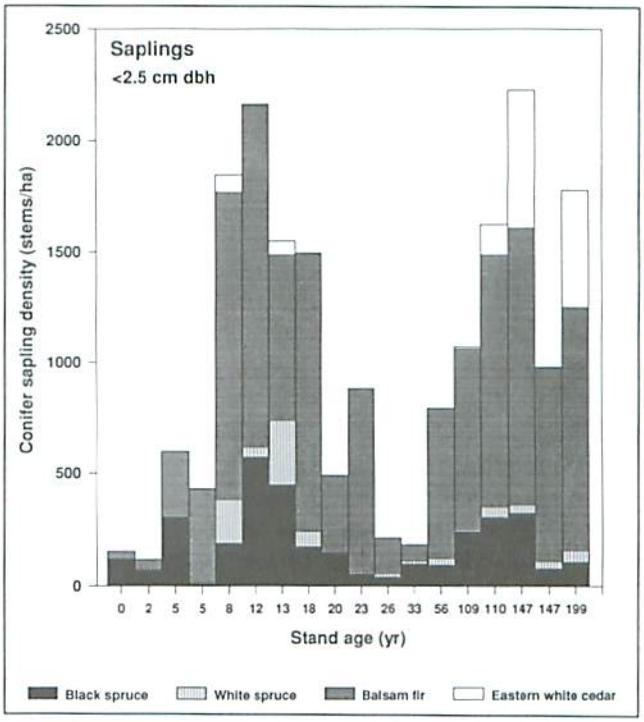

Figure 2. Density of sapling conifer species across 18 stands.

Figure 2 provides a summary of the results for all species of conifers in the sapling size range in order to investigate further the trend in sapling density across stands. First, conifer sapling trends also reflect trends typical of boreal succession. Conifer regeneration in the older uncut stands is mainly balsam fir (*Abies balsamea* [L.] Mill.) and, to a lesser degree, black spruce. Balsam fir has the ability to establish and grow when shaded by larger trees. Balsam fir saplings are probably occurring in the small forest gaps created by windfall, insects, disease, and natural tree senescence in some of the older uncut stands of our study. In fact, canopy openings may be an important mechanism in moving succession of even-aged pine–aspen stands forward to uneven-aged stands such as old-growth mixtures of balsam fir, black spruce, eastern white cedar (*Thuja occidentalis* L.), and white birch (*Betula papyrifera* Marsh.) (Frelich and Reich 1995). If fire occurs often, these canopy gaps may not form, and true canopy succession may not occur (Frelich and Reich 1995). Deciduous species such as trembling aspen and white birch cannot easily establish in these forest gaps because they are less shade tolerant and require more disturbed soil. Shaded conditions of the older uncut stands and space created by natural gaps in the dense stands are therefore leading to the observed balsam fir and black spruce regeneration. The former is more dominant because it is more shade tolerant than black spruce. It can develop underneath pioneer deciduous canopies after a disturbance and can also invade

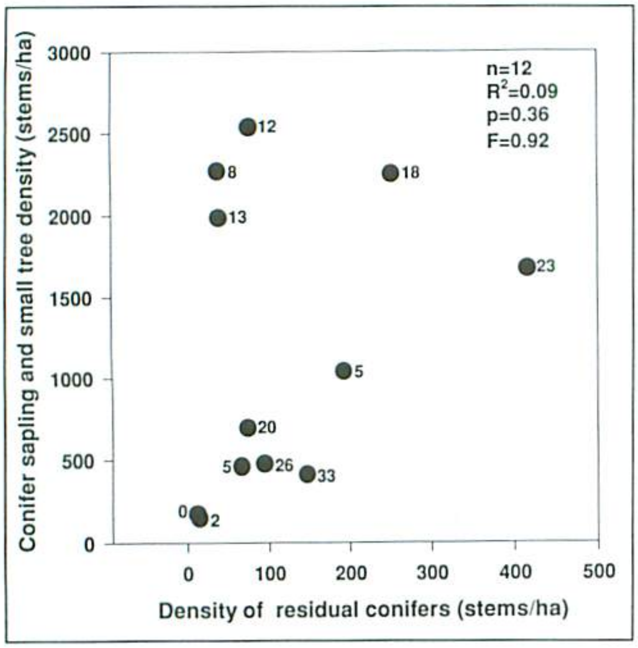

Figure 3. Simple linear regression of residual conifer density and conifer regeneration density for 12 cut stands. Numbers beside symbols correspond to stand age.

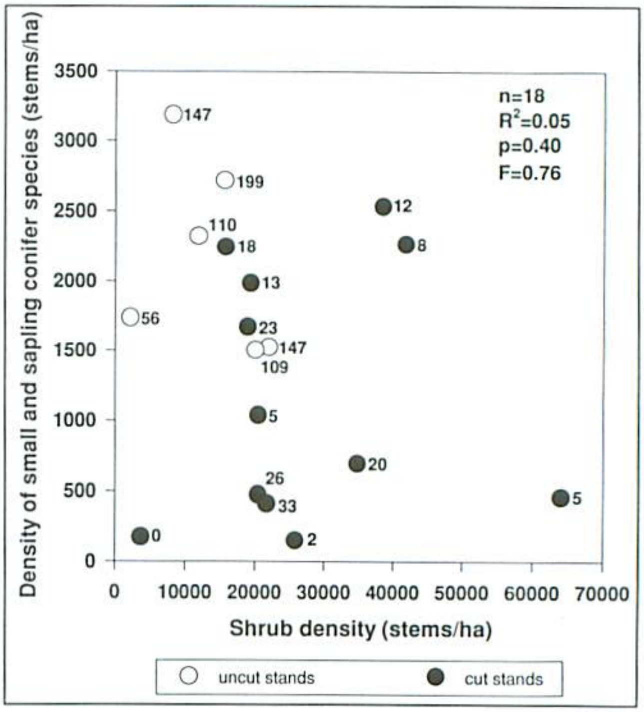

Figure 4. Simple linear regression of shrub density and conifer regeneration density for 18 stands. Numbers beside symbols correspond to stand age.

spruce stands that are beginning to break up (Carleton and MacLellan 1994).

Secondly, balsam fir saplings are more abundant than black spruce in most cut stands, except the three youngest stands. Therefore, most of the regeneration in the cut stands is balsam fir. Had the 12 youngest stands been fire disturbed, black spruce probably would have dominated in some of them, because it, unlike balsam fir, has semiserotinous cones that allow effective post-fire establishment.

No significant relationship was found between the density of residual conifers and conifer regeneration (Figure 3). In the mixedwood stands of our study, the amount of residual conifer left behind after cutting is not controlling conifer regeneration in postcutting stands, as one might expect. Clearly, another factor, such as predisturbance vegetation composition, or a set of factors (possibly including residual conifer growth) is controlling postdisturbance vegetation composition.

Nor was a significant effect of shrub density on the density of conifer regeneration found (Figure 4). Shrub development can negatively impact conifer regeneration via above- and below-ground competition for light/space and nutrients/water, respectively. In our study, regression analyses indicate that shrub development is not affecting the amount of conifer regeneration in the stands after a disturbance.

Summary of observations

Multivariate analysis of the tree and shrub data revealed that although similarly aged forest stands were similar in terms of density of trees and shrubs, an overall age gradient across the successional stands was not seen (Twolan-Strutt and Welsh[3]). In other words, age did not explain much of the variation in the tree and shrub abundance data. This work and the work presented in this paper clearly show that age, residual conifer density, and shrub development alone are not controlling conifer regeneration of these stands. Postdisturbance forest stand vegetation composition is complex and likely attributed to more than one factor. Therefore, extensive data on the predisturbance vegetation composition, time since disturbance, type of disturbance, intensity of disturbance, and shrub development of forested areas are needed to predict the postdisturbance vegetation composition adequately. Until these data are available for a wide range of forest stands, one cannot develop objective ecological wildlife or forest indicators or predict the impact of forestry practices on the forest ecosystem.

[3] Ibid.

Acknowledgments

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Variation in vertebrate communities among three successional stages of aspen-dominated boreal mixedwood forests in Alberta

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Abstract

Vegetation, birds, mammals, and amphibians were surveyed in young, mature, and old aspen-dominated mixedwood forests in Alberta to evaluate both changes in vertebrate communities and patterns of covariation between vertebrate and vegetation communities during the first 150 years of succession. Most vertebrates were observed in all three successional stages, although abundance differed among stages for many species. More than half of the vertebrates were most abundant in old forests, possibly owing to the presence of large live trees, large snags, and abundant down woody materials. For 25% of the vertebrates, abundance was positively related to canopy heterogeneity, indicating that small open areas within forests may be important.

Conifer-preferring vertebrates were most abundant in areas with many coniferous trees. Patterns of covariation between species and vegetation were similar, but not identical, for bird, mammal, and amphibian communities; bird communities varied more during succession than did mammal and amphibian communities.

Résumé

Nous avons effectué un relevé de la végétation, des oiseaux, des mammifères et des amphibiens dans des peuplements jeunes, mûrs et surâgés de la tremblaie mixte albertaine. L'étude visait à évaluer les changements survenant dans les communautés de vertébrés durant les 150 premières années de cette succession et à discerner les types de covariation existant entre les communautés de vertébrés et la végétation pendant cette période. Les plupart des vertébrés étaient présents dans des peuplements représentant les trois stades de succession, mais l'abondance de nombreuses espèces variait selon les stades. Plus de la moitié des vertébrés étaient le plus abondants dans les peuplements surâgés, profitant peut-être des grands arbres vivants, des grands chicots et de la matière ligneuse abondante sur le sol. Chez 25 % des vertébrés, l'abondance était en relation positive avec l'hétérogénéité du couvert forestier; il est donc possible que les petites clairières aient un rôle important à cet égard.

Les vertébrés préférant les forêts de résineux étaient le plus abondants dans les secteurs où ces essences étaient abondantes. Les communautés d'oiseaux, de mammifères et d'amphibiens présentaient par rapport à la végétation des types de covariation semblables, mais non identiques : durant la succession, les communautés d'oiseaux variaient plus que celles de mammifères et d'amphibiens.

Introduction

Aspen (*Populus tremuloides* Michx.) mixedwood forests are widespread throughout North America's 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 forests, because old aspen forests have larger trees, more large snags (standing dead trees), and more down woody materials (DWM) than do young aspen forests. In addition, old aspen forests have greater spatial complexity of live and dead material than that found within young aspen forests (Peterson and Peterson 1992), and that complexity may allow more species to coexist.

Abundance and spatial distribution of live and dead trees within aspen forests, however, are not linearly related to forest age (Lee et al. 1995). Wildfires kill trees in spatially heterogeneous patterns, such that following wildfires, some live trees and snags from the previous forest may remain. During the next 50 years, most of the prefire cohort of live trees dies and the snags fall, resulting in mature forests being characterized by moderate-sized live trees, many small snags that were produced by self-thinning of the postfire cohort of trees, and few gaps in the canopy.

As mature forests grow older, some canopy trees die from diseases, and some fall to create gaps in the canopy. Canopy gaps allow more light to reach the forest floor, resulting in shrubs, aspen suckers, and grass becoming abundant in those areas (Peterson and Peterson 1992). Thus, the complexity of live and dead vegetation in aspen-dominated mixedwood forests may be moderate when forests are young, decline as the forests approach maturity, and then increase to the highest level in old forests (Lee et al. 1995). Although not well studied, similar patterns may be expected for vertebrates. Identifying how vertebrate communities change throughout succession within Alberta's aspen mixedwood forests has become an urgent priority, because the pulp and paper industry is conducting large-scale, short-rotation logging in this area. In this study, we evaluated changes in bird, mammal, and amphibian communities 1) during three successional stages (25–30 years, 50–65 years, and >120 years) in aspen-dominated boreal forests and 2) in relation to vegetation characteristics of the forests. In addition, we compared patterns of variation among bird, mammal, and amphibian communities to evaluate whether the different taxa had similar patterns.

Methods

Using forest cover information, we selected four stands from each of three aspen-dominated successional stages (young 25–30 years old, mature 50–65 years old, and old >120 years old) within boreal mixedwood forest in east-central Alberta. All stands were greater than 80 ha and had regenerated following wildfires. Aspen was the most abundant tree species in the forest canopy, although balsam poplar (*Populus balsamifera* L.), white birch (*Betula papyrifera* Marsh.), white spruce (*Picea glauca* [Moench] Voss), and balsam fir (*Abies balsamea* [L.] Mill.) were also present.

We positioned six sites randomly in the interior of each of the stands. To quantify differences in live and dead vegetation among the successional stages, we determined tree species composition and density from low-level aerial photographs (scale 1:1000). Densities of snags (>2 m high) were determined based on the inter-snag distance, volumes of DWM were determined within 5-m transects, densities of shrubs more than 1 m tall were determined within 25.0-m^2 quadrats, and percentages of the ground surface covered by herbs, grasses, and mosses were determined within 0.11-m^2 quadrats. Breeding birds were surveyed using point counts. Mammals and amphibians were surveyed using live traps, snap traps, pitfall traps, and scat surveys.

We categorized vertebrates based on the successional stage in which they were most abundant. Within each of those three categories, species were ordered using $\log[2*O/(M+Y)] - \log[2*Y/(M+O)]$, where Y, M, and O were the mean number of individuals in young, mature, and old forests, respectively.

Covariation between vertebrate communities and the vegetation characteristics was evaluated using canonical correspondence analyses (CCA) (ter Braak 1992). We standardized abundances of vertebrates at each of the sites so that each species had a mean abundance of 10.0 and a standard deviation in abundance of 1.0.

To evaluate whether "species groups" had similar patterns of covariation among areas, we used the literature to categorize vertebrates based on whether they preferred coniferous mixedwood forests or deciduous mixedwood forests or had little preference between coniferous and deciduous mixedwood forests. Differences in species scores on the CCA functions were compared among taxa and among preferred habitat types using analysis of variance (ANOVA) and Student-Newman-Keuls range tests. Species were not included in any analyses unless they were detected more than five times, because observations in non-typical habitats may have influenced the results for species that were detected few times.

Results

Most vertebrates were detected in all three successional stages (Figure 1). Most species (27 birds, 6 mammals) had their highest abundance in old forests, few species had their highest abundance in mature forests (3 birds, 3 mammals, 2 amphibians), and an intermediate number of species had their highest abundance in young forests (10 birds, 5 mammals) (Figure 1). More species had their highest abundance in old forests than was expected at random ($\chi^2 = 17.8$, $P < 0.01$, df = 2). That pattern tended to be stronger for birds than for mammals (Figure 1), but differences between taxa were not significant ($\chi^2 = 3.3$, $P = 0.20$, df = 2; too few amphibian species were present to be included in this analysis). Eighteen species (11 birds, 7 mammals) were less than half as abundant in mature forests as they were in either young or old forests (Figure 1).

The major pattern of covariation among vertebrate species abundances and vegetation characteristics (i.e., CCA function 1) was significant ($F = 6.38$, $P < 0.001$, based on a bootstrap Monte Carlo test; ter Braak 1992) and accounted for 10% of the variation in the vertebrate species abundances and 29% of the

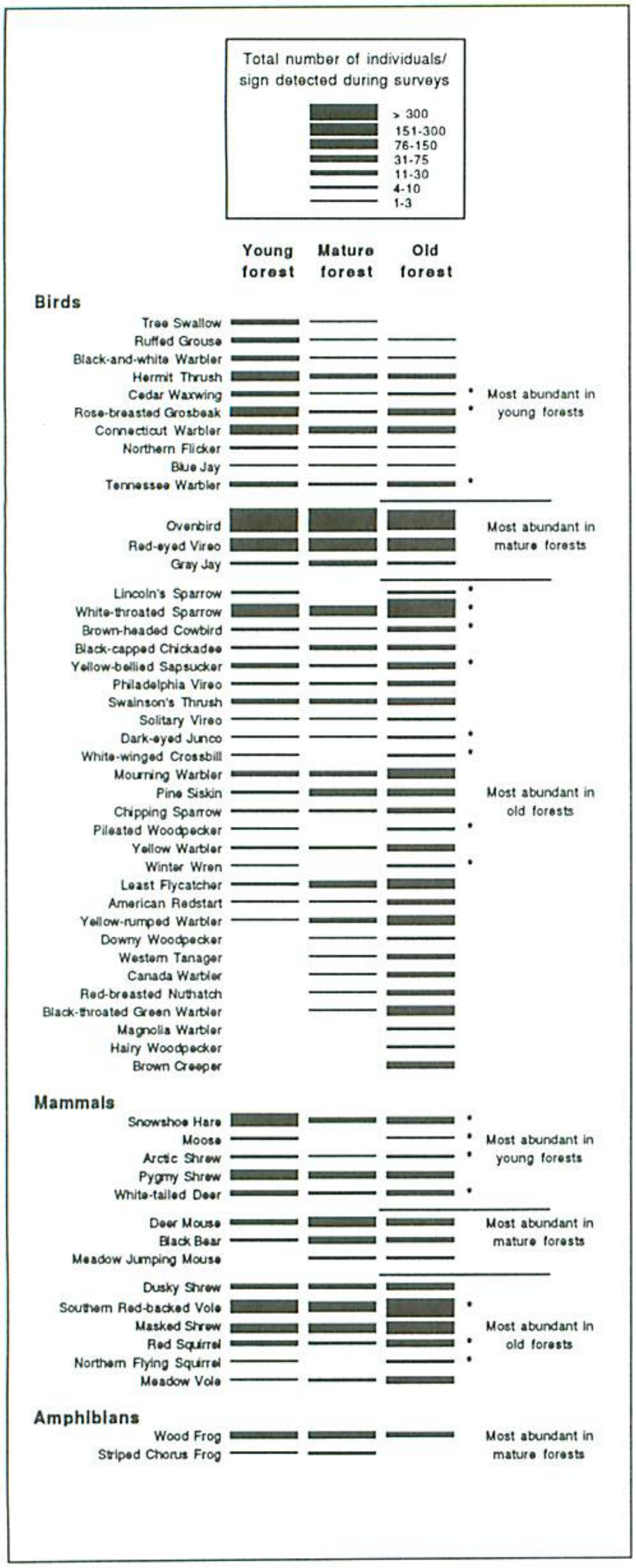

Figure 1. Number of individuals/sign detected during surveys within three successional stages of aspen-dominated boreal mixedwood forest in Alberta. Within taxonomic groups, species were ordered from those most abundant in young forests to those most abundant in old forests. Asterisks indicate species that were less than half as abundant in mature forests as they were in either young or old forests.

covariation between vertebrate species abundances and vegetation characteristics. This function was labeled "successional stage" because it was positively correlated ($P < 0.05$) with abundance of large trees, large snags, and large DWM and negatively correlated with density of small trees and small DWM (Figure 2). Vertebrates most abundant in young, mature, and old stands occurred at low, moderate, and high scores, respectively, on the first CCA function (Figure 2; scores were significantly different among these three categories, $F = 55.5$, $P < 0.001$, df = 2, 53). The second CCA function was also significant ($F = 3.9$, $P < 0.001$) and accounted for 5% of the variation in vertebrate species abundances and 15% of the covariation between vertebrate species abundances and vegetation characteristics. This function was labeled "canopy heterogeneity" because it was positively correlated with vegetation characteristics (density of large snags, grass cover, and shrubs) that have high levels in forests with many canopy gaps and negatively correlated with the vegetation characteristic (herb cover) that is high under closed canopies (Figure 2). Vertebrates most abundant in mature stands occurred at relatively lower scores on the second CCA function than vertebrates most abundant in young or old forests (Figure 2; $F = 41.4$, $P < 0.001$, df = 2, 53).

The third CCA function was significant ($F = 3.4$, $P = 0.02$) and accounted for 5% of the variation in vertebrate species abundances and 13% of the covariation between vertebrate species abundances and vegetation characteristics. This function was positively correlated with density of coniferous trees and negatively correlated with density of shrubs (Figure 3). Scores from the first and third, but not the second, CCA functions differed among vertebrates that preferred deciduous versus coniferous forest ($F = 4.5$, $P = 0.02$, df = 2, 53; $F = 8.8$, $P < 0.001$, df = 2, 53 for the first and third CCA functions, respectively), with vertebrates preferring deciduous forest occurring at lower values (Figure 3). Fourteen of the 17 vertebrates that preferred coniferous forests were located in the upper right quadrant of the biplot, indicating that those species had their highest abundances in old aspen-dominated boreal forests with abundant coniferous trees (Figure 3).

The range in variation in CCA scores for birds was greater than that for mammals and amphibians (Figures 2 and 3). Mean CCA scores, however, did not differ among the three vertebrate classes on any of the three statistically significant functions ($F = 0.3$, $P = 0.72$, df = 2, 53; $F = 2.5$, $P = 0.09$, df = 2, 53; $F = 0.1$, $P = 0.87$, df = 2, 53 for the first, second, and third CCA functions, respectively).

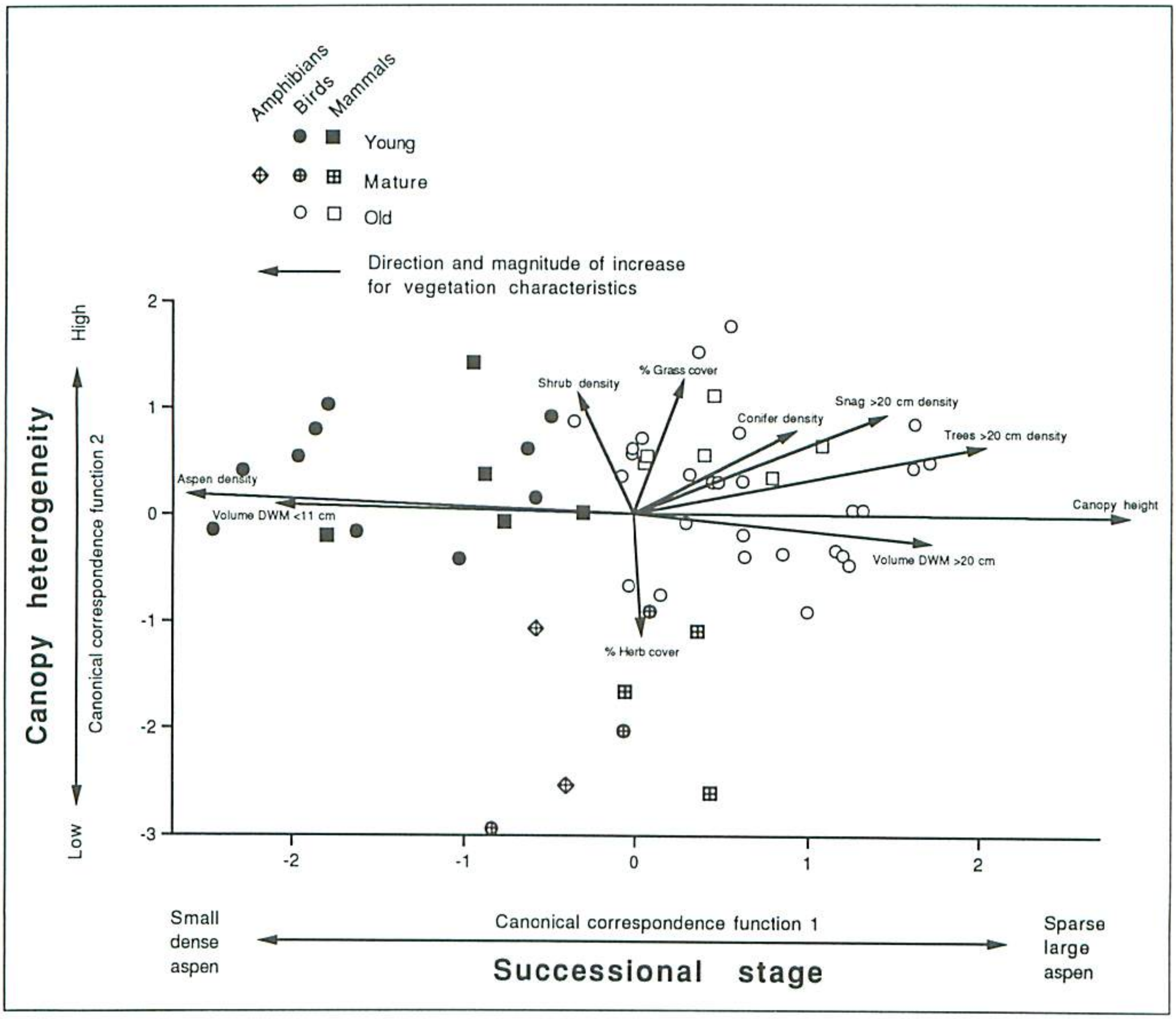

Figure 2. Biplot, constructed from the first and second CCA functions, depicting variation in vertebrate communities in relation to variation in vegetation characteristics within aspen-dominated mixedwood forests in Alberta. Species have been categorized based on their relative abundance in young, mature, and old aspen-dominated boreal mixedwood forests. Locations of species on the biplot indicate where they were most abundant in two-dimensional CCA space. Arrows for each of the vegetation characteristics indicate the direction, within CCA space, that the characteristic increased, and lengths of the arrows indicate the degree of correlation between the vegetation characteristic and the CCA functions. Arrows for vegetation characteristics that had weak relationships with the CCA functions were not included.

Discussion

The main pattern of covariation between vertebrate communities and vegetation characteristics involved species and characteristics that varied monotonically with successional stage. To a lesser degree, vertebrate communities varied in relation to vegetation that was associated with canopy heterogeneity and coniferous tree density. Approximately two-thirds of the vertebrate species had their highest abundance in old aspen forests. Consequently, until more data on the habitat requirements of boreal forest vertebrates become available, it would be prudent to retain adequate amounts of old aspen-dominated forest in the landscape to act as refugia (Franklin 1993).

Approximately 25% of the vertebrates were most abundant in young forests, whereas only 10% were most abundant in mature forests. In addition, 17 species (43%) were less than half as abundant in mature forests as they were in either young or old forests. Those patterns may have occurred because some characteristics of the vegetation were similar in young and old forests but different in mature forests. Seven of the bird

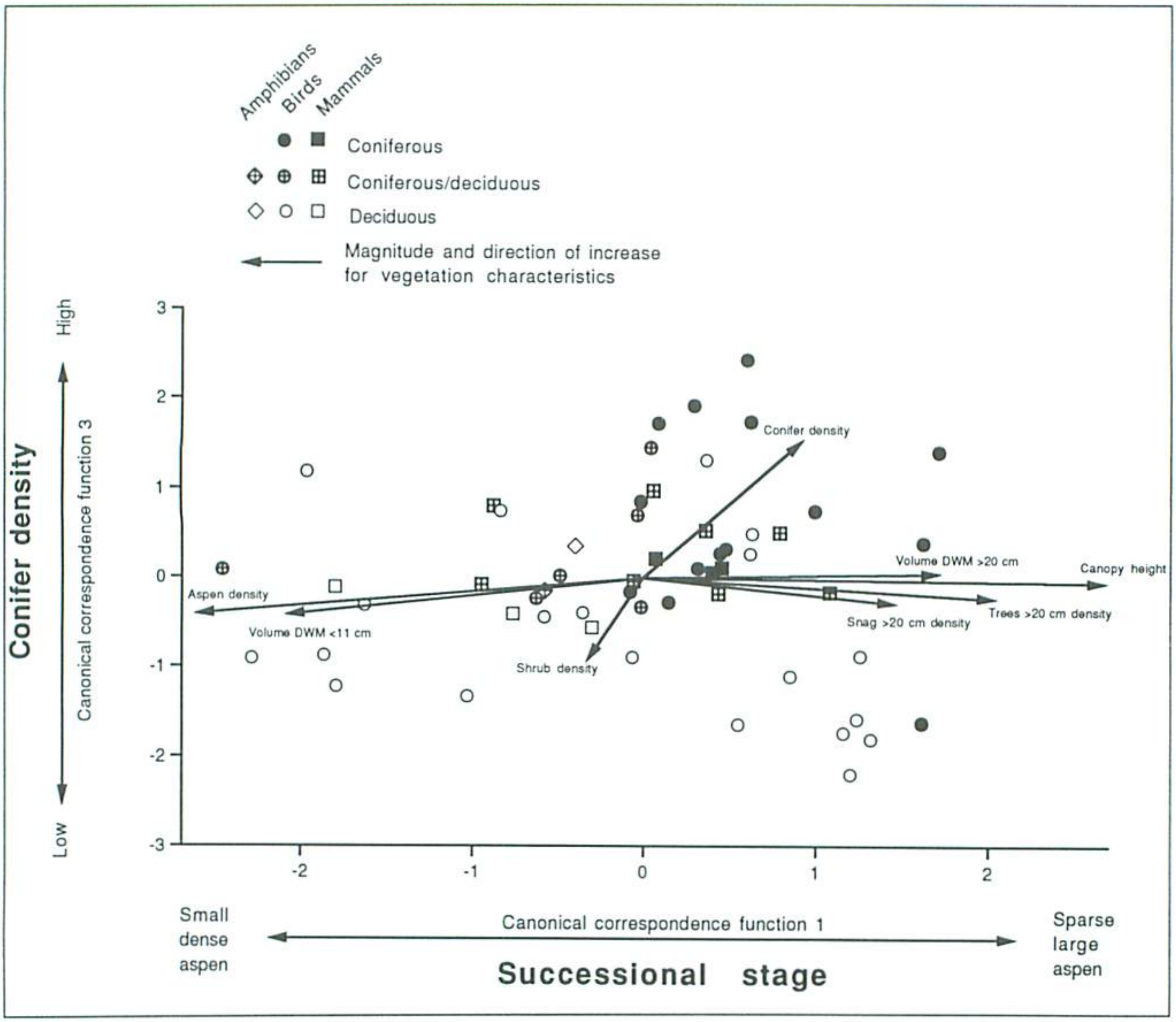

Figure 3. Biplot, constructed from the first and third CCA functions, depicting variation in vertebrate communities in relation to variation in vegetation within aspen-dominated mixedwood forests in Alberta. Species have been categorized based on their preference for coniferous and deciduous boreal mixedwood forests.

species and four of the mammal species with bimodal patterns of abundance foraged and nested on the ground and in shrubs. Those species may have been at relatively high abundance in young and old forests because shrubs and grasses were more abundant there than in mature forests. Six dead-tree specialists (three birds and three mammals) may have been at higher abundance in young and old forests than they were in mature forests because they nested and foraged in large trees and snags that were more abundant in young and old than in mature forests. Young forests that are created following harvest may be of lower quality to vertebrates than young forests that are created naturally, because large live and dead residual trees may not be present in harvested areas. Consequently, it may be beneficial to alter harvest operations so that some large live trees, large snags, and large DWM are left in cutover areas. As a tertiary pattern of covariance in vertebrate communities, abundance of conifer-preferring vertebrates covaried with density of coniferous trees. In the future, the amount of mixedwood forest in the boreal forest landscape may be negatively affected by harvesting techniques that promote regeneration of pure aspen stands in many areas and pure coniferous stands in other areas. It may be possible, however, to alter harvesting operations such that much of the coniferous understory is not harmed during harvest and mixedwood stands regenerate in harvested areas (Navratil et al. 1994).

Similar patterns of covariance for bird, mammal, and amphibian communities were surprising, because the habitat features used by each class differed; birds use shrubs and arboreal habitats, whereas mammals and amphibians use shrubs and the forest floor. Finding similar patterns for all vertebrate classes indicated either that the classes responded to the same habitat features or that within aspen-dominated mixedwood forests, canopy and understory vegetation characteristics covaried. The second alternative appears to be more probable, because many of the canopy and understory attributes covaried.

It is tenuous to extrapolate from this study that was conducted in a natural pyrogenic system to systems dominated by human disturbance, such as logging, because the spatial diversity of living and dead vegetation in postfire habitats is large, whereas habitats may become homogenized following human disturbances (Mladenoff et al. 1993). Consequently, if results from this study are to be applied to landscapes manipulated by humans, then the applicability of our conclusions should be tested in those human-modified ecosystems.

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Is abundance a good indicator of habitat quality for boreal forest songbirds?

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Abstract

Abundance of breeding songbirds was estimated for a number of boreal forest habitats using point count surveys. A breeding index, based on breeding behavior and information from banding records, was calculated for each site, and abundance and breeding evidence were compared. Overall, there is a strong positive relationship between abundance and breeding estimates for most species. Breeding success was compared between low- and high-abundance sites for species that showed significant changes in population over three years. High-abundance habitats did not vary significantly, whereas low-abundance habitats not only varied significantly, but also had significantly fewer breeding records in low-population years. Our results suggest that low-abundance sites are sinks where reproduction is insufficient to sustain a breeding population. Management implications and recommendations are discussed.

Résumé

Nous avons estimé l'abondance des oiseaux chanteurs nicheurs pour un certain nombre d'habitats forestiers, au moyen de dénombrements ponctuels. Nous avons calculé pour chaque station un indice de reproduction fondé sur le comportement reproducteur et sur les données de baguage, puis comparé l'abondance aux signes de nidification. Dans l'ensemble, il existe pour la plupart des espèces une relation positive marquée entre les estimations d'abondance et de nidification. Pour les espèces dont les effectifs ont beaucoup changé au cours des trois dernières années, nous avons aussi examiné la variation du succès reproducteur dans les stations à grande abondance et à faible abondance. Les stations à grande abondance ne présentaient aucune variation significative, tandis que celles à faible abondance présentaient une variation significative et même un nombre significativement moindre d'observations de nidification pour les années où les oiseaux étaient relativement peu nombreux. Il semble donc que les stations à faible abondance constituent des puits où le taux de reproduction ne suffit pas à maintenir une population nicheuse. Les auteurs présentent les répercussions de ces résultats pour la gestion et formulent des recommandations.

Introduction

Recent concern that many Neotropical migrants and other songbirds breeding in the boreal forest are suffering population declines has increased the importance of understanding relationships between species abundance estimates and potential reproductive success (Robbins et al. 1989; Askins et al. 1990; Hussell et al. 1992). It can be difficult, however, to obtain accurate estimates of the number of breeding birds in forested landscapes (e.g., Wiens 1973). Techniques for quantifying avian abundances typically involve surveys of singing males during the breeding season (Blondel et al. 1981; Bystrak 1981; Welsh 1995). Counts of each species are recorded based on species identification from songs and calls, and mapping censuses provide further detailed information about the number of birds and their territories (Robbins and Van Velzen 1974; Falls 1981). Although point counts are good predictors of the number of males present, they may not correspond with the number of breeding individuals (Van Horne 1983; Robbins et al. 1989; Blake 1991; Gavin 1991).

A wildlife species can occur in many different habitats within a local region. There can be different probabilities of survival, reproduction, and catastrophes leading to extinction associated with each habitat, dependent on the suitability of the habitat for each species. One method of evaluating songbird habitat involves the calculation of return rates and estimates of breeding success for each species from mark–recapture data (DeSante 1991). These probabilities dictate the quality of the habitat. Habitat quality can be considered the relative ability of the habitat to maintain a species' population (Van Horne 1983). Studies have shown that some habitats in which individuals of a species occur are not of sufficient quality to maintain a population (Rodenhouse and Best 1983; Van Horne 1983; Bergerud 1988). The populations in sink habitats have greater mortality than reproduction and rely on immigration from source populations to persist. Pulliam and Danielson (1991) suggest that a large proportion of the population can exist in sink habitats. According to their studies, it is essential to measure reproductive success in the range of habitats that a species occupies in order to evaluate whether these habitats can sustain a population. As abundance is the basis of most ratings of wildlife habitat quality, it is critical to compare estimates of reproductive output and abundance. In this study, the relationship between point count estimates of breeding bird abundance and a reproductive index calculated from breeding observations and banding results was investigated.

Methods

Data were collected on the distribution and abundance of 27 bird species in the boreal forest near Rinker Lake in northwestern Ontario (1992–1994). Estimates of abundance were based on 10-minute Forest Bird Monitoring Program point counts (Welsh 1995) at 73 stations. Information gathered from banding and observations of breeding behavior were used to derive an index of breeding success at each site for each species. For complete details on methods, see Mather and Welsh.[1]

Results

A simple linear regression model between the breeding index and the abundance estimate was fitted for each of 27 species to investigate the relationship between the number of breeding birds and singing birds. Fourteen species showed significant positive relationships, whereas 13 were not significant. When these 13 species were combined in a nested analysis, the relationship between breeding and abundance was significantly positive, $p < 0.05$ (SAS Institute Inc. 1988, proc GLM). This suggests that the nonsignificant results were due to low sample sizes. Overall, the abundance, estimated from point counts, seems to be positively related to the breeding index.

Breeding success rate was compared with abundance. Based on the breeding index, the breeding success per pair was calculated. Preliminary analysis of eight species showed that seven species had no change in success rate with increasing abundance. One species, the golden-crowned kinglet (*Regulus satrapa*), showed a significant decline. Thus, although the abundance of golden-crowned kinglets increased, the number of breeders did not. The final report contains an analysis of the full data set of 27 species.

[1] Mather, M.H.; Welsh, D.A. Sustaining wildlife populations in managed forestlands; the relationship between abundance and breeding success in forest songbirds. Nat. Resour. Can., Can. For. Serv.–Sault Ste. Marie, Sault Ste. Marie, ON. NODA/NFP Tech. Rep. (In prep.)

Trends in abundance were also analyzed (Routereg Analysis; Collins 1994) at each site over the three years to determine whether the sites showed significant patterns in population change. Nine species showed significant positive or negative trends over some combination of the three years (1992–1993, 1993–1994, or 1992–1994). The 73 sites were divided into three abundance categories for the nine species: high density, average density, and low density. These nine species were separately analyzed in high- and low-abundance sites for significant between-year changes in number. Of the 12 between-year comparisons made (those with adequate sample size), there were eight significant changes at low-density sites and only one significant change at a high-density site.

Discussion

Regression analysis showed that the estimated number of breeding birds is positively related to the abundance of singing birds. This provides support for the assumption that higher-abundance populations indicate areas with more valuable habitat for breeding birds. The results from the breeding success per pair analysis showed that, typically, breeding success rate did not change with increasing abundance. For the golden-crowned kinglet, however, breeding success per pair declined with increasing abundance. This could be due to density-dependent effects on breeding behavior; unfortunately, we also suspect that our methodology was biased against detection of breeding at high density. To evaluate accurately the quality of habitat types for different species, it is important to monitor each species separately and examine the resulting relationship between breeding and abundance.

The results from the population trend analysis and subsequent paired comparisons in different-density sites suggest that, in many species, habitats with low bird density have a low reproductive value. Populations at low-density sites are much more variable and, hence, inherently less stable. Evidence that breeding success is unstable or insufficient to maintain the existing population in low-abundance areas has also been shown in a number of bird studies: great tit (*Parus major*) (Krebs 1971), Kirtland's warbler (*Dendroica kirtlandii*) (Probst and Hayes 1987), bobolink (*Dolichonyx oryzivorus*) (Gavin 1991), and ovenbird (*Seiurus aurocapillus*) (Gibbs and Faaborg 1990; Porneluzi et al. 1993; Villard et al. 1993). Based on these results, it can be concluded that the temporal existence of population sinks is indicated by low densities of singing males in many species of boreal forest songbirds. In particular, when a species' population is locally high, habitats with low densities may represent less than adequate habitat for successful reproduction.

Conclusions and management implications

The positive relationship between abundance estimates and the breeding index suggests that, in general, values for habitat quality based on number of birds detected are probably reliable. Although further validation is essential, these results provide support for the continued use of the abundance-based quality indices for conservation. As well, the general pattern of no significant change in breeding rate with increasing abundance supports this conclusion. The decline in golden-crowned kinglet reproductive output demonstrates the potential difficulty in assuming that sites with higher abundance are always best and underscores the need for caution and the continuing collection and evaluation of relevant data.

The relatively high frequency of significant changes in number at the low-abundance sites is an indication of relative instability, presumably owing to the greater importance of extinction and colonization events. This result provides further support for emphasizing conservation of high-quality sites with larger, more stable populations. Conservation of large areas of low abundance (sink habitats) is unlikely to conserve populations, because there are strong indications that they are dependent on high-quality source habitats.

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Organic and nutrient removals associated with harvesting northern Ontario boreal mixedwood stands

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Abstract

A preliminary investigation of biomass and element distribution in typical boreal mixedwood stands on a range of sites across northern Ontario was conducted during 1989–1992. Biomass and contents of nitrogen, phosphorus, potassium, calcium, and magnesium were determined by species and component (foliage, branches, stemwood, bark, stumps, and roots). On a subset of plots, contents of available elements in the forest floor and mineral soil to the depth of rooting were also determined. These data were used to approximate depletions of elements associated with different intensities of harvest, ranging from removal of conifer boles only to full-tree harvesting of all species.

Résumé

De 1989 à 1992, nous avons effectué une étude préliminaire sur la répartition de la biomasse et des éléments nutritifs dans une série de stations typiques de la forêt mixte boréale, d'un bout à l'autre du nord de l'Ontario. Nous avons calculé la biomasse ainsi que la teneur en azote, phosphore, potassium, calcium et magnésium des composantes (feuillage, branches, bois du tronc, écorce, souche et racines) pour chacune des essences. Dans un sous-ensemble de parcelles, nous avons également déterminé la teneur en éléments assimilables de la couverture morte et du sol minéral jusqu'à la profondeur des racines. Ces données nous ont permis d'évaluer de façon approximative l'appauvrissement du sol, pour les divers éléments, résultant de diverses intensités d'exploitation allant d'un prélèvement sélectif des troncs de conifère à la récolte d'arbres entiers de toutes les essences.

Introduction

In Ontario, boreal mixedwoods are defined as associations of up to five main component species: 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.), and white birch (*Betula papyrifera* Marsh.). The composition of individual stands varies, although, to meet the definition of mixedwood, no more than 75% of the total basal area should be either hardwood or softwood (McClain 1981). In the aggregate, boreal mixedwoods occupy some 40–50% of northern Ontario's productive forest area (McClain 1981).

Various sites, including a range of tills, as well as soils of lacustrine, alluvial, and aeolian origin, support or potentially support good growth of boreal mixedwood forest. On good sites, boreal mixedwoods are productive. Standing crops of 400–500 $m^3 \cdot ha^{-1}$ and mean annual increments of 6–7 $m^3 \cdot ha^{-1} \cdot yr^{-1}$ can be achieved, although lower values are more common. Good productivity of mixedwoods follows from the fact that, under favorable conditions, component species of the boreal mixedwood association (particularly trembling aspen and white spruce) are high-yielding. Further, many hold that mixedwoods in general are more productive than single-species stands because the various component species utilize sites more completely, so that individual trees do not compete with one another to the same degree as in a monoculture.

Nutrition of boreal mixedwood stands has received little attention. Harvest under most conditions is typically followed by a vigorous regrowth, often of aspen and field layer species. This is usually attributed to more favorable light, temperature, and moisture conditions in the newly exposed forest floor, which promote germination and sprouting. These same conditions promote mobilization of forest floor nutrients as well, and further increases in available nutrient concentrations occur as a result of the interruption of uptake associated with tree removal. This flush of nutrients, or "assart effect," acts to sustain the new growth. The effect is short-term, although, from a nutritional perspective, important in conserving nutrients on site. Forest harvesting may also have long-term effects on forest sustainability. Forty years ago, Rennie (1955), studying the nutrition of pine, other conifer, and hardwood plantations on Yorkshire heaths, questioned the then-prevailing view that even nutrient-poor soils could, because of the presumed low demand for nutrients exerted by forest, as opposed to agricultural, crops, support vigorous timber production in perpetuity. The question has been, in the years since, the subject of numerous investigations, using various approaches and involving many species and sites, but it has never been adequately answered. Only a limited number of investigations have been conducted in boreal mixedwood forest, however, although some information is available from research on pure stands of component species. Boyle and Ek (1972), for example, studying a trembling aspen-dominated mixedwood in north-central Wisconsin, concluded that harvesting of entire aboveground portions of trees—i.e., full-tree logging—would not cause serious depletions of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), or magnesium (Mg) for a minimum of two rotations at accepted growth rates, although growing and harvesting trees on shorter rotations might cause more rapid depletions of reserves. Likewise, Gordon (1981, 1983) suggested that, although some pure sprucewoods in Ontario might be at risk, especially black spruce stands on dry outwash sand plains or on organic soils, boreal mixedwoods on average could probably sustain full-tree logging. Timmer et al. (1983), in a similar evaluation of potential full-tree harvesting impacts on forest stands in north-central Ontario, did suggest, however, that future shortages of Ca, P, and K could occur in their trembling aspen as well as two of their three conifer types.

Past harvesting practices in boreal mixedwood stands left considerable quantities of organic matter and nutrients on site in the form of unutilized material, either standing or felled, which, upon decomposition, served to nourish the regrowth forest. Thus, site impoverishment through depletion of nutrients was not an issue, and the few studies that addressed this did not yield alarming results. However, with mixedwood forests occupying a broad range of sites and accounting for a substantial portion of the northern Ontario forest estate, and with substantial increases in rates of utilization, the question still remains as to the effects of such removals on the future productivity of at least some sites. Thus, in 1989, a project was undertaken to study the potential impacts of harvesting strategies on a range of northern Ontario boreal mixedwood stands. The objectives included the following:

- to determine, for a range of sites supporting boreal mixedwood forest in each of northeastern, north-central, and northwestern Ontario, total standing crop and nutrient contents by components;
- to simulate the impacts of various harvesting strategies on the nutrient reserves of the sites; and
- to devise and recommend strategies to minimize nutrient depletion in harvested products, especially from more fragile sites.

Methods

Within each of northeastern, north-central, and northwestern Ontario, two nonadjacent areas within which were identified areas underlain by three broadly defined soil types—soil of fine, intermediate, or coarse texture—were selected, for 18 locations in total. In northeastern Ontario, work was concentrated around Sudbury and Elliot Lake; in north-central Ontario, around Folyet, Chapleau, Hearst, and Hornepayne; and in northwestern Ontario, east and west of Thunder Bay. At each location, 8–10 0.04-ha temporary sample plots were established in typical, semimature to mature (50–60 years on average) boreal mixedwood stands. Stand tables by 0.1-cm diameter at breast height (DBH) and species were developed. Representative sample plots were selected from among the 8–10 per location for further study. Equations of regional applicability relating dry weight and DBH by species and component (including foliage, flowers and fruits, large branches, fine branches, stemwood, stumps, and roots) were developed by sampling, drying, weighing, and pooling by region selected trees of each species from these plots, following the method of Hegyi (1972). Representative samples of foliage, fruits, large branches, fine branches, stemwood, stem bark, stumps, and roots were collected in the early autumn at each location; samples were oven dried at 70°C and analyzed for N, P, K, Ca, and Mg by methods previously indicated (see Morrison 1990). Concentrations were used in conjunction with the allometric equations to calculate per area contents of N, P, K, Ca, and Mg for each location.

In the northeastern Ontario plots, forest floor and mineral soil samples by 10-cm depth increments were collected, analyzed according to previously indicated methods (see Morrison 1990), and combined with soil weights to give per area contents of total N, available P, and exchangeable K, Ca, and Mg. The data were used to simulate organic matter and element removals associated with different harvesting strategies, ranging from removals of conifer stems only to total biomass removal.

Results

Total standing biomass values by region and soil type are given in Table 1, with an overall mean for all plots of around 145 000 kg•ha^{-1}, no clear-cut difference between sites, and a suggestion of lower total standing

Table 1. Mean above- plus belowground tree biomass (kg•ha-1) on fine-, medium-, and coarse-textured soils in three geographic regions of northern Ontario.

Soil type	North-eastern Ontario	North-central Ontario	North-western Ontario
Fine	177 200	169 900	99 800
Medium	148 900	164 400	137 100
Coarse	138 300	187 800	78 700
Average	155 100	174 000	105 200

biomass values in northwestern Ontario compared with the other two regions. The conifer contribution to the total biomass (not given) averaged about 36% in northeastern Ontario, 43% in north-central Ontario, and 45% in northwestern Ontario. Aboveground biomass, broken down by live crown (i.e., leaves and branches), dead crown (i.e., dead branches), and boles (i.e., stems including bark), is given in Table 2. Boles comprised about 75–83% of total aboveground biomass in all cases.

Distribution of the principal macroelements for plots separated by soil type in the northeastern region only is given in Table 3. The order of abundance of elements in the tree stands in all cases was Ca > N > K > Mg > P. In whole ecosystems, N and Ca were the most abundant elements; the least abundant were P and Mg. Depletions associated with different harvesting scenarios are given in Table 4. Extracting conifer boles only, for example, removed only 1.5–2.0% of the total ecosystem N and approximately the same proportions of ecosystem P. Increasing the harvest to include all species, but extracting boles only as in shortwood or tree-length systems, increased the N drain to 8.1–10.1% and the P drain to 7.1–10.6%, depending upon site. When the entire aboveground portion of the stand is taken (as in full-tree harvesting), there was a three- to fourfold increase in N and P loss compared with tree-length harvesting. The most pronounced losses associated with full-tree harvesting, however, were of K and, to a lesser extent, Ca and Mg, depending upon soil type.

Discussion

Until recently in northern Ontario, the predominant management strategy with respect to boreal mixedwood stands was to "commercially clearcut" them (i.e., high-grade them for their conifer content)—wasteful to some, but, when restricted to conifer bole removal only (either shortwood or tree-length), a relatively benign practice with respect to organic and nutrient losses. With an average 40% conifer content for the stands examined, commercial clear-cutting for conifers removed, on average, only 16–17% of the total tree biomass. Extending stems-only harvesting to all species (i.e., clear-felling using either a shortwood or tree-length system) increased yields nearly fourfold to 64–65% of the total tree biomass. These proportionally better gains presumably are related to better recoveries from the hardwood component. Full-tree harvesting systems (involving cutting and skidding of the full aboveground portion of the tree for delimbing at roadside) increased biomass removal further to about 80% of the total on site.

Losses of nutrients increased with degree of removal. Although exact amounts removed varied from stand to stand, depending on total biomass and on the particular combination of species present and on site, it is evident that removal of hardwoods resulted in a much more than proportional increase in losses of most nutrients, owing to generally higher concentrations of most elements in hardwood tissues. Further, losses were not directly proportional to increased biomass removals in the change from tree-length to full-tree systems. Whereas biomass removal increased only one-quarter with full-tree as opposed to a stems-only harvest, the removal of N increased 3.5-fold; P, 3.4-fold; K, 2.6-fold; Ca, 1.6-fold; and Mg, 1.9-fold.

Natural mechanisms do exist whereby element losses are replaced. Atmospheric deposition as well as soil processes such as N fixation and mineral weathering regularly add measurable quantities of mineral elements to forest ecosystems (although a portion is lost into the groundwater). In north-central Ontario, for example, annual inputs of N, P, K, Ca, and Mg in precipitation alone to a tolerant hardwood ecosystem averaged 6.5, 0.27, 1.2, 3.9, and 0.9 kg•ha-1—although, in the cases of K, Ca, and Mg, these quantities were far more than offset by losses into the drainage (Morrison et al. 1992). The principal input of elements, however, is through mineral weathering, which varies substantially between sites. The paucity of data on *in situ* soil weathering, however, attests to its difficulty of measurement. Mineralization of elements stored in organic matter on or in the forest floor is likewise an important source of nutrients for the future stand. Whereas a short-term assart effect follows harvest, the release of minerals from more recalcitrant materials in the forest floor and, particularly, the release associated with the breakdown of coarse woody debris are important in the long term. In natural forests, coarse woody debris from tree mortality and branch fall is abundant.

Table 2. Distribution (kg•ha-1) of aboveground biomass among major components of boreal mixedwood forest on fine-, medium-, and coarse-textured soils in three geographic regions of northern Ontario.

	Northeastern Ontario			North-central Ontario			Northwestern Ontario		
Component	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse
Live crown[a]	31 100	22 100	20 400	26 200	20 900	28 500	15 800	20 200	6 600
Dead crown[b]	4 300	2 600	2 500	2 700	2 600	2 600	2 300	3 000	2 600
Boles[c]	114 800	97 400	89 500	114 100	114 000	129 800	54 800	87 000	40 300
Total	150 200	122 100	112 400	143 000	137 500	160 900	72 900	110 200	51 900

[a] Foliage, fruits, live branches.
[b] Dead branches.
[c] Including bark.

Table 3. Mean distribution (kg•ha-1) of total nitrogen, phosphorus, potassium, calcium, and magnesium in above- and belowground tree components, forest floor, and mineral soil on fine-, medium-, and coarse-textured soils in northeastern Ontario.

Stratum	N	P	K	Ca	Mg
Fine					
Tree, above	483	50	296	667	76
Tree, below	108	16	61	177	16
Forest floor	500	85	44	337	30
Mineral soil	442	9	41	452	218
Total	1533	160	442	1633	340
Medium					
Tree, above	385	34	269	432	51
Tree, below	80	12	64	149	14
Forest floor	302	33	39	129	12
Mineral soil	544	7	16	23	3
Total	1311	86	388	733	80
Coarse					
Tree, above	356	32	239	518	52
Tree, below	113	13	61	192	14
Forest floor	161	33	29	123	11
Mineral soil	457	18	12	161	13
Total	1087	96	341	994	90

Table 4. Depletion of macroelements as a proportion of ecosystem total in relation to harvest intensity.

	Depletion of macroelements (%)		
Harvest	Fine-textured soil	Medium-textured soil	Coarse-textured soil
Nitrogen			
Conifer extraction	2.0	1.7	1.5
Tree-length	8.4	8.1	10.1
Full-tree	31.5	29.4	32.8
Phosphorus			
Conifer extraction	1.7	2.1	1.3
Tree-length	7.1	10.6	9.5
Full-tree	31.0	39.6	33.4
Potassium			
Conifer extraction	6.2	6.7	4.6
Tree-length	21.6	28.1	27.5
Full-tree	66.9	69.3	70.2
Calcium			
Conifer extraction	5.6	6.9	4.6
Tree-length	23.3	34.8	32.7
Full-tree	40.9	58.9	52.1
Magnesium			
Conifer extraction	1.7	5.6	3.6
Tree-length	10.2	33.1	31.0
Full-tree	22.3	64.4	58.2

As little extra yield accrues from full-tree as opposed to tree-length harvesting (even when chipped at roadside), the latter is preferable from a long-term nutritional perspective—especially when care is taken to leave the slash well distributed over the site. If full-tree harvesting is opted for, redistributing slash over the sites should be considered, or, at least, logging should be conducted during the winter months, when hardwood leaves as well as the oldest age-class of conifer leaves will have fallen.

Acknowledgments

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Impacts of climate change on boreal mixedwood forests in Ontario and ways to mitigate them

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Abstract

This paper describes the general negative influences of global climate change, with a focus on the belt of mixedwood forests in Ontario. The main environmental stress of the future is going to be the worsening of water balance as a result of increased evapotranspiration. In spite of the generally subhumid climate of Ontario, these effects are already being seen in soils with low water retention ability, of which Ontario has large areas. The consequence for boreal mixedwood forests will be a reduction in the number of species, with the shallow-rooted species being the most affected.

A series of practical measures, aimed at mitigating the general effects of global climate change and adapting existing forest ecosystems to ensuing changes, is proposed. For mitigation of climate change effects, the emphasis is placed on immediate reforestation after harvest and on restoration of forestry cover on the bare areas during a maximum time frame of 10 years. For adaptation of existing ecosystems, consideration is given to silvicultural means of reducing the vulnerability of existing young to mature forests to water stress effects through thinning and promotion of deeply rooted species.

Résumé

La présente communication décrit les effets négatifs globaux du changement climatique planétaire, avec une attention particulière à la zone de forêt mixte de l'Ontario. La principale source de stress environnemental à venir sera un déséquilibre accru du bilan hydrique, à cause d'une augmentation de l'évapotranspiration. Malgré le climat généralement subhumide de l'Ontario, ces effets sont déjà sensibles dans les sols dont la capacité de rétention d'eau est faible. Or, ces sols occupent de vastes superficies en Ontario. Le phénomène entraînera une réduction du nombre des espèces dans la forêt mixte boréale et touchera principalement les essences à enracinement superficiel.

Nous proposons une série de mesures visant à atténuer les effets globaux du changement climatique planétaire et à adapter les écosystèmes actuels aux changements à venir. En ce qui concerne l'atténuation des effets causés par le changement du climat, nous mettons l'accent sur un reboisement immédiat après toute récolte et sur la restauration du couvert forestier des secteurs dénudés, dans les dix ans au maximum. En ce qui concerne l'adaptation des écosystèmes, il faudrait chercher à réduire la sensibilité des forêts jeunes à mûres aux effets du déficit hydrique, au moyen de certains travaux sylvicoles, comme l'éclaircie et les mesures favorisant les essences à enracinement profond.

Introduction

At the end of the second millennium of civilized life in the West, humankind is facing an enormous and complex challenge—climate change. This threat is made more worrisome by both its global character and the difficulty in obtaining consensus on the need to act against a slow but sure trend, when apparently more pressing needs appear every year. Foresters, as environmental operators who manipulate the principal carbon dioxide (CO_2) sink, which could restore the globe to its previous condition, are confronted with an immense challenge: understanding the biological grounds of the threat and devising means to fight it.

Climate and soil are critical factors for the distribution and productivity of tree species. For millennia, the variability of climatic elements remained confined to certain limits, offering regionally constant climatic averages under which the major forest ecosystems lined up, from the equator to the poles. As the atmosphere is enriched in CO_2 and other "greenhouse gases," it traps more of the reflected longwave radiation, which causes its temperature to rise. The situation continues to worsen because of increased burning of fossil fuels, especially coal, and diminishing forested areas, which, together with forest soils, are the greatest CO_2 sinks. In Ontario, the zone of boreal mixedwood forests—ecosystems productive and rich in species—has great importance in terms of both productivity and ecological stability. This paper attempts to identify the ecological influences likely to be exerted by the changing environmental scenario in areas typically occupied by mixedwoods, and it proposes practical measures to mitigate their effects.

Approach

As part of general circulation models (GCMs), which predict the warming of the atmosphere at different geographic scales and with different rates, we attempted to detect the warming signal from the long-range climatic information in Ontario. For this, we analyzed the existing records of temperature and precipitation for weather stations with very long periods of observations. Owing to lack of space, only the results for Parry Sound, Ontario (lat. 45°20'N; long. 80°00'W), will be given here, although results from other stations with long-term records are similar.

Next, considering pertinent information collected at our stationary ecological research station in the Kirkwood forest (close to Thessalon, Ontario), we assumed that the most important ecological factor that may subject the forest to water stress is not the precipitation amount, which is always higher than evapotranspiration in the belt of mixedwood forests, but the ability of soil to store this water and offer it to vegetation after rain events have ended. In that regard, owing to its high hydraulic conductivity, the more permeable a certain soil, the shorter the residence time of water in it. Thus, for reconstituting the soil's water balance, we first determined biologically the wilting point for some sandy soils (sunflower method). Then, based on daily temperature records for Blind River, and considering the most recent predictions of GCMs, we determined the Thornthwaite potential evaporation (ETp) for three hypotheses: 1) with current temperatures—ETp_0, 2) with an increase of 2°C above current temperatures—ETp_2, and 3) with an increase of 4°C above current temperatures—ETp_4. Thus, past records of temperature were used to obtain an estimate of ETp, whereas the records of precipitation were used to determine the daily water balance, considering the soil's water content at wilt point as the lowest threshold of the accessible water.

Results

Climate change in the Boreal Mixedwood Forest

It has been predicted that the annual average temperature of the earth's surface, already slightly increased at around 15°C, will continue to increase by an additional 1.5–4.5°C in about 50 years. The analysis of long-range daily temperature records for the Parry Sound, Ontario, station indicates a clear warming trend, based on annual temperature averages (Figure 1), with a rate slightly more than 1°C per century. Owing to increased heat levels, it is apparent that precipitation has also slightly increased (Figure 2). In a warmer atmosphere, the water is most likely recycled faster, which may lead to a more active atmosphere than in the past.

Obviously, these new trends affect the neighboring forest ecosystems, gradually modifying the direction of natural succession. The increased temperature has a general influence on the duration of the growing season, which expands steadily. From the viewpoint of forest productivity in areas with an unrestricted water supply, this influence is positive. To that effect, we may add the as yet unquantified "fertilization" influence of higher CO_2 content on photosynthesis. However, these effects are small. At the same time, increased temperature results in accrued atmospheric demand for evapotranspiration. The effect of temperature on ETp, together with precipitation, is presented in Figure 3 in clusters of three days for the period May–July, when the most active diameter growth occurs. It is obvious that, at the peak of summer, an increase of 2°C in temperature results in an increase of 1 mm in daily accrued ETp.

In the permeable soils of Ontario, characterized by fast infiltration and downward movement of water, increased ETp may represent a significant additional stress placed on the ability of trees to satisfy their need for water. At this stage, the magnitude of climate modification does not represent a threat to the existence of boreal mixedwood forests; however, as an additional and continuous water stress operating on the species composition of mixedwoods, we might expect this pressure to act as a screening process that may eliminate shallow-rooted species in years with reduced precipitation. More than in the past, the wave of higher water content that sweeps permeable soils during and immediately after a rainfall event will quickly leave the root zone of shallow-rooted species, remaining available only for the deeply rooted species. Thus, the above-mentioned screening, operating particularly during droughty years, will result in the retention of only those species that are able to obtain water in spite of its reduced availability.

Climate change and soil water regime

The biological determinations of the wilting point done in the Kirkwood forest, made by layer up to a depth of 120 cm, have revealed that deep, coarse, sandy soils that have some organic matter content only in the superficial layer, up to 10–15 cm in depth, are characterized

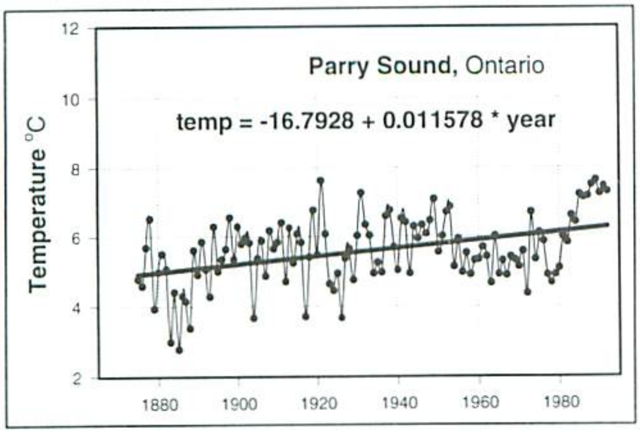

Figure 1. Variation of the mean annual temperature between 1887 and 1992.

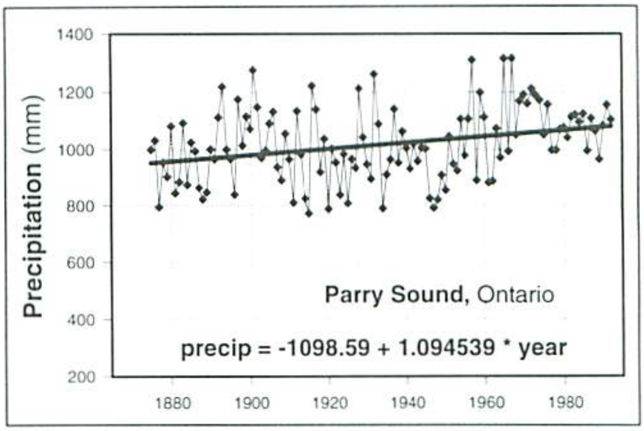

Figure 2. Variation of the annual sum of precipitation between 1887 and 1992.

by a very low amount of unavailable water. In fact, our research has differentiated two stages: beginning of wilting and the death of plants. Summed for the whole soil profile up to 150 cm, beginning of wilting occurs when the soil still has 35–45 mm of water; at the death of plants, the soil contains only 25–30 mm of water. Given the fact that the local coarse sand has a hydraulic conductivity in the range 0.2–1 cm/min, the roots of typical red pine (*Pinus resinosa* Ait.) plantations will be without a steady water supply in less than a day. This happens mostly as a result of deep infiltration, which continues during the nighttime, and not as a result of consumptive use, which depends on sunshine and other factors. Evidently, mixedwood forests over permeable soils, which have not yet been the subject of thorough water regime studies, experience similar conditions. As shown in Figure 4, rainfall events result in transient increases in soil water storage above the thresholds of 25–50 mm of unavailable water. Soon after, mostly as a result of infiltration, the soil reverts, sometimes for long intervals, to a water content of around 25 mm for a 150-cm depth of soil, which is the bone-dry condition of the sand. With an even higher soil hydraulic conductivity over areas with gravel, the water supply conditions are even more severe.

Mitigation measures

We realize that the integrity of the boreal mixedwood ecosystem, as we know it, is threatened. We must therefore examine large-scale measures that can be employed for the maintenance of this ecosystem, for both the economic and the social benefits it provides, as well as for its potential to contribute to the restoration of the condition of the atmosphere to that which existed before the industrial era.

In the first place, we must determine, in specific, well-represented variants of boreal mixedwood forest, what species are threatened by a future, less favorable soil water regime and what the consequences will be on an ecosystem's productivity. For economic aims, the vigor of our cultural intervention has to be adapted to maintaining the highest proportion of the most valuable species in the mixture, while avoiding the risk of leading it toward a monospecific ecosystem. For conservation purposes, interventions through thinnings may have to be more vigorous, as the aim will be to maintain the existing biodiversity in its entirety, obviously with differing species' abilities to resist a stressed, almost hostile environment from the viewpoint of water supply.

Based on these principles and realities, we propose the following as an embryonic policy on which Ontario, specifically the Ministry of Natural Resources, should base its new forest management policies in response to climate change. It should be understood that, at this time, these measures may not be all-encompassing; cooperation of forestry specialists is being sought to make this policy as comprehensive as possible. In a first approximation, the proposed policies aim at 1) mitigating climate change effects through new stands and 2) adapting existing ecosystems to future, changed conditions:

1. The proposed *mitigation measures* are based on the need to cover the territory allocated to forestry with active CO_2 retrievers and the demonstrated fact that the effectiveness of the forest in this retrieval is a function of productivity and health.

   1.a. Immediate reforestation after harvest.

   1.b. Restoration of forest cover on bare areas that can sustain forest production in a maximum of 10 years, thus increasing the efficiency of solar energy conversion to biomass.

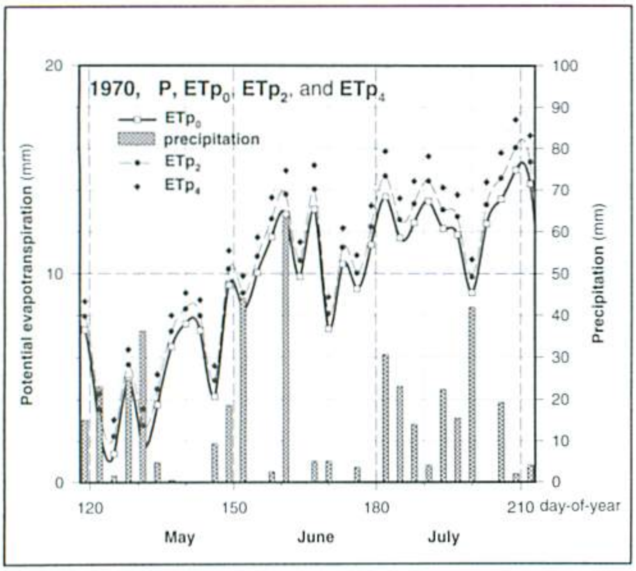

Figure 3. Typical spring–summer rainfall distribution and evolution of ETp0, ETp2, and ETp4; Blind River, Ontario.

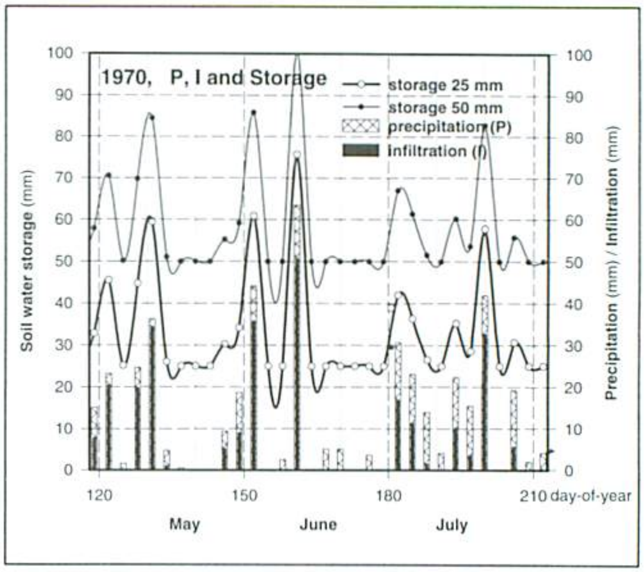

Figure 4. Typical evolution of soil water storage, precipitation (P), and infiltration (I) under ETp0; Blind River, Ontario.

1.c. Increasing the CO_2 sink role of forests through forest growth activation by thinning operations in young to mature stands, and reducing their potential as a CO_2 source from dead biomass through the fight against diseases and pests.

1.d. Strict application of principles and techniques of intensive silviculture, including use of genetically improved strains of trees, on prime sites.

1.e. Increasing the productivity through better matching of species to sites, including by expansion of red oak (*Quercus rubra* L.) on deep sands, for sites prone to water stress.

1.f. Intensification of forest fire prevention activity, to reduce the role of forests as sources of CO_2.

2. The proposed *adaptation measures* examine the possibilities to modify existing, natural ecosystems in view of climate warming. However, it has to be accepted that there isn't much latitude as to how an existing ecosystem, particularly a natural one, can be adapted to these new conditions. As well, it needs to be noted that the proposed measures have not been attempted yet, even at an experimental scale, nor is there available experience in this area anywhere in the world.

2.a. Reduction of the vulnerability of forests to the ecological effects of climate warming through extensive thinning operations, carried out as soon as commercial material can be obtained.

2.b. Maintenance of genetic diversity through modified harvest regeneration practices.

2.c. Periodic control of species composition along the rotation.

2.d. Application of intensive silvicultural treatments to suitable mixedwood sites.

2.e. Expansion of stationary ecological research, with emphasis placed on soil water availability.

Conclusions

Humankind has to look with extreme concern to the issue of global climate change. If this problem is not addressed with determined policies that relate to both the sources and the sinks of carbon, global climate change will result in unthinkable consequences. A factor that must be considered is that predictions made on the basis of GCMs usually stop at a range of 50 to a maximum of 100 years. Do we have any grounds to believe that this process will stop then? Can anyone show a credible mechanism that will stop climate change in the absence of action on the sinks and sources of CO_2? Even with immediate, vigorous interventions on the sources and sinks, with the known inertia of the atmosphere to respond to mitigation measures, a continuing warming for 30–50 years after these measures are implemented is likely.

Also, as the proposed measures are in fact what should be normal forest management practice, we should devote immediate attention to this issue, even before the political level fully understands the need for action. The threat of climate change confronts the forestry sector in all regions of the globe and at all levels, with a longer time frame and a shorter policymaking horizon than other recent forest sector concerns. Thus, it requires consistency, long-term commitment, and sustained effort.

Microclimatic influences of small forest openings on white spruce and trembling aspen regeneration

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Abstract

An experiment designed to investigate the influence of microclimate on white spruce (*Picea glauca* [Moench] Voss) establishment was installed in a trembling aspen (*Populus tremuloides* Michx.) stand near Chapleau, Ontario, in 1993. Openings of the following sizes were created: circular openings 9 and 18 m in diameter, east–west strips 9 and 18 m wide, and a 1.5-ha clearcut. Solar radiation, air temperature, and soil temperature were strongly affected by the size of opening. Frost damage to planted white spruce was greatest in the clearcut and decreased with decreasing size of openings. Regeneration of aspen was substantial except in the smallest circular opening. A well-developed shrub and herb layer was present in all openings and suppressed the growth of planted white spruce.

Résumé

En 1993, près de Chapleau (Ontario), nous avons installé un dispositif expérimental dans un peuplement de peuplier faux-tremble (*Populus tremuloides* Michx.), afin d'étudier l'incidence du microclimat sur l'établissement de l'épinette blanche (*Picea glauca* [Moench] Voss). Nous avons pratiqué des ouvertures circulaires de 9 et 18 m de diamètre, des ouvertures en bandes est-ouest de 9 et 18 m de largeur et une coupe à blanc de 1,5 ha. La taille de l'ouverture avait une incidence marquée sur le rayonnement solaire, la température de l'air et la température du sol. Chez les semis d'épinette blanche, l'intensité des dégâts dus à la gelée était directement reliée à la taille des ouvertures et a donc été la plus forte dans la coupe à blanc. La régénération du peuplier faux-tremble était importante, sauf dans la plus petite des ouvertures circulaires. Une strate herbacée et arbustive bien développée était présente dans toutes les ouvertures, où elle empêchait la croissance des semis d'épinette blanche.

Introduction

Attempts to establish white spruce (*Picea glauca* [Moench] Voss) in large clearcuts in the boreal forest have met with frequent failure (Stiell 1976). A number of factors may be responsible, including competition from broad-leaved species and grasses, damage from late spring frosts, and planting check. Establishment problems may be partly related to the microclimate of the clearcut. Risk of frost is higher and humidity lower on clearcuts, directly affecting seedling establishment. As well, competing vegetation is stimulated by high light levels and soil temperatures.

An experiment to investigate the establishment of white spruce in different sizes of openings in a trembling aspen (*Populus tremuloides* Michx.) forest was initiated in 1993 near Chapleau, Ontario. This paper highlights some of the differences among openings in microclimate, frost damage to white spruce, growth of white spruce, and regeneration of aspen.

Approach

The study was carried out in a trembling aspen stand, which originated after harvesting in the early 1950s. In 1993, dominant aspen averaged 19 m tall, and basal area averaged 36 m^2/ha. The soil was a deep, well-drained silt.

Forest harvesting was carried out in February and March of 1993 to create the following openings: six 9-m-diameter circular openings, six 18-m-diameter circular openings, three 9-m-wide east–west strips, three 18-m-wide east–west strips, and one 100 x 150 m clearcut.

White spruce seedlings were planted at various positions throughout the openings in the spring of 1993. Seedspots, consisting of six white spruce seeds placed on a 20 x 20 cm scalp, were established at the same time. Some of the areas planted with white spruce were kept weed-free with annual applications of glyphosate herbicide.

Table 1. Microclimatic characteristics at centers of openings, June 15–September 6, 1993.

Treatment	Solar radiation (% of above-canopy)	5-cm soil temperature (°C)	Minimum air temperature (°C)
Clearcut	100	16.0	6.8
18-m strip	68	15.2	7.7
9-m strip	57	15.3	9.0
18-m circle	55	14.6	8.6
9-m circle	26	14.0	9.6
Forest	18	14.2	10.0

Table 2. Damage to white spruce seedlings after a frost event in May 1993.

Treatment	Frost damage (% of seedlings with medium or heavy damage)
Clearcut	75
18-m strip	56
9-m strip	47
18-m circle	52
9-m circle	2
Forest	2

Measurements of solar radiation (1-m height), soil temperature (5-cm depth), and air temperature (15-cm height) were carried out during 1993 at the centers of the openings and under the intact forest canopy (Carlson and Groot 1996). Diameter and height of planted white spruce seedlings and height and density of aspen suckers were measured in the fall of 1994, after two growing seasons had passed.

Results and discussion

Microclimate

Solar radiation is strongly controlled by the shape, size, and orientation of small forest openings. Solar radiation under the intact forest canopy averaged 18% of that in the middle of the clearcut (Table 1). The center of the 9-m circular opening received little direct solar radiation; as a consequence, solar radiation there was only slightly greater than in the forest. The centers of the 9-m strip and the 18-m circular opening received similar amounts of solar radiation (57% and 55%, respectively), whereas solar radiation at the center of the 18-m strip was just over two-thirds of the average value for the clearcut. Solar radiation affects plant growth directly, through its influence on photosynthesis, and indirectly, through its influence on other microclimatic factors (e.g., soil temperature). Forest managers can design the configuration of forest openings to control solar radiation and, hence, plant growth within the openings.

Soil temperature results paralleled those of solar radiation, with the highest 5-cm soil temperatures occurring in the clearcut and the lowest temperatures in the forest and 9-m circular opening (Table 1). The difference in 5-cm soil temperature between the clearcut and the forest for the period mid-June to late September averaged 2°C. Differences in soil temperatures among openings were greatest early in the measurement period and declined as surface vegetation cover increased (Carlson and Groot 1996). High soil temperatures stimulate aspen suckering (Maini and Horton 1966), whereas white spruce root growth is optimum at lower temperatures (Heninger and White 1974).

Minimum air temperatures were strongly affected by size of opening. On average, minimum temperatures were 3°C lower in the clearcut than under the forest canopy (Table 1). On calm, clear nights, this difference was as much as 6°C (Groot and Carlson 1996). Obviously, risk of frost damage increases with opening size.

White spruce regeneration

A damaging frost occurred in late May 1993, shortly after the white spruce seedlings were planted. The degree of frost damage was related to opening size, with almost no damage occurring under the forest canopy or in the 9-m circular openings, and the greatest damage occurring in the clearcut (Table 2).

Tree seedlings that did not receive herbicide treatments differed little in second-year diameter among planting locations (Figure 1). Although environmental conditions differed among the planting locations early in the season and at 1-m height, the rapid regrowth of lower vegetation eliminated these differences at seedling height for most of the growing season.

White spruce seedlings showed a strong response to vegetation control after two growing seasons. At the center of the 18-m strip, the diameter of seedlings in the herbicide treatment was almost twice that of seedlings in the unherbicided treatment (Figure 2). In the forest north of the strip, however, seedling diameters were similar in herbicided and unherbicided treatments.

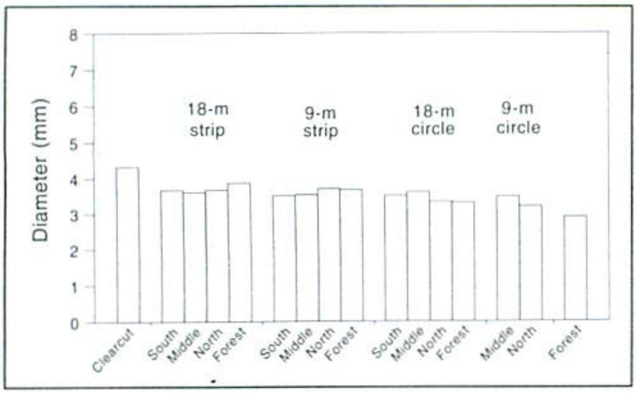

Figure 1. Second-year diameter of white spruce seedlings without vegetation control.

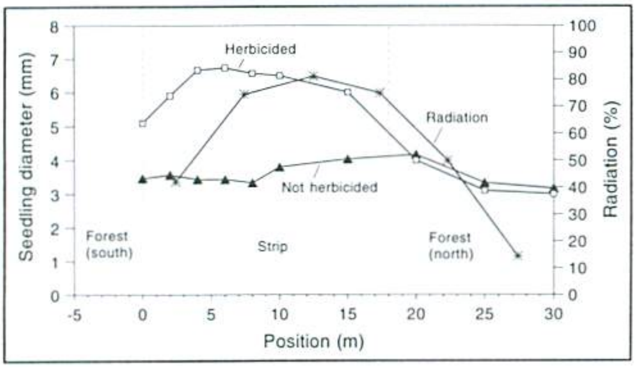

Figure 2. Second-year diameter of white spruce seedlings in herbicided and nonherbicided portions of the 18-m strip. Radiation is relative to above-canopy values.

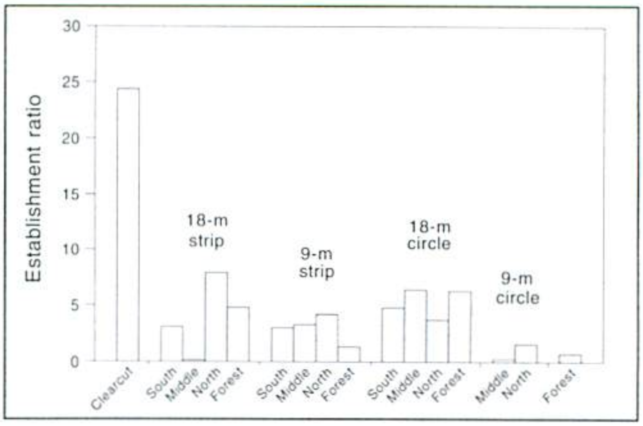

Figure 3. White spruce seedling establishment ratios (seedlings established per 100 seeds sown) at various positions within small canopy openings.

Table 3. Density of trembling aspen suckers at centers of openings, two growing seasons after harvest.

Treatment	Density (stems/ha)
Clearcut	140 000
18-m strip	89 000
9-m strip	51 000
18-m circle	96 000
9-m circle	5 000
Forest	2 000

White spruce establishment from seed was generally poor. Second-year establishment ratios were less than 10 seedlings per 100 seeds sown, except in the clearcut (Figure 3). Heavy competition and smothering by leaf litter make white spruce establishment from seed a poor prospect on fertile upland sites. Drastic site preparation (e.g., blading) may create conditions more suitable for establishment from seed, but the removal of the nutrient-rich forest floor layers may cause growth reductions (Ball 1990).

Trembling aspen regeneration

Density of trembling aspen suckers was greatest in the clearcut, but substantial numbers also established in the 18-m-diameter circular openings and in both the 9- and 18-m-wide strips (Table 3). Density of aspen suckering was likely related to soil temperature.

The decrease in aspen density with opening size does not imply a decrease in competition for white spruce. Development of other competitors, such as beaked hazel (*Corylus cornuta* Marsh.), large-leaved aster (*Aster macrophyllus* L.), bush honeysuckle (*Diervilla lonicera* Mill.), and bracken fern (*Pteridium aqulinum* [L.] Kuhn), was rapid. When the combined effects of the overstory and understory are considered, competition for white spruce was intense regardless of opening size, accounting for the lack of response of white spruce to small canopy openings when vegetation was not controlled (Figure 1).

Conclusions

Forest openings can moderate the microclimate relative to clearcuts, but openings must be rather small to provide this amelioration. For example, the microclimate of the 18-m strip was more similar to that of the clearcut than to that of the forest interior. On fertile sites, changes in near-surface microclimate caused by overstory manipulation diminish rapidly as understory vegetation develops.

When understory vegetation is controlled, small openings can provide an ideal environment for the establishment of planted white spruce. Seedlings suffer little competition and are sheltered from low minimum temperatures. In this study, early growth was best at herbicided locations in the center of 18-m-wide strips. Establishment of white spruce from seed on small scalps has poor prospects on fertile sites.

Acknowledgments

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Biological control of trembling aspen and largetooth aspen using *Chondrostereum purpureum*

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Abstract

Research at the Canadian Forest Service–Sault Ste. Marie into the use of naturally occurring fungi as biological control agents for hardwood sprouting species has progressed to the field stage. *Chondrostereum purpureum* (Pers. ex Fr.) Pouzar, a fungus indigenous to the forests of Canada, has shown considerable promise as a potential biocontrol agent for use in forest management. In a 1994 field trial, *C. purpureum* was applied to freshly cut trembling aspen (*Populus tremuloides* Michx.) and largetooth aspen (*Populus grandidentata* Michx.) stumps at three different application dates: late June, late August, and late September. Assessments conducted the following growing season revealed that the percentage of stumps with sprouts was significantly reduced by the application of the fungus. Although the application of the fungus also increased sprout mortality, it affected neither the average number of sprouts per stump nor their mean maximum height. The percentage of stumps with sprouts was also found to vary significantly with the time of cutting. The late September cutting produced the greatest number of sprouts, whereas the late August cutting produced the fewest.

Résumé

Les recherches menées par l'équipe de Sault-Sainte-Marie du Service canadien des forêts sur l'utilisation de champignons naturellement présents dans le milieu, comme méthode de lutte biologique contre les feuillus drageonnants, en sont maintenant au stade des essais sur le terrain. À cet égard, le *Chondrostereum purpureum* (Pers. ex Fr.) Pouzar, champignon indigène des forêts canadiennes, s'est révélé particulièrement prometteur. Dans le cadre d'un essai réalisé en 1994, on a appliqué ce champignon à des souches fraîches de peuplier faux-tremble (*Populus tremuloides* Michx.) et de peuplier à grandes dents (*Populus grandidentata* Michx.) à trois moments différents de la saison de végétation, soit à la fin juin, à la fin août et à la fin septembre. Lors des évaluations réalisées la saison suivante, nous avons constaté que la proportion des souches produisant des drageons était significativement moindre chez les souches traitées. L'application du champignon augmentait également le taux de mortalité des drageons, mais n'avait aucune incidence sur le nombre moyen de drageons par souche ni sur la hauteur maximale moyenne de ces tiges. Nous avons aussi remarqué que la proportion des souches présentant des drageons variait de façon significative selon le moment de la coupe : la coupe pratiquée à la fin septembre produisait le plus de drageons, tandis que celle pratiquée à la fin août en produisait le moins.

Introduction

Public opposition to the use of synthetic herbicides in Canada's forests has resulted in a growing interest in alternative vegetation management strategies (Wagner 1993). In recent years, the "bioherbicidal" or "mycoherbicidal" approach has been put forward as a viable alternative to traditional synthetic herbicides (Markin and Gardner 1993). This method of vegetation management is based upon the principle that weeds can be controlled by massive inoculation with a host-specific indigenous fungal pathogen (Hasan and Ayres 1990).

Fungi are usually used as the biocontrol agents of choice. Selection of the right organism is key to the success of a biocontrol program (Hasan and Ayres 1990). *Chondrostereum purpureum* (Pers. ex Fr.) Pouzar, the causal agent of silver leaf disease, has shown considerable promise as a potential biocontrol agent for use in forest management (Wall 1990; De Jong et al. 1991). The organism is a basidiomycete fungus that is widespread in North American forests and fruit orchards. It acts like a saprophyte on wounded hardwoods, but often it becomes parasitic by invading the cambium in an injured area and causing mortality of stump sprouts (Wall 1986, 1990; De Jong et al. 1990). De Jong et al. (1991) reported that black cherry (*Prunus serotina* Rhrh.) could be effectively controlled in the Netherlands by applying a suspension of fragmented *C. purpureum* mycelium on freshly cut stumps. One of the main drawbacks of manual weed control in forestry is the rapid resurgence of species that sprout (Wall 1990). It is hoped that the use of a biocontrol agent in conjunction with manual weed control will act to reduce or eliminate either stump sprouting or root suckering, or both. The list of species on which

C. purpureum can be used to control effectively or to eliminate stump sprouting includes trembling aspen (*Populus tremuloides* Michx.), largetooth aspen (*Populus grandidentata* Michx.), speckled alder (*Alnus incana* [L.] Moench ssp. *rugosa* [Du Roi] Clausen), pin cherry (*Prunus pensylvanica* L.f.), red maple (*Acer rubrum* L.), and white birch (*Betula papyrifera* Marsh.).

Stem wounds, created either by frilling the bark of an intact stem or by severing the stem above the root collar, provide an ideal environment for infection by *C. purpureum* (Wall 1990). Under these conditions, the spores' sclerotia or mycelia are protected from desiccation until infection is firmly established within the host tissues (Hasan and Ayres 1990). In nature, infection occurs through physical wounds created by ice, wind, animals, insects, and other diseases such as shoot blight (Jacob and Sheppard 1991).

This paper reports upon an experiment located in northeastern Ontario to determine the usefulness of *C. purpureum* as an inhibitor of stump sprouting, when the fungus was applied to freshly cut stumps of trembling aspen and largetooth aspen at three different times over the 1994 growing season.

Materials and methods

Formulation

Chondrostereum purpureum was cultured on a mixture of wheat bran-distilled water in a ratio of 1:4 w/w for 10 days at 25°C. To prepare the field formulation, 100 g of the wheat bran culture was mixed with 400 mL of 1% (w/v) gum xanthan containing 10% (w/v) glycerol on the morning of the field application.

Site

The experimental site is located in Kirkwood Township in the District of Algoma, approximately 10 km north of the town of Thessalon, Ontario. The original forest stand of red maple, spruce (*Picea* spp.), and aspen was harvested in 1991, and a dense stand of trembling and largetooth aspen subsequently developed. At the time of the experiment, there were about 23 000 aspen stems per hectare on the experimental site. The average height of the aspen was 3.5 m, and the average stem diameter, 15 cm above ground level, was 21 mm. Approximately 60% of the stems in the stand were trembling aspen, and 40% were largetooth aspen. At the time the experiment was established, in addition to trembling and largetooth aspen, white birch, hard maple (*Acer saccharum* Marsh.), and pin cherry were also present.

Experimental design

The experiment was established using a randomized block design. Each block contained three treatments applied at three application times. Each treatment was replicated four times.

Plots were 3 m wide and variable in length. Plot length was determined by the distance required to locate approximately 20 aspen stems (trembling aspen and largetooth aspen combined) within the 3-m-wide strip. Plots averaged 6 m in length. An additional 10 freshly cut aspen stumps were located in the buffer zones surrounding each of the plots receiving the biological control treatment. These stumps were treated with the formulation minus the biocontrol agent to determine if the formulation affected stump sprouting.

A minimum 2-m buffer surrounded each plot. Because lateral aspen roots can extend up to 30 m from the parent tree (Jones and DeByle 1985), roots extending beyond plot boundaries were severed in mid-May 1994 to a depth of approximately 35–50 cm using an agricultural subsoiler drawn by a farm tractor. Weather conditions throughout the 1994 growing season were monitored using a 21XL micrologger (Campbell Scientific). Temperatures at the specified cut stump height were monitored by sliding thermocouple probes between the bark and wood interface.

Prior to the plot being cut, each aspen stem was identified by a numbered metal tag and the average aspen height per plot calculated. In addition, the species of aspen was determined and the stem diameter at a height of 15 cm was measured. In August 1995, each treated stump was examined for the presence of sprouts and basidiocarps of the fungus. On stumps with sprouts, the number of sprouts per stump and the condition of each sprout were recorded. The height of the tallest sprout on each stump was also measured.

Treatments

Trembling and largetooth aspens were cut on June 27, August 23, and September 22, 1994. The stems were severed at a height of 15 cm above ground level using a Husqavarna (Model 235) brush saw. All woody species within the plot borders were felled. Cut plant material was manually removed from the plot area to increase soil temperature and therefore encourage stump sprouting (Maini and Horton 1966). The plots were assigned to one of three treatments: control (no herbicide and no biological control agent), herbicide, or the biological control agent. Additional stumps were treated with blank formulation to determine the effect of the formulation on stump sprouting. Triclopyr ([3,5,6-trichloro-2-pyridinyl]oxy acetic acid) formu-

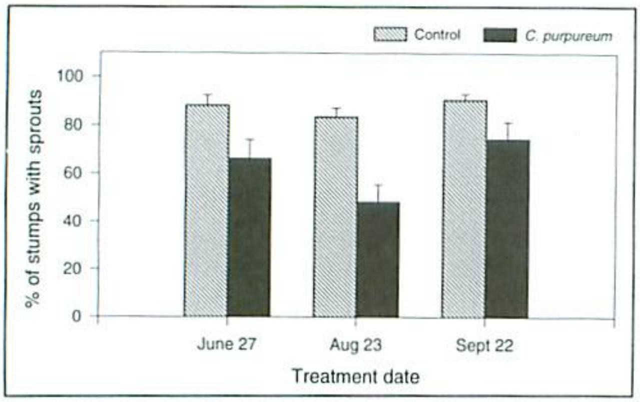

Figure 1. Effects of C. purpureum *and treatment date on the ability of aspen stumps to produce sprouts.*

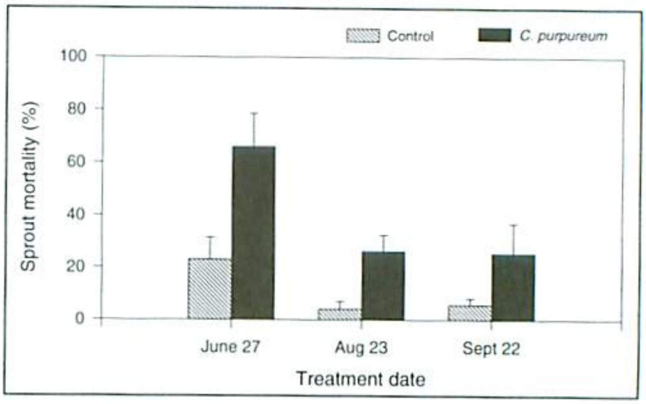

Figure 2. Effects of C. purpureum *and treatment date on the mortality of new aspen sprouts.*

lated as Release® silvicultural herbicide was applied in the herbicide treatment. The formulation containing the biocontrol agent was applied to the top of the cut stumps using a standard 500-mL bicycle water bottle. Following the application of the formulation to the stump, the material was evenly spread over the top of the stump using a paint brush. Triclopyr was applied to the cut stumps using a Solo backpack sprayer equipped with a single brass Teejet 1503 nozzle. The herbicide was mixed with Neutra lite 45 mineral oil (Petro Canada) at a ratio of 1:3 (v/v). The herbicide/mineral oil solution was applied to both the cut surface of the stump and the sides of the stump to the point of runoff.

Isolation of *C. purpureum* from treated stumps

To determine if *C. purpureum* infected the stumps and to obtain an indication of the rate of growth, three stumps from each plot were cut at the root collar during the last week of October 1994. The stumps were stored individually in paper bags at 2°C. Isolation of the fungus was done by cutting the stump in half with a band saw. Four small pieces of wood at the bark–wood interface were taken every 1 cm from the root collar to the top of the stump. The samples were placed on 3% malt agar amended with 500 ppm streptomycin sulfate, 100 ppm neomycin sulfate, 100 ppm chlorotetracycline, and 10 ppm methyl benzamidazole carbamate phosphate and incubated at 25°C in the dark. The presence of *C. purpureum* was identified by examining the culture microscopically.

Results and discussion

Sprouting from trembling aspen and largetooth aspen stumps did not differ significantly between the June ($P = 0.37$), August ($P = 0.82$), and September ($P = 0.91$) treatments (data not shown). In addition, differences in the average number of sprouts per stump were also found to be nonsignificant. As a result, trembling aspen and largetooth aspen data sets were combined.

The application of the blank formulation to the freshly cut stumps did not significantly affect the ability of aspen stumps to sprout ($P = 0.43$), the number of sprouts per stump ($P = 0.088$), sprout mortality ($P = 0.33$), and the height of the tallest sprout ($P = 0.74$) (data not shown). The percentage of stumps with sprouts was significantly ($P < 0.01$) reduced by the application of *C. purpureum* (Figure 1). At the beginning of August in the year following treatment, an average of 88% of the control stumps had sprouted, compared with 63% of the treated stumps. Likewise, mortality was significantly ($P < 0.01$) higher among sprouts originating from treated stumps (39%) than among sprouts originating from untreated stumps (11%) (Figure 2). However, the application of the biological control agent did not significantly ($P = 0.09$) affect the average number of sprouts per stump (Figure 3). Differences in total height among sprouts originating from both treated and untreated stumps also did not differ significantly ($P = 0.08$) (Figure 4).

De Jong et al. (1990) found excellent results of biocontrol with *C. purpureum*. For example, 61% of black cherry trees inoculated with this fungus died within two years, whereas 56% of glyphosate-treated trees and 1% of control trees died. Wall (1990) reported that there was initially little evidence of infection in aspen and, as a result, little evidence of sprout reduction. However, inoculation with *C. purpureum* completely prevented sprouting of white birch and resulted in significant sprout mortality in pin cherry.

The percentage of stumps with sprouts varied significantly ($P = 0.05$) with time (Figure 1). The late September cutting produced the highest percentage of stumps with sprouts, whereas the late August cutting produced the fewest. Time of cutting altered neither the average number of sprouts per stump ($P = 0.46$; Figure 3) nor maximum sprout height ($P = 0.40$; Figure 4). Sprout mortality was significantly ($P < 0.01$) higher following the late

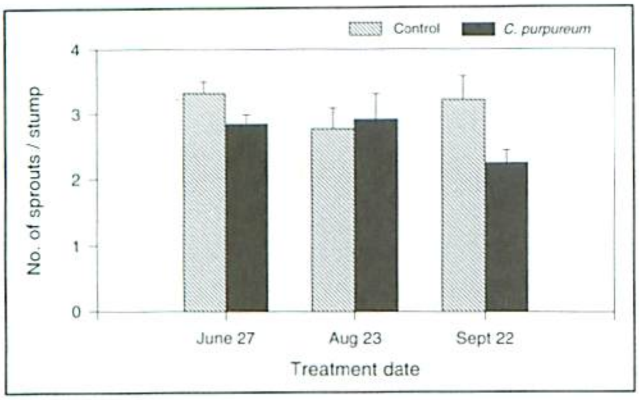

Figure 3. Effects of C. purpureum *and treatment date on the numbers of new sprouts formed by treated stumps.*

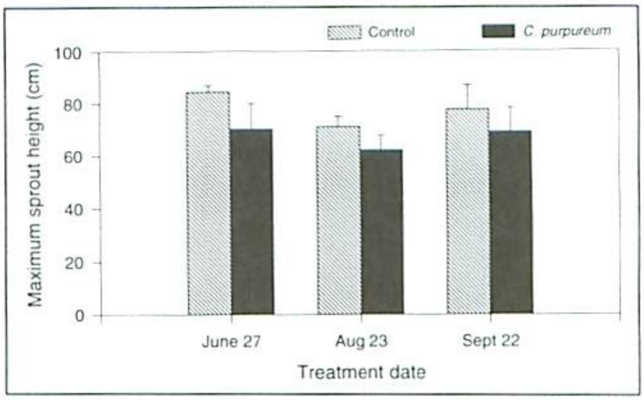

Figure 4. Effects of C. purpureum *and treatment date on the maximum height of new aspen sprouts.*

June treatment than following the other treatments (Figure 2). In part, this result could be due to the fact that the sprouts that originated following the June cutting were at least two months older than the other sprouts at the time of the final assessment.

Chondrostereum purpureum was not isolated from any of the control stumps or from those that received only the formulation, but it was isolated from all stumps treated with the fungus. As a result, observed treatment effects are a response to the same fungus applied to the treated stumps. As expected, owing to the longer incubation periods, penetration of the fungus was greatest in the stumps treated in June, and in the majority of cases the fungus had spread from the top of the stump down to the root collar. Penetration was least in the September treatment, spreading only 4–6 cm down the stump. Wall (1991) found that when yellow birch (*Betula alleghaniensis* Britton) and beech (*Fagus grandifolia* Ehrh.) were inoculated with *C. purpureum*, subsequent penetration and canker development varied with season of inoculation. In his study, the tree's resistance to invasion by the fungus was greatest in the spring and decreased toward midsummer, after which time it appeared to increase again. Working with willow (*Salix* sp.), Spiers and Hopcroft (1988) found that wounds on willow were susceptible to *C. purpureum* infection throughout the year. However, decay depth was least in June and July. In our study, there were no significant interactions between treatment effects and time of cutting effects for any of the assessed variables. This means that the biological control agent had a similar effect on percentage of stumps with sprouts, number of sprouts per stump, sprout mortality, and maximum sprout height at all three treatment times.

Spiers and Hopcroft (1988) found that germ tube extension following a 24-hour incubation period on 2% water agar increased dramatically at temperatures above 17.5°C, with the optimum at 25°C and a rapid decline to zero at 38°C. Wall (1986) found that a temperature of 37°C for seven days was lethal. However, during the field applications in our study, stump surface temperature reached temperatures as high as 43°C, which indicates that the formulation had a positive effect on reducing the susceptibility of the fungus to excessive heat.

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TECHNICAL SESSION I(B): MANAGING MIXEDWOOD ECOSYSTEMS—TOOLS AND CONCEPTS

Moderator

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Utilization of boreal mixedwoods

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Abstract

Until recently, Ontario had large reserves of underutilized hardwood stands in the boreal region of the province. A rapid expansion of hardwood manufacturing facilities since 1991 has resulted in the commitment of much of the northern hardwood reserves. Utilization of boreal hardwoods in Ontario is primarily for the production of commodity products, whereas the Nordic countries and, increasingly, South America produce a more balanced mix of value-added and commodity products. To protect market share and increase profits for the Ontario forest industry, it is recommended that structural and policy changes be made, including a shift to a larger proportion of value-added products; an increase in industrial research and development, mill upgrades, employee training, and product marketing; and the establishment of silvicultural guidelines to increase stand yields closer to the site's potential.

Résumé

Jusqu'à récemment, l'Ontario disposait de réserves importantes de peuplements de feuillus sous-utilisés dans la zone boréale de la province. Depuis 1991, l'expansion rapide des installations de transformation du bois de feuillus a entraîné un engagement important de ces réserves. En Ontario, les feuillus de la zone boréale sont principalement exploités pour la production de matière première, tandis que dans les pays d'Europe nordique, comme dans ceux d'Amérique du Sud de plus en plus, on maintient un mélange plus équilibré de matière première et de produits à valeur ajoutée. Afin que le secteur forestier ontarien puisse protéger sa part du marché et augmenter ses profits, nous recommandons certaines modifications aux structures et aux politiques : que l'on accroisse la proportion des produits à valeur ajoutée; que l'on intensifie la recherche et le développement industriels, l'amélioration des usines, la formation des employés et la commercialisation des produits; que l'on élabore des lignes directrices sylvicoles permettant d'obtenir de chaque peuplement un rendement se rapprochant plus de son potentiel.

Harvested volumes and species mix

From 1962 to 1987, Canada increased its share of the world's solid wood-based commodities, whereas this production decreased in the former Soviet Union and the Nordic countries (Kuusela 1990) (Table 1).

In Ontario, the boreal regions accounted for 83.5% of the entire provincial pulp harvest and 74.4% of the entire provincial sawlog and veneer harvest in 1991. Of this harvest, conifers made up 88% (50% sawlogs and veneer, 50% pulp/miscellaneous logs), and only 18% consisted of hardwoods (38% sawlogs and veneer, 62% pulp/miscellaneous logs) (OMNR 1991).

Until 1991, there was a huge underutilized[1] volume of hardwoods in boreal Ontario (OMNR 1991). Since 1991, there have been many new commitments of the hardwoods in northern Ontario (primarily for new and expanded commodity-oriented strand board sawmills and pulp and paper mills).

Between 1978 and 1982, Ontario's average annual harvest yield (all species) was only 0.56 m^3/ha of exploitable forest. Canada's average was 0.71 m^3/ha. If Ontario's new and expanded hardwood manufacturing facilities coming on line in this decade double the annual harvest (from 1991) and if management steps are not taken to increase stand yields, Ontario will still be below many other jurisdictions in yields per hectare.

Of Ontario's major boreal mixedwood (BMW) conifer species, available balsam fir (*Abies balsamea* [L.] Mill.) volumes are still being projected (perhaps inaccurately) on black spruce (*Picea mariana* [Mill.] B.S.P.) growth and yield information (MacDonald 1991). However, this species seldom survives to rotation age owing to spruce budworm (*Choristoneura fumiferana* Clemens) infestations. Competition for conifers (from BMW mills) will place more harvest pressure on balsam fir.

All sustainable annual volumes for the major BMW species in Ontario are being committed for harvest in this decade, with the exception of associated species, such as eastern larch (*Larix laricina* [Du Roi] K. Koch),

[1] For the purpose of this paper, "utilization" is defined as the current harvested volume, species mix, and finished products being produced from all boreal mixedwood species.

Table 1. Development of proportional shares of boreal countries' solid wood products (as a percentage of world totals).

Product	Country	1962	1980	1987
Industrial wood	Canada	8.7	10.6	11.3
	Nordic	8.1	6.7	6.0
	USSR	24.6	19.1	17.9
Sawn lumber	Canada	6.0	9.8	12.3
	Nordic	4.8	5.3	4.3
	USSR	31.2	21.8	20.3

Source: Kuusela (1990).

eastern white cedar (*Thuja occidentalis* L.), and a few currently uncommitted pockets of white birch (*Betula papyrifera* Marsh.).

Industrial and nontimber-related pressures in Ontario may soon decrease the annual volumes of currently available BMWs. In North America, Russia, and China, BMW utilization is primarily still for commodity wood, pulp, and paper products, whereas in the Nordic countries there is a more balanced mix of both value-added and commodity utilization of BMW.

The Nordic countries "have specialized in products which require high technical skills and increased capital, but require less wood and labour" (Kuusela 1990). The decreases in employment levels at the value-added production level are most often offset by increased employment in marketing, distribution, and product design. These employment opportunities, however, are mostly away from the primary production site (i.e., closer to or within the actual markets).

Boreal mixedwood stands are generally slow growing and situated away from primary commodity markets. Many wood-based commodities are now being produced from fast-growing plantation species in the tropics and mid-latitude regions. This latter development is probably the largest single threat to Ontario's current BMW utilization.

Most Nordic and a few North American forest companies have focused on maximizing the slow growth and superior density of BMWs to their favor by developing value-added production, design, marketing, and distribution. These developments include such items as engineered wood products, specialty plywoods, furniture and window components, machine stress rated lumber, flooring, prefabricated building components, decorative panels and moldings, specialty pulps, and paper products.

Value-added for BMW operations requires major investments in capital for automated processing equipment, staff training, product research and development (R&D), marketing, packaging, customer relations, and distribution. Commodity BMW operations focus primarily on volume, processing efficiency, and quality, whereas sales are often through wholesalers. Commodity revenues fluctuate with supply and demand. Value-added revenues tend to be more stable, as these operations often curtail production in depressed markets.

North America's BMW sawmills generally work on speed and volume and have to plane their product, whereas Nordic mills pay attention to wood species, saw slowly and accurately, and seldom plane their product. Nordic sawmills put out a higher proportion of high-grade lumber per cubic meter of logs than do North American BMW mills.

Many BMW pulp and paper producers are now seeking to achieve a balance of commodity and value-added niche markets in their product mix.

Examples of BMW value-added industries

Two integrated forest companies in Finland have developed new products and end uses for a variety of specialty birch and spruce plywoods. These products sell at three times the price of commodity and construction-grade plywoods.

A growth industry in Nordic countries is prepackaged specialty hardwood flooring products made from short and small-diameter logs. New technologies have cut labor costs and automated production; therefore, the product is similar to solid flooring, yet less expensive.

Devon Mills in Chapleau, Ontario, produces and markets internationally prefabricated log homes from poplar (*Populus* spp.) and jack pine (*Pinus banksiana* Lamb.). E.B. Eddy Forest Products in Espanola, Ontario, has, as a corporate goal, set out "to increase the proportion of value-added products manufactured, with major emphasis on paper grades" (E.B. Eddy Ltd. 1994).

Many sawmills in Europe are now producing clear, finger-jointed window components, machine stress rated lumber, and gluelam beams, using mill ends or low-grade lumber. Automated "cut-up shops" with laser scanning capabilities are used for this work.

Trust Joist MacMillan of Boise, Idaho, has developed and is now successfully marketing a composite product called "Timber Strand TM." made from aspen flakes oriented in the same direction. These are remanufactured into various engineered wood products. The company places equal emphasis on product development, downstream control of marketing, distribution, and production.

Tembec Forest Products in Ville Marie, Quebec, has diverted 15% of its poplar pulp furnish to upgrade and convert its commodity plywood mill into a laminated veneer lumber plant.

Implications for Ontario

Nontimber values will likely reduce current BMW harvest volumes, necessitating increased stand yields and improved utilization. "Any change from basic commodity production will be successful only if there are fundamental changes in [the] . . . philosophy [of production, marketing, and management]. The industry must change from a volume approach to a value approach. Give customers what they want, not what producers think they need" (Russell 1988).

Commodity wood products from temperate fast-growing plantation species are now being vigorously marketed in Ontario's major centers for BMW dimension lumber and framing studs. Expanded R&D on various BMW log species qualities is required. For example, "raw material quality has been identified as an important parameter, because decayed wood results in pulps of inferior strength and brightness compared to pulps produced from sound wood" (Thom 1988).

Mills should gear manufacturing and harvesting of all BMW species available to them. "Utilization of both hardwoods and softwoods from the mixedwood forests offers opportunities," but only if "the species balance is in perfect proportion to the long term mill production" (Smith 1988).

The result of full BMW species utilization is that "harvesting can be confined to areas closer to the mill. This reduced radius has some great potential to encourage prime site management and accelerated silviculture expenditures on both hardwood and softwood areas" (Smith 1988).

The present Ontario tenure system may not be conducive to proactive and full BMW utilization. "As time goes on we should be looking to amalgamate the land base or harvesting rights under one dual tenure disposition. To achieve full advantage of the opportunities mixedwood has to offer, management has to be under the direction and operation of one decision maker" (Denney 1988).

To achieve full BMW stocking, "reforestation responsibility would have to be modified to give both hardwood and softwood operators reforestation responsibility" (Denney 1988).

Job losses from automation and value-added products could be offset by increased expenditures on silviculture, marketing, product R&D, and downstream operations.

Recommendations for Ontario

1. Establish utilization policies and incentives to encourage a lower rotation age for balsam fir where feasible to bring about utilization.

2. Advise BMW mills and the financial community of the potential loss of future harvests due to nontimber values.

3. Phase out present commodity plants that are most likely to be affected by low-cost offshore competition.

4. Promote new value-added mills that can take advantage of BMW's special slow-growing characteristics over commodity mills to achieve a better value-added versus commodity mix in the industry.

5. Establish special tax incentives for value-added operations, R&D, mill upgrades, employee training, and marketing.

6. Convince Ontario BMW mills that they can be more profitable by doing more with less, but that they must look beyond the mill gate. They must be a part of the entire product design and distribution.

7. Promote on-site processing and wood quality sorting. Price crown stumpage based on the various log qualities within each tree to ensure that high-value logs go to value-added producers.

8. Encourage integrated logging and forest management authorities to be responsible for all species on a given land base.

9. Gear mill processing equipment to handle the species and quality of logs that are on the land base now and that are likely to be present in future. BMW mills require long-range analysis of log quality.

10. Establish BMW silvicultural guidelines that best suit increasing yield and nontimber values.

11. Provide the forest industry with opportunities to integrate forest management, utilization, product R&D, and employee training in intensive silviculture and product marketing.

12. Stop the practice of government bailouts of financially troubled or bankrupt mills that are not converting to value-added products or that face insurmountable competition from low-cost competitors.

Acknowledgments

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Partial cutting in boreal mixedwoods: comparison of productivity and site impacts with three harvesting systems

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Abstract

During 1993, the Forest Engineering Research Institute of Canada conducted studies in the Black Sturgeon partial-cutting trials. The studies assessed three harvesting systems for their productivity, soil disturbance, damage to residual stems, and operational efficiency: 1) manual felling with a cable skidder, 2) feller-buncher with a grapple skidder, and 3) single-grip harvester and a forwarder. Manual felling with cable skidding was not very successful because of operator problems (lack of motivation) and difficult stand conditions. The feller-buncher/grapple skidder operation was fairly productive and resulted in some mineral soil exposure, but it caused high levels of damage to residual trees. A feller-buncher with no tail swing would resolve most of the problems. The cut-to-length system was reasonably productive and caused the least amount of damage to residual trees of the three systems, but it did not expose mineral soil.

Résumé

En 1993, l'Institut canadien de recherches en génie forestier a mené des études lors des essais de coupe partielle réalisés dans le cadre du projet Black Sturgeon. Ces études visaient à évaluer trois systèmes d'exploitation quant à leur productivité, à leur efficacité opérationnelle, à la perturbation du sol ainsi qu'aux dégâts causés aux troncs résiduels : (1) abattage manuel, avec utilisation d'un débardeur à câble; (2) utilisation d'une abatteuse-groupeuse et d'un débardeur à pince; (3) utilisation d'une abatteuse-tronçonneuse à tête multifonctionnelle et d'un porteur. Le premier système n'a pas donné de très bons résultats, à cause de problèmes humains (manque de motivation de l'opérateur) et de conditions stationnelles difficiles. Le deuxième système a été assez productif et a permis une certaine exposition du sol minéral, mais il a causé beaucoup de dégâts aux arbres résiduels; on pourrait régler le problème en employant une abatteuse-groupeuse sans balancement arrière. Enfin, le tronçonnage sur place a été assez productif; c'est cette méthode qui a causé le moins de dégâts aux arbres résiduels, mais elle n'a produit aucune exposition du sol minéral.

Introduction

This report describes the Forest Engineering Research Institute of Canada's (FERIC) participation in a project on partial cutting of boreal mixedwood forests in northwestern Ontario, spearheaded by the Canadian Forest Service–Sault Ste. Marie. A long-term objective of the boreal mixedwood research program is to gain a better understanding of ecosystem response to disturbance.

FERIC's role within this project was to assess the operational effectiveness of various harvesting systems used in partial-cutting treatments of boreal mixedwood stands in Avenor Inc.'s Black Sturgeon Forest Management Agreement Area near Nipigon, Ontario. The systems studied were manual felling with extraction by cable skidder, a feller-buncher/grapple skidder system, and a harvester/forwarder system.

Methodology

To assess the productivity of the various systems, FERIC conducted detailed time studies of the different machines in both clear-cut and partial-cut blocks. Only the partial-cutting block results are presented here. The soil disturbance levels and the damage to residual trees were assessed after the completion of the harvest operations. Four-meter-wide cruise lines were established 25 m apart and oriented perpendicular to machine travel. In the cruise corridors, all trees were tallied and visually inspected for wounds greater than 10 cm^2. Soil disturbance plots measuring 4 m^2 were located along the cruise lines, and soil disturbance severity levels were tallied within those plots.

The study area had favorable, freely drained terrain. The stands had various proportions of aspen (*Populus tremuloides* Michx.), white birch (*Betula papyrifera* Marsh.), white spruce (*Picea glauca* [Moench] Voss), jack pine (*Pinus banksiana* Lamb.), and balsam fir (*Abies balsamea* [L.] Mill.); the fir were almost completely decadent as a result of an earlier spruce budworm (*Choristoneura fumiferana* Clemens) outbreak. The partial cut's objective was to preserve some young aspen growing stock and to create favorable seeding-in conditions for spruce, but without excessive light penetration (to keep competing vegetation at moderate levels). Because of the variable nature of the mixedwood stands, operators were given only general removal instructions. They were asked to create a more open stand that retained an overstory of healthy aspen, jack pine, and some spruce seed trees (at least 10/ha). All living merchantable firs and defective aspen, pine, or spruce stems were to be removed.

Results

System productivity in partial cutting

Table 1 presents the productivity observed for each system in the partial-cutting blocks.

The cut and skid crew productivity was generally low because of difficult working conditions (dead fir), inexperience with partial cutting, and the operators' low motivation level. The employees were slow to adapt to the requirements of the special prescription, especially for a fairly complex treatment like partial cutting in mixedwoods. This system usually works well in partial-cutting scenarios in more favorable stand conditions, such as in selection harvesting of tolerant hardwoods, but the large proportion of dead fir in the blocks and the inexperience of the operators led to less than optimal results.

As expected, the productivity of the feller-buncher was lower in the partial cutting than in the clearcut. This was mainly a result of delays in stem selection and extra care in bunching. Also, because of the excessive tail swing of the John Deere 693 feller-buncher, the machine could work only on the upward trip and had to return empty to the road after every strip so as to leave the butt end of the trees facing the road. This would not be a problem with feller-bunchers featuring no tail swing. Although the productivity was reduced, the feller-buncher was surprisingly effective at the felling stage in partial cutting because it could keep the stems vertical after felling, which facilitated the retrieval and bunching of the trees. The productivity of the grapple skidder was not affected significantly by working among standing residual trees during the short-duration studies. Over the long term, however, some reduction would be expected because of the greater care needed to minimize hitting standing stems.

Table 1. Productivity of each system in sample partial-cutting blocks.

	Productivity (trees/productive machine-hour)	Productivity (m^3/productive machine-hour)
Cut and skid	38	5.2
Feller-buncher	91	22.1
Grapple skidder	114	27.9
Harvester	66	13.1
Forwarder	244 (logs)	17.0

The productivity of the single-grip harvester was good, but lower than expected, mainly because of the high proportion of dead fir in the blocks. Harvester heads are not well equipped for crushing and brushing unmerchantable material out of the way. The residual stand was not as attractive as in the feller-buncher blocks, because a lot of unmerchantable material, especially the dead fir, was left standing or leaning. The forwarder worked very productively during the trial, mainly because of the favorable ground conditions and the short forwarding distances. This machine was well suited to the partial cuts because of its gentle and nimble loading of wood among the residual stems. Both short-wood machines also featured good visibility and maneuverability, important assets in partial cutting.

Damage to residual trees

Table 2 presents the level of damage to residual merchantable stems in the partial-cutting blocks.

The proportion of damaged stems in the cut and skid block was high and indicates that the skidder operators were not very careful to minimize rubbing on the trees alongside the trails. The wounds were also fairly large, with a large proportion of inner wood exposed. These results could be significantly improved with proper operating techniques.

The proportion of wounded trees in the feller-buncher blocks ranged from very high (30%) in the first block harvested to 11% in the last block harvested, averaging 19% overall. This would confirm that experience helps in reducing the frequency of damage. The wound locations suggest that a lot of damage was caused by the grapple skidder wheels rubbing along trees on the side of the trail, by the feller-buncher tail swing, and also from contacts of the felling head on residual stems. Generally, the severity of the wounds was high in all blocks.

The harvester/forwarder blocks showed the lowest levels of damage to residual trees, with an average of 5%

Table 2. Damage levels to residual stems in the partial-cutting blocks.

	Proportion of wounded trees (%)	Average wound size (cm^2)
Cut and skid	19	165
Feller-buncher/ grapple skidder	19	420
Harvester/forwarder	5	40

of wounded trees. Also, the average size of the wounds was much smaller than with the other two systems. The average height of the wounds suggests that the main damage sources were the boom of the machines and the forwarder pickets during travel.

Ground disturbance

Table 3 provides the ground disturbance survey results. It should be noted that the trial blocks were on very favorable ground, and some of the last blocks were harvested after ground freeze-up.

In the cut and skid blocks, the ground disturbance levels were quite low, with 96% of the area not having any mineral soil exposed. In the feller-buncher blocks, there was a bit more shallow mineral soil exposure than with cut and skid crews, although generally disturbance levels were very light. The short-wood system caused virtually no ground disturbance, although it should be noted that the blocks were harvested over frozen ground. The proportion of the blocks showing machine trails was lower with the short-wood machines than with the other systems, because of the long reach of the harvester boom, which allowed a wider trail spacing.

Table 3. Ground disturbance results.

	% disturbed		
Disturbance class	Cut and skid	Feller-buncher/ grapple skidder	Harvester/ forwarder[a]
Undisturbed	52	34	62
Humus disturbed	38	48	17
Shallow mineral soil exposure	3	7	1
Deep mineral soil exposure	1	1	0
Nonassessable	6	10	20
Area showing machine passage	37	56	21

[a] All blocks harvested after freeze-up.

Discussion

One of the problems associated with short-duration operational trials is that productivity results are of limited interest, as they represent the first part of a learning curve for a new type of treatment. The partial-cutting prescription in these stands was also fairly complex and would have required more time for the different operators to assimilate. The unionized context of the operation caused many operator changes, so that the productivity data represent a mix of several operators and crews, each with different abilities and motivation levels.

The results on damage to residual trees suggest wide variations in the aptitudes of the various systems at performing partial cutting while minimizing damage to residual stems. Again, however, the fact that this treatment was quite new to all operators should be considered. Damage levels would probably decrease with experience.

Ground disturbance results show that no systems produced severe ground disturbance levels, although this was expected, considering the good ground conditions in the trial blocks and also the fact that some of the blocks were harvested after freeze-up. However, the low levels of mineral soil exposure in most blocks may possibly not be desirable if species to regenerate need some mineral soil exposure to achieve germination and establishment.

Conclusions: suitability of the systems for partial cutting of mixedwoods

The operation with manual felling and cable skidding was not very successful, largely because of operator problems rather than technical problems. The budworm-killed fir in the stands created very difficult working conditions for workers on the ground. Worker motivation is a critical requirement for success.

The feller-buncher/grapple skidder system worked reasonably well but caused fairly high levels of damage to residuals in the initial stages. A more appropriate feller-buncher (i.e., no tail swing) would resolve many of these problems. The slightly heavier levels of mineral soil exposure in this system may be attractive for mixedwood regeneration purposes.

The cut-to-length system provided reasonably good productivity and caused the least amount of damage (frequency and severity) to residual stems. It featured wide trail spacings, but its ability to expose mineral soil lightly was not demonstrated.

For further information

The full internal report, "Partial cutting in boreal mixedwoods: comparison of productivity and site impacts with different harvesting systems. Summary of productivity, soil disturbance and damage results," is available from FERIC on request (IR-1994-09-07).

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Experience with cut-to-length systems in northwestern Ontario

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Abstract

The forest industry and the impact of its harvesting practices upon the environment have come under increasing public scrutiny. Stone-Consolidated Corporation has accepted the challenge by introducing a cut-to-length system to its harvesting operations. The company's goals for the new system are to identify the positive and negative impacts of its usage in mixedwood management, commercial thinning, and advance growth protection.

Résumé

Le public exerce une surveillance de plus en plus étroite sur l'industrie forestière et sur l'impact de ses méthodes d'exploitation. La société Stone-Consolidated a relevé ce défi en mettant à l'essai un système de tronçonnage sur place. Elle souhaite ainsi cerner les effets positifs et négatifs de cette méthode, en ce qui concerne la gestion des peuplements mixtes, l'éclaircie commerciale et la protection de la régénération préexistante.

Introduction

The effects of forest harvesting activities on the environment are issues of growing public concern. The environmental assessment hearings into timber management practices in Ontario and the associated activities of environmental groups have increased public awareness of forest operations with regard to the issues of clearcut size, site disturbance, and biodiversity. During the 1970s and 1980s, the Scandinavian forest industry experienced similar public and governmental pressures to reduce the impact of forest operations on the environment. This resulted in the development of a new concept in forest harvesting machines called cut-to-length (CTL) systems. A feller/processor cuts, delimbs, and processes wood into selected lengths at the stump. A forwarding unit loads and carries the wood to a roadside landing. The CTL system has modified harvesting capabilities, low ground pressure, and many other features designed to protect environmental values.

Stone-Consolidated Corporation (SCC) began actively looking for a suitable system for its Sustainable Forest Licences (SFLs) in 1991. After reviewing the various systems available on the market, an interested SFL contractor expressed confidence in the FMG/Timberjack system and a willingness to participate in a feasibility study. An FMG/Timberjack 990 Harvester and a 910 Forwarder were acquired for trial purposes. The text of this report is based on the CTL feasibility study that was prepared prior to acquiring the trial unit.

The experiences acquired during this trial have positive implications for use in boreal mixedwood forests, although the CTL system has not been used in that type of situation at this time.

Disadvantages of the system that were anticipated included the following:

- technical equipment requires skilled operators;
- biomass on the site reduces site preparation effectiveness;
- heavily limbed trees cannot be processed;
- truck payload is reduced owing to fresh wood having higher moisture contents; and
- dealer support and training are vital to the success of the system.

The original feasibility study had identified the following areas where the system would benefit SCC operations:

- advance growth;
- site disturbances;
- wood quality;
- timber reserve harvesting;
- biomass left at the stump;
- workforce factors;
- seasonal cut restrictions; and
- commercial thinning.

Advance growth

Advance growth refers to the presence of trees of a merchantable species in the understory of an existing forest stand. The term usually refers to trees less than 2 m in height, usually either black spruce (*Picea mariana* [Mill.] B.S.P.) or white spruce (*Picea glauca* [Moench] Voss).

In February 1992, the CTL system was located in a harvesting block that had an advance growth stocking level of less than 60%. The area was subdivided into an area of 57 ha, which was harvested with the CTL system, and an area of 20 ha, which was harvested by conventional feller-buncher/grapple skidder methods.

In July 1992, after completion of the harvest, a regeneration survey was conducted on the site. The CTL harvest area was 53% stocked to black spruce advance growth. The conventionally harvested area was stocked at less than 20%. The latter area will require site preparation and planting treatments to regenerate the site to acceptable levels. The implications of these results for silvicultural costs are significant. In addition, advance growth, as its name implies, contains trees much larger than planting stock. Over 40% of the regeneration in this block is taller than 1 m. A conservative estimate would be that the site resembles a five-year-old plantation.

Advance growth occurs more commonly in mature stands with low stocking of merchantable stems. Machine productivity is reduced on these sites, and consequently harvesting costs are higher. Although we do not have a solid production comparison between low-volume and average-volume stands, it is expected that production in low-volume stands will be reduced by approximately 30%, based on trial data.

Stands containing advance growth represent less than 10% of SFL productive land base, but, where conditions are favorable, it is cost-effective to stratify harvest blocks and preserve advance growth. If postcut surveys indicate that stocking levels are less than 50%, planting stock would be used to fill gaps and maintain a proportionate cost savings.

Site disturbances

A specific trial was not established to compare site disturbances between the CTL and conventional systems.

Skidding operations produce the highest ground pressures of the equipment used for conventional logging. Forest Engineering Research Institute of Canada studies indicate that grapple skidders exert between 10.4 and 15.1 psi. Data provided by FMG/Timberjack indicate the highest ground pressure generated by the CTL system would range from 7.3 to 7.7 psi. This information suggests that ground pressure from the CTL system is approximately 40% less than that from conventional logging systems.

As both CTL machines travel on a bed of limbs produced by the processing function, their ground pressures are further reduced. Studies by SCC staff on the relationships of slash cover to site disturbances found 48% less disturbed area on sites with heavy logging slash compared with areas with a light slash loading.

Site protection is already strongly regulated on many forest operations in the United States and Canada. In Minnesota, logging permits on state lands specify that operations will be terminated if ground rutting occurs. In British Columbia, rehabilitation measures are required if more than 25% of the cut block experiences depressions of 10 cm or greater.

Ground conditions in the spring and summer of 1992 were much wetter than normal for the Fort Frances area. Skidding operations were causing extensive site disturbances, particularly in low areas and on silt and clay sites. CTL operations did not significantly disturb the ground on any of the operating areas during the spring or summer.

Wood quality

Wood quality is governed by many parameters, which can be a limiting factor in wood handling or pulping processes.

Wood quality was assessed throughout the trial period using standard company quality inspection forms. Wood length, particularly long wood, was of greatest concern initially. Table 1 illustrates the length variation of pulpwood produced by the CTL system in February, March, and June 1992. It shows that the production of over-length wood was reduced from 8% to 1% during that period.

Both operations were sorting sawlogs. Although the percentage of long wood is approximately the same, the CTL system produces 7.2–3.5% less short wood than conventional slashing. Mill representatives indicated that a constant wood length would benefit mill operations. Short wood, particularly wood in the 5- to 7-foot range, results in the production of short plugs following slashing in the groundwood mill, which in turn cause problems for the automatic loading.

Table 1. Comparison of pulpwood lengths produced by CTL and conventional systems, 1992.

	Wood production (%)			
	Long (>101")	Acceptable (96–100")	Short (<96")	Sample size (pieces)
Cut-to-length				
February	8	83	9	200
March	1.7	98	0.3	400
June	1	95	4	1029
Conventional slasher				
June	1.5	91	7.5	700

The contractor anticipated wood deliveries to occur one week after harvesting, compared with a four- to five-week average for conventional operations. This is of significant benefit to the ground wood system, where higher moisture content can reduce manufacturing costs and increase pulp quality. Forked logs were described as a "nightmare" to mill operations from both the operational and safety perspectives. Forked logs plug conveyors and often require removal by chain saw, a hazardous condition for laborers. As a forked log cannot fit through the CTL head, the quality and safety problems are eliminated.

Undersize wood is a common quality issue on SFL operations. As the CTL system processes one stem at a time and has automated diameter measurement, topping diameter can be closely controlled. These features also enable the system to increase sawlog yield. The contractor estimated a 20–30% increase in sorting efficiency. Delimbing of wood with the CTL system has not been a problem with spruce and most jack pine (*Pinus banksiana* Lamb.). However, the machine has difficulty and loses production with some heavily limbed jack pine trees. Stands containing a high proportion of these trees are more suited for conventional methods.

Loads of wood produced by the CTL system generally contain more debris than loads produced by conventional systems. The forwarder operator is required to pick up many small grapple loads of wood from the forest floor, where loose limbs often become mixed with pulpwood. The amount of debris varies according to operator and individual skills.

Timber reserve harvesting

Timber reserves for the protection of wildlife habitat and water quality isolate approximately 15% of productive forestland on SFL areas. Access to the areas adjacent to these reserves is established during harvesting operations. The CTL system would be able to extract timber from the reserve areas without compromising the purpose of the reserve. A partial removal of timber from reserve areas would maintain the reserve over time by providing growing space for ingrowth, reducing fixed operating costs by increasing available volume, and increasing the effective land base.

Biomass left at the stump

Virtually all mechanized logging operations on SFL lands are full-tree harvesting systems. Delimbing and slashing are performed by stroke delimbers and mobile slashers. Consequently, piles of limbs and tops parallel road networks where this system is used. Roadside slash causes several problems. From the aesthetic perspective, the piles are unattractive, particularly along main haul roads. Debris restricts water flow from ditches and through culverts, and productive land is lost as a regeneration opportunity. Current logging contracts require the contractor to burn slash piles after the fire season. Effectiveness varies widely depending on weather, access, species, and topography.

Roadside delimbing has its benefits. It is the most efficient method to delimb trees produced by conventional harvesting systems. Removing slash from the site reduces the fire hazard and increases site preparation effectiveness, because slash does not interfere with site preparation tools. Government agencies and environmental groups are expressing increasing concern over biomass removal caused by conventional logging and its effects on long-term site productivity. The concern is higher for thin-soiled sites and sites low in organic content than for sites containing deeper clays or silts. Roadside delimbing reduces the amount of cones left on the harvest site, thus removing a potential natural seed source that would maintain genetic integrity.

Workforce factors

The workforce was recognized as a key component of CTL systems prior to the establishment of the trial. However, the equipment is technically demanding and requires operators who are able to solve mechanical and electrical problems and program the computer to provide the required dimensional criteria. Operators of CTL systems require more maintenance discipline than operators of conventional harvesting equipment. All functions of the machines are required to be kept in good repair to sustain productivity. The lack of protective guarding on the equipment makes the machines susceptible to damage from careless operation.

Table 2. Comparison of noise levels produced by CTL and conventional systems, 1992.

	Decibels at:		
Machine	50 m	100 m	150 m
Feller-buncher	66	55	n/a
Delimber	66	52	n/a
Slasher	82	70	56
CTL	62	48	40

The CTL system was expected to provide a working environment that increased worker safety, had a better ergonomic design, reduced noise levels, and increased job enrichment. All of these operator benefits were realized. The CTL system is capable of producing approximately 10 000 cords per year with four operators.

Seasonal cut restrictions

Harvesting operations are restricted from occurring in blocks near tourist operations during the summer season owing to the noise levels of the equipment. In the current timber management plans, there are over 50 blocks with seasonal cut restrictions. Some of these blocks provide good summer logging opportunities but must be winter-cut to avoid disturbing tourists. Consequently, flexibility between summer and winter operating locations is lost, and higher road construction and contractor moving costs are incurred.

The noise levels produced by the CTL system are much lower than those produced by conventional harvesting and processing equipment. Table 2 illustrates measurements taken in February 1992. The data indicate that the CTL is much quieter than the slasher and, at distances beyond 150 m, has virtually no noise impacts. The ability of the system to work so quietly should allow more flexibility with harvest restrictions.

Commercial thinning

Commercial thinning is standard practice in Scandinavia and represents 39% of total harvest volume. It provides an opportunity to salvage suppressed and dying trees, regulate spacing, improve stand vitality, and remove undesirable species, thereby increasing forest yields. In order to evaluate the economic feasibility of commercial thinning, trials were conducted on three sites. The intent of the trials was to determine the ability of the machines to perform commercial thinning and to assess production rates. On average, CTL production in thinning operations was 50% of clear-cut harvesting operations. It is expected that thinning will be conducted in stands near existing road systems that will provide high yields with low access and haul costs.

The biological responses of the stands will be monitored over the next several years to determine growth response, tree mortality, blowdown, and natural regeneration.

Innovative techniques for advanced silvicultural operations in mixedwoods[1]

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Abstract

Historically, silvicultural operations have been designed, prescribed, or driven by costs per tree or hectare, resulting in a preference for softwoods and clearcuts. Practitioners preferred operations using large prime movers, large or multiple-rowed site preparation tools, and broadcast and aerial vegetation management tools and techniques. More recently, the emphasis in the boreal forest has been on multispecies utilization (hardwoods and softwoods), more stringent site degradation controls, and innovative harvest designs and timetables. Silvicultural techniques must address the new challenges and operational limitations associated with small cut blocks, overstories and patch residuals remaining on the site, reduced use of broadcast chemical vegetation management, and a multientry harvest timetable. This has driven the Canadian Forest Service's Technology Development Unit in Edmonton to develop, demonstrate, and field test the biological and operational effectiveness of advanced small and innovative tools and techniques associated with site preparation and tending. These include high-speed and high-powered horizontal and elevated bed mixers for site preparation on a variety of prime movers, mini-excavators for selective scalping or mounding, and selective chemical, chemi-mechanical, and mechanical vegetation management, as well as stand tending.

Résumé

Dans le passé, les travaux sylvicoles étaient conçus, prescrits et choisis en fonction de leur coût à l'arbre ou à l'hectare, ce qui favorisait les essences résineuses et la coupe à blanc. Les exploitants préféraient les méthodes nécessitant de gros tracteurs, des machines de préparation du terrain de grande taille ou à plusieurs rangs ainsi que des outils et techniques de gestion de la végétation en plein ou par voie aérienne. Depuis quelque temps, dans la forêt boréale, on privilégie l'utilisation de plusieurs essences feuillues et résineuses, une lutte plus serrée contre la dégradation des stations ainsi que le choix de calendriers et systèmes d'exploitation innovateurs. Les techniques sylvicoles doivent aujourd'hui prendre en compte les nouvelles difficultés et les nouvelles limites opérationnelles imposées par la taille réduite des parterres de coupe, par le couvert forestier et les parcelles résiduelles à laisser dans la station, par l'utilisation réduite du débroussaillage chimique en plein et par les calendriers d'exploitation prévoyant une récolte en plusieurs étapes. Ces contraintes ont incité l'Unité du développement technologique du Service canadien des forêts, à Edmonton, à entreprendre la mise au point, la démonstration et l'essai (sur le plan de l'efficacité biologique et opérationnelle) d'outils et de techniques avancés, innovateurs et légers, pour la préparation du terrain et les soins culturaux. On a notamment mis à l'essai : des cultivateurs grande vitesse puissants, horizontaux, surélevés et adaptés à plusieurs tracteurs, pour la préparation du terrain; des mini-excavatrices, pour le dégazonnement sélectif et le buttage; des méthodes chimiques, mécanochimiques et mécaniques, pour le débroussaillage sélectif et les soins culturaux.

[1] Paper not available.

Prescribed fire in boreal mixedwood management

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Abstract

The use of prescribed fire, properly applied, can significantly help in the management of the various tree species that comprise the boreal mixedwood. The immediate benefits of prescribed fire on harvested boreal mixedwood sites are for the removal of woody debris (slash) and for forest floor reduction. Such removal by fire helps in preparing the site for planting or seeding. Prescribed fire can be an important tool in vegetation management on the site. The use of conifer seed trees provides cheap, natural regeneration. Use of a forest ecological classification system, along with harvesting information, can assist in understanding how to apply fire correctly to the site.

Résumé

Le brûlage dirigé, utilisé adéquatement, peut être très utile à la gestion des diverses essences qui composent la forêt mixte boréale. Les avantages immédiats de cette méthode pour les peuplements exploités sont l'élimination des débris ligneux (rémanents) et la réduction de la couverture morte. Le brûlage facilite ainsi la préparation du terrain en vue de la plantation ou de l'ensemencement. La méthode peut aussi constituer un outil précieux de débroussaillage. dans ce contexte, l'utilisation de semenciers d'essences résineuses est une manière économique et naturelle d'assurer la régénération. Par ailleurs, l'utilisation d'un système de classification écologique des forêts et de données sur les récoltes antérieures peut aider à choisir la méthode de brûlage qui convient le mieux.

Introduction

The boreal forest is a fire-adapted ecosystem (Wein and MacLean 1983). Certain portions of the boreal forest have been classified as boreal mixedwood. This, too, has had a long history of fire disturbances. McClain (1981) reported that 45–50% of northern Ontario's productive forest could be classed as boreal mixedwood. By virtue of its often high productivity, the boreal mixedwood offers a strong argument for intensive forest management (Ketcheson 1981).

The boreal mixedwood is defined by this workshop as an area with climatic, topographic, and edaphic conditions that favor 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. Associated species such as jack pine (*Pinus banksiana* Lamb.) and white pine (*Pinus strobus* L.) can be a significant component. This definition contains the tree species that are used in defining the mixedwood fuel group of the Canadian Forest Fire Behavior Prediction (FBP) System (Forestry Canada Fire Danger Group 1992). However, the FBP mixedwood fuel type is broken down further into four groups. The first two groups are the leafless stage that occurs in the spring and autumn (fuel type M-1) and the green stage that occurs when the deciduous trees have leaves (fuel type M-2). In stands with a dominance of dead balsam fir, resulting from repeated defoliation from the spruce budworm (*Choristoneura fumiferana* Clemens), the fuel groups are classified as a leafless stage with a dead balsam fir component (fuel type M-3) and a green stage with a dead fuel component (fuel type M-4). The dead balsam fir allows for faster rates of spread and frontal fire intensities. In all mixedwood fuel types, the proportion of conifers or dead balsam fir affects the fire's spread potential. The FBP System indicates the complexity of predicting fire behavior in the boreal mixedwood.

It appears logical because of fire's historical presence in the mixedwood to use prescribed burning in forest management. Merrill and Alexander (1987) defined prescribed burning as "The knowledgeable application of fire to a specific land area to accomplish predetermined forest management or other land management objectives." Guidelines for prescribed burning in mixedwood have been produced by McRae (1985, 1986). Traditionally, prescribed fire has been used as a site preparation tool after harvesting to remove forest debris left behind by harvesting, to ease access over the site for planting. In addition, prescribed fire has been used in seedbed preparation on some sites by removing the top layers of the forest floor (duff). Removal of these layers improves the germinate survival by eliminating material that is generally more prone to drying out during prolonged droughts. Wearn et al. (1982) showed some typical mixedwood sites through a photo-series containing pictures taken from the same vantage point of various mixedwood sites both before and after burning.

The purpose of this paper is to review some options and procedures to improve the success of the prescribed burn conducted on a boreal mixedwood site. It is hoped that by doing so, prescribed fire will be recognized as a sound and viable site preparation treatment for forest management.

Forest management

Prescribed fire can be used to promote the early successional trembling aspen by allowing it to reproduce vegetatively through root suckering. This is easily accomplished by burning at low Buildup Index (BUI) values of the Canadian Forest Fire Weather Index (FWI) System (Canadian Forestry Service 1987), which will prevent deep burning into the forest floor, thereby allowing the root systems to survive and sprout. Often, aspen left standing after the harvest provides necessary root stock. On the other hand, fire can also be used to eliminate the aspen. This may be felt necessary where the density of aspen is high and some control is desired. Aspen can be eliminated by burning deep into the forest floor (high BUI), which kills the root systems, or by burning prior to spring leaf flush (Weber 1991).

As all birch in the fire will be killed, these cannot be utilized as a possible seed source. However, if pockets of birch inside the prescribed burn were protected, then these could provide seed source also. This may not be warranted, owing to the possible large effort needed to save the birch pocket. White birch adjacent to the burn site can be used as seed source for restoring birch onto the burn site. It must be remembered that the light birch seed can be transported long distances by the wind, so that areas far inside the burn away from the perimeter will still have a good chance of producing birch seedlings.

A successful prescribed fire will kill all conifer trees on the site as a result of either foliage consumption or lethal temperatures. Because of this, it is often used to eliminate balsam fir, a late successional species, to promote the earlier successional species. Unfortunately, residual spruce trees will also be killed by the prescribed fire. On harvested sites, this may be beneficial when these trees are of poor form and will never be commercially viable. Conifer regeneration must be either planted or seeded in, as normal seed sources are removed by the harvesting of the spruce. Seeds contained in cones on slash scattered on the ground will be destroyed by the fire and cannot be expected to provide any regeneration. A viable alternative would be the use of seed trees, left behind after harvesting, to act as a seed source. The use of prescribed fire allows for the preparation of the seedbed and the heat needed to release seed from the semiserotinous black spruce cones. The seed tree approach provides a low-cost regeneration treatment and promotes root-firm trees. Chrosciewicz (1976) showed that a seed tree approach could work well for black spruce.

Associated species, such as jack pine and white pine, are fire-adapted species that can benefit from the use of prescribed fire. Jack pine has adapted through serotinous cones (Cayford and McRae 1983), which makes their use in a seed tree application (20 trees/ha) successful (Chrosciewicz 1988). However, the thin-barked jack pine seed trees will be killed by even low-intensity fires. White pine, on the other hand, with its height and thick bark, survives low-intensity fires and acts as a seed tree. The use of low-intensity understory prescribed burns can be used to produce an excellent seedbed for the white pine and to control vegetative competition in the unharvested stand (McRae et al. 1994). When coupled with seed-years, regeneration can be cheaply established. Often, single white pine seed trees are left standing after a clear-cut operation. Such trees should not be expected to survive a high-intensity prescribed fire.

Prescribed fire planning

Although the forester does not need to know fully the technical aspects of actually conducting the prescribed fire, as this is done by fire staff, the forester may want to understand how the fire may impact the site and ways of improving the success of the fire.

Woody residue reduction

Woody residue (slash) reduction was found by McRae (1985) to be constant, despite the values of the fuel moisture codes of the FWI System: 66% consumption of the 0- to 6.9-cm slash diameter size-class and 20% consumption of larger pieces (≥7.0 cm in diameter). This was a surprise, as it had been expected that consumption would be proportional to the value of the fuel moisture codes. However, the fuel was fresh, in that it had been cut only during the prior winter, and insufficient time had passed to allow the larger pieces (≥3.0 cm in diameter) to dry out. In cases in which higher residue consumption is desired, it may be necessary to wait a year to allow the larger fuel pieces to cure better. Table 8 for upland spruce in McRae (1980) may provide a better consumption estimate for cured slash. It should be remembered that prescribed fire can be applied to 100% of the treatable area, unlike some mechanical treatments (e.g., windrows) that leave large areas untreated.

Forest floor reduction

Reduction of the forest floor (duff) will differ depending upon whether the site is found in the Clay Belt Region of Ontario or elsewhere in the province. Poor drainage in the Clay Belt Region generally means wetter sites and poorer chances for the removal of the forest floor. Only until drought-type conditions exist will duff consumption increase. McRae (1985) suggests that this begins to occur at a BUI of 50. It appears that below a BUI of 50, moisture evaporating at the duff surface is just replaced by moisture below in a wicking-type process. Estimates of duff consumption and depth of burn are given in McRae (1985). Depth of burn in the boreal mixedwood is substantially less than the values recorded on jack pine sites (Stocks and Walker 1972).

On boreal mixedwood sites outside the Clay Belt Region, depth of burn is substantially more (McRae 1980) at higher BUI values. However, there is virtually no depth of burn at low BUI values (≤25). This is explained by the fact that the litter layer of the forest floor often consists of predominately hardwood leaves. Over a winter, this layer of leaves is compacted by the weight of the snow. Such a compacted layer burns poorly in terms of both fire spread and consumption (low porosity and surface area) until dryer conditions prevail.

Forest ecosystem classification systems

McRae and Blake (1995) explain how forest ecosystem classification (FEC) systems can be used to improve the prescribed burning success. FEC systems are useful in identifying potential forest floor types (fuel). Some types, such as the lichens and feathermosses (*Pleurozium schreberi* [B.S.G.] Mitt.), dry quickly after precipitation and carry fire well, whereas others (*Sphagnum* sp.) dry slowly and can cause poor burn coverage over the site. Burning full-tree harvested sites on wet sphagnum sites may be unsuccessful. FEC systems can be used to understand ground vegetation abundance, especially when the prescribed burn is delayed more than one year after harvesting, as the moist microclimate produced can hinder fire growth. Fire coverage on wetter sites or where ground vegetation is a problem may be improved by using the helitorch and avoiding the use of the Ontario Aerial Ignition Device (ping-pong machine).

Vegetation management

The purpose of prescribed burning for vegetation control is not so much the elimination of competitors, but the reduction in their density to allow the crop trees to become established (free-to-grow). A scheme used by Rowe (1983), based on fire effects on the individual plant species, classified plants as invaders, evaders, avoiders, resisters, or endurers. Vegetation management using fire should use this as a basis for understanding how prescribed fire can be used on boreal mixedwood sites.

Considerations in site selection

The probability of completing a prescribed fire is higher when a site is considered safe to burn by the fire boss. To ensure this, the harvested site (treatment area) should be expanded to natural fire barriers (e.g., lakes, streams, swamps, etc.). Harvested sites or plantations adjacent to and downwind from a proposed prescribed fire should normally be avoided because of increased risk of fire escape.

Summary

Prescribed fire is a viable site preparation option in the management of the various tree species that comprise the boreal mixedwoods. Fire impacts, such as fuel reduction and vegetation control, will depend upon the fire weather conditions (as related to the fuel moisture codes and fire behavior indices of the FWI System) prevailing at the time of burning. Use of an FEC system can help in determining the best burning procedures for the site. Proper harvesting techniques can reduce the risk of fire escape and can increase the chances of completing the prescribed fire objectives successfully.

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Vegetation management techniques for mixedwoods

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Abstract

Like coniferous stands, mixedwoods will require management to meet landowners' objectives. Most vegetation management techniques used for conifers can be modified for use in mixedwoods, such as animal grazing, motor-manual and mechanical cutting, and ground application of herbicides. Sheep graze almost all vegetation below 1.5 m, but spruce is not a favored species. Motor-manual cutting can be done to remove undesirable competition selectively from conifers and thin hardwoods in a single operation. Mechanical cutting can be carried out in midsummer and be more successful than motor-manual methods. Ground-applied herbicides can selectively remove undesirable vegetation, and aerial applications also have potential. Because the biological principles underlying each technique are understood, the methods can be successfully modified for use in mixedwood stands.

Résumé

Tout comme les peuplements de résineux, les peuplements mixtes doivent être bien gérés pour pouvoir répondre aux objectifs des propriétaires. D'ailleurs, on peut adapter aux peuplements mixtes la plupart des techniques de gestion de la végétation utilisées pour ceux de conifères : broutage dirigé, débroussaillage au moyen d'un outil manuel motorisé, débroussaillage mécanique, application d'herbicides à partir du sol, etc. Le mouton broute presque toutes les plantes jusqu'à une hauteur de 1,5 m, mais il n'aime pas l'épinette. Le débroussaillage au moyen d'un outil manuel motorisé permet d'éliminer sélectivement les plantes exerçant une compétition sur les conifères et d'éclaircir les feuillus, en une seule opération. Le débroussaillage mécanique peut être effectué au milieu de l'été et donner de meilleurs résultats que l'utilisation d'un outil manuel motorisé. L'application d'herbicides à partir du sol permet d'éliminer sélectivement les plantes indésirables; la pulvérisation aérienne pourrait aussi s'avérer utile. Comme on comprend bien les principes biologiques de chacune de ces techniques, il est possible de les adapter avec succès aux peuplements mixtes.

Introduction

The white spruce (*Picea glauca* [Moench] Voss)–trembling aspen (*Populus tremuloides* Michx.) complex is characteristic of the extensive mixedwood section of the Boreal Forest Region. Typically, white spruce is overtopped by the faster-growing aspen, resulting in reduced spruce growth. Removing overstory aspen can improve spruce growth substantially. Mixedwoods, like conifer-dominated forests, require active management in order to meet a landowner's objectives. Numerous vegetation management techniques are available (Wagner et al. 1995), and most can be applied to mixedwoods. Nonchemical approaches suitable for the establishment, sapling, and polewood stages of hardwood development include animal grazing, motor-manual or mechanical cutting, and girdling, respectively. Herbicide applications may be used at any stage of stand development.

Animal grazing

Carefully regulated grazing by domestic livestock, such as sheep, has been successfully used to control competing vegetation in the Pacific Northwest (Krueger 1987). Cattle and goats are not recommended for crop tree release. Sheep are best suited for nonselective control of herbs and grasses and woody vegetation less than 1.5 m tall. In Ontario, sheep grazing has been used on a trial basis to release spruce plantations. With proper flock management, herbs, grasses, and low shrubs can be removed, and aspen taller than 1.5 m and spruce will be left unharmed. This will encourage a spruce–aspen mixedwood stand.

Factors that influence the success of grazing treatments for vegetation control include site characteristics; flock management; livestock species, number, and distribution; crop species and age; and forage use (Pickering and Richard 1993). Hiring shepherds who understand and practise good flock management is critical.

Guidelines for the use of domestic sheep for forest vegetation management in British Columbia and Ontario have been developed (Lautenschlager et al. 1993; Newsome et al.[1]).

Costs of sheep grazing are high and vary with locality, contractor availability, shepherd experience, size of flock, weather, treatment specifications (especially quantity of vegetation to be grazed), and many other factors. Costs can be reduced by using large flocks (i.e., 500–2000 sheep) and rotating them through a number of sites.

Motor-manual and mechanical cutting treatments

Cutting can be accomplished using a large variety of tools, including axes, Sandviks, chain saws, clearing saws, and mechanical brush cutters (Ehrentraut and Branter 1990). Manual cutting has often been resorted to when herbicide use was unacceptable (Harrington and Tesch 1992; Obermeyer 1992; Weber 1992). Manual treatments are typically used only for controlling woody vegetation, although grubbing has been used in grass-dominated areas (McDonald and Fiddler 1992). Manual methods are suited to small areas, rough terrain, or places where stem-specific treatments are required.

Motor-manual (i.e., brush saws) and mechanical brush cutters are used to remove woody vegetation from around conifers and thin young hardwoods. Mechanical brush cutters have either vertical-shaft or horizontal-shaft cutting heads. Vertical-shaft cutting heads with free-swinging knives (e.g., Silvana Selective and Munger) simply sever the vegetation. They work fast and require less power than horizontal-shaft cutting heads. A variety of these machines (e.g., Silvana Selective/Ford Versatile, Timberjack [FMG] 0450, and Valmet 701 plantation cleaning machines) have recently been introduced to Canada (Ryans 1994; St-Amour 1994; Mitchell and St-Amour 1995).

Horizontal-shaft brush cutters (e.g., Seppi, Brushco Hydraulic brush cutter, and Hydro-axe) require more power and are slower because they pulverize the vegetation. Horizontal-shaft brush cutters are used to cut vegetation nonselectively. One option for mixedwood management is to select a cutting tool that can cut above the height of a uniformly sized conifer crop and cut all vegetation to that height. This results in a mixedwood, because it slows hardwood growth and encourages some conifer stems to compete for dominance.

Cutting is most effective when the species to be cut are not overly dense and do not resprout or resucker. Most conifers are easily controlled by this method. Many hardwood species resprout vigorously after cutting. Cutting when carbohydrate reserves are low (i.e., in the active growing season) reduces regrowth of sprouts. This has been proven for numerous species, including dogwood (*Cornus* spp.), red alder (*Alnus rubra* Bong.), thimbleberry (*Rubus occidentalis* L.), and trembling aspen (Buell 1940; Harrington 1984; LePage 1991; Wagner et al. 1995). Ragged cuts provide better control than smooth cuts. Research on the Fallingsnow Ecosystem Project indicates that the Silvana Selective/Ford Versatile provides better control (greater mortality and less suckering) of aspen than brush saws, although the degree of control varies with stem size and cut height.

Treatment objectives, operating costs, machine characteristics, and site conditions determine which type of cutting tool should be used. Each tool has advantages and disadvantages (Otchere-Boateng and Ackerman 1990). Social considerations may also influence which vegetation management strategy should be used. For example, motor-manual cutting is the alternative preferred by the public of Ontario (Decision Research 1995).

Cost limits the use of both motor-manual and mechanical cutting. Costs of cutting vary with density and size of vegetation to be cut, locality, contractor availability and preference for tools, crew experience, weather, treatment specifications, terrain, and many other factors.

Girdling

Girdling involves cutting away the bark and cambium layer (phloem) from around the stem using axes, hatchets, Sandviks, machetes, power saws, or specific girdling tools (e.g., Vredenburg, Kyuquot girdler, scorp, mechanical tree girdlers). This technique is best suited for selective control of hardwoods that are polewood size or larger. Selective treatment of hardwoods by girdling in a mixedwood stand prior to harvest reduces sprouting density, increasing the potential for conifer establishment, and results in a mixedwood stand.

Girdling the stem of a tree severs the normal flow of carbohydrates from the crown to the root system, starving the roots and slowly killing the tree. The most effective time to girdle is when root reserves are at their lowest—i.e., in the spring after leaf flush and during the period of active growth. The girdle must be wide enough to ensure that the tree will not heal the wound.

[1] Newsome, T.; Wikeem, B.; Sutherland, C. 1993. Sheep grazing guidelines for managing vegetation on forest plantations in British Columbia. B.C. Min. For., Kamloops, BC. Unpubl. Rep. 45 p.

It takes 2–4 years for the effects of the treatment to show (Bancroft 1989).

As with cutting, each girdling tool has advantages and disadvantages (Otchere-Boateng and Ackerman 1990). Costs are the most limiting factor and will vary with stem size and density, locality, contractor availability, preference for tools, crew experience, weather, treatment specifications, terrain, and many other factors.

Ground application of herbicides

In Ontario, the most commonly used herbicides for forestry purposes include glyphosate, 2,4-D, triclopyr, hexazinone, and simazine. Herbicides may be applied with ground application equipment or from the air, depending on what the chosen product is licensed for. Ground application methods include directed foliar, streamline, basal, and stump sprays; soil spot application; and stem injection (Kidd 1987; Wagner et al. 1995). Hand-held equipment includes numerous sprayers (e.g., motorized and nonmotorized backpack sprayers, spotguns, wick and granular applicators) and stem injectors (e.g., basic hack and squirt, Hypo-hatchet®, and Ezject®) (Otchere-Boateng and Ackerman 1990). Soil spot applications with equipment like the spotgun effectively reduce aspen densities and remove grass competition in mixed aspen–white spruce stands. Stem injections and basal treatments have been used to thin hardwoods in both the sapling and polewood stages (Wagner et al. 1995).

Machines include vehicle-mounted ground sprayers (e.g., boom, cluster nozzle, high-pressure gun, airblast, wick and granular applicators), helicopters, and airplanes (Desrochers and Dunnigan 1991). Broadcast applications do not always fit with mixedwood management strategies, but herbicides have been applied aerially with enough precision to produce selectively thinned strips of conifers (Lautenschlager 1985). This technique shows promise for encouraging mixedwood stands at regulated densities.

The most desirable method of herbicide application to promote mixedwoods may be ground application by directed methods to allow selective control of unwanted stems/species. Successful herbicide use depends on several factors, including crop and weed species matrix, phenology of the vegetation, herbicide and applicator used, and weather conditions before and after application. Each herbicide has a unique mode of action and therefore controls vegetation differently. The herbicide label should always be consulted prior to use.

As with all other tools, each herbicide and each application method have advantages and disadvantages (Otchere-Boateng and Ackerman 1990), with the high cost of ground application being the most limiting factor. Costs of ground application of herbicides vary with herbicide and application equipment used, terrain, size and density of vegetation, locality, contractor availability, crew experience, weather, treatment specifications, and many other factors.

Conclusions

Existing vegetation management tools and techniques can be successfully used in mixedwood management scenarios as long as the resource manager has a clear idea of the desired outcome, some knowledge of plant species autecology (response to treatments), and a good understanding of the treatment being applied.

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Timing and duration of herbaceous vegetation control around four northern coniferous species

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Abstract

Optimum timing and duration of herbaceous vegetation control during the early development of forest plantations can be assessed using critical period analysis. Critical periods are being developed for black spruce (*Picea mariana* [Mill.] B.S.P.), jack pine (*Pinus banksiana* Lamb.), eastern white pine (*Pinus strobus* L.), and red pine (*Pinus resinosa* Ait.) seedlings. Six patterns of herbaceous vegetation control—three continuous years, first-year only, first two years, second and third years, third-year only, and no control—were examined. Third-year survival and height were not affected by herbaceous vegetation for any conifer species. Stem diameter, however, decreased substantially without vegetation control. Third-year diameters for eastern white pine, jack pine, black spruce, and red pine without vegetation control were 55, 56, 61, and 64%, respectively, of that observed for trees under three continuous years of vegetation control. Stem volume of all species without vegetation control was reduced by 27–36% of that observed under three years of control. Height/stem diameter ratios decreased as the degree of vegetation removal increased. Critical period analysis indicates that herbaceous vegetation control is important immediately after planting for both tolerant and intolerant conifer species. Preliminary critical period models also indicate that stem diameter gains are proportional to the number of years of herbaceous vegetation control.

Résumé

L'analyse des périodes critiques permet de bien choisir la date et la durée des mesures de lutte contre les plantes herbacées dans les jeunes plantations forestières. Nous sommes en train de déterminer ces périodes critiques pour les semis d'épinette noire (*Picea mariana* [Mill.] B.S.P.), de pin gris (*Pinus banksiana* Lamb.), de pin blanc (*Pinus strobus* L.) et de pin rouge (*Pinus resinosa* Ait.). Pour ce faire, nous avons mis à l'essai six régimes de lutte contre les plantes herbacées : trois années de suite; première année seulement; première et deuxième années; deuxième et troisième années; troisième année seulement; aucune lutte. La végétation herbacée n'a eu aucune incidence sur la hauteur et le taux de survie en troisième année de chaque essence résineuse. Cependant, le diamètre des tiges était beaucoup plus faible en l'absence de désherbage. En effet, les pins blancs, les pins gris, les épinettes noires et les pins rouges des parcelles non traitées ont produit des tiges dont le diamètre atteignait respectivement 55, 56, 61 et 64 % de celui atteint par les tiges dans les parcelles traitées trois années de suite. De même, en l'absence de désherbage, le volume des tiges de toutes les essences était réduit de 27 à 36 % par rapport aux parcelles traitées trois années de suite. Enfin, le rapport hauteur/diamètre diminuait à mesure que l'élimination de la végétation herbacée était plus complète. L'analyse des périodes critiques révèle que la lutte contre les plantes herbacées est importante immédiatement après la plantation, qu'il s'agisse de résineux tolérants ou intolérants. Les modèles préliminaires obtenus au moyen de cette analyse montrent en outre que le gain en diamètre est proportionnel au nombre d'années de lutte.

Introduction

The critical period concept, first developed in agriculture (Zimdahl 1988), defines the time period during crop development within which weed control must occur to prevent yield loss. Figure 1 demonstrates the critical period principle for trees in the first five years after planting. Two curves are created: the weed-free curve indicates the pattern of tree growth increase with increasing years of vegetation control; the weed-infested curve indicates the decline in growth with increasing years of not receiving vegetation control. The left and right extremes of each curve represent the same treatment. For example, zero years weed infested is equal to five years weed free.

The critical period is defined by the position and length of time where the curves cross. In the Figure 1 example, the critical period is between one and three years after planting. No significant growth loss occurs without vegetation control before the critical period, and there is no gain in doing vegetation control after the critical period, because no additional growth results from continued vegetation control. So, the critical period defines the time period after planting within which vegetation must be controlled to avoid growth loss.

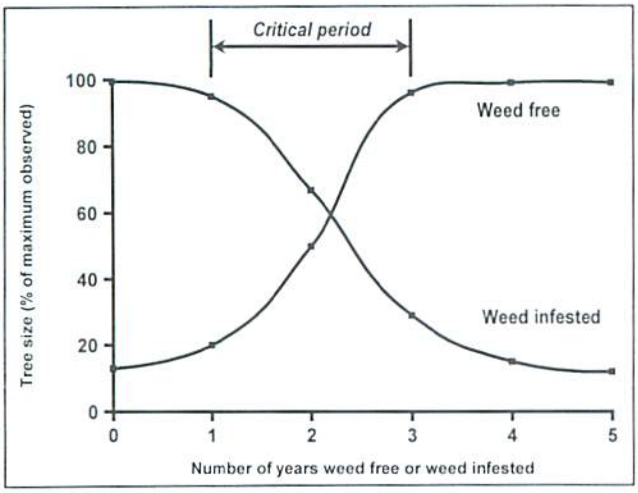

Figure 1. Example of critical period threshold relationship for the first five years of a tree seedling's life.

An elegant feature of these curves is that they can be used to test different hypotheses about the temporal effects of plant competition. Figure 2 depicts six hypothetical outcomes, ranging from very wide critical periods (A and B); through early (C), middle (D), and late (E) periods; to no critical period (F).

The objective of this study is to identify and compare critical periods of herbaceous vegetation removal for black spruce (*Picea mariana* [Mill.] B.S.P.), jack pine (*Pinus banksiana* Lamb.), eastern white pine (*Pinus strobus* L.), and red pine (*Pinus resinosa* Ait.) during the first five years after planting. The study, begun in 1992, has completed three years of growth.

Methods

Black spruce, jack pine, eastern white pine, and red pine are established in a randomized complete block, split-plot design, with 10 treatments, 4 replications, and 30 trees per subplot near Sault Ste. Marie, Ontario. Each main plot is 28 x 28 m in size, and trees are planted on a 2 x 2 m spacing. Herbaceous vegetation (grasses, ferns, and forbs) is being removed in a sequential pattern for the first five years after tree planting: no vegetation removal; annual vegetation removal; one, two, three, and four years of consecutive removal after planting; and waiting one, two, three, and four years after planting before annual removal is initiated. Glyphosate herbicide at 2 kg a.e./ha in 93 L/ha water is applied with a backpack sprayer at the beginning of each growing season. Tree growth (height, stem diameter) and vegetation abundance (cover, biomass, leaf area) are recorded annually.

Results and discussion

Six of the 10 treatments were distinct by the end of the third year: three continuous years of vegetation control, first-year only, first two years, second and third years, third year only, and no vegetation control. Untreated plots have from 50 to 80% vegetation cover, corresponding to between 1300 and 3000 kg/ha dry vegetation biomass and a Leaf Area Index (LAI) from 1.3 to 2.5. Herbicide applications reduced cover to between 8 and 30%, having from 100 to 800 kg/ha dry biomass with an LAI from 0.1 to 0.75. Because glyphosate is not soil active, subsequent vegetation recovery achieved levels of abundance similar to those of untreated plots within one year after treatment. Repeated herbicide applications have reduced cover to lower levels each successive year.

No differences in tree survival or height growth have emerged from the treatments. Stem diameter, however, decreased substantially without vegetation control. Third-year diameters for eastern white pine, jack pine, black spruce, and red pine without vegetation control were 55, 56, 61, and 64%, respectively, of that observed for trees under three continuous years of vegetation control (Figure 3). The weed-free curves indicate that stem diameter increased with increasing years of vegetation control. Whereas the trends were nearly linear for eastern white pine and black spruce, curves for jack and red pine reached a maximum after two years of control. The weed-infested curves show that stem diameter decreased 13, 14, 20, and 21% for red pine, black spruce, eastern white pine, and jack pine, respectively, after only one year of association with herbaceous vegetation. All weed-infested curves continued to decline through year 3, but there is an indication that the rate of decline was leveling off between years 2 and 3, especially for jack pine.

Stem volume of all species without vegetation control was reduced to between 27 and 36% of that observed under three years of control. Height/stem diameter (H:D) ratios decreased as the degree of vegetation removal increased. The H:D ratio decreased with increasing degree of vegetation control for all species. The H:D ratios after three continuous years of vegetation control were 27, 29, 32, and 41 for eastern white pine, red pine, jack pine, and black spruce, respectively. Under untreated conditions, the H:D ratios increased to 42, 43, 56, and 59 for eastern white pine, red pine, jack pine, and black spruce, respectively.

The critical period curves for the first three years indicate that all four species are responding similarly (Figure 3). For stem diameter, models A and C (Figure 2)

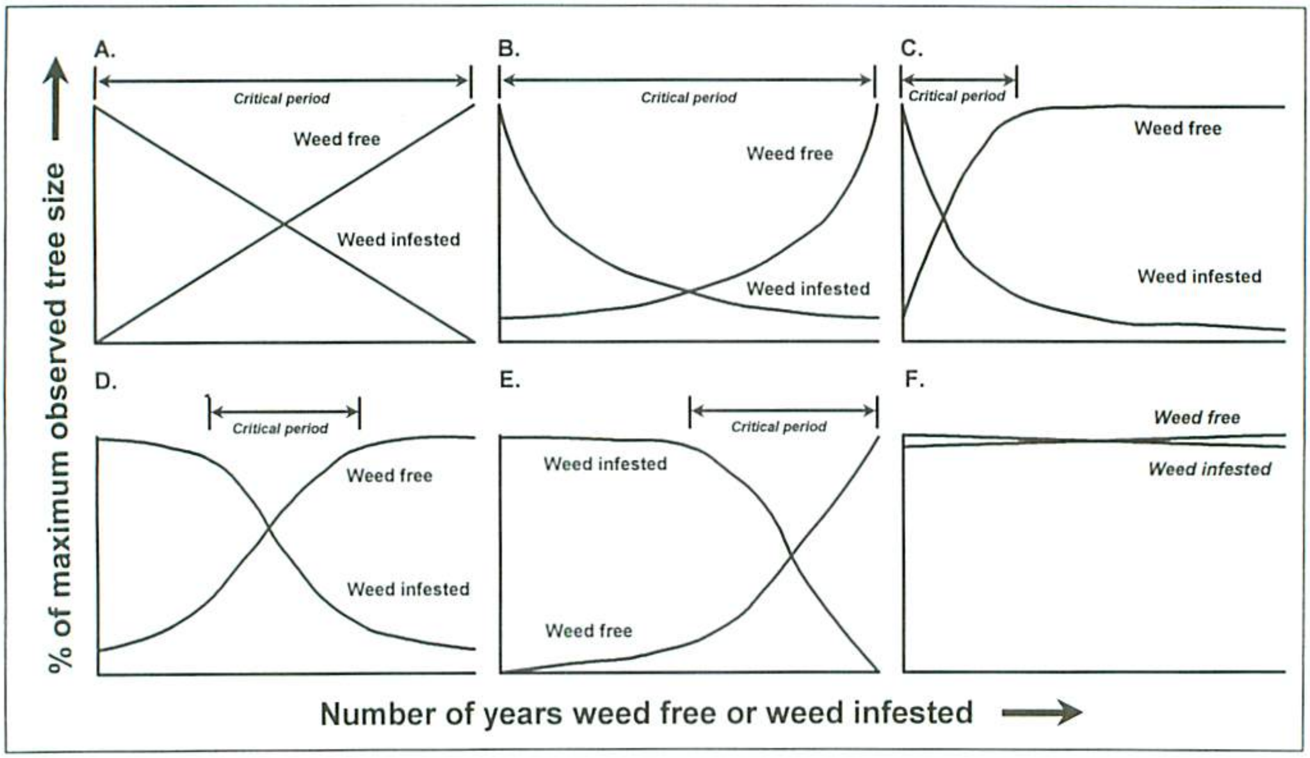

Figure 2. Six hypothetical models from critical period analysis. Patterns range from very wide critical periods (A and B); through early (C), middle (D), and late (E) periods; to no critical period (F). Model A indicates that growth losses are proportional to the number of years during which trees are associated with vegetation. Model B indicates that any association with vegetation substantially reduces tree growth. Models C, D, and E indicate that competitive interactions between trees and surrounding vegetation occur in the early, middle, and late portions, respectively, of the time during which stand development was studied. Model F indicates that no significant interference has occurred between trees and surrounding vegetation.

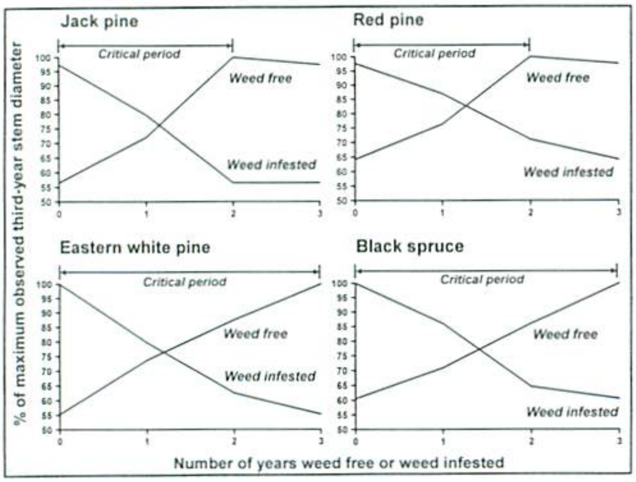

Figure 3. Critical period graphs for jack pine, red pine, eastern white pine, and black spruce, based on the percentage of maximum observed stem diameter in the third year after planting.

are emerging. Jack pine and red pine are following model C; eastern white pine and black spruce are following model A. Therefore, intolerant (jack and red pine) and tolerant species (eastern white pine and black spruce) may have different critical periods. Species with greater tolerance are responding more positively to increasing durations of vegetation control than are intolerant species. Model F has emerged for both height growth and survival of all conifer species, indicating that herbaceous vegetation is not important for these aspects of growth. Continuation of this study over the next several years will confirm whether these patterns continue or change.

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White spruce establishment in boreal mixedwoods using pelleted hexazinone

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Abstract

Overmature, high-graded, or shrub-dominated mixedwoods occupy some of the most fertile sites in the boreal forest. In many cases, no coniferous seed source remains following disturbance. Conifers can be reintroduced by artificial means only. Conventional site preparation, e.g., corridoring, is expensive, incurs considerable environmental disruption, and requires follow-up tending. Thrifty stands of white spruce (*Picea glauca* [Moench] Voss) can be established, even in highly competitive shrubby mixedwoods, simply by underplanting white spruce and dropping hexazinone pellets in a grid pattern on the forest floor, without site preparation or tending.

Résumé

Des peuplements mixtes dominés par les arbustes, surâgés ou écrémés occupent certaines des stations les plus fertiles de la forêt boréale. Dans bien des cas, la perturbation a éliminé toute source de semence de résineux, et il faut réintroduire ces essences artificiellement. Or, le dégazonnement par bandes et les autres méthodes classiques de préparation du terrain coûtent cher, perturbent considérablement le milieu et nécessitent par la suite des soins culturaux. Une façon simple et économique d'obtenir un peuplement d'épinette blanche (*Picea glauca* [Moench] Voss), même à partir d'un peuplement mixte où les arbustes exercent une forte compétition, consiste à planter les épinettes en sous-étage et à déposer des pastilles d'hexazinone en quadrillage sur la couverture morte. Cette méthode ne nécessite aucune préparation du terrain ni aucun soin cultural.

Introduction

Nearly 40 years ago, Sutton (1965a,b) found that competing vegetation in a shrubby overmature mixedwood was controlled better by a given amount of granular herbicide applied in little spaced heaps of granules than by evenly broadcast granular herbicide. The herbicide was Du Pont's Dybar® (fenuron).

Contained in the report on that work was the suggestion that a formulation of the herbicide as *aggregates* of granules might be advantageous. The root mat of competing woody weeds seemed to be more susceptible to localized but relatively concentrated plumes of herbicide (in descending soil moisture) than to the same amount of the herbicide diffused downward through the soil at a lower concentration.

Gridballs®: results from the 1978 experiments

In the mid-1970s, Du Pont experimentally produced Gridball® pellets in various sizes ranging from 0.5 to 2 cm^3 and containing 10 or 15% of the active ingredient. In 1978, we used 2-cm^3 10% Gridballs® in studies at two mixedwood sites near Chapleau, Ontario. The studies were designed to assess the potential for underplanting white spruce (*Picea glauca* [Moench] Voss) through heavy mixedwood competition, *without* preliminary site preparation and *without* subsequent tending—in fact, without any treatment other than the placing on the undisturbed forest floor of one Gridball® per planted spruce.

Promising results after 7 years (Sutton 1986) were even better after 15 years (Sutton 1995). Of the two grid spacings (163 x 163 cm and 95 x 95 cm) in the formal experiment, the closer has been the more successful; considering only the 5 tallest trees per 10 x 10 m plot (16 trees initially) after 15 years, total heights averaged 226 cm with Gridballs®, 98 cm without; stem diameters at ground level averaged 43 mm with Gridballs®, 16 mm without.

In an associated plot extra to the formal experiment, 81 white spruce planted at 1 x 1 m spacing with Gridballs® at the same spacing (but offset to maximize the separation between the spruce and the herbicide pellets) after 15 years had a survival rate of 78%, in spite of heavy browsing by jackrabbits during the first few years after planting, and formed a thrifty plantation averaging 243 cm in total height and 39 cm in current annual height increment. It should be remembered that there had been no site preparation and no tending.

Power Pellets®: preliminary results from a 1993 study

Encouraging as are the results from the Gridball® study, the technique needs further proving. In 1993, funding under the Northern Ontario Development Agreement (NODA) and support for the project by Rob Edmonds of McChesney Lumber Division, E.B. Eddy Forest Products, Ltd., provided the opportunity to establish an operational study (NODA Project 4043) on McChesney limits in Biggs Township south of Foleyet to assess further the potential of pelleted hexazinone for establishing white spruce in boreal mixedwoods and to compare that technique with conventional corridoring site preparation and mounding site preparation.

Although the manufacture of Gridballs® was discontinued some years ago, Du Pont has since developed a new formulation of pelleted hexazinone, Power Pellets®. Each pellet, which is about the same size and shape as a tablet of Tylenol 3®, contains 43% more active ingredient than did the 2-cm^3 10% Gridball®. The product is registered in the United States but not yet in Canada.

McChesney had already established a good track record with corridoring and has many examples of good survival and thrifty early growth. However, corridoring is not cheap, and competition soon begins to encroach; there is a built-in need for at least one release treatment.

Mounding was included in the study because of the lack of information about the response of white spruce to the technique in boreal Ontario. Experience with various other species in Scandinavia and British Columbia (Sutton 1993) and Ontario (Wood et al. 1988; Sutton 1991; Sutton et al. 1991, 1992; Sutton and Weldon 1993) has been mixed.

Two stock types were used in the NODA study, bareroot and containerized. As it happens, the study provides a textbook example of the value of using stock of more than one kind.

A randomized block factorial was used as the experimental design, with the three main treatments—corridoring, mounding, and Power Pellets®—replicated four times. Plots were split between operationally planted bareroot and containerized stock. In all, 2400 trees have been assessed annually for performance.

Survival rates among containerized stock were 93% or higher at the end of the third growing season. This shows both that there was nothing wrong with the containerized stock and that there was nothing lethal about any of the three main treatments.

Among bareroot stock, first-year survival on the mounds was as high as that for containerized stock; in the corridors, however, survival was only 89% at the end of the first growing season and had dropped to 71% by the end of the second growing season. These results confirm that the unprepossessing appearance of the bareroot stock warranted the assumption that the stock lacked vigor. It also seems reasonable to suppose that survival rates among bareroot stock in the three main treatments reflect differential levels of stress experienced by outplants of low vigor in the three main treatments: corridoring > hexazinone > mounding. The differences in survival rates between bareroot and containerized stock clearly illustrate the value of using more than one stock lot in field experimentation.

The growth of surviving bareroot stock in the hexazinone treatment after three years is on a par with that of bareroot stock on mounds; growth of bareroot stock in corridors has been somewhat slower. Vigorous resurgence of competition, both centrally and laterally along corridors, by the end of the third growing season has already begun to curb height growth. Among containerized stock, third-year height increment differs by only 1 cm among the three main treatments; total heights after three years show a differential of 4 cm. Growth patterns differ between bareroot and containerized stock types.

Calculations show that fewer than half the number of hexazinone pellets that would have been needed to give a 2 x 2 m coverage were applied operationally; the actual spacing was thus substantially wider than that which gave good results in the earlier Gridball® experiment. Furthermore, the saturated condition of the forest floor at the time of planting might have rendered the hexazinone less effective here. Nevertheless, the success of the Gridball® treatment took some years to become apparent. As well, in the supplementary (Gridball® vs. Power Pellet®) study, in which pellet grids were closer than in the main study because of less disruption by slash and other obstacles, early results (see below) suggest a promising response, at least to Power Pellets®. It is too early to draw final conclusions about the relative merits of the main treatments.

We are also attempting to quantify the resurgence of competition. Periodically during the three growing seasons to date, we have measured the amount of photosynthetically active light reaching 360 selected outplants.

Gridballs® versus Power Pellets®

Included in this NODA work is a small experiment to compare directly the effect of Gridballs® versus Power Pellets® versus no herbicide on the performance of white spruce outplanted through a selectively harvested but otherwise untreated mixedwood adjacent to the main experiment. Planting of alternate lines of bareroot and containerized stock was completed on the same day as the planting of the main experiment.

The stand conditions in the supplementary experiment approximate those of the hexazinone treatment of the main study; instead of the nominal grid of 2 x 2 m used in the main experiment, however, four Gridballs® or four Power Pellets® were equally spaced 50 cm away from each outplant in the herbicide-treated plots. High survival rates of containerized stock preclude herbicide-related mortality to outplants.

After three growing seasons, growth among stock of both types has been significantly greater in the Power Pellet® treatment than in either of the other treatments.

Conclusions

The viability of pelleted hexazinone as a sole treatment to establish white spruce in competitive mixedwoods is supported by the thriftiness of two such plantations established in 1978 and by the significant response of white spruce to Power Pellets®, unassisted by other treatments in the 1993 study. Further work is needed to determine the optimal densities and distribution of hexazinone pellets, but there seems to be no compelling need to undertake either site preparation or early tending for establishing white spruce.

Acknowledgments

We wish to express our appreciation of the great support given the project by Rob Edmonds and the McChesney staff generally; throughout, they have had an excellent constructive attitude toward the project and have been a real pleasure to work with. We are indebted also to Jamie Corcoran of DuPont Canada, Inc., for contributing the Power Pellets® and related information used in this study. We also thank colleague and technician Mike Adams, for processing CR-21 tapes after each series of photosynthetically active light measurements. Funding for Project 4043 under NODA is acknowledged.

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A decision support system for remote tourism values in boreal mixedwood forests

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Abstract

This decision support system (DSS) predicts the likely responses of remote fly-in outpost camp clients to a wide range of changes around the vacation experience. Variables relating to timber management feature prominently in the study. These variables were presented in digitally controlled photorealistic images. The DSS documents the likely changes associated with any variation in the product in terms of changed market share. As such, the DSS should prove itself as a useful tool in the timber management planning context.

Résumé

Nous présentons un système d'aide à la décision (SAD) permettant de prédire les réactions probables de la clientèle d'un poste avancé de tourisme aérien à une vaste gamme de changements qui toucheraient le cadre de villégiature. Nous avons mis l'accent sur les changements ayant trait à la gestion forestière, et ceux-ci sont présentés sous forme d'images réalistes produites numériquement. Le SAD décrit les réactions probables associées à toute variation du produit, en termes de part du marché. À ce titre, le système devrait constituer un outil précieux pour la planification forestière.

The survey instrument

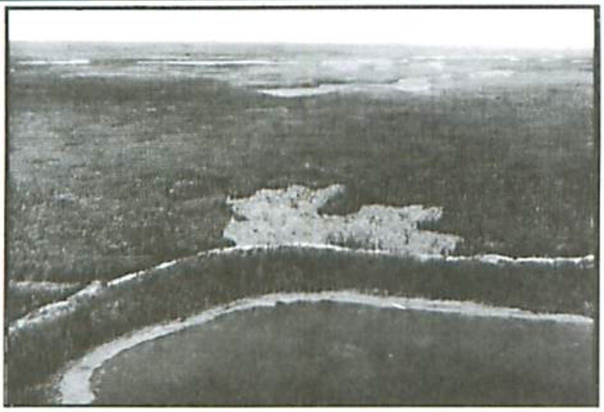
The Tourism Effects Research Program at the Centre for Northern Forest Ecosystem Research (CNFER) of the Ontario Ministry of Natural Resources in Thunder Bay is charged with researching effects of Crown land timber management on tourism in Ontario. One of the research products recently developed at CNFER is a decision support system (DSS) that models the likely effects of timber management on the experience of remote fly-in tourists.

The DSS is based on a survey of over 1000 attendees of travel trade shows in the U.S. midwest and Toronto, the major market areas of remote tourism. Respondents were classified according to their experience as clients and also according to their interests in lodges or outpost camps. Thus, separate models for each subgroup can be specified. At the core of the survey was a discrete choice experiment (Woodworth and Louviere 1983; Louviere 1988) in which hypothetical profiles of remote destinations in northern Ontario (see Figure 1 for an example) were presented to respondents. Respondents were asked to choose one of two alternatives at any one time. Each profile contained a description of the type of accommodation, its size, the price charged, the type and quality of fishing, the chances of seeing wildlife, and the presence or absence of timber management in proximity to the destination lake. Although noise generated by harvesting operations was also described in writing, other variables rendered themselves for visual representation in an oblique aerial view of a remote lake (top image of Figure 1). In this oblique aerial view, eight attributes were varied systematically in a digital imaging technique. Figure 2 represents the dialog screen of the DSS with the eight attributes controlled in the oblique aerial scene; it also lists the levels of the distant scene and the shoreline scene.

In total, 64 landscape scenes were digitized using Adobe Photoshop on the Macintosh. Each scene was then changed through cutting and pasting procedures to represent the type of timber management as prescribed by a fractional factorial design plan. For example, if the design plan called for a profile showing a 100-m buffer, the cut was located in such a way that a 100-m buffer, together with the appropriate age, size, and residuals, was apparent. For a more detailed description of the experimental design procedure applied in this study, see Anderson et al. (1995), and for a more detailed description of the imaging procedure, see Orland et al. (1995).

The decision support system

Analysis of such an experiment is conducted with a multinomial logit (MNL) regression, which produces



Area immediately around your facility on the destination lake

Example: view 4–6 miles away

Example: shoreline view

Accommodation:
Outpost camp (running water, hot shower)
4-day $590, 7-day $845
No other fishermen on the lake
15 minutes fly-in time
Setting:
Occasional wildlife along shore
No shore noise
Fishing:
Good walleye fishing
Excellent northern pike fishing
No lake trout fishing
No bass fishing
Limits & Expectations:
Catch and release only, one trophy can be kept
Mostly moderate size fish, occasional trophy
Distance:
575–725 miles (long day drive)

Figure 1. Example of a choice profile.

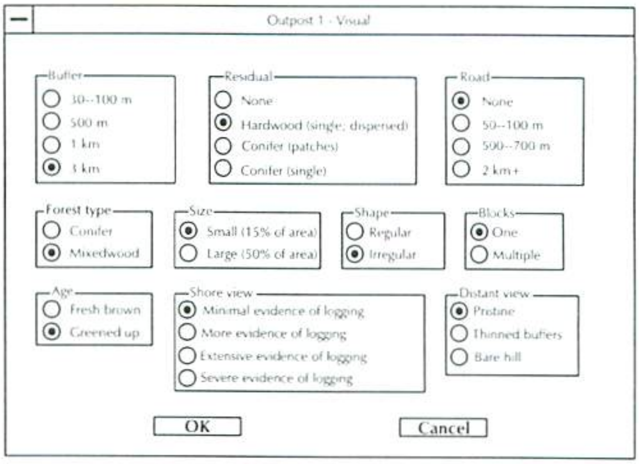


Figure 2. Dialog screen with visual attributes.

an estimate for each parameter level. Space limitations do not permit the reporting of any detailed findings here. The major attraction of the MNL model is that it can be used to calculate the probability of choice for any profile within the experimental domain. This feature can be used to package the findings in a DSS that can be operated in the MS Windows environment and allows the interactive and spontaneous evaluation of any possible scenario by recalculating the market shares for the various configurations.

The DSS contains a "configuration screen" (Figure 3), which contains two complete descriptions for outpost camps (a similar DSS has been developed for lodge operations) that are positioned as competing against each other. In the starting configuration, as illustrated in Figure 3, both outposts are presented as operations in a "pristine" setting with excellent fishing quality and a high price. The DSS predicts that in such a situation, each outpost acquires a market share of 47%, whereas 4% of respondents would pursue some other non–fly-in fishing opportunity, and 1.8% would not fish any longer. This configuration can be changed by activating the button "Outpost 1" with the mouse, which causes a second screen, the "dialog screen," to appear (Figure 2). The full bullets indicate the actual configuration selected. The selection can be changed with simple clicks on the mouse. Please note that Figure 2 contains only the attributes relating to timber management, which are summarized as "pristine" in the configuration screen. All other attributes are presented in a second screen, not discussed in this paper.

Results

The model is sensitive to many changes in a manner that is consistent with expectations. For example, reducing the availability of walleye (*Stizostedion vitreum* [Mitchill,

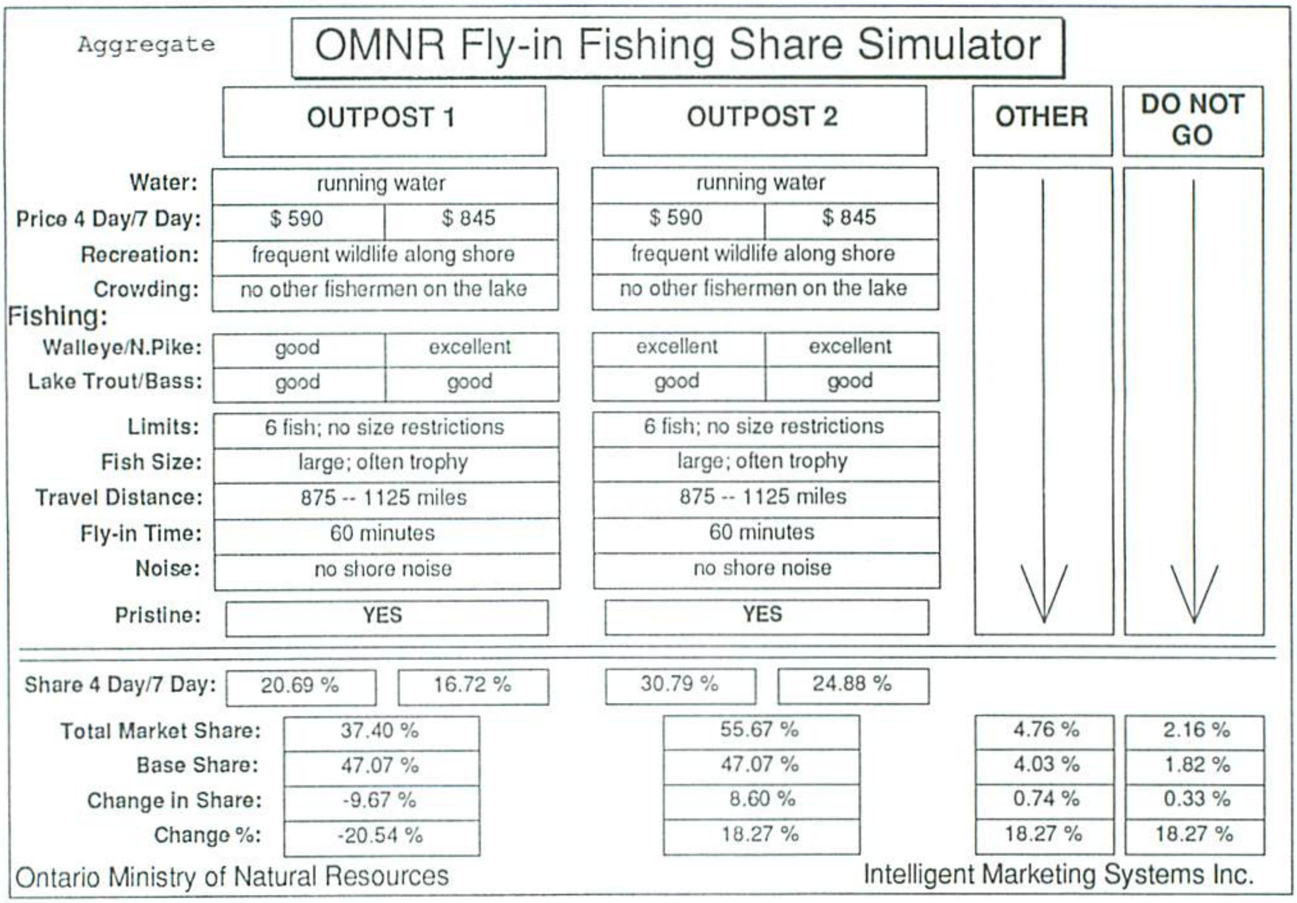


Figure 3. Configuration screen.

1818]) from "excellent" to "good" (i.e., from approximately 25 fish to 12 fish per day) results in a 9.8% decline in market share for that operation. Similarly, if timber operations were conducted in the vicinity of an outpost camp with only a 100-m buffer zone prescribed, the model predicts a decline in market share for that operation by 11.2%. Other variables relating to timber management did not show the same magnitude of effect, but all variables contain at least one significant level. The model can also be used to estimate the price adjustment required to offset a loss in quality of any one aspect of an operation. For example, if logging is conducted at a 100-m distance from an outpost lake, as opposed to leaving the camp in a pristine setting, the operation would need to reduce its four-day price by $160 to $430 and its seven-day price by $225 to $620 in order to regain the previous market share.

The current version of the DSS is a conceptual tool, in that it documents likely effects on a general level. It is not capable of predicting the changes in a site-specific context. Nevertheless, models of this nature should be able to serve as useful decision support tools.

Acknowledgments

This work was funded by the Ontario Ministry of Natural Resources. Thanks go to the consultants D. Anderson, University of Wyoming, Laramie, WY; T. Daniel, University of Arizona, Tucson, AZ; J. Louviere, University of Sydney, Sydney, Australia; B. Orland, University of Illinois, Urbana, IL; and M. Williams, Intelligent Marketing Systems, Edmonton; as well as countless individuals in Ontario who contributed their expertise.

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Predictive adaptive management—applying natural resource management research

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Abstract

To advance forest management in an "ecosystem context," we must begin implementing larger-scale (at least watershed-level), operationally meaningful forest management research. Adaptive management offers that potential, and, with proper modifications (predictive adaptive management, or PAM), it could incorporate social interests. The PAM approach 1) includes appropriate publics in management decisions, 2) addresses regional and local concerns, 3) implements existing knowledge, 4) integrates research teams, and 5) implements ecosystem management even lacking complete knowledge. After appropriate publics agree on desired outputs, monitoring is restricted to documenting implementation (did the operation conform to specifications?) and delivery of identified outputs. Monitoring provides information for successional predictions and feedback for future PAM operations.

Résumé

Pour faire progresser la gestion forestière dans le sens d'une «démarche écosystémique», nous devons entreprendre dans ce domaine des recherches qui soient utiles sur le plan opérationnel et embrassent une grande superficie (au moins un bassin-versant entier). La gestion adaptative offre de telles possibilités. Une variante de cette méthode, la gestion adaptative prévisionnelle (GAP), permet de prendre en considération les facteurs sociaux. Elle consiste à : (1) faire participer les groupes concernés aux décisions de gestion; (2) répondre aux préoccupations locales et régionales; (3) appliquer les connaissances actuelles; (4) intégrer les équipes de recherche; (5) mettre en oeuvre une gestion écosystémique même si les données sont incomplètes. Une fois que les groupes concernés se sont entendus sur les résultats souhaités, la surveillance se limite à vérifier si la mise en oeuvre s'est faite conformément aux exigences et si les résultats souhaités ont été obtenus. Cette surveillance produit des données pour la prévision de la succession et une rétroaction en vue des opérations futures de GAP.

Introduction

Scientific information and expert knowledge should serve as the basis for natural resource management direction. That information should identify alternative approaches to satisfying management objectives. Hanley (1994) states that what management needs is technical expertise to apply what is known, a long-term commitment to monitoring, and adaptive management. Many scientists, however, continue to provide high-quality but short-term information for small-scale problems, ignoring operationally meaningful questions (Baskerville 1994; Hanley 1994). Lack of confidence in the general applicability of conclusions from nonoperational studies often restricts the usefulness of that research to the unit examined. Results from those studies, therefore, are commonly not implemented in the field. Baskerville (1994) believes that most forest research is not used (not usable), because neither the scientist nor the practitioner developed an operational statement of the problem to be solved.

Much natural resource management research has focused on single problems and associated solutions. A knowledge of both statistics and ecosystem functioning, however, suggests the importance of ecological interactions. Unfortunately, interactions are often ignored in single-problem approaches. To advance forest management in an "ecosystem context," we must begin implementing larger-scale (at least watershed-level), operationally meaningful forest management research. Adaptive management offers that potential, and, with proper modifications (predictive adaptive management, or PAM, below), could incorporate currently untapped social interests.

Adaptive management

Adaptive management is a "soft system," "holistic" (Checkland and Scholes 1990) approach, whose value in agricultural and resource management has been recognized (Wilson and Morren 1990). The adaptive management approach, pioneered by C.S. Holling, was recently summarized by Walters and Holling (1990). Paraphrasing Lee (1993), adaptive management is implementing management decisions as experiments, whose results are used to modify management policy. Adaptive management anticipates unexpected outcomes; therefore, adaptive managers make measurements to provide information for improved future management decisions. Many problems become apparent only in settings of sufficient size and complexity; therefore, adaptive management experiments are conducted in large ecosystems that offer the possibility of observing cumulative and other large-scale effects. According to Lee (1993), we conduct adaptive management experiments because 1) large ecosystems have some properties that cannot be observed at a small scale; 2) some effects, although visible in principle, are too small to observe on anything but a "laboratory" (small experimental) scale; and 3) ecosystem-level interventions may be present already because of policy decisions, or policy may be unable to wait for complete information. The obstacles faced in an analysis of large ecosystems, however, are many and real, and several are outlined by Lee (1993).

Although Everett et al. (1994) believe that managers must conduct ecosystem management as adaptive management experiments, it is unlikely that adaptive management is the "only way" (Wilson and Morren 1990). Adaptive management has, however, been recognized as a way to gain meaningful information for a variety of natural resource management issues, including agriculture (Wilson and Morren 1990), wildlife (Irwin and Wigley 1993), and sustainable ecosystems (Bormann et al. 1994). Just as "ecosystem management" has become a North American natural resource agency buzzword and policy philosophy (Lautenschlager 1996), adaptive management approaches are becoming the North American research paradigm, primarily because landscape-level management decisions must continue in the absence of exact knowledge.

Predictive adaptive management (PAM)

Extant adaptive management approaches have real advantages but also some disadvantages. Although it is understood that adaptive management requires "clearly articulated objectives, a stated understanding of system operation, rapid feedback and evaluation, and redirection of management" (Everett et al. 1994), it is unclear who sets, or who should set, the objectives, and what system components should (need to) be monitored. These apparent difficulties led to the predictive adaptive management (PAM) approach that I've outlined below.

The PAM approach 1) includes appropriate publics in management decisions, 2) addresses regional and local concerns, 3) implements existing knowledge, 4) integrates research teams, and 5) implements ecosystem management even lacking complete knowledge. Specifics associated with the PAM approach are not, nor should they be, rigid. (*There is no one right way. The appropriate approach will be linked to the region, ecosystem, public desires, and time in which it is initiated.*) The approach is designed to provide enough specifics to address different situations; however, because goals and specific objectives are agreed upon (and potentially modeled) "up-front," only identified specifics need to be followed through time. *One need not study everything*—a notion often associated with ecosystem research. Rather, researchers, including individuals from the interest groups involved (Ontario Ministry of Natural Resources [OMNR], industry, environmental interest groups, local publics, and others), agree on desired objectives/outputs and the steps required to achieve them.

After agreeing on desired outputs, monitoring is restricted to documenting implementation (did the operation conform to specifications?; if not, how did it differ?) and delivery of identified outputs (e.g., trees to the mill, established desired regeneration, clean water, self-sustaining martin populations) through time. These provide feedback for future PAM operations; it is an adaptive approach. As Hanley (1994) says, sound and efficient monitoring of management effects is a highly technical and difficult problem, yet it is critically important for knowing whether management is achieving stated objectives.

The primary differences between PAM and existing forest management planning are that, for PAM:

1. A variety of interested parties, with the help of modeling, agree on and then plan for locally important desired outcomes before management begins. (Modeling is used to predict the consequences of alternatives before any one alternative is implemented. Posttreatment monitoring and modeling predict longer-term "successional" outcomes.)

2. Monitoring includes a) pretreatment, plan-specific, abiotic, and/or biotic components of interest; b) operational ability to execute the plan; and c) posttreatment abiotic and/or biotic components of interest. (Note: Only identified, output-associated components of interest are monitored!)

3. In terrestrial systems, managing at the landscape level (one or more watersheds) is a key to achieving a variety of outputs.

Steps required to implement the PAM approach

The first, obvious, step is to identify the intended management area. After the physical area has been identified, the suspected concerned publics are identified,[1] then a core[2] team is chosen. Core team members have general knowledge of the area, people, and natural resources. They work with the publics and appropriate specialists (modeling, natural resource, economists) throughout the life of the project. This team then:

1. *Identifies the management practice(s) of concern* (in both a scientific and social context). If the practice identified is a valid concern, it is likely operationally common and available for large-scale research. Management practices examined in any PAM experiment should be limited to the most important (one or two, plus a control). For adaptive management or PAM experiments, replicating in time, rather than in space, should be considered—learning by doing (Walters and Holling 1990).

2. *Identifies the problems that the management practice(s) may cause, and how those problems might be reduced or eliminated (alternatives).* This will require the input of expert knowledge and a synthesis of the pertinent available literature. As Hanley (1994) states, what management needs first is technical expertise to apply what is already known. It may also require modeling the major variables.

At this stage, an expanded, ecosystem/concern-specific design team is identified.[3] *The expanded team* commits to developing management proposals—the modeling component is required to separate potential large-scale operational effects from statistically significant, but biologically meaningless, effects.

3. *The expanded team begins the predictive/design phase.* Desired outputs and trade-offs are identified, and balances struck. The first PAM plan is generated. This plan may include one or more alternative operational paths to achieve objectives—these potential path(s) should be modeled, and the outcome of the models agreed upon by the team.

4. *The expanded team solicits and incorporates input from concerned publics* who may propose different management outputs or output balances. Individuals representing concerned publics become team consultants and/or team members, depending on their expertise, interest, and time. *The initial plan and associated models may be modified* to accommodate new output balances. "Best available science" is used to settle technical disputes, but, depending on circumstances, philosophy may define some or all goals and the desired outputs. Costs of implementing specific management choices and achieving associated outputs will be monitored, however, so the costs of various philosophical approaches will be documented. (Steps 3 and 4 are closely linked, and environmental input may be important in step 3 or gathered in this step (4) as part of the modification process.)

5. *The expanded team develops an operational plan for implementing the agreed-upon management in the field.*

6. *The expanded team outlines the plan(s), the broad goals, and specific objectives (outputs) for local (affected communities) residents in public meetings.* If consultants[4] have become part of the expanded team, they should contribute at these presentations. (Depending on the reception, PAM plans may be modified following these meetings.)

7. *Pretreatment monitoring* (stream water quality, plant and/or animal species presence, density, reproduction, structural components, genetic characteristics, etc.) *begins.* Only the ecosystem components identified as desired outputs are monitored. (Remember that monitoring is the only way to know whether management achieved its objectives.)

8. *The operational experiment begins,* and operational costs of the PAM plan and control (required) are monitored. Replicating in time may be more important than replicating in space—replicating in both will provide benefits.

9. *Plan implementation is documented.* (Did the operation conform to specifications: patterns, disturbances, intensities, residuals, etc.?). Were the operational and physical components the expanded team hoped to implement achieved? (This will help explain variable, unexpected outcomes.)

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1 OMNR (1995) provides an overview of appropriate publics.

2 The OMNR is responsible for the management of Crown land. Appropriate staff within the OMNR, therefore, will always be involved, usually as members of the core team, whenever the management of Crown land is being considered.

3 The expanded team includes the core team and members of key interest groups (business, tourism, environmental, sporting, native, forest industry, etc.; see OMNR [1995] for additional appropriate groups) who may be concerned about or affected by the proposed management.

4 May be business, tourism, environmental, sporting, native, forest industry, etc.

10. *Results are monitored.* The core team models trajectories of the variables of concern (outputs), identifies major differences from predictions, uses this information to improve future predictions (adaptive management), and continues monitoring. Knowledge gained from similar PAM projects can be used as feedback for designs of future PAM projects. (The appropriate project duration will be determined by the time required to achieve [or fail to achieve] experimental objectives. Minus one to plus five years posttreatment may be sufficient for some forestry experiments; much longer may be required to determine whether other objectives were met.)

Conclusions

Small-scale (micro) scientific research must continue in appropriate areas (Wilson and Morren 1990; Hanley 1994), but larger-scale ecosystem (watershed-level) experiments are required to understand ecosystem effects. Operational-scale problems will require operational-scale experiments if their complexity is to be understood and if results are to provide potential solutions. PAM offers that potential and a format for significant public participation beginning at an early stage. It includes a variety of publics at appropriate stages in the decision-making process and can be used to address a variety of natural resource management issues. Specific issues, related goals, and identified outputs are of great interest to society and to the people who must make decisions based on the best available information (managers and policymakers); scientists should, however, be an integral part of the prediction team.

Acknowledgments

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TECHNICAL SESSION II: MIXEDWOOD ECOSYSTEM RESPONSE TO DISTURBANCE

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Can harvesting emulate natural disturbances in boreal mixedwoods?

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Abstract

The *Crown Forest Sustainability Act* requires the development of harvesting systems that emulate the role of natural disturbance in northern Ontario forests. We have embarked on a series of research projects to determine how well we can emulate fire with harvesting. Initial results indicate that, whereas broad landscape patterns may be similar between harvesting and fire, functional differences may be more important. We have found that plant species composition, plant species diversity, and soil nutrient relationships differ among similar sites that were burned in a wildfire, harvested and then burned, or harvested only. These results suggest that ecosystem function is different on sites that were harvested or burned and that it may prove difficult to emulate natural disturbance through harvesting.

Résumé

Pour respecter les exigences de la *Loi sur la durabilité des forêts de la Couronne* dans les forêts du nord de l'Ontario, il faudrait élaborer des systèmes d'exploitation ayant des effets semblables à ceux des perturbations naturelles. Nous avons donc entrepris une série de projets de recherche visant à déterminer dans quelle mesure il est possible d'exploiter la forêt de manière à produire des effets semblables à ceux d'un incendie. Selon nos premiers résultats, il semble que l'exploitation et l'incendie peuvent produire des paysages semblables sur une grande échelle, mais que les différences d'ordre fonctionnel sont importantes. En effet, nous avons observé des différences quant aux espèces végétales présentes et à la concentration relative des éléments nutritifs entre des stations semblables ayant subi un feu de friches, ayant été exploitées puis brûlées ou ayant été seulement exploitées. Il semble que les fonctions écosystémiques varient selon que la station a subi un incendie ou une coupe. Il pourrait donc s'avérer difficile d'obtenir, en exploitant la forêt, des effets semblables à ceux d'une perturbation naturelle.

Introduction

Recent management and policy initiatives in North America direct resource management agencies to develop resource management systems that emulate natural disturbance. For example, in Ontario, the *Crown Forest Sustainability Act* (1994) provides policy and legislative direction requiring the development of forest practices that, within the limits of silvicultural requirements, emulate natural disturbances and landscape patterns.

However, the extent to which harvesting can emulate the effects of natural disturbance has not been fully determined. In northwestern Ontario, fire has historically been the most frequent disturbance (Ward and Tithecott 1993) and is the benchmark with which harvesting must be compared. Some aspects of ecosystem *structure* may be affected similarly by fire and harvesting, including removal of the canopy, fragmentation of forest cover across landscapes, and changes in tree size-class and age-class distributions. For these characteristics, harvesting may be an effective means of duplicating the impacts of fire. In contrast, ecosystem *function* may be quite different on sites affected by fire compared with harvested sites. Sources of regeneration, especially soil and canopy seed banks, often play an important role in postfire regeneration but may be destroyed following harvesting (Carleton and MacLellan 1995). In addition, nutrient cycling is quite different on burned sites compared with harvested sites. Virtually all studies of fire impacts on soil have found increased pH, higher levels of cations, and higher rates of nitrogen mineralization, which are a result of conversion of biomass to ash and increased soil temperatures (Viro 1974; Woodmansee and Wallach 1981; Christensen 1987). Harvesting may also cause higher soil surface temperatures owing to canopy removal, but rapid biomass mineralization generally does not result. In fact, a net decline in site nutrient capital may occur after harvesting, depending on initial site fertility, harvesting technique, and postharvest treatment (Foster and Morrison 1987; Kimmins 1987).

Methods

We compared soil and vegetation characteristics among sites that had experienced wildfire, harvesting followed by wildfire, harvesting only, or no disturbance. The site was approximately 130 km north of Thunder Bay, Ontario, along the Armstrong Highway. A lightning-caused wildfire occurred on June 12, 1988, and burned in a mixedwood stand composed of black spruce (*Picea mariana* [Mill.] B.S.P.) in the overstory and balsam fir (*Abies balsamea* [L.] Mill.) and birch (*Betula* spp.) in the midstory. The fire spread west and jumped across the highway into a portion of the stand that had been harvested the previous winter. A portion of the harvested area escaped the fire. All of the disturbed sites were similar in soil and topographic characteristics and were of the same Forest Resources Inventory (FRI) cover type. We established 32 10 x 10 m plots in each of the three disturbed sites (wildfire, harvest and wildfire, harvest only) and in an undisturbed portion of the original stand, for a total of 128 plots. Vegetation was sampled as species abundance (% cover), and soils were sampled using standard methods. See Johnston and Elliott (1996) and Johnston[1] for details of sample design and soil analysis.

Results and discussion

Multivariate analysis was used to determine general relationships between soil characteristics, vegetation, and disturbance type. These relationships were further tested using univariate nonparametric tests. Figure 1 presents an ordination diagram indicating that several species were highly related to several of the soil chemical characteristics. In particular, *Polytrichum juniperinum*, *Equisetum sylvaticum*, and several species of *Carex* were highly correlated with high levels of pH, calcium, magnesium, and phosphorus found on the wildfire and harvest plus wildfire sites. In contrast, species such as *Dicranum polysetum*, *Gaultheria hispidula*, and *Pleurozium schreberi* were associated with high levels of aluminum and iron, typical of the cold, wet acid soils found under a closed conifer canopy.

Table 1 presents the differences in soil variables among sites as shown by the Mann-Whitney U test. Aluminum was lower and calcium was higher on the burned cutover than on the other sites; magnesium was higher on both the burned and unburned cutovers. Phosphorus was highest on the burned cutover; however, because of high intrasite variability, it was not statistically different from that on the other sites. pH was greatest on the burned cutover and the unburned cutover sites. Differences among sites for iron, nitrogen, and sodium were not significant.

These data suggest that species composition and soil chemical characteristics are different among sites that have experienced harvesting, fire, or a combination of both. In addition, the site that experienced both fire and harvesting was more similar to the wildfire site, suggesting that fire is a stronger integrating influence than harvesting. I suggest that this is due to the dramatic change in soil chemistry brought about by the ashing of biomass following fire, a phenomenon that does not occur following harvesting. These results suggest that it will be difficult to emulate natural disturbance (fire) with harvesting unless some type of prescribed fire is incorporated into forest management systems.

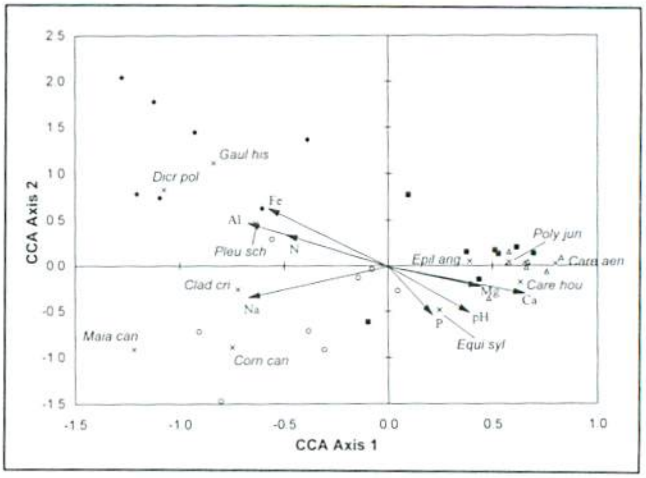

Figure 1. Canonical correspondence analysis (CCA) ordination of herb and soil data showing the relationships between species, plots, and soil variables. Species indicated by X. Sample plot symbols: Standing timber, ◆; wildfire, △; burned cutover, ■; unburned cutover, o. Poly jun = Polytrichum juniperinum; *Equi syl* = Equisetum sylvaticum; *Dicr pol* = Dicranum polysetum; *Pleu sch* = Pleurozium schreberi; *Gaul his* = Gaultheria hispidula; *Care aen* = Carex aenea; *Care hou* = Carex houghtoniana; *Epil ang* = Epilobium angustifolium; *Corn can* = Cornus canadensis; *Maia can* = Maianthemum canadense; *Clad cri* = Cladonia cristatella.

Source: Johnston, M.H. A comparison of fire and harvesting impacts on soil-vegetation relationships in a black spruce mixedwood ecosystem in Northwestern Ontario. (In review.)

[1] Johnston, M.H. A comparison of fire and harvesting impacts on soil-vegetation relationships in a black spruce mixedwood ecosystem in Northwestern Ontario. (In review.)

Table 1. Comparison of soil characteristics at a depth of 0–5 cm among four study sites. Values within a column followed by different letters are significantly different; for the rest, differences are nonsignificant (Mann-Whitney U test, pairwise comparisons with Bonferroni correction, $P < 0.0125$). Values in parentheses are one standard error.

Sites	Mineral concentration (g/Mg)							
	Al	Ca	Fe	Mg	N	Na	P	pH
Standing timber	519.2 b	345.9 a	41.1	66.2 a	0.20	24.5	3.7 a	4.5 a
	(112.9)	(83.7)	(14.7)	(7.8)	(0.02)	(2.4)	(0.3)	(0.1)
Wildfire	299.4 b	496.2 a	9.7	73.2 a	0.10	21.0	3.7 a	4.8 a
	(44.3)	(130.0)	(4.0)	(16.2)	(0.02)	(2.0)	(0.4)	(0.1)
Burned cutover	109.2 a	1391.9 b	4.2	313.1 b	0.10	19.7	8.1 a,b	5.3 b
	(28.6)	(162.2)	(1.7)	(76.7)	(0.01)	(2.4)	(1.3)	(0.1)
Unburned cutover	342.9 b	512.7 a	14.9	121.5 a,b	0.12	29.2	6.8b	5.1 a,b
	(52.6)	(78.7)	(5.2)	(17.0)	(0.02)	(3.4)	(0.4)	(0.2)

Source: Johnston, M.H. A comparison of fire and harvesting impacts on soil–vegetation relationships in a black spruce mixedwood ecosystem in Northwestern Ontario. (In review.)

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Long-term effects of harvest methods on a boreal mixedwood plant community

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Abstract

A naturally regenerating boreal mixedwood forest was measured 37 years after harvesting to determine whether harvest methods produced different plant communities and improved the status of spruce (*Picea* spp.). The harvest methods were clear-cutting, cutting only softwoods, and poisoning hardwoods before cutting softwoods.

Harvest methods did not produce significantly different communities. This may be due to 1) the "initial floristics" character of boreal forests, 2) confounding of treatment effects by complex environmental gradients, and 3) the "softness" of the harvest methods. Harvest methods did not appear to improve softwood status. The strongest phytosociological trend was the turnover in canopy composition from hardwood to mixedwood to softwood. Understory species followed this trend.

Résumé

Dans un peuplement mixte de la forêt boréale se régénérant naturellement après une coupe survenue il y a 35 ans, nous avons effectué des mesures afin d'établir si les méthodes d'exploitation utilisées ont produit des communautés végétales différentes et amélioré la situation générale des épinettes (*Picea* spp.). Ces méthodes étaient la coupe à blanc, la coupe sélective des résineux et la destruction chimique des feuillus suivie d'une coupe des résineux.

Les communautés végétales ne différaient pas de façon significative. Ce résultat peut être attribuable : (1) à la composition floristique «initiale» de la forêt boréale; (2) au masquage de l'effet des traitements par des gradients écologiques complexes, et (3) le dégré de soin pratiqué pendant la récolte. En tout état de cause, les méthodes n'ont pas amélioré la situation des résineux dans le peuplement. La tendance phytosociologique la plus marquée était le remplacement de l'étage supérieur de feuillus par un type mixte, puis par un couvert de résineux. Le sous-étage a évolué selon la même tendance.

Introduction

In the early 1950s, managers noted that the contemporary way of cutting upland boreal mixedwoods—i.e., removing only softwoods—was not producing satisfactory natural softwood regeneration, especially spruce. The RC17 project was initiated to determine methods of improving the natural postharvest regeneration of conifers, especially black spruce (*Picea mariana* [Mill.] B.S.P.) and white spruce (*Picea glauca* [Moench] Voss), to these potentially fertile mixedwoods.

In 1990, the author recognized that the RC17 site provided an opportunity to fill some current gaps in research. Although studies of short-term response of overstory species to various harvesting methods were common, studies of the whole plant community's response were scarce, and studies of long-term effects on either were almost nonexistent. Therefore, remeasurement of the RC17 site was undertaken to determine whether the plant communities were significantly different 37 years after harvest; to determine whether harvest treatments affected the status of conifers, particularly spruces, relative to hardwoods and balsam fir (*Abies balsamea* [L.] Mill.); and to search for the main phytosociological trends.

Methods

Detailed methods for this study are presented in Robertson (1994). The RC17 experimental area is a 150-ha site approximately 15 km southeast of Manitouwadge, Ontario. It has a rolling topography, with extremely shallow (<5 cm; some exposed bedrock) to very deep (2 m) sandy to silty loam soils (Hughes 1967). At the time of harvesting, the fire-origin forest on the site was almost 200 years old, composed of various mixtures of the typical boreal tree species. It was described as an open and decadent overmature mixedwood forest (Sutton 1964), severely understocked owing to some large blowdowns (MacLean 1954).

The study area consisted of 20 approximately 7-ha plots. Prior to treatment, Hill's soil depth and moisture classification was done. Four overstory treatments were applied to the plots: clearcut (CC), softwoods-only cut (SC), hardwoods poisoned (HP), and a deferred cut (DC) (Hughes 1967). For CC, trees of all species with a diameter at breast height (dbh) greater than 11.4 cm were cut. For SC, only merchantable trees of spruce, balsam fir, and jack pine (*Pinus banksiana* Lamb.) greater than 11.4 cm dbh were cut. The CC and SC plots were cut in 1953. For the HP treatment, hardwoods were frill-girdled, with 2,4,5-T applied to the frills in 1954 and 1955. The HP and DC plots were cut between 1961 and 1963, with only merchantable softwoods cut, as in SC. In all plots, trees were limbed and topped where felled, and logs were horse-skidded to strip roads, where they were cut into bolts.

In 1990, vegetation was sampled at 15–20 randomly selected points in 15 of the original 20 plots. Tree (dbh ≥ 5 cm), shrub (dbh < 5 cm; height ≥ 50 cm), and herb (height < 50 cm) strata were measured separately. Cover, frequency, and importance values were determined for each stratum. For trees, density, dominance (basal area), dbh, age, and height were also determined. Ratios of softwoods to hardwoods, spruce to hardwoods, and spruce to balsam fir were calculated for several measures. Density was also reported for shrubs. Vegetation types were determined from the collected data, using the forest ecosystem classification (FEC) for northwestern Ontario (Sims et al. 1989).

Median polish, an exploratory analysis, and analysis of variance (ANOVA) were used to search for treatment differences in species' measures. Spatial pattern indices for trees were compared. Species richness and indices of species diversity (Shannon's H', Simpson's λ) and evenness (modified Hill's ratio) were calculated for plots. Between-plot resemblances of species composition and abundance were calculated by percent dissimilarity and chord distance. Correspondence analysis, an indirect ordination, and classification analysis (Ward's method) were performed on cover data for each stratum, and for all combined, to reveal dominant vegetation patterns and whether these related to harvest method or to soil moisture and depth. Canonical correspondence analysis, a direct ordination, was performed on the same data sets to quantify the extent of any such relationships.

Results and discussion

Effect of harvest treatments on phytosociological communities

Thirty-seven years after harvesting, the plant communities that had regenerated from the four harvest treatments were not significantly different from each other. Correspondence analyses showed no grouping of sample units from the same harvest treatments. In the canonical correspondence analyses, eigenvalues for harvest treatments were very low, accounting for <3% of total variance. The classification analyses produced five or six main clusters with no evidence of grouping by harvest treatments, and very low column (treatment) effects for the median polish analyses also indicated that species did not respond jointly to the harvest treatments. ANOVA showed that most species did not respond individually to harvest treatments. For those that did, several showed significant differences in only one measure. For different species, significant differences were not consistently among the same treatments.

Species diversity, evenness, and richness for plots varied as much within treatments as among them. Similarly, resemblance measures did not indicate that plot pairs with the same harvest treatment were any more similar than those with different treatments. Resemblance was generally high, indicating that all plots had similar species composition and abundances.

Spatial pattern indices showed that most tree species were randomly distributed. However, white birch (*Betula papyrifera* Marsh.) was clumped in all treatments except HP. This corresponds somewhat to expectations: in CC, cutting hardwoods should have stimulated stump sprouting, causing clumping; in SC and DC, damage to hardwoods during softwood harvesting may have done the same; in HP, poisoning should have deterred sprouting, preventing clumping.

Effect of harvest treatments on softwood and spruce status

Cutting stimulates vegetative reproduction of hardwoods in boreal mixedwoods; cutting only softwoods reduces it (Navratil et al. 1991). The more disturbance during harvesting, the more advance softwood growth is destroyed. Therefore, the largest treatment differences should be between CC and HP, with softwoods being more prominent in HP than in CC. According to ANOVA, total hardwood and softwood densities did not differ significantly among treatments, and tree species had no significant differences that supported the expected trend. In fact, those for white birch ran contrary to expectations: its density and cover were significantly lower in CC than in the other treatments.

Despite this lack of significant differences, there was some support for expected trends in ratios of species groups. Softwood to hardwood ratios (S:H) and spruce to hardwood ratios were higher for HP and DC than for CC and SC. This is especially notable, as it supports the expected trend, even though SC and CC plots had uncut HP and DC plots as spruce seed supplies, whereas HP and DC had virtually none. Spruce to fir ratios were also higher in treatment HP than in the others, especially CC. Although no statistical test for these ratios exists, they seem to indicate some success of HP and DC in improving the status of spruces in comparison to clear-cutting. However, for S:H, CC and HP were generally not the extremes: it was usually lower in SC than in CC and higher in DC than in HP.

As cutting only softwoods reduces disturbance to advance growth, more softwoods in SC, DC, and HP should be of preharvest origin than those in CC. Matching expectations, most conifers in DC and HP were advance growth, whereas this was true only for white spruce in CC. However, most conifers in SC originated after harvest. Abundant conifer seed supplies for CC and SC may have confounded this measure. Ages did not indicate that HP, SC, and DC delayed hardwood reproduction in comparison to CC.

From the rough comparisons made, changes in abundance of tree species from pre- to postharvest did not consistently follow expected trends. The greatest increase in balsam fir density was in SC and DC, but white birch also increased more in SC than in other treatments, including CC. The increase in trembling aspen (*Populus tremuloides* Michx.) density was negligible in HP and great in CC, as expected, but it was also large in SC. White spruce density decreased only in CC, increasing in all other treatments, which suggests that the "softwoods-only cut" treatments may have improved its regeneration.

Dominant vegetation patterns

Soil moisture and depth did not account for species distributions and abundances. Correspondence analyses showed no evident grouping by soil moisture and only very weak grouping by some depth categories. Canonical correspondence analyses produced very low eigenvalues for soil depth and moisture, accounting for <6% of the total variance. Clusters in the classification analyses also had no relation to these variables.

The analyses did indicate that there were relatively distinct plant associations on the study site, independent of the harvest treatments. For the correspondence analysis of all strata combined, ordinations of the species and of sample units labeled by FEC vegetation types (V-types) showed that the main trend on the first axis was from hardwood to mixedwood to softwood stands, accounting for 9–20% of total variance. A tabular comparison of species and sample units, ordered by scores on this axis, emphasized this trend. In each vegetation stratum, three fairly distinct zones of species could be identified in the table, corresponding to hardwood/mixedwood/softwood stands. These were also noticeable, although less distinct, for the sample units. The classification analyses clustered sample units of similar FEC V-types, confirming these associations.

Ordinations of the different strata were very similar, suggesting that understory species had affinities to canopy types. The herb species ordination was more similar than that of shrubs to the ordinations of tree species and of combined strata, indicating that herb associations with canopy types were stronger than those of shrubs. These associations suggested that all species were responding to an underlying environmental gradient (or complex of gradients) or that understory species were responding to microenvironments created by overstory species. The ordinations and tabular comparison showed that relationships of understory species to canopy types were not exclusive; species had broad, overlapping distributions, forming a continuous mosaic. This blending of plant communities was confirmed by some mixing of FEC V-types in clusters of the classification analyses.

Management implications

Several aspects of this study make its results relevant to today's practices in boreal mixedwoods. It compares cutting only softwoods, the typical harvest method until very recently, with clear-cutting, the current trend as hardwood use increases. It examines the success of natural regeneration at maintaining the conifer component in mixedwoods, particularly spruce, after different harvest methods. It compares the success of natural regeneration at producing a diverse forest, with typical species of all strata, after different harvest methods. This matches our present (and future) concern to maintain all components of natural ecosystems, ensuring their healthy functioning. Given this, the finding that there are no significant differences among the plant communities created by the four harvest methods needs close examination.

Confounding by complex gradients and broad species tolerances

Studies have shown that vegetation patterns of boreal forests cannot be explained by simple, univariate gradients and that boreal communities cannot be clearly classified into distinct plant associations (Maycock and Curtis 1960; Swan and Dix 1966). Boreal species have broad, overlapping tolerances in response to complex gradients of interdependent environmental factors. The inability of soil depth and soil moisture, alone or together, to describe the major pattern of vegetation in this study seems to corroborate this. The RC17 site had a complex geomorphology and probably a correspondingly complex multidimensional gradient of environmental factors. Therefore, any effects that the harvesting methods had on the forest may have been obscured by the effects of these complex gradients and by broad species tolerances.

Strong "initial floristics" character of the forest

The boreal forest is a disturbance-dominated ecosystem, adapted to frequent occurrence of fire, insect attacks, diseases, and windfall. Therefore, most boreal species are capable of rapid, prolific regeneration, many by vegetative reproduction (Carleton 1979; Heinselman 1981). Because of these traits, boreal forests, following fire or harvest, often regenerate to a composition and structure very similar to those of the original forest (Ellis and Mattice 1974; Heinselman 1981). In this study, tree species composition and relative abundances 37 years after harvesting were similar to those before it, and understory composition was also similar. Therefore, this strong "initial floristics" (Egler 1954) character of boreal forests may have minimized the effects of the four overstory treatments.

Cautionary note: "soft" harvesting methods

The above paragraphs imply that the complex environmental gradients, broad species tolerances, and "initial floristics" character of boreal forests minimize the effects of harvest methods, so that, regardless of what we do, boreal mixedwoods will regenerate to a composition and structure similar to their predisturbance state. However, it should be noted that this study differs from current practices in some significant ways. The RC17 site was horse-logged, a practice that creates less site disturbance than the mechanical logging commonly done today. Even the clear-cut plots were harvested to only an 11-cm dbh limit. Harvesting was also "softer," in that it was tree-length, rather than full-tree. So, although the complex natural ecology of the site, together with the strong "initial floristics" character of boreal forests, may have "overpowered" or obscured the effects of the harvest treatments, this may not be the case with today's methods.

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Principles and impacts of site preparation in boreal mixedwoods

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Abstract

Two interdisciplinary studies of mechanical and chemical site preparation have been established as part of the Black Sturgeon Boreal Mixedwood Research Project. One, initiated in 1992, compares high-speed soil mixing with more conventional screefing and herbicide application following conventional, clear-cut harvesting. The second, initiated in 1995, compares soil mixing, screefing, mounding, and herbicide site preparation under partially cut versus clear-cut harvest conditions. Preliminary results and interpretation of seedling and vegetation response for the 1992 study are reported.

Résumé

Dans le cadre du Projet Black Sturgeon de recherches sur la forêt mixte boréale, nous avons entrepris deux études pluridisciplinaires sur les méthodes mécaniques et chimiques de préparation du terrain. La première de ces études, entreprise en 1992, visait à comparer le travail du sol à grande vitesse à un dégazonnement plus classique et à la préparation du terrain au moyen d'herbicides, après une coupe à blanc ordinaire. La deuxième étude, entreprise en 1995, porte sur le travail du sol, le dégazonnement, le buttage et l'utilisation d'herbicides et permettra de comparer l'effet de ces méthodes selon que le terrain a subi une coupe partielle ou une coupe à blanc. Nous présentons ici nos résultats préliminaires et, pour l'étude de 1992, une interprétation de la réaction des semis et de la végétation.

Introduction

Boreal mixedwoods present numerous challenges when it comes to the selection of appropriate harvesting and regeneration strategies. Productive and diverse in nature, the traditional management option of clear-cutting and conventional site preparation has not always provided favorable results. A further complication is the need to balance timber supply objectives with consideration for forest health, wildlife habitat, and aesthetics. One common challenge is that of promoting spruce regeneration in complex and dynamic ecosystems without severely altering or degrading these ecosystems. Two interdisciplinary studies of mechanical and chemical site preparation have been established as part of the Black Sturgeon Boreal Mixedwood Research Project. One, initiated in 1995, compares soil mixing, screefing, mounding, and herbicide site preparation under partially cut versus clear-cut harvest conditions. The second, initiated in 1992, compares high-speed soil mixing with more conventional screefing and herbicide application following conventional, clear-cut harvesting. A brief description of both studies is provided. For the 1992 study, the response to date of crop trees and competing vegetation is also presented.

Site preparation under partially cut versus clear-cut harvest conditions

Partial cutting of only a portion of the merchantable volume is a relatively new harvesting practice in the boreal mixedwood forests of Ontario. Consequently, forest managers have limited experience with follow-up site preparation treatment options and their effects on regeneration and stand integrity. Blade corridoring or tunneling, as it is sometimes referred to, utilizing large crawler tractors, is one method that has been used historically on upland mixedwood sites having a heavy residual component of nonmerchantable species. Ease of access for planters and control of non-crop vegetation are most often the objectives of these treatments. Few attempts have been made to site prepare with the goal of minimizing unnecessary disturbance or damage to the forest floor and residual trees, and there has been little research into the impacts of these silvicultural manipulations under partially cut stands. Fundamental research into the effects of conventional and new site preparation treatments on both crop trees and their associated ecosystems is therefore needed prior to implementing operational-scale site preparation of partially cut stands.

In 1993, initiation of the Black Sturgeon Boreal Mixedwood Research Project, located approximately 50 km northwest of Nipigon, Ontario, provided an opportunity to investigate a series of site preparation strategies following both partially cut and clear-cut harvesting systems. Part of the postharvest site preparation and regeneration portion of the overall project, the objectives are to evaluate the influence of mechanical site preparation treatments on organic matter decomposition and element mobilization, spruce regeneration and the development of competing vegetation, and the effects and spread of root decay fungi.

The research site is situated in a large area of second-growth mixedwood forest made up of stands that fall predominantly within the herb- and shrub-rich mixedwood vegetation types of the forest ecosystem classification for northwestern Ontario (Sims et al. 1989). The soils are predominantly fresh, well-drained, and fertile fine to coarse sands, with varying amounts of silts and cobbles. Following harvesting (Scarratt et al., these proceedings), the experimental postharvest site preparation treatments were conducted on a series of 20- to 35-m^2 plots randomly assigned to partial-cut and clear-cut blocks applied during the mid- to late summer of 1995. The treatments were as follows:

- no site preparation, boot screef and plant;
- high-speed strip mixing utilizing the Meri Crusher model MJ.80;
- mixed mounds (80 L in volume), made from hand-shoveled, mixed soil produced by the Meri Crusher;
- spot screefing 1 x 1 m patches of the organic layer utilizing a Kubota R 420 wheeled loader, backhoe bucket;
- spot mounding of the mineral soil over the undisturbed organic layer into 75- to 80-L mounds utilizing the Kubota backhoe; and
- area herbicide application of Vision® @ 5 L/ha utilizing a backpack sprayer.

All treatments were applied to the partial-cut and clear-cut blocks harvested by the full-tree system (feller-buncher and grapple skidder). Chemical/mechanical site preparation utilizing the Bracke cultivator set at 2 x 2 m and applying Vision® (5 L/ha) was used to treat additional clear-cut blocks, so that they could serve as an operational comparison to the experimental treatments.

Regeneration studies will begin in the spring of 1996, commencing with the planting of treated areas with white spruce (*Picea glauca* [Moench] Voss) and black spruce (*Picea mariana* [Mill.] B.S.P.) container stock. Conifer regeneration from seed is another option being considered under the partially cut stands. Seeding microsites will be evaluated using the screefed and mixed treatments established in 1995.

Comparison of high-speed mixing with screefing and herbicide application

High-speed soil mixing (incorporating surface organic layers into underlying mineral soil) is a relatively new site preparation method that has the potential to control competing vegetation (McMinn and Hedin 1990) and to improve soil condition, such as aeration and moisture relationships, for conifer regeneration (Örlander et al. 1990). Mixing instead of removing the organic layer completely will preserve the longer-term nutrient status of the soil and can enhance tree growth (Moehring 1977; Foster and Morrison 1989). Mixing that incorporates the surface organic materials deep into the mineral soil can have a moderating effect on the rate of mineralization of nutrients by avoiding the temperature extremes commonly experienced by the exposed surface organic layers (Salonius 1983). Wood and bark can also conserve soil fertility when buried, as the microbial activity that results from their decomposition can temporarily immobilize nutrients (Binkley 1986).

Current site preparation practices in boreal mixedwoods typically involve some form of organic matter removal (e.g., blade screefing or disc trenching), often combined with use of a herbicide to discourage competing vegetation. However, mechanical site preparation alone has demonstrated little or, at best, short-term control of competing vegetation and, in addition, has been criticized on the grounds that it promotes nutrient depletion and so threatens long-term sustainability (MacKinnon and McMinn 1988).

An interdisciplinary study based on mixing compared with conventional screefing and herbicide treatments was initiated in 1992 on sites occupied by an uneven-aged mixedwood of mainly trembling aspen (*Populus tremuloides* Michx.) and balsam fir (*Abies balsamea* [L.] Mill.).

Approach

Clear-cut harvesting using a conventional cut and skid, full-tree system with roadside delimbing was conducted on the study blocks during the late fall of 1992. Site preparation was conducted during the spring of 1993 on a series of 10 x 10 m plots randomly assigned to each of four blocks. The treatments were as follows:

- no site preparation, boot screef and plant (control);
- removal of the surface organic layer in 100-cm-wide strips (strip screefing) and total removal (area screefing) using an excavator bucket;

- high-speed mixing of the surface organic layer with the underlying mineral soil in 80-cm-wide strips (strip mixing) and 100% coverage (area mixing) using a prototype rototiller developed by the Forest Engineering Research Institute of Canada; and
- area herbicide application (Velpar® L @ 13 L/ha) applied with a backpack sprayer.

Plots were planted with 1.5-year-old black spruce container stock seedlings one week following the completion of mechanical site preparation. Seedling survival, height, and current height increment were monitored annually. Vegetation height and leaf area coverage for each species were assessed during August of 1994 and 1995 using crop tree-centered circular plots.

Results

Seedling survival at the end of the first growing season was high for all treatments, averaging 99%, with 93% being classed as healthy. By 1995, overall survival was still 93%, with 82% being classed as healthy.

By September 1995 (i.e., three growing seasons after planting), black spruce seedling performance showed the greatest increases on herbicided plots. Seedling total height and volume were significantly greater ($p < 0.5$) on the herbicided plots than on either the controls or the mechanical site preparation treatment. Stem volume averaged 134% higher on herbicided plots than on the control plots. Neither seedling heights nor volumes differed significantly ($p < 0.5$) between the plots treated mechanically and the control plots.

Vegetation index, which is the product of average leaf area and height of target species assessed inside of crop tree-centered cylinders, provides a useful means of comparing the relative growing space volume occupied by noncrop species (Towill and Archibald 1991). By the third season following site preparation, the combined vegetation index for all species revealed no significant differences ($p < 0.5$) between treatments. Several woody competitors, including trembling aspen, mountain maple (*Acer spicatum* Lam.), and wild red raspberry (*Rubus idaeus* L. var. *strigosus* [Michx.] Maxim.), were frequently recorded during the August 1995 vegetation assessment. Both strip- and area-mixed plots had significantly lower vegetation indices for trembling aspen compared with the screefed, herbicided, or control plots. Mountain maple, prevalent in the preharvest understory, was reduced considerably as a result of harvesting and by the end of the third growing season had not recovered appreciably on any of the treatments or the controls. Similarly, the vegetation indices of wild red raspberry did not vary appreciably between any of the treatments.

Discussion and summary

The results presented to date are preliminary in nature and limited in scope. However, by the third growing season, performance of planted black spruce was clearly superior on the herbicide-treated plots compared with the mechanical and control treatments. Although the development of trembling aspen was reduced on mixed plots, the overall growing space volume of noncrop species was not reduced, particularly on strip-mixed plots. Other species most likely filled in the growing space given up by aspen. None of the mechanically treated plots had crop tree performance results that exceeded those of the control treatment. A more in-depth analysis of the data will be undertaken in the following months and the results published in information reports and journal articles. Concurrent with this work, results will be published on the implications of these treatments on soil nutrition, disease control, and the biodiversity of soil flora and fauna. All parameters being monitored to date, including the performance of black spruce and vegetation development, will be assessed over the longer term to determine any shifts in the current trends.

The response of mixedwood ecosystems to disturbance is a fundamental goal of this study and the Black Sturgeon Boreal Mixedwood Research Project. The long-term goal for both of the projects described herein is to develop the knowledge base needed to establish a strong ecological foundation for the sustainable development of boreal mixedwoods. Cooperative, multidisciplinary projects such as these are the new way of doing business in forestry research and stand the greatest chance of addressing the many questions posed by practitioners interested in integrated resource planning for boreal mixedwood ecosystems.

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Pathological implications of partial cutting in boreal mixedwood stands

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Abstract

Four major areas of pathological concern are associated with partial cutting of boreal mixedwood stands: preexisting stem decay in trembling aspen (*Populus tremuloides* Michx.); blowdown of residuals with decayed roots; buildup of inoculum of Armillaria root rot through its colonization of stumps and root systems of harvested trees, with implications for survival of residuals and regeneration; and stem decay resulting from wounds suffered to residuals during harvesting and regeneration operations. Least is known about the impact of *Armillaria* in partially cut stands. Selection of boreal mixedwood stands suitable for preventive disease management requires assessment of the quality of the aspen component as well as the level of root rot infection already in the stand and the potential for damaging increases resulting from partial cutting.

Résumé

Dans la forêt mixte boréale, la coupe partielle soulève quatre grandes préoccupations quant aux maladies des arbres : la carie du tronc déjà présente chez le peuplier faux-tremble (*Populus tremuloides* Michx.); les dommages causés par le vent aux arbres résiduels atteints d'une carie de racines; l'accumulation d'un inoculum de pourridié-agaric lorsque le pathogène envahit les souches et les racines des arbres récoltés, laquelle accumulation peut nuire à la survie des arbres résiduels et de la régénération; les arbres résiduels infectés par la carie du tronc à cause de blessures subies pendant les travaux de récolte et de régénération. Le point qui demeure le moins connu est l'incidence du pourridié-agaric sur les peuplements ayant subi une coupe partielle. Dans la forêt boréale, la sélection des peuplements mixtes se prêtant à une gestion préventive nécessite une évaluation de l'état des peupliers faux-trembles, du taux de pourridié-agaric déjà présent dans le peuplement et du risque d'augmentation nuisible de cette maladie à la suite de la coupe partielle.

Introduction

Managing boreal mixedwoods to minimize disease will result in numerous challenges for forest managers in areas including planning, harvesting, site preparation, and regeneration. Successful attainment of management objectives will be assisted by awareness of pathological concerns associated with partial cutting of boreal mixedwood stands. Four major areas of pathological concern are associated with partial cutting of boreal mixedwood stands: preexisting stem decay in trembling aspen (*Populus tremuloides* Michx.); blowdown of residuals with decayed roots; buildup of inoculum of Armillaria root rot through its colonization of stumps and root systems of harvested trees, with implications for survival of residuals and regeneration; and stem decay resulting from wounds suffered to residuals during harvesting and regeneration operations.

Preexisting stem decay in trembling aspen

Trembling aspen is a major component of many boreal mixedwood stands (McClain 1981). It can be managed for the production of a variety of products, including veneer. These logs, however, should be free of significant defects such as decay and excessive branchiness. Trembling aspen is vulnerable to a number of stem decay fungi, most notably the false tinder fungus (*Phellinus tremulae* [Bond.] Bond & Boriss.) (Basham 1958), which is responsible for 75–80% of advanced stem decay in Ontario (Basham 1993). This decay fungus, although not generally a serious problem in trees under 30 years of age, has an increasing impact as trees age (Weingartner and Basham 1985). *Phellinus tremulae* infects stems primarily through branch stubs 1.5 cm or more in diameter, although infection can also occur through stem wounds (Basham 1993).

Selection of stands for partial cutting will require consideration of their current age, desired product(s), rotation age, and the current amount of stem decay present in the stand. Stands already suffering high amounts of stem decay will be unprofitable choices for investments in intensive management, because the amount of decay will increase with age.

Therefore, assessment of the presence and amount of stem decay in the stand should be an essential component of the stand selection process. Decay caused by *Phellinus tremulae* is indicated by the presence of one or more conks of the fungus on the stem. The decay column can be expected to extend from approximately 1 m below the lowest conk to 1 m above the uppermost conk on the stem. In addition, trees exhibiting excessive branchiness or poor self-pruning (a situation that will be exacerbated after the stand is opened) have a higher risk of infection (Basham 1993).

Partial cutting in stands with some evidence of decay should be directed toward removal of trees with conks. These trees, if left to rotation, will have extensive internal decay, making them hazardous to fell and reduced in value as well as a source of inoculum in the stand, leading to infection of other crop trees.

Blowdown of residuals

Wind damage will be an important factor in the evaluation of the success of partial-cutting efforts in boreal mixedwoods, and in this case the pathological factor of root rot must be considered. Tensile strength of roots on the windward side, the mass of the root–soil plate, and root resistance in bending and compression on the lee side are three of four forces opposing uprooting (Bouchon 1987). Each of these three factors is negatively affected by root rot. White spruce (*Picea glauca* [Moench] Voss) and black spruce (*Picea mariana* [Mill.] B.S.P.), with their shallow rooting habit, will be particularly vulnerable to windthrow if their root systems have been damaged by Armillaria (*Armillaria ostoyae* [Romagnesi] Herink) or tomentosus (*Inonotus tomentosus* [Fr.] Gilbertson) root rots.

This situation is evident at the Black Sturgeon Boreal Mixedwood Research Project. Of 100 white and black spruce included in a wounding study, 16 had been windthrown within two years of the partial cut. Several of these had root systems with obvious damage due to root decay. Loss of residuals with decayed root systems, especially spruces, is, therefore, to be expected. Retention of the spruce component as either seed trees or sawlogs must take these losses into account, especially if the stand is known to have preexisting high levels of Armillaria or tomentosus root rots.

Buildup of *Armillaria* inoculum

Armillaria root rot is the most damaging root disease in Ontario, infecting a wide range of broadleaf and conifer hosts, including the species comprising boreal mixedwood stands. Losses due to Armillaria root rot occur through mortality, reduced increment, windthrow, and butt cull. Most of the boreal mixedwood stands that will be managed for disease control are already infected to some extent with *Armillaria*. The challenge will be to prevent the level of *Armillaria* infection from increasing substantially as a result of the partial cuts.

In many candidate stands, the *Armillaria* inoculum level is already high owing to mortality of the balsam fir (*Abies balsamea* [L.] Mill.) understory, heavily attacked by the spruce budworm (*Choristoneura fumiferana* Clemens). Many of these trees were already infected with *Armillaria*, and their death provides an excellent food base upon which the *Armillaria* lives saprophytically. Roots of adjacent healthy trees that come in contact with the infected balsam fir roots are liable to infection also, as are those that are penetrated by rhizomorphs extending from the infected roots and stumps. The infected balsam fir stumps and root systems can remain sources of inoculum for many years.

Stumps and root systems of other species removed during partial cutting, many of which are also infected with *Armillaria*, add to the food base for the pathogen and become potent infection sites throughout the stand for many years. These infection sites can have a profound effect on the success of regeneration, both natural and planted, which will follow.

These projections of a significant increase in *Armillaria* in the partially cut stands need to be tested, and methods to reduce the impact of this phenomenon must be developed. In western North America, stump removal is being tried as a method for control of both *Armillaria* and another serious root pathogen of west coast forests, *Phellinus weirii* (Murr.) Gilbertson (Morrison et al. 1988). This method, however, may be suited only to clearcuts owing to the disturbance to the root systems of adjacent trees. Biological control through the introduction of saprophytic organisms (e.g., other decay fungi) and soil microbials capable of displacing or preempting *Armillaria* in the food base is also being investigated (Fedorov and Bobko 1989; Pearce and Malaczuk 1990; Dumas 1992; Dumas and Boyonoski 1992) and may prove the most effective means of controlling this pathogen in partial cuts.

Stem wounds and subsequent decay

Wounding to stems of residual conifers and hardwoods, resulting from harvesting and regeneration operations, must be minimized. Wounds are points of entry for decay and stain fungi and also induce physiological reactions in the host, which alter the color and permeability of the wood (Tippet and Shigo 1981). In the case of aspen, stem wounds may become infected with *Phellinus tremulae* or other decay fungi (Basham 1991), and, as a result, the management objective of producing sound, clear logs will not be met. Likewise, regeneration operations (e.g., scarification) can damage aspen suckers and result in high levels of *Armillaria* (Basham and Navratil 1975) and infection by a number of stem decay fungi (Basham 1982).

Conifer residuals may be left either as sawlogs or as seed sources for natural regeneration. Wounds lessen the likelihood that the trees will survive long enough to produce a cone crop, especially given that for many years spruce budworm can prevent a cone crop from developing by destruction of the cone primordia (Blais 1952). In our study concerning wounding in the Black Sturgeon Boreal Mixedwood Research Project, 42 of the 100 trees selected died within two years after they were wounded during harvesting operation. Of these, 16 were windthrown, whereas the remaining 26 died standing, probably as a result of a combination of several factors, including the wounds, root rot, budworm and bark beetle attack, and exposure. Stem wounds can also result in decay, staining, included bark, and deformation, all of which are unacceptable if sawlogs are the objective.

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Regeneration following the use of different harvesting systems in boreal mixedwood stands

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Abstract

The impacts of different combinations of harvesting systems (clear-cutting, partial cutting) upon natural regeneration in boreal mixedwood stands are discussed. This paper presents a preliminary compilation of stocking and density of balsam fir (*Abies balsamea* [L.] Mill.) and spruce (*Picea* spp.) regeneration before and two years after harvesting. As anticipated, the results reveal noticeable differences between the two clear-cutting and three partial-cutting systems. However, no definite conclusions can be drawn at this stage of the analysis.

Résumé

Il s'agit ici de discuter des impacts de différentes combinaisons de systèmes d'exploitation forestière de coupe à blanc et de coupe partielle sur la régénération naturelle dans les peuplements boréaux mixtes. Ce communiqué présente une compilation préliminaire du stocking et de la densité de la régénération d'avant et de deux ans après la coupe du sapin baumier (*Abies balsamea* [L.] Mill.) et de l'épinette (*Picea* spp.). Tel que prévu, les différences existantes entre les deux méthodes de coupes à blanc et les trois méthodes de coupes partielles sont remarquables au niveau des résultats. Toutefois, à ce stade de l'analyse nous ne pouvons pas tirer de conclusions définitives.

Introduction

This study focuses on regeneration and is part of the Black Sturgeon Boreal Mixedwood Research Project. The first objective, which is a short-term one, is to report on changes in the amount of preestablished regeneration of tree species after harvesting by different methods. The second objective, which is both a short- and a long-term one, is to quantify the presence and evolution of regeneration, preestablished or not.

Silvicultural systems are increasingly complex because of their different, site-specific objectives. This, together with the availability of a variety of types of equipment and their possible combinations, can only lead to the need for more planning. Even clear-cutting is highly variable. Some questions being asked by forest managers are: Should we attempt to save preestablished regeneration? Should we plant, leave the branches on site, use a feller-buncher or a single-grip harvester?

This short list is, of course, far from exhaustive, but it points out the fact that when applying different silvicultural systems, the forester must think like a chess player. In other words, if a particular action is taken, what will happen 1 or 10 moves later? Of course, this means that information is needed, and it is hoped that this study will give quantitative answers that can be applied to more than one combination or objective of silvicultural systems.

Approach

Three blocks of 10 ha each were assigned to each harvesting system. Four plots of 10 x 20 m each were distributed within each block to increase the chances that they would receive some disturbance representative of the harvesting system. Each plot was subdivided and assessed using 50 2 x 2 m quadrats. Also, plots were intentionally chosen that generally had over 80% stocking of balsam fir plus spruce regeneration to be used as an indicator of harvesting disturbance.

The five treatments, excluding control (no harvesting), are as follows:

- clear-cutting using a feller-buncher mounted on a tracked-type excavator and a rubber-tired grapple skidder delivering full-tree lengths to roadside;
- clear-cutting using a single-grip harvester mounted on a tracked-type excavator and a rubber-tired grapple skidder delivering tree-length stems to roadside;
- partial cutting with two-thirds of the tree removed, using the same equipment as in the first type of clear-cutting;
- partial cutting with two-thirds of the tree removed, using chain saw manual felling and a rubber-wheeled cable skidder to pull full-tree conifer and tree-length trembling aspen (*Populus tremuloides* Michx.) to roadside; and

- partial cutting with two-thirds of the tree removed, using a single-grip harvester mounted on a rubber-tired prime mover and rubber-tired transporter, hauling cut-to-length trees to roadside.

After harvesting, each quadrat was assessed in terms of the regeneration and brush, and the disturbance was evaluated. A general disturbance assessment using systematic point sampling over the blocks was done, and it will be compared with the disturbance from the plots and weighted accordingly. These results are not ready to be presented here; hence, no definite conclusions should be drawn from the numbers presented below.

Results and discussion

The preharvest stocking of balsam fir ranged from 83 to 93% among treatments (inside the plots), and the stocking of spruce from 21 to 34%. The preharvest stocking of the combined species—i.e., 84–93%—did not differ much from the balsam fir stocking. The postharvest stocking levels of balsam fir within plots, from the lowest to the highest percentage, were 22% for the clear-cutting feller-buncher, 25% for the clear-cutting single-grip harvester, 60% for the partial-cutting feller-buncher, 60% for the partial-cutting chain saw, and 71% for the partial-cutting single-grip harvester. For spruce, in the same order, the postharvest stocking levels were 6, 8, 11, 16, and 23%, respectively. Again, the postharvest stocking of both species combined was virtually identical to the balsam fir stocking.

A first step to harmonize the comparison among treatments within the plots is to express the number of stocked quadrats after harvesting as a percentage of the number of stocked quadrats before harvesting. For balsam fir, this percentage was 25% for the clear-cutting feller-buncher, 29% for the clear-cutting single-grip harvester, 64% for the partial-cutting feller-buncher, 70% for the partial-cutting chain saw, and 79% for the partial-cutting single-grip harvester. For spruce, in the same order, the percentages are 30, 32, 52, 59, and 68%, respectively. The percentages for the two species combined were virtually identical to those for balsam fir.

The pretreatment densities within the plots were more variable than the preharvest stocking values and ranged from 16 120 to 23 400 stems/ha for balsam fir and from 1000 to 2600 stems/ha for spruce. After treatment, the absolute densities of balsam fir were 1350 stems/ha for the clear-cutting feller-buncher treatment, 1950 stems/ha for the clear-cutting single-grip harvester, 9000 stems/ha for the partial-cutting feller-buncher, 8530 stems/ha for the partial-cutting chain saw, and 9600 stems/ha for the partial-cutting single-grip harvester. When the number of seedlings after harvesting is expressed as a percentage of the number of seedlings before harvesting, the same ranking among treatments as for the stocked quadrats is observed, but with lower percentages. For balsam fir, the postharvest density was 8% of what it was before harvesting for the clear-cutting feller-buncher, 9% for the clear-cutting single-grip harvester, 38% for the partial-cutting feller-buncher, 48% for the partial-cutting chain saw, and 58% for the partial-cutting single-grip harvester. For spruce, there was a change in order for the clear-cutting systems—i.e., 23% for the clear-cutting feller-buncher and 13% for the clear-cutting single-grip harvester—whereas the partial-cutting systems were in the same order, at 37% for the partial-cutting feller-buncher, 50% for the partial-cutting chain saw, and 53% for the partial-cutting single-grip harvester. Note that in the partial-cutting systems, density retention percentages of balsam fir and spruce were very similar within the treatment blocks, whereas stocking retention percentages were approximately 10% higher for balsam fir than they were for spruce. For the clear-cutting feller-buncher treatment, the retention of density of spruce was only noticeably higher than the balsam fir density retention.

Conclusions

As mentioned above, until the data from the disturbance assessment are analyzed, it cannot be confirmed if the results from the two clear-cutting systems are far apart or if the results from the three partial-cutting systems are close to one another. It is obvious that preestablished regeneration is present two years after harvesting. Among variables collected but not presented in this paper is competition of mountain maple (*Acer spicatum* Lam.) and beaked hazelnut (*Corylus cornuta* Marsh.). Trembling aspen regeneration is, of course, the new kid on the block. The chess game has just begun.

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Bird community changes in response to different harvest levels in boreal mixedwoods[1]

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Abstract

Bird communities were monitored before and after different harvest techniques in experimental areas near Black Sturgeon Lake, Ontario. Mixedwoods were dominated by balsam fir (*Abies balsamea* [L.] Mill.) and trembling aspen (*Populus tremuloides* Michx.), with admixtures of spruce (*Picea* spp.), white birch (*Betula papyrifera* Marsh.), and pines (*Pinus* spp.). Patch cuts had similar but slightly fewer species and altered abundances. Clearcuts had fewer species, major species differences, and lower abundances. Understanding of postharvest bird and habitat changes and habitat structure–bird relationships will assist managers in making choices among potential alternative harvest methods when considering provision of bird habitat supply.

Résumé

Nous avons examiné les communautés d'oiseaux avant et après l'utilisation de diverses techniques de récolte dans des parcelles expérimentales situées près du lac Black Sturgeon, en Ontario. Il s'agissait de peuplements mixtes dominés par le sapin baumier (*Abies balsamea* [L.] Mill.) et le peuplier faux-tremble (*Populus tremuloides* Michx.), avec présence variable d'épinettes (*Picea* spp.), de bouleau à papier (*Betula papyrifera* Marsh.) et de pins (*Pinus* spp.). Dans les parcelles soumises à un jardinage par bouquets, à peu près les mêmes espèces d'oiseaux étaient présentes, mais ces espèces étaient légèrement moins nombreuses, et leur abondance respective était modifiée. Dans les parcelles soumises à une coupe à blanc, les espèces étaient à la fois différentes et moins nombreuses, et l'abondance de chacune était réduite. L'élucidation des changements survenant après une coupe, dans les communautés d'oiseaux et leurs habitats, ainsi que des relations entre la structure des habitats et les oiseaux qui y vivent aidera les responsables de la gestion forestière à choisir parmi les nouvelles méthodes d'exploitation celles qui procurent aux oiseaux les habitats voulus.

[1] Paper not available.

Influence of environmentally considerate silviculture on small mammal communities at cut edges in an Ontario boreal mixedwood forest

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Abstract

Small mammals were livetrapped at cut edge sites before and after seven different harvest treatments were applied to a northern Ontario boreal mixedwood forest. Discriminant function analysis revealed trends that support findings of other researchers and appear to have biological significance. Stronger treatment discrimination found with postharvest data suggests that alternative harvest techniques influence small mammal edge communities. Many species were important in discrimination of controls and clearcuts from other treatments, with deer mice (*Peromyscus maniculatus* Wagner) showing a slightly stronger influence than the others. Discrimination of controls from clearcuts was largely determined by yellownosed voles (*Microtus chrotorrhinus* Miller).

Résumé

Au moyen de pièges ne tuant pas l'animal, nous avons recensé les petits mammifères vivant sur le bord de parterres de coupe, avant et après l'utilisation de sept méthodes de récoltes, dans une forêt mixte boréale du nord de l'Ontario. L'analyse discriminante nous a permis de cerner des tendances qui confirment les constatations d'autres chercheurs et semblent avoir une importance sur le plan biologique. Les méthodes nouvelles présentaient une discrimination plus marquée, en ce qui concerne les captures postérieures à la récolte, ce qui nous porte à croire que l'emploi de ces techniques a une incidence sur les communautés de petits mammifères vivant en bordure des parterres de coupe. De nombreuses espèces jouaient un rôle important dans la discrimination des parcelles-témoins et des coupes à blanc par rapport aux autres traitements, la souris sylvestre (*Peromyscus maniculatus* Wagner) exerçant à cet égard une influence légèrement plus forte que les autres espèces. La discrimination des parcelles-témoins par rapport aux coupes à blanc était surtout déterminée par le campagnol des rochers (*Microtus chrotorrhinus* Miller).

Introduction

"Featured species," such as moose and bear, have historically been considered in forest management, whereas the more numerous small mammals, such as mice, voles, and chipmunks, have not. Small mammals are important to the forest ecosystem, as they disperse seeds and mycorrhizae, cause soil mixing and aeration, ingest insects, seeds, and plants (Kirkland 1985), and are a food source for other wildlife. Because recent federal and provincial government policies call for an ecosystem-based approach to forest management, managers must now consider small mammals in forest planning (Canadian Council of Forest Ministers 1992; Ontario Forest Policy Panel 1993).

Despite the importance of small mammals to the forest ecosystem, few studies in Ontario have considered how timber extraction affects small mammals (Martell and Radvanyi 1977; Martell 1983). Forest managers make provisions for other wildlife by planning harvest reserves around sensitive areas and travel corridors for featured species (Ontario Ministry of Natural Resources 1988). These measures increase the amount of forest edge associated with harvested land and could affect small mammal communities differently at cut edges than within cut areas (Kirkland et al. 1985). Effects of increasing harvest edge on small mammal communities are largely unknown and unstudied (Mills 1995), making it difficult for forest managers to assess the effect of current practices on the small mammal community.

This study investigates the relationship between harvest practices and the small mammal edge community as part of the Black Sturgeon Boreal Mixedwood Research Project. The project aims to investigate the effect of seven different harvesting techniques (clearcuts conducted by full-tree and tree-length extraction, partial cuts by full-tree, part-tree, and cut-to-length extraction, patch cuts by part-tree extraction, and uncut controls) on the boreal mixedwood ecosystem. The Black Sturgeon Boreal Mixedwood Research Project is described further in other papers in this volume (see, for example, Scarratt et al., these proceedings).

Table 1. Summary of discriminant analysis by function (DF#), and selected species correlations with functions, for 1993 and 1994 data with inclusion of all species captured (A), and with selected species removed (B).

	1993 A			1993 B			1994 A			1994 B		
Information	DF1	DF2	DF3	DF1	DF2	DF3	DF1	DF2	DF3	DF1	DF2	DF3
Eigenvalue	19.979	8.559	1.508	2.077	0.874	0.405	70.428	5.960	1.961	36.123	3.816	1.527
P-value before function removed	0.001	0.068	0.566	0.591	0.811	0.885	0.272	0.958	0.997	0.439	0.984	0.999
% variance	63.71	27.29	4.81	60.47	25.44	11.78	88.47	7.49	2.46	85.7	9.05	3.62
Correlation with:												
Clethrionomys gapperi	–0.025	0.196	0.135	0.357	–0.179	0.785	–0.010	0.063	0.332	–0.036	0.157	0.246
Peromyscus maniculatus	–0.013	–0.106	0.369	–0.246	–0.162	0.447	0.079	–0.117	–0.190	0.133	–0.071	0.059
Microtus chrotorrhinus	0.024	0.141	–0.198	0.154	0.393	0.843	0.053	0.208	0.425	0.027	0.440	0.164
Synaptomys cooperi	–0.544	0.250	0.123				0.097	0.380	0.512			
Sorex cinereus	0.100	0.417	0.292									

Two questions about small mammals and alternative harvesting practices are addressed in this paper. First, is there a difference in how alternative harvesting practices affect small mammal communities at cut edges? Second, does choice of harvesting technique affect certain species more than others in the small mammal community? This study is unique in North America because it monitors small mammal communities at cut edges in association with more harvesting techniques, within the same forest type, than any previous study.

Approach

Twenty small mammal livetrapping grids, five stations wide and nine stations long, were centered on the cut edge of harvest blocks in the Black Sturgeon Boreal Mixedwood Research Project. Each trapping grid covered 2 ha and consisted of 45 stations. One trap was placed at each station and baited with a mixture of whole oats and sunflower seeds during prebaiting and trapping. Bedding was placed in the traps on the first night of trapping and was changed as required during the trapping session.

Each small mammal grid was trapped with Longworth live traps for one session in the fall before the 1993 harvest and with Sherman live traps for three sessions after harvest in the summer of 1994. Each trapping session involved three days of prebaiting followed by three nights of trapping. Traps were locked open during prebaiting and during the day to avoid animal death from overheating. If more than 40% of the animals caught on the third day of trapping had not been captured previously in that trapping session, then a fourth day of trapping was conducted. Upon capture, animals were marked with #1 National Band ear-tags for later identification. The location, tag numbers, species, sex, sexual condition, and weight of each animal were recorded. Finally, the animal was released at the site of capture.

The minimum number of animals alive for each species on each grid was determined as outlined by Efford (1992). Numbers from the three 1994 summer trapping sessions were averaged before further analysis was conducted. Discriminant function analysis was then used to determine if the small mammal edge communities changed in association with alternative harvesting treatments and which species were most sensitive to the various timber harvesting techniques.

Results

Discriminant function analysis of 1993 data found a strong relationship (P = 0.0012) between cut edges of harvest types before harvest when all small mammal species were considered (Table 1). This result was largely influenced by a small number of southern bog lemmings (*Synaptomys cooperi* Baird) (r = –0.544 in function 1) and masked shrews (*Sorex cinereus* Ker) (r = 0.417 in function 2) (Table 1). As treatments had not yet been applied, these differences could be attributed to features of the original forest, the possibility

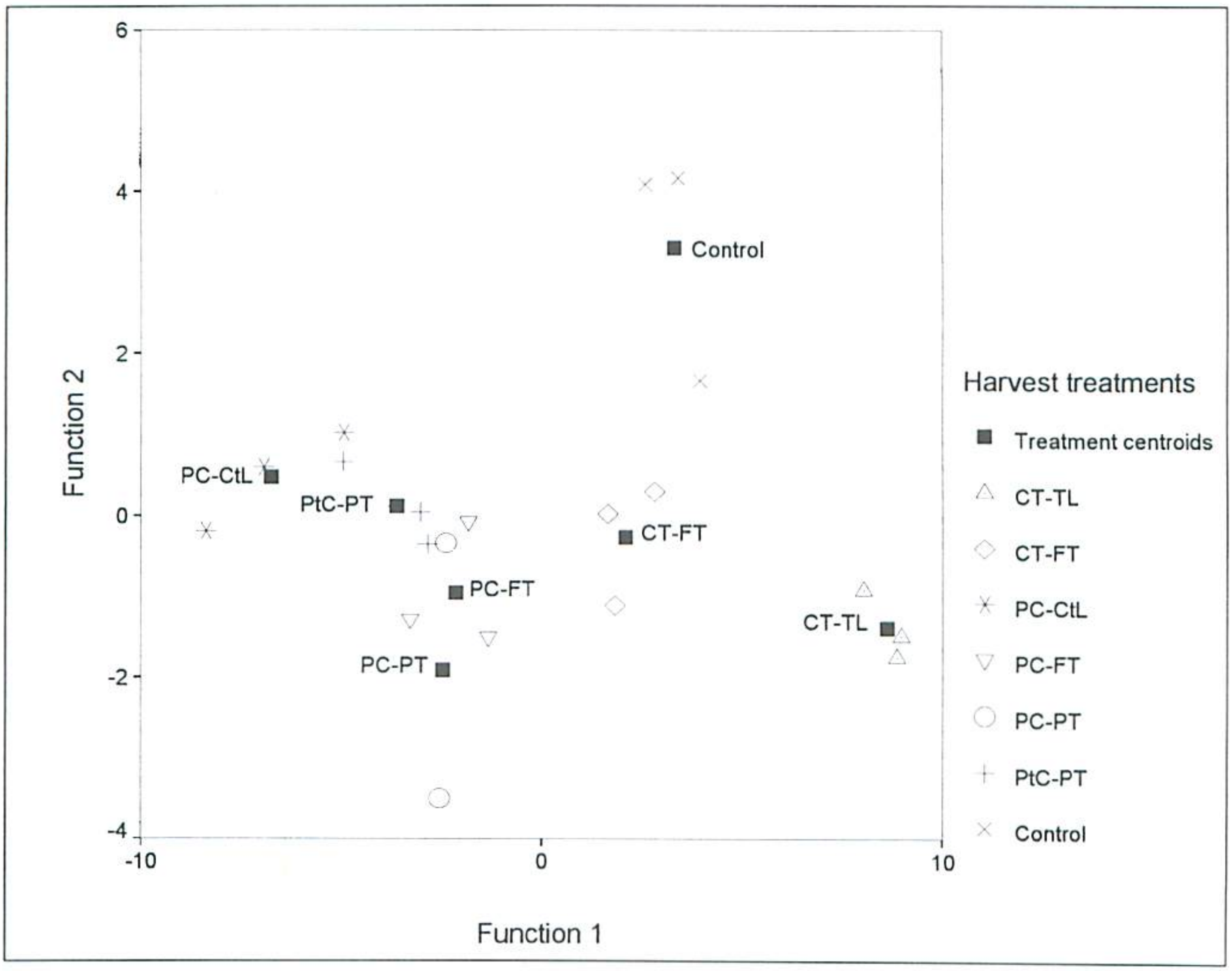

Figure 1. Ordination diagram for postharvest data, after removal of S. cooperi *from analysis, showing the centroids and observations for each of the seven harvest treatments (control = uncut; PtC-PT = patch cut–part tree; PC-PT = partial cut–part tree; PC-FT = partial cut–full tree; PC-CtL = partial cut–cut-to-length; CT-FT = clearcut–full tree; CT-TL = clearcut–tree length).* Peromyscus maniculatus *correlated most strongly with function 1,* M. chrotorrhinus *with function 2 (see Table 1).*

that these species are ephemeral elements of this small mammal community (Kirkland 1985), or chance alone. As differentiation between these alternatives was impossible, *S. cooperi* and *S. cinereus* were eliminated from the 1993 analysis. When analysis without these species was repeated, there was poor separation of the treatments ($P = 0.5906$) (Table 1). This showed that the forest was fairly homogeneous to all species except for *S. cooperi* and *S. cinereus* before harvest.

Discriminant analysis of 1994 data showed *S. cooperi* was again important in discrimination between harvest treatments. When *S. cooperi* was removed from analysis, 1994 data showed clearer discrimination of the harvest treatments than the 1993 data ($P = 0.4394$) (Table 1). Although not significant at the $P < 0.05$ level, the eigenvalue for the first function, 36.123, indicates that there is much more variance between harvest treatments than within harvest treatments. Trends observed in these data agree with conclusions of other researchers (Kirkland and Knipe 1979; Martell and Macaulay 1981) and could be of biological significance. The first discriminant function described 85.7% of the variance between treatments (Table 1). It provided good separation of partial and patch cuts from clear-cut and uncut (control) treatments (Figure 1). Deer mice (*Peromyscus maniculatus* Wagner) showed the strongest correlation with the first function ($r = 0.133$) (Table 1) and was most prevalent on clear-cut treatments in 1994 (Figure 2). The second discriminant function explained 9.05% of the variance between harvest treatments and correlated strongly with yellownosed voles (*Microtus chrotorrhinus* Miller) ($r = 0.440$) (Table 1). This function separated clear-cut and uncut treatments (Figure 1). It also separated the patch cut treatment and the three partial-cut treatments

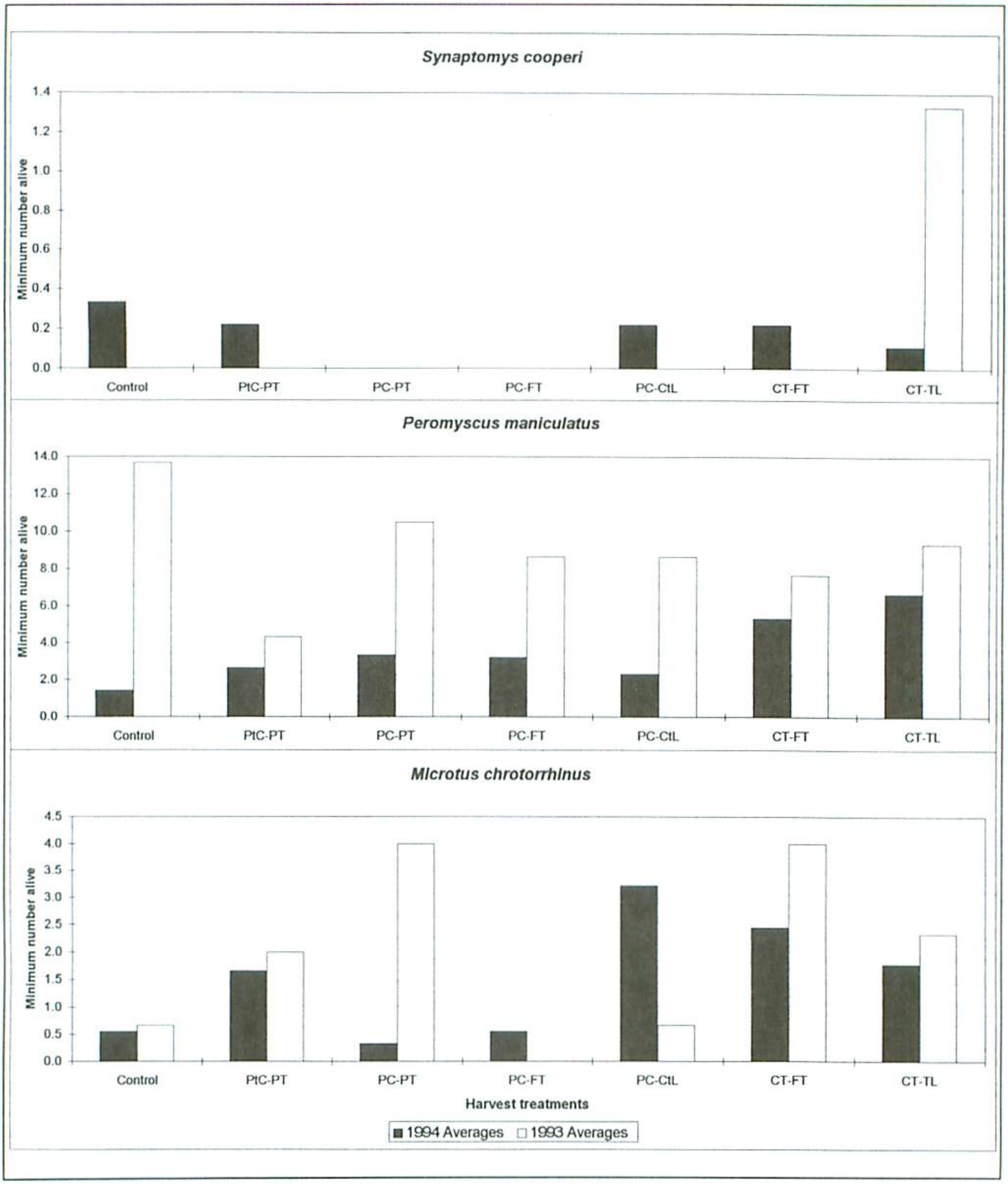

Figure 2. Average minimum number alive for Synaptomys cooperi, Peromyscus maniculatus, *and* Microtus chrotorrhinus *in 1993 and 1994 on seven harvest treatments (control = uncut; PtC-PT = patch cut–part tree; PC-PT = partial cut–part tree; PC-FT = partial cut–full tree; PC-CtL = partial cut–cut-to-length; CT-FT = clearcut–full tree; CT-TL = clearcut–tree length). Two values averaged for PC-PT, three values for all other treatments.*

from each other. *Microtus chrotorrhinus* were most prevalent on edges of the cut-to-length partial-cut and the clear-cut treatments (Figure 2).

Discussion

The separation observed between the harvesting treatments (Figure 1) suggests that there are differences in how the small mammal edge community responds to alternative harvesting practices. No one species can be used as an indicator of these responses in the first postharvest year, as no single species could explain the majority of between-treatment variance in the first discriminant function.

It appears that choice of harvesting technique could affect *P. maniculatus* and *M. chrotorrhinus* more than the other species of this community. Martell and Radvanyi (1977) showed that *P. maniculatus* did not dominate the small mammal community in cut land until the end of the second summer after harvest. The current study involved the period only up to the first summer after harvest and found that *P. maniculatus* displayed the highest densities in clear-cut lands and correlated more strongly with the first discriminant function than any other species. These facts considered together suggest that *P. maniculatus* may be in the process of dominating the clear-cut community. Analysis of the 1995 data may eventually display this trend.

Kirkland and Knipe (1979) describe *M. chrotorrhinus* as preferring sites with boulders, logs, and overhanging roots with a semiopen canopy. From visually observing the sites, it appears that the alternative harvesting treatments do leave differing amounts of slash. Partial-cut treatments also seem to have more overhanging roots, as a result of windfall, than other treatments. If these factors are important, they could explain the high correlation between *M. chrotorrhinus* and the second discriminant function, which differentiated controls from clearcuts and somewhat separates the patch and partial-cut treatments.

Conclusions

This study indicates that use of alternative harvesting regimes probably does affect the small mammal edge community. Monitoring of *P. maniculatus* and *M. chrotorrhinus* at the cut edges after harvest is important, because habitat structure characteristics there may benefit them. Correlation between habitat structure features, harvesting technique, and the small mammal community would greatly assist forest managers in writing harvest prescriptions that are considerate of the small mammal community.

Acknowledgments

We thank the Northern Ontario Development Agreement for providing funds for this study. We also thank the 1994 Environmental Youth Corps and Summer Experience Programs for funding summer assistants.

Finally, we would like to thank all summer assistants as well as the many volunteers who helped with this program for their enthusiasm and hard work throughout the fall of 1993 and the summer of 1994.

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The impact of forestry practices on amphibian populations

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Abstract

The status of amphibian populations is relatively unknown in the boreal mixedwoods of Ontario. The present study focuses on two objectives in the context of the Black Sturgeon Boreal Mixedwood Research Project in northwestern Ontario. The first is to evaluate the salamander populations as potential bioindicators of the impact of forestry practices on forest soils. The second focuses on the impact of harvesting treatments on frog reproduction. Spruce slabs set as cover boards during the summer of 1994 have been verified for the presence of salamanders from June to August 1995. No salamanders were found under the cover boards. Insufficient weathering of the cover boards along with low population densities may explain these results. In total, four blue-spotted salamanders (*Ambystoma laterale*) have been captured in pitfall traps during the 1994 and 1995 field seasons. Preliminary data on frog reproduction inside and outside treatment blocks have been insufficient for statistical analysis. Further frog monitoring could yield information on the impact of forestry practices on frog reproduction.

Résumé

L'état des populations d'amphibiens dans la forêt boréale mixte est relativement peu étudié. Ce projet vise deux objectifs dans le cadre du projet d'étude de la forêt mixte Black Sturgeon dans le nord-ouest ontarien. Le premier cherche à évaluer le potentiel de l'utilisation des salamandres comme bioindicateurs de l'impact des pratiques sylvicoles sur les sols forestiers. Le second se veut d'évaluer l'impact de ces pratiques sur les populations de grenouilles lors de la période de reproduction. Des planches d'épinettes disposées en 1994 furent vérifiées pour déceler la présence de salamandres au cours de l'été 1995. Aucune salamandre ne fut observée sauf pour un total de quatre salamandres à points bleus qui furent capturées dans des pièges disposés pour la capture d'insectes. Une faible population ainsi qu'un vieillissement insuffisant des planches peut expliquer ces résultats. Des données préliminaires sur la reproduction des grenouilles au cours du printemps de 1995 a cédé des résultats qui ne peuvent être vérifiés statistiquement. Une autre saison de suivi de l'activité des grenouilles pourrait satisfaire une analyse plus poussée.

Introduction

Research on the use of amphibians is increasingly popular as a means of investigating ecologically sound silviculture. Many successional processes rely on interactions between trophic levels and on moisture regimes, as well as on the presence of microhabitats that favor decomposition of organic matter (Heatwhole 1962). Comprehensive ecosystem studies rely on the investigation of the ecosystem's various components, its inhabitants, and their dynamics at various levels.

The soil ecosystem is the interface at which small vertebrates such as amphibians play a role in nutrient cycling. They play an important part in the consumption of small invertebrates and their larvae. As predators, they could serve as an indicator of the abundance of microorganisms that are key to the decomposition of organic debris essential for plant productivity.

Concern over frog populations has been growing over the past few years. Hypotheses of habitat loss, pollutants, and global warming have all been formulated but not yet validated (Phillips 1994). The American toad (*Bufo americana*), the spring peeper (*Rana pipiens*), the wood frog (*Rana sylvatica*), and the gray treefrog (*Hyla versicolor*) are commonly distributed species in northern forests. Frogs will prey on insects and their larvae at ground level. *Hyla versicolor*, a tree-dwelling species, thrives on moths and budworm.

The present study is part of the Black Sturgeon Boreal Mixedwood Research Project, begun in 1993. It addresses the need for long-term, multidisciplinary research focused on stand-level ecosystem response to disturbance and silvicultural manipulation.

Two main objectives are identified in the amphibian project. The first is to establish the potential use of the cover board technique (DeGraaf and Yamaski 1992) in estimating red-backed salamander (*Plethodon cinereus*) and blue-spotted salamander (*Ambystoma laterale*) populations in the boreal mixedwoods. The second objective is to assess the relationship between harvesting practices and frog breeding activity. The results from this project could potentially lead to the development of a biomonitoring tool for the succession of amphibian populations and their responses to habitat modifications.

Approach

The study area is situated approximately 120 km northeast of Thunder Bay, Ontario, and approximately 45 km north on the Black Sturgeon Road. Two stands have received silvicultural treatments (clearcuts, partial cuts, and patch cuts) on 10-ha blocks. Each treatment is to be compared with uncut control blocks.

Spruce cover boards totaling 1 m^2 in area were placed at the corner of five permanent sample plots used for other purposes in the Black Sturgeon Boreal Mixedwood Research Project. The cover boards have been left to weather for one year and remain on site for long-term monitoring. Salamander populations were monitored during the summer of 1995 using the cover board technique. Additional investigations outside the treatment blocks were carried out during the 1994 and 1995 field seasons to identify salamander populations in the general area. These searches consisted of turning over decaying woody debris and rocks to observe salamanders that were using these microhabitats.

Frog monitoring was performed at five points in each of the treatment blocks. Four points were situated at the four corners of each block 50 m in from the boundaries. The fifth point was located at the center of the block. At each point, breeding activity was monitored as per the Amphibian Road Call Counts methodology (Gartshore et al. 1993). Information on species and call intensity was noted. Calls in each quadrant at the sampling point were considered as one count for the presence of each species identified. A maximum of 20 counts per species could be recorded in each treatment block. Every block was monitored three times from the last week of May to the last week of June. The highest count per species was used to calculate an average number of counts per treatment.

Results

The results obtained to date are quite limited owing to the nature of the sampling technique, sampling periods, and biological variables. No salamanders were observed under the cover boards in the treatment blocks. The searches outside each block proved unsuccessful. However, four *A. laterale* were captured in pitfall traps used in the arthropod component of the Black Sturgeon Boreal Mixedwood Research Project. The limited data, however, do not allow for statistical analysis of salamander populations. It was observed that the cover boards have undergone some weathering, but the interface between the boards and the soil was often noted to be dry.

The frog monitoring during the 1995 field season yielded limited data for analysis. Averages of less than one count per block for *H. versicolor* eliminate this species from analysis, but its presence is noted in the area. No calls of *R. sylvatica* were heard.

The highest counts of *B. americana* and *R. pipiens* calls have been averaged as frequency of counts per treatment.

The results presented in Table 1 do not indicate any statistical relationship between silvicultural treatment and frog breeding activity. The only marked variation is noted between the average counts of *B. americana* in the control blocks and those observed in the clearcut and partial-cut treatments. However, the large standard deviation and limited sample do not allow for any further inference.

Table 1. Average frequency (standard deviation) of *B. americana* and *R. pipiens* per treatment.

Species	Control (n = 3)	Clear-cut (n = 6)	Partial cut (n = 8)	Patch cut (n = 3)
B. americana	11.2 (6.4)	4.3 (3.1)	4.9 (2.7)	8.3 (3.2)
R. pipiens	8.7 (6.7)	9.5 (3.4)	8.5 (5.5)	16.0 (1.0)

Pitfall trap captures have confirmed the presence of four frog species: *B. americana, R. pipiens, R. sylvatica,* and *H. versicolor.*

Discussion

The salamander component of the project is in its initial stages. The cover board technique relies on sufficient weathering and a colonization period. As observed, the underside of a great number of boards does not exhibit favorable conditions for colonization by salamanders at this time. The slow weathering process may be hindering the influx of salamanders. The apparent low population density of *A. laterale* is possibly explained by the location of the study area at the northern limit of its distribution (Smith and Barlowe 1982; Johnson 1989). However, many specimens have been observed in forested habitats in Sleeping Giant Provincial Park, approximately 60 km to the southwest.[1]

[1] G. Holburn, Ontario Ministry of Natural Resources, personal communication, 1995.

The frog monitoring component yields sketchy results at best. This is mainly due to the limited data set collected. The monitoring period was late in starting owing to the date at which the project's second phase received approval, which limited the number of replicates possible. Frog monitoring should begin in early April, as species such as *R. sylvatica* have been noted to begin calling as soon as the day temperatures reach 10°C and have also been heard as early as late March (Johnson 1989). This species is worthy of observation because of its feeding habits on spruce budworm (*Choristoneura fumiferana* Clemens). Further investigation should reveal possible linkages in the stands where budworm activity has occurred. Further monitoring is required to increase the chances of establishing relationships between silvicultural practices and frog populations.

Recommendations

The salamander component of the project has been established as a long-term monitoring setup. Once weathering progresses, the salamander populations will eventually recolonize the cover boards. The process may, however, take some time because of the limited existing population of *A. laterale*. Periodic monitoring, at three- to five-year intervals, could produce results that could then be linked to arthropod populations and nutrient cycling.

The frog component could benefit from another field season beginning in early April. This would allow for the inclusion of early breeders and increase the number of replicates in each treatment, which in turn would allow some statistical analysis to determine the impact of silvicultural systems on frog breeding activity.

Acknowledgments

The researcher acknowledges the contribution of Green Plan funding for the two years of the project to date. The contribution of spruce slabs from Lappe Lumber in the Thunder Bay area was appreciated; without it, the project would have been greatly limited.

Additional data collected by Dr. Kevin Barber of the Canadian Forest Service have helped in confirming the presence of amphibian species on each of the treatments. Finally, without Dr. John Scarratt's vision for ecosystem research and constant support, this project would never have proceeded.

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Impacts of harvesting on carabid beetles

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Abstract

Biodiversity is one parameter by which the faunal richness and functionality of the ecosystem can be assessed. The ground-dwelling compartment of a forest ecosystem harbors a wide range of invertebrates. Predators such as carabid beetles are at the top of the invertebrate food chain and are amenable to sampling with pitfall traps. Three 10-ha blocks of boreal mixedwood were assigned to treatments of control, partial-cutting, and clear-cutting harvesting using a feller-buncher/grapple skidder combination. Approximately 1600 carabids representing 23 species have been collected and identified (1993–1994); collections from 1995 are being processed. Preliminary results show no losses of species but an increased dominance of *Pterostichus adstrictus* Eschscholtz on harvested blocks compared with controls.

Résumé

La biodiversité d'un écosystème est un des paramètres permettant d'évaluer sa richesse faunique et sa fonctionnalité. La composante terricole d'un écosystème forestier renferme une vaste gamme d'invertébrés; parmi ces animaux, les prédateurs comme les carabidés se situent au sommet de la pyramide alimentaire et se prêtent bien à l'échantillonnage au moyen de pièges à fosse. Nous avons soumis trois parcelles de 10 ha de forêt mixte boréale à des traitements différents : (1) aucune coupe; (2) coupe partielle; (3) coupe à blanc au moyen d'une abatteuse-groupeuse et d'un débardeur à pince. Dans ces parcelles, en 1993 et 1994, nous avons capturé et identifié environ 1 600 carabidés, appartenant à 23 espèces. Les captures de 1995 sont en cours de traitement. Selon nos résultats préliminaires, les parcelles soumises à une coupe ne présentent aucune perte d'espèce par rapport à la parcelle témoin, mais elles sont davantage dominées par le *Pterostichus adstrictus* Eschscholtz.

Introduction

Environmental health and integrity are becoming increasingly important considerations in operational forestry. Biodiversity is one parameter by which the faunal richness and functionality of an ecosystem can be assessed. The ground-dwelling compartment of a forest ecosystem harbors a wide range of invertebrates, such as carabid beetles, which are amenable to sampling with pitfall traps, thus providing relative measures of activity. These predators are at the top of the invertebrate food chain and are important in processes such as pest control and nutrient cycling. Their relative diversity and the availability of identification tools (Lindroth 1961, 1963, 1966, 1968, 1969a,b) and convenient cataloging references (Bousquet and Larochelle 1993) provide field entomologists with invaluable means of tackling such projects. The carabid study described here comprises one module of a multidisciplinary study of the environmental effects of different harvesting regimes in the Black Sturgeon Boreal Mixedwood Research Project.

Approach

Three 10-ha forest blocks were assigned to each treatment of control, partial cutting, and clear-cutting (clearcut A), the harvesting accomplished by feller-buncher and grapple skidder in late 1993. A further site preparation treatment was assigned and will be carried out on half of each clear-cut block (clearcut B) in August 1995 (see Scarratt et al., these proceedings, for more detail). The years 1993 and 1994 represent preharvest and postharvest periods, respectively. In 1993, only a single trapping period (late August to early September) was possible between establishment and treatment assignment of the blocks and the beginning of harvesting. There were only two replicates of the clearcut B treatment available for 1993, resulting from a late change in treatment assignments. There were seven samples taken in 1994 (early June to early September), but only the four odd-numbered samples were processed as dictated by available resources.

Carabid beetles were sampled with 12 1-L plastic pitfall traps of 11-cm diameter and protected from rain with plastic dinner plates. Two parallel lines of six traps each, 40 m apart, were installed, with the traps spaced 10 m apart. About 200 mL of undiluted ethylene glycol was used as a collection and preservative fluid. Traps were emptied about every two weeks and their contents transferred to 70% ethanol. Carabid beetles were then extracted, pinned, labeled, and identified according to Lindroth (1961, 1963, 1966, 1968, 1969a,b) and Bousquet and Larochelle (1993).

Histograms of the abundance of carabids for 1994 are expressed as a single cumulative total of each species resident on the three replicate blocks of each of the four treatment groups. Preliminary statistical analyses are based on separate treatment of the 1993 data and comparison with a combined data set for 1994, representing cumulative catches (sum of four samples) but maintaining the integrity of the replicate blocks. Carabid catches were also standardized by the number of trapnights to compensate for some losses of traps disturbed by mammals. The discussions, recommendations, and software of Ludwig and Reynolds (1988) were used to direct, compute, and present diversity indices. One-way analysis of variance (ANOVA) (Dixon 1992) was conducted to search for treatment differences with embedded t-tests as a preliminary exploratory procedure. Experiment-wise error rate was maintained at $\alpha = 0.05$ using a Bonferroni adjustment for six comparisons. Heterogeneity of variance was assessed with Levene's test at $\alpha = 0.01$ (Milliken and Johnson 1984), and natural logarithm, square-root, or power transformations were investigated and applied if necessary; proportional data and evenness indices were arcsine transformed. If homogeneity could not be achieved, reference is made to the Brown-Forsythe F-test for unequal variances. Only the nontransformed means and standard errors are reported here.

Preliminary results

In the 1993 preharvest sample, the total catch of carabid beetles amounted to 184 specimens from nine species; the seasonal total for 1994 was 1415 from 23 species. All species collected in 1993 were again captured in 1994. Histograms depict the distribution of captures among species in 1994 as a seasonal total of the three replicate blocks for each treatment (Figure 1). *Pterostichus adstrictus* Eschscholtz and *Calathus ingratus* Dejean were the two most abundant species in all four treatment groups. The nine most abundant species were common to all treatment groups and are ranked in the same order on the two clear-cut groups. There was a general trend toward increased numbers of species (totals of 10, 13, 13, and 19 from control, to partial cut, to clearcut A, and to clearcut B, respectively). Similarly, there was an increased proportional representation by *P. adstrictus*.

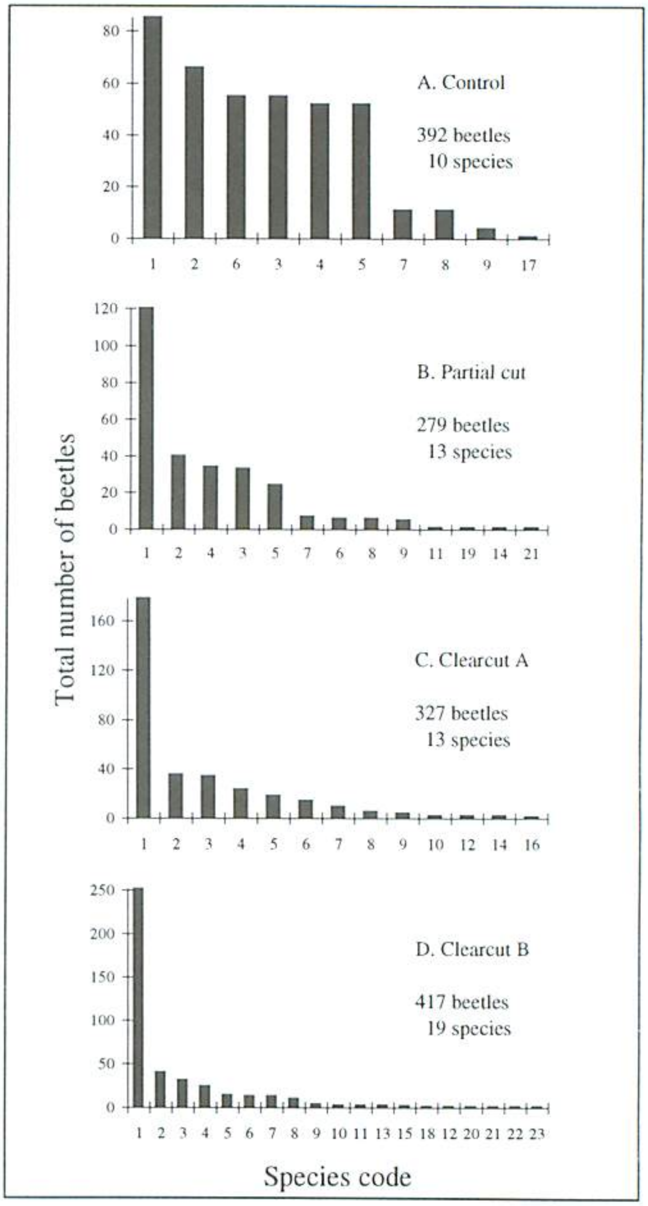

Figure 1. Distribution of seasonal totals of carabid beetle captures for each of four harvesting treatments for 1994 obtained by pooling data from the three replicate blocks. Not all species are present on all three replicate blocks of each treatment. Species codes: 1 – Pterostichus adstrictus *Eschscholtz; 2 –* Calathus ingratus *Dejean; 3 –* Pterostichus pensylvanicus *LeConte; 4 –* Sphaeroderus nitidicollis brevoorti *LeConte; 5 –* Platynus decentis *(Say); 6 –* Agonum retractum *LeConte; 7 –* Scaphinotus bilobus *(Say); 8 –* Pterostichus punctatissimus *(Randall); 9 –* Synuchus impunctatus *(Say); 10 –* Poecilus lucublandus *(Say); 11 –* Pterostichus coracinus *(Newman); 12 –* Harpalus fulvilabris *Mannerheim; 13 –* Harpalus solitaris *Dejean; 14 –* Cymindis cribricollis *Dejean; 15 –* Agonum placidum *(Say); 16 –* Notiophilus semistriatus *Say; 17 –* Pterostichus melanarius *(Illiger); 18 –* Amara erratica *(Duftschmid); 19 –* Harpalus laticeps *LeConte; 20 –* Syntomus americanus *(Dejean); 21 –* Bembidion rapidum *(LeConte); 22 –* Carabus serratus *Say; 23 –* Badister obtusus *LeConte.*

Table 1. Summary of carabid collection parameters and derived indices for differentially harvested mixedwood forest blocks before harvest (1993) and after harvest (1994).

	Year	Treatment				ANOVA	Transform
		Control	Partial cut	Clearcut A	Clearcut B[a]		
No. of blocks (n)	1993	3	3	3	2		
	1994	3	3	3	3		
Carabids per block	1993	20.3±0.9 A[b]	11.3±2.2 B	17.3±0.7 AB	18.5±1.5 AB	P=0.0128	Raw
	1994	130.7±17.8	93.0±5.5	109.0±13.1	139.0±31.7	P=0.3868	Raw
Carabid capture rate (no./100 trapnights)	1993	10.6±0.5 A	5.9±1.1 B	9.0±0.3 AB	9.6±0.8 AB	P=0.0128	Raw
	1994	22.0±2.9	13.8±0.8	16.6±2.1	22.1±4.3	P=0.1744	Raw
Proportion of *Pterostichus adstrictus* (% of total carabids)	1993	21.2±2.8	21.4±10.9	22.5±9.4	21.3±3.7	P=0.9992	Arcsine
	1994	22.9±4.4 A	43.2±3.2 B	54.9±2.6 BC	60.7±3.6 C	P=0.0004	Arcsine
Pterostichus adstrictus capture rate (no./100 trapnights)	1993	2.3±0.3	1.2±0.8	2.1±0.9	2.1±0.5	P=0.7087	Raw
	1994	4.8±0.7 A	6.0±0.4 A	9.0±0.9 AB	13.4±2.6 B	P=0.0106	Raw
Calathus ingratus capture rate (no./100 trapnights)	1993	1.4±0.2	1.0±0.3	2.1±0.3	2.1±1.6	P=0.7471[c]	Raw
	1994	3.7±0.5 A	2.0±0.2 AB	1.8±0.1 B	2.1±0.5 AB	P=0.0203	Raw
No. of species captured (Hill's N0)	1993	5.7±0.3	5.0±0.0	5.7±1.2	5.0±0.0	P=0.5000[c]	Raw
	1994	8.7±0.3 A	9.7±0.7 AB	10.7±1.2 AB	12.7±0.3 B	P=0.0237	Raw
No. of abundant species (Hill's N1 = $e^{\text{Shannon's Index}}$)	1993	–[d]	–	–	–	–	–
	1994	6.2±0.2	5.5±0.5	4.7±0.4	4.5±0.3	P=0.0528	Raw
No. of very abundant species (Hill's N2 = 1/ Simpson's Index)	1993	–	–	–	–	–	–
	1994	5.6±0.1 A	4.2±0.5 B	3.0±0.2 BC	2.6±0.2 C	P=0.0003	Raw
Species evenness (Hill's E5 = (N2–1)/(N1–1))	1993	–	–	–	–	–	–
	1994	0.89±0.01 A	0.70±0.02 B	0.55±0.03 C	0.46±0.03 C	P<0.00005	Arcsine

[a] Site preparation treatment to be applied in 1995.
[b] Means (±se) within a row followed by a different letter are significantly different at the experiment-wise P < 0.05 level correcting for six pairwise comparisons.
[c] Brown-Forsythe F-test for heterogeneous variances.
[d] Data insufficient for computation.

Table 1 summarizes some of the collection parameters and derived indices along with the results of the within-year, one-way ANOVAs of the replicate blocks. Total number of carabids captured differed among treatments in 1993 (P = 0.013), when there were fewer beetles captured on the partial-cut blocks compared with the controls. In 1994, there were similar treatment trends, but these were not significantly different (P = 0.387). Capture rates of carabids standardized to 100 trapnights followed the same pattern.

The overall treatment difference in proportional abundance of *P. adstrictus* was highly significant in 1994 (P = 0.0004), with the control treatment significantly lower than the three harvested treatments and the partial cuts lower than the clearcut B treatment. There were no differences measured in 1993 (P = 0.999). When comparing only the September collections of 1994 (not tabulated), there was still a significant ANOVA (P = 0.022) attributable to a difference between the two extremes of control and clearcut B treatments. These proportional data can be related back to actual capture rates of *P. adstrictus,* which differed in 1994 (P = 0.011) but were not significantly different in 1993 (P = 0.709). There was no treatment-related difference in capture rates of *C. ingratus* in 1993 (P = 0.747); following harvest, however, there were differences (P = 0.020), and, in contrast to that of *P. adstrictus,* capture rate of this species was higher on the control than on the clearcut A treatment.

Significant differences in number of species, suggested by the abundance histograms (Figure 1), are statistically demonstrated in Table 1 (Hill's N0). There was a significant treatment effect on the mean number of species in 1994 ($P = 0.024$) attributable to the extremes of control and clearcut B treatments. There were no differences detected in the data for 1993 prior to harvest. The number of abundant species (Hill's N1) did not differ significantly in 1994. However, the number of very abundant species (Hill's N2) differed significantly in 1994 ($P = 0.0003$), with control greater than the three harvested treatments, the partial cut greater than the clearcut B treatment, and the clearcut A treatment intermediate between but not significantly different from the other harvested treatments. Evenness measures (Hill's E5) showed dramatic differences ($P < 0.00005$) in 1994, with the treatments falling into three discrete groups of control, partial cut, and clearcut treatments.

Discussion and conclusions

The restricted sampling in 1993 hampers explicit characterization of the treatment blocks before harvest. An attempt has been made to point out similar or disparate trends where possible. There are differences among the treatments in 1994 when we consider proportional representation of *P. adstrictus*; these differences, in turn, are related to real differences in capture rates of this species. This was not evident in 1993. Inspection of the September 1994 data (a subset of the pooled data) shows measurable treatment differences; the data are therefore consistent with an interpretation of treatment-induced effects and not just spurious differences resulting from pooling seasonal data. The increased dominance of carabid captures by *P. adstrictus* on the harvested blocks is probably the key component contributing to the dramatic decrease in the evenness measures. The modified Hill's ratio (E5) approaches zero as one species becomes increasingly more dominant and is relatively unaffected by species richness, especially rare species (Ludwig and Reynolds 1988). The 1993 data were insufficient for calculation of N1, N2, and E5.

Niemelä et al. (1993), in a retrospective study, found not only higher species richness (number of species in equal sample sizes) of carabids in regenerating stands, but also a more even distribution of relative abundance compared with mature forests. Duchesne and McAlpine (1993) also found more species on clear-cut sites (11.3) than on control (4.1), although these were not significantly different, nor was *P. adstrictus* among the species they discussed. The significance of the differences between our two sets of clearcuts, before the site preparation has been applied, will be better assessed with additional data.

These preliminary results begin to describe carabid communities in transition. Species have not been lost as a result of harvesting, but, because of the paucity of preharvest data, little can be said about the influence of immigration. The increased domination of the catches on harvested blocks by *P. adstrictus* influences measures of diversity and is especially evident in the disparate indices of species evenness. *Pterostichus adstrictus* is a common species of the northern coniferous forest but "prefers open country" (Lindroth 1961) and has wider habitat tolerances than its close relative *Pterostichus pensylvanicus* LeConte (Goulet 1974). The moisture requirements for oviposition sites may be a key factor in their habitat tolerances (Goulet 1974), which could explain the initial response of *P. adstrictus* in this study. Incorporation of the 1995 data and future sampling will help to better characterize the dynamic changes in these communities.

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Harvesting and site preparation impacts on soil microarthropods

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Abstract

The impacts of various current and alternative harvesting and site preparation practices on soil microarthropod abundance, distribution, and species diversity are being studied in boreal mixedwood sites in northern Ontario. In general, in the absence of site preparation treatments, numbers of mites decreased after clear-cutting. Collembolan numbers were unaffected by harvesting, but clear changes in species diversity as a result of different harvesting practices were identified. Population densities and species diversity in partial cuts tended to resemble values obtained in the uncut forest, rather than in clearcuts. Preliminary results indicate that screefing and mixing treatments had dramatic effects on the numbers of both Collembola and mites and on the species diversity of the collembolan fauna. Plots treated by strip mixing showed more signs of recovery than those subjected to the screefing treatment. No deleterious effects on the soil microfauna were evident in plots treated with herbicide (Velpar®).

Résumé

Dans des stations de forêt mixte boréale du nord de l'Ontario, nous étudions l'incidence de diverses méthodes actuelles ou nouvelles de récolte et de préparation du terrain sur l'abondance, la répartition et la diversité taxonomique (au niveau de l'espèce) des microarthropodes du sol. En général, si aucun travail de préparation du terrain n'est effectué, l'abondance des acariens diminue après une coupe à blanc. Nous n'avons constaté aucun changement dans l'abondance des collemboles après la récolte, mais nous avons relevé des différences de diversité taxonomique selon les méthodes de récolte. Après une coupe partielle, la densité des populations et la diversité taxonomique tendaient à se rapprocher des valeurs observées dans les parcelles témoins plutôt que de celles observées après une coupe à blanc. Selon nos résultats préliminaires, le dégazonnement et le travail du sol avaient un impact énorme sur l'abondance des collemboles et des acariens et sur la diversité taxonomique des collemboles. Les parcelles où le sol avait été travaillé par bandes présentaient plus de signes de rétablissement que celles soumises à un dégazonnement. Nous n'avons observé aucun signe de dommage à la microfaune du sol dans les parcelles traitées à l'herbicide Velpar®.

Introduction

One of the fundamental requirements of managing forests in Canada today is that practices must be consistent with sustainable development. The concepts of minimizing environmental impacts and conserving biodiversity are therefore important not only in their own right, but also because they are of concern to the public of Canada and to Canada's trading partners. Soil organisms play vital roles in organic matter decomposition and nutrient cycling, dispersal and control of soil-borne pathogens, and soil formation. Thus, they are critical components of a sustainable soil system. Yet the effects of current and alternative harvesting and site preparation techniques on soil fauna are poorly understood (Shaw et al. 1991).

The objectives of the present study were to compare and evaluate the environmental impacts of different harvesting and site preparation treatments on soil microarthropod biodiversity and functions in a boreal mixedwood.

Approach

The study was carried out at the Black Sturgeon Boreal Mixedwood Site (BSBMS) (harvested by feller-buncher and grapple skidder in 1993) and the Eskwononwatin Lake Site (harvested by feller-buncher and grabble skidder in 1992, site prepared in the spring of 1993). Details of the research sites and treatments are provided by Scarratt et al. (these proceedings) and Sutherland (these proceedings). In this report, only the first-year postharvest data (1994) from replicates in Stands 1 and 2 at the BSBMS are considered (no burn plots). In the site preparation study, only the following

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Table 1. Effect of harvesting on numbers of mites and Collembola. One-way analysis of variance (ANOVA) was carried out to determine treatment effects. For mites, $F = 5.775$, $p = 0.040$; for Collembola, $F = 0.801$, $p = 0.492$. For each taxon, means followed by the same letter do not differ significantly from one another (SNK; $p < 0.05$).

	Mean no. of individuals/core		
	Uncut control	Partial cut	Clearcut
Mites	495 a	357 b	377 b
Collembola	181 a	140 a	142 a

Table 2. Effect of harvesting on species diversity of Collembola. Hill's Diversity Numbers, where N0 is the total number of species, N1 is the number of abundant species, and N2 represents the number of very abundant species.

	Uncut control	Partial cut	Clearcut
N0	37	34	28
N1	11.5	11.0	7.8
N2	6.7	7.2	4.6

treatments are considered: cut control, herbicide (Velpar®), strip-mix (S-Mix; 120 rpm—20 cm depth—slow rate of travel), and strip-screef (S-Screef).

At each time of sampling, two cores were taken from each replicate plot. Each core was divided into 2-cm sections, and soil microarthropods were extracted from soil cores using a modified Macfadyen High Gradient Extractor. Collembola were identified to species, other arthropods to broad taxonomic groups. Data and analyses presented in this paper are based on seasonal totals for each treatment replicate. Seasonal trends in treatment response, details of individual species response, community dynamics, feeding activity, and pretreatment data will be considered elsewhere.

Preliminary results

Effects of harvesting treatments

In the first year postharvest, the abundance of mites was reduced in the clear-cut and partial-cut sites, compared with values obtained in the uncut control (Table 1). In contrast, the harvesting did not affect total abundance of Collembola (Table 1). However, the species diversity of the collembolan community, as represented by Hill's Diversity Numbers (Hill 1973), was affected. Although these measures of diversity did not differ appreciably between the uncut controls and the partial cuts, N0 (total number of species) and N1 and N2 (which incorporate the concept of species richness and evenness) were all reduced on the clearcuts (Table 2).

Table 3. Effect of site preparation treatments on number of mites. One-way ANOVA to test for treatment effects was carried out for each year. For 1993, $F = 42.84$, $p < 0.001$; for 1994, $F = 6.148$, $p < 0.01$. Within each year, means followed by the same letter do not differ significantly from one another (SNK; $p < 0.05$).

	Mean no. of individuals/core			
	Cut control	Herbicide	S-Mix	S-Screef
1993	730 a	311 ab	77 b	7 b
1994	423 a	319 ab	123 b	130 b

Effects of site preparation treatments

Numbers of mites were significantly reduced in S-Mix and S-Screef plots compared with cut controls in the first and second years following site preparation, but population levels in herbicide-treated plots did not differ significantly from the controls (Table 3). A similar pattern was observed in the population data of Collembola (Figure 1). The total numbers of Collembola were significantly reduced in S-Screef and S-Mix plots compared with cut controls (Student-Newman-Keuls test, or SNK; $p < 0.05$) in both years. Collembolan abundance in plots treated with herbicide did not differ significantly from cut controls in either year. In the first year after site preparation, collembolan species diversity was greatly reduced in the Screef and S-Mix plots (Table 4). The most affected groups were those that were "less abundant species" (i.e., as reflected in lower values for N0 and N1). However, by the second year posttreatment, diversity indices in all treatments were similar (Table 5).

Discussion

The results of the present study on the effects of harvesting on soil microarthropods tend to agree with those of Bird and Chatarpaul (1986), who also reported that 17 months postharvest, mites were significantly reduced in a clearcut compared with numbers in the uncut (red pine [*Pinus resinosa* Ait.], white pine [*Pinus strobus* L.], and aspen [*Populus tremuloides* Michx.]) forest. In their study, as in the present study, collembolan numbers were not significantly affected.

There was no significant difference between the conventional S-Screef site preparation treatments and the experimental S-Mix treatment with respect to their effects on the

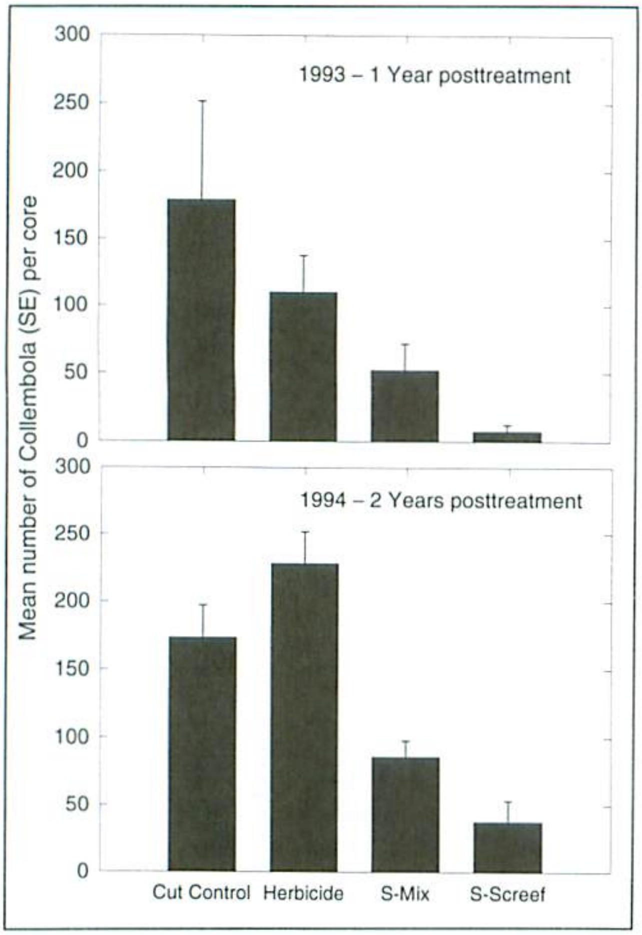

Figure 1. Effect of site preparation treatments on total numbers of Collembola. One-way ANOVAs were performed on data for each year to test for treatment effects. For 1993, $F = 11.574$, $p < 0.001$; for 1994, $F = 18.442$, $p < 0.001$.

abundance of Collembola and mites. Both resulted in significant decreases in populations. However, species diversity in the S-Mix plots in the second year posttreatment was higher than in the S-Screef plots, giving evidence of a more rapid recovery. There was no evidence that the conventional herbicide treatment with Velpar® affected microarthropod numbers or collembolan species diversity.

All of the species of Collembola collected on harvested or site-prepared plots either were present in the pretreatment census or were also found in the uncut controls posttreatment. In other words, the collembolan fauna present in treated plots was simply a subset of the fauna in the surrounding forest. As Collembola are flightless soil dwellers with poorly developed dispersal capacity, any rapid invasion of novel species specially adapted to the environmental conditions prevailing on the treated plots would not be expected. Thus, a large, diverse pool of species in the uncut forest would give the best chance that species would be available to fill ecological roles under the different conditions in areas subjected to different management practices.

Table 4. Species diversity of Collembola in control and site-prepared plots in the first season posttreatment. Hill's Diversity Numbers, where N0 is the total number of species, N1 is the number of abundant species, and N2 represents the number of very abundant species.

	Cut control	Herbicide	S-Mix	S-Screef
N0	29	30	15	9
N1	9.7	11.4	6.6	5.8
N2	5.8	8.6	5.1	5.2

Table 5. Species diversity of Collembola in control and site-prepared plots in the second season posttreatment. Hill's Diversity Numbers, where N0 is the total number of species, N1 is the number of abundant species, and N2 represents the number of very abundant species.

	Cut control	Herbicide	S-Mix	S-Screef
N0	27	29	26	23
N1	7.8	9.5	8.7	9.7
N2	5.4	7.5	6.4	6.8

Conclusions

The results presented to date are preliminary in nature, and any ranking of harvesting or site preparation practices according to their impacts on the soil fauna is premature. This project is only part of an interdisciplinary investigation into the effects of various management practices on functioning of the boreal forest ecosystem. The results of this study, as well as data collected in subsequent years, will be considered in conjunction with results obtained in other studies in the Black Sturgeon Boreal Mixedwood Research Project, to produce an integrated look at the ecosystem response to different management options.

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Genetic diversity—an indicator of sustainability

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Abstract

Sustainable forestry practices in the Boreal Mixedwood Forest require indicators that reflect changes in long-term biological potential as stands and landscapes are changed through human intervention. High levels of genetic diversity provide the biological mechanisms needed to maintain productivity and forest health during periods of environmental change. Experiences in Europe and elsewhere clearly indicate that reductions in genetic diversity predispose forests to environmentally related declines in health and productivity. Recent studies also indicate that some harvesting practices may disrupt the dynamics of fundamental genetic mechanisms, which maintain genetic diversity. In the boreal forest, genetic diversity differences between intact and impacted gene pools provide a yardstick to determine whether or not the adaptive and long-term evolutionary potential of tree populations has been compromised by forestry practices.

Résumé

Dans la forêt mixte boréale, les pratiques forestières durables exigent des indicateurs traduisant les changements de potentiel biologique à long terme qui surviennent lorsque des peuplements ou des paysages sont soumis à des interventions humaines. Or, durant les périodes de changement environnemental, seule une grande diversité génétique peut assurer les mécanismes biologiques nécessaires au maintien de la productivité et de la santé des forêts. En effet, des expériences réalisées en Europe et ailleurs ont clairement démontré qu'une réduction de la diversité génétique des forêts rend celles-ci vulnérables aux effets des changements environnementaux sur leur santé et leur productivité. Par ailleurs, des études récentes révèlent que certaines méthodes de récolte peuvent perturber la dynamique des mécanismes génétiques fondamentaux qui assurent le maintien de la diversité génétique. Dans la forêt boréale, le patrimoine génétique des populations d'arbres ayant subi un tel impact est moins diversifié que celui des autres populations, et cette différence constitue un jalon permettant de déterminer si le potentiel d'adaptation et d'évolution à long terme des populations d'arbres est menacé par les pratiques forestières.

Introduction

The *Crown Forest Sustainability Act* of 1995 requires that forest management practices promote the continued health and productivity of Ontario's forest ecosystems. Resource managers are now faced with the question of how to assess sustainability. Ecological approaches to assessing sustainability typically estimate species diversity and abundance across a spectrum of indicator species, ranging from soil microorganisms to large carnivores and ungulates. In addition, plant community structural analyses describe changes in habitat opportunities imposed by silvicultural activities. Together, these approaches may suggest silvicultural impacts on broad ecosystem functions.

Evaluation of silvicultural impacts on forest tree genetic diversity and subsequent monitoring of genetic diversity provide the resource manager with an indicator of long-term forest sustainability that is based upon a fundamental underpinning of biological diversity. Molecular gene markers can be used effectively to estimate how silvicultural practices affect the dynamic genetic processes of genetic selection, gene migration, and inbreeding rates, all of which determine genetic diversity levels in populations. This knowledge is critical for designing and evaluating the silvicultural systems that maintain existing genetic diversity in Ontario's remaining undisturbed forests and for developing policies and strategies to rehabilitate and enhance forest gene pools that have been adversely impacted by past forest practices.

Implications of reduced genetic diversity

Healthy, productive ecosystems are well adapted to their local environments. This fitness is achieved through the processes of mutation, genetic recombination, gene migration, and natural selection. Sustainable forest ecosystem management requires that multiple generations of forest trees and associated species occupy the same sites over relatively long periods of time. True sustainability also implies that these multiple generations will maintain a level of biomass productivity and population health that can support an economically viable forest industry. However, maintenance of productivity requires that tree populations be able to evolve and adapt to environmental changes that inevitably occur over multigenerational time spans.

A population's ability to adapt to changing environments is a function of its inherent genetic diversity, which is the array of different genes available in that population's gene pool. Genetic diversity results from the dynamic genetic processes of mutation, selection, recombination, and migration and so is unique for each population. The frequency of a given gene in a population is an indication of how it is responding to these dynamic processes. For example, genes occurring in large natural populations in high frequency (75% occurrence or higher) are probably well adapted to current or recent environmental conditions, whereas genes in low frequencies (less than 25% occurrence) may be less well adapted to current or recent environments. Rare genes (less than 1% occurrence) may have arisen from recent mutations and are slowly increasing in frequency. However, if they are deleterious recessive genes and are detrimental to the organism, they can be maintained in populations at very low levels.

It is becoming very apparent from recent research on European forest tree species that when genetic diversity is reduced, forest productivity and health decline dramatically and ecosystem stability is threatened (Gregorius et al. 1985). Loss of genetic diversity is seen to be the underlying determinant in the dieback of northern and central European silver fir (*Abies alba* L.) populations, which have one-half the genetic diversity of healthy southern European populations (Bergmann et al. 1990). In both Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* [L.] Karst.), impacts on growth and tolerances to airborne pollutants are related to population genetic diversity levels (Oleksyn et al. 1994; Raddi et al. 1994). Detailed genetic analyses of European beech (*Fagus sylvatica* L.) trees growing in an environmentally stressed stand indicate that certain rare genes provide tolerance to stresses, whereas trees without these genes are sensitive to environmental stresses (Müller-Starck 1985).

Evidence of reduced genetic diversity in artificial forests relative to natural forests has been found in white spruce (*Picea glauca* [Moench] Voss) (Rajora and Dancik 1995) and in Scots pine (Gömöry 1990). The potential loss of genetic diversity owing to intensive tree improvement and artificial regeneration has long been a concern for tree breeders (Namkoong et al. 1988), and comparisons between natural populations and selected breeding populations have shown a decrease of 25–35% in genetic diversity (Cheliak et al. 1988; Hamrick 1991). However, Williams et al. (1995) have shown that a modern, advanced-generation tree improvement program, using a multiple-population breeding strategy, can retain as much as 96% of the genetic diversity measured in natural forest populations.

Impact of silvicultural practices on genetic diversity

The effects of silvicultural practices on residual genetic diversity of naturally regenerating stands have, in general, been ignored. Natural regeneration is becoming the preferred regeneration method in Ontario, wherever possible, because of its lower cost and because it is expected to mimic natural ecological processes more closely than artificial regeneration methods. However, long-term sustainability as measured by forest health and productivity is threatened by silvicultural practices that do not take into account the maintenance of genetic diversity in residual parental and regenerated progeny stands. Harvesting practices such as negative silvicultural selection (high-grading) and liquidation cutting of target species have serious genetic consequences.

Cutting intensities that significantly reduce breeding population densities risk genetic loss and reduced population fitness by greatly increasing the potential for inbreeding. For example, the inbreeding rate of a residual high-density (122 trees per hectare) Scots pine seed tree stand was 12% (Yazdani et al. 1985), compared with 24% in a residual low-density (18 trees per hectare) seed tree harvest (Yazdani and Lindgren 1992). Mixedwood species are similarly affected by selective harvesting regimes, as Murawski et al. (1994) have shown in the tropical hardwood *Shorea megistophylla*. When the *Shorea* component of a Sri Lankan mixedwood forest was harvested to 20% of its original density, inbreeding increased from 13% in the uncut forest to 29% in the residual forest.

Furthermore, cutting intensities that reduce overall genetic diversity in residual parental stands prior to establishment of the progeny stand present a risk to that population's ability to adapt and evolve in response to changing environmental conditions. For example, Buchert et al.[1] measured genetic diversity in two eastern white pine (*Pinus strobus* L.) stands before and after seed tree harvesting reduced each breeding population by 75%, leaving 50 trees per hectare. The concurrent loss in genetic diversity, calculated for several genetic diversity measures, ranged from 25% to

[1] Buchert, G.P.; Rajora, O.P.; Hood, J.V.; Dancik, B.P. Effects of harvesting on genetic diversity in old growth stands of eastern white pine (*Pinus strobus* L.) in Ontario. (Paper submitted.)

50%. Although the study stands were physically and genetically different, and despite the fact that silvicultural treatment varied somewhat between stands, the changes in genetic diversity were of the same magnitude in each stand. Each stand lost about 25% of the assayed marker genes as a result of harvesting. Most significantly, the latent genetic potential, or that portion of the genetic complement that facilitates adaptation to changing environments (Bergmann et al. 1990), was reduced by more than 50% in each stand. The close concurrence between stands suggests that genetic diversity losses of these magnitudes can be expected in similar old-growth eastern white pine harvesting scenarios. It also suggests that when old-growth eastern white pine is harvested at higher cutting intensities, greater losses in genetic diversity may occur.

Estimation of genetic diversity by genetic markers

Analysis of genetic diversity commonly involves the detection of isozymes, which are multiple molecular forms of individual enzymes. As each isozyme is a product of a specific gene, isozymes are convenient genetic markers. An individual's isozyme gene pattern is determined by a procedure known as electrophoresis. A sample of leaf, bud, or seed tissue from an individual tree is ground in buffer and placed in a gel matrix. When an electric current is applied, isozymes are separated as they migrate differentially through the matrix according to their net molecular charge. Enzyme-specific stains applied to the gel after electrophoresis visualize relative migration rates of different isozymes present in the sample. Genetic identities of the sampled individuals are determined from the stain patterns on the gel.

Comparative electrophoresis of individuals sampled from a given population provides estimates of the frequencies of various genes present in the sampled populations. These gene frequency estimates are used to calculate various genetic diversity parameters for specific populations and allow comparison between different populations. In this way, it is possible to assess the effects of silvicultural practices on residual genetic diversity in impacted populations.

Benchmarks and indicators of sustainability

The ability to assess and compare genetic diversities of different populations gives forest managers a tool to determine how silvicultural practices are affecting the forest's long-term adaptive and evolutionary potential. Ontario's virgin old-growth forests and younger natural forests resulting from natural successional processes contain pristine, intact gene pools. The complements of genetic diversity in these gene pools are the products of generations of natural, dynamic processes and are the benchmarks that will help define sustainable forestry. Deviations from these benchmarks are indicators that forestry practices may be jeopardizing long-term forest adaptability and point to future problems in forest health and productivity.

A provincially mandated effort is needed to assess genetic diversity in representative stands of important species in order to develop these benchmarks. As populations are adapted to their local environments, benchmarks should be established regionally. Such benchmarks can then be compared with stands that have undergone harvesting to determine the effects of silvicultural practices on residual genetic diversity. Benchmarking can also precede harvesting activities in appropriate stands, and postharvest genetic diversity can be calculated from a subset of the preharvest data set. Additionally, a set of regional benchmarks will allow measurement of the effectiveness of artificial regeneration methods, including intensive and extensive tree improvement activities, in maintaining genetic diversity for long-term forest sustainability.

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Ontario Growth and Yield Program in mixedwoods[1]

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Abstract

The Ontario Ministry of Natural Resources established a province-wide Growth and Yield Program in the spring of 1991. Initial emphasis of the program was on establishing a baseline network of permanent sample plots across the province. In 1994 and 1995, emphasis shifted to the modeling aspects of the program, while at the same time attempting to complete a minimum set of permanent sample plots across the province.

Résumé

Le ministère des Ressources naturelles de l'Ontario a lancé au printemps 1991 un Programme de croissance et rendement forestier à l'échelle de la province. Au début, ce programme visait avant tout à établir un réseau de parcelles-échantillons permanentes de référence. En 1994 et 1995, on a plutôt mis l'accent sur les aspects du programme liés à la modélisation, tout en cherchant à terminer la mise en place d'un réseau minimal de parcelles-échantillons d'un bout à l'autre de la province.

[1] Paper not available.

MINIWORKSHOPS

Understory protection in Alberta's boreal mixedwoods: selecting the best silvicultural system for stands with conifer understory

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Abstract

Conifer understory in deciduous and deciduous–conifer stands is a valuable resource in the boreal mixedwoods. A wide range of options is available for managing these stands and for protecting and promoting the understory component. Steps to select the most appropriate silvicultural and harvesting system are discussed using an example of aspen (*Populus tremuloides* Michx.) overstory–white spruce (*Picea glauca* [Moench] Voss) understory stands. The steps require definition of the management objectives, evaluation of stand suitability, and assessment of the wind damage risk. The rating of required wind protection level combines the trees' wind resistance characteristics, site evaluation, and windiness of the region. The expected growth response of released spruce, after harvesting aspen overstory, and spruce and aspen yields at the second harvest are examined.

Résumé

Dans la forêt mixte boréale, le sous-étage de résineux de certains peuplements de feuillus et mixtes constitue une ressource précieuse. Or, il existe une vaste gamme de méthodes permettant de gérer ces peuplements, d'y protéger le sous-étage et de favoriser la croissance de celui-ci. Nous présentons les étapes de la sélection d'un système de sylviculture et d'exploitation approprié, en prenant comme exemples des peuplements à étage supérieur de peuplier faux-tremble (*Populus tremuloides* Michx.) et à sous-étage d'épinette blanche (*Picea glauca* [Moench] Voss). Ces étapes exigent que l'on fixe les objectifs de gestion, détermine si la station convient aux méthodes, puis évalue les risques de dégâts dus au vent. Le degré de protection contre le vent est coté selon la présence de caractéristiques permettant aux arbres de résister au vent, l'évaluation de la station et le caractère plus ou moins venteux de la région. Nous examinons la réaction de croissance que pourraient avoir les épinettes dégagées, après la récolte des peupliers faux-trembles de l'étage supérieur, ainsi que le rendement en épinette et en peuplier faux-tremble que devrait produire la récolte suivante.

Selecting a silvicultural system

From the silvicultural perspective, stands with conifer understory present numerous options that can satisfy a variety of management objectives. Depending on the management objectives, the options may vary from a "do nothing" alternative to complex alternative silvicultural systems (Table 1). By definition of silvicultural systems, the first alternative—"do nothing"—falls into the category of natural shelterwood and follows the natural successional pattern of stand development. The alternatives B, C, and D involve clear-cutting systems or clear-cutting with retained seed trees. Plantation technology—alternative B—was the most often used option in the past, prevailing for boreal mixedwoods in the 1960s to 1980s and involving clear-cutting, site preparation, planting, and variable levels of tending and competition control.

The last alternative of conifer understory protection while harvesting deciduous or deciduous–conifer overstory is discussed in this paper using an example of white spruce (*Picea glauca* [Moench] Voss) understory–aspen (*Populus tremuloides* Michx.) overstory stands. Decision-making steps in selecting the most appropriate silvicultural system involve the definition of management objectives, evaluation of stand suitability, and assessment of windthrow risk (including site evaluation).

Resource management objectives

The management objectives addressed here are 1) to enhance conifer production, 2) to promote natural regeneration of spruce and aspen, and 3) to sustain mixedwoods on the site.

The silvicultural strategy follows the two-stage silvicultural and harvesting model (Brace and Bella 1988). In this model (Figure 1), a first harvest takes place when overstory aspen is 60–80 years old and understory spruce about 20–60 years old. In the first harvest, all

Table 1. Management and silviculture options for deciduous and mixedwood stands with conifer understory.

A. "Do nothing"	- extended rotation or use of other silvicultural systems at later stages of stand development - natural shelterwood system
B. Plantation technology	- clear-cutting, site preparation, planting, and tending
C. Deciduous production	- clear-cutting and no treatments
D. Deciduous production with natural regeneration of shade-tolerant conifers	- clear-cutting with retained conifer seed trees - variant of seed tree system
E. Conifer understory protection, simultaneous conifer and deciduous production	- two-stage silviculture and harvesting model - array of the silvicultural systems with the incremental levels of harvesting protection of understory; wind protection of retained understory; harvesting difficulty and conifer yield

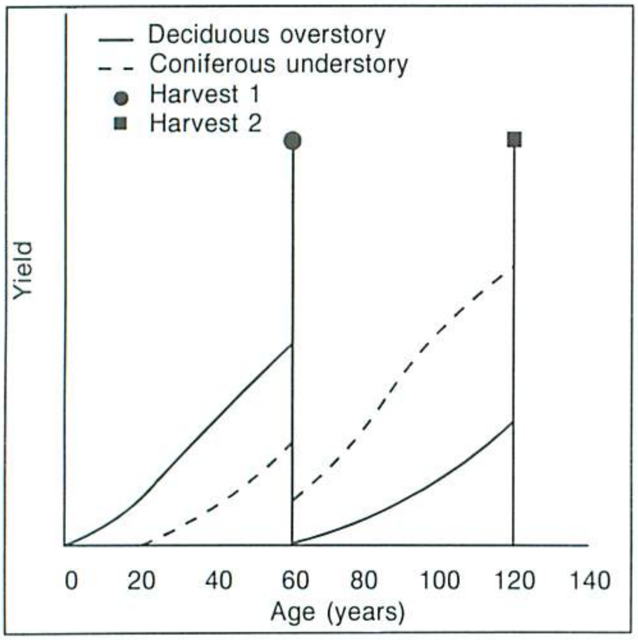

Figure 1. Generalized two-stage harvesting and silviculture model.

Source: Brace and Bella (1988).

aspen forming overstory and all spruce over a diameter at breast height (DBH) utilization limit are harvested, leaving a released spruce understory. Following harvest, aspen resuckers in the available spaces, resulting in a stand comprising species clumps as well as intermixed hardwoods and conifers.

The second harvest is taken approximately 60 years later when both aspen and spruce would be harvested. During the time between the first harvest at age 60 and the second harvest at the total age 120 years, new regeneration of spruce should occur from seed cast by seed-bearing released understory trees or from seed trees of the overstory purposely retained after the first harvest (Navratil et al. 1989).

Evaluation of stand suitability

Density and spatial distribution of white spruce understory

Results of preharvest and postharvest assessments of white spruce densities in Alberta's harvesting trials show that 40–80% of white spruce understory is destroyed or damaged while harvesting aspen overstory when intermediate and high levels of protection are employed. The amount of spruce protected can be controlled by the choice of harvesting equipment, equipment operating techniques, and levels of planning and supervision (Brace Forest Services 1992; Sauder 1992).

Based on the above estimates, the preharvest understory density should therefore be about double the targeted postharvest densities. What the targeted postharvest densities should be will greatly depend on management objectives and windthrow risk level. The maximum spruce yield (expressed in total volume at the second harvest) may be achievable if the postharvest densities exceed 850 spruce trees per hectare (Table 2) and spruce trees are uniformly distributed (Navratil[1]).

Windthrow risk assessment

Tree resistance to windthrow

Resistance of a tree to windthrow results from a combination of several tree characteristics (Navratil 1995). Height is important, because wind speed, and therefore wind load on a tree, increases exponentially with distance from the ground. In the pooled data from the Alberta harvesting trials, cumulative windthrow dam-

[1] Navratil, S. Silvicultural systems for managing deciduous and mixedwood stands with white spruce understory. *In* Silviculture of temperate and boreal broadleaved–conifer mixtures. Proc. Symp., Feb. 28–March 1, 1995, Richmond, BC. (In press.)

Table 2. White spruce yield at second harvest in relation to understory density.

	White spruce[a] yield (m³/ha) at following densities of white spruce understory (trees/ha) after first harvest:		
Trial location	250	580	850
Drayton Valley[b]	162	346	468
Whitecourt	142	310	428
Hinton	132	294	411

[a] Estimated spruce age = 110 years.

[b] Projections based on calculations of five-year periodic annual increment (PAI) (the first five years after release) and compounded mortality (1% per annum) as reported in Navratil et al. (1994). Densities of 246, 577, and 851 trees/ha, respectively, were used in the calculations.

age five years after release for spruce trees with heights up to 7 m was less than 5%, whereas trees taller than 10 m had cumulative windthrow damage of 10–25%.

The slenderness coefficient, expressed as a height/DBH ratio, often serves as an indicator of wind and snow damage resistance. It is correlated with the crown size and particularly crown length. The slenderness coefficient has been intensively studied in Europe, where the importance of maintaining well-tapered trees for protection against wind and snow damage is emphasized. The desirable height/DBH ratios vary with species and site. In central Europe, a ratio of 80–90 is acceptable for Norway spruce (*Picea abies* [L.] Karst.) (Navratil 1995).

At present, in the absence of more specific local data for white spruce, we consider white spruce understory trees with height/DBH ratios equal to or greater than 100 and taller than 7 m as being in a high-risk category.

Windiness of the region

Wind gusts produce most of windthrow. Expected return periods for maximum gusts, meaning the average length of time between gusts of a given wind speed, calculated from long-term meteorological records can be useful for highlighting the areas requiring special attention in wind protection planning (Flesch and Wilson 1993).

The directional analysis of maximum gusts is essential for the planning of the sheltering effect of stands located upwind from the stands requiring protection (released white spruce understory). Figure 2 illustrates a simplified diagram of wind behavior where a sheltering stand is on the windward side of the open area. The open area may represent a cutblock with released white spruce understory. Wind speed changes depicted in Figure 2 show that when a wind leaves the

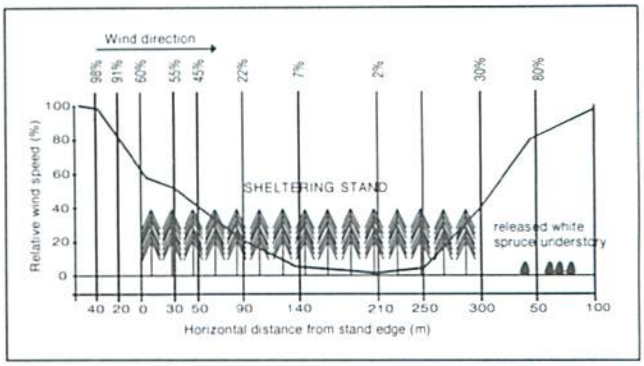

Figure 2. Example of wind speed in a forest stand and adjacent open areas.

Source: Navratil (1995).

stand, it accelerates to about 30%; at 50 m into the clearing, it reaches 80%; and at about 100 m, it reaches 100% of the original speed.

Site evaluation

Site, primarily soil characteristics, directly affects windthrow hazard of released spruce. Susceptibility to windthrow is related to the effectiveness of root anchorage, which, in turn, is governed mainly by the depth and size of structural roots.

Windthrow risk is expected to be higher on moist and wet sites. The presence of endemic windthrows with flat root systems and signs of gleying in upper soil horizons may assist in diagnosis of these sensitive sites (Navratil 1995). The rise of soil moisture on moist sites after harvesting aspen overstory could seriously affect wind stability of released spruce.

The overall windthrow risk can then be estimated from the assessments of wind resistance characteristics of understory trees, site evaluation, and windiness of the region and site. Subsequently, the required level of wind protection can be assigned—low, medium, high—which, in turn, will guide the choice of silvicultural and harvesting system to be used.

There are three ways in which windthrow damage can be minimized by the appropriate silvicultural system:

- improving the windfirmness of understory trees *prior to* total removal of aspen canopy using variants of the shelterwood system;
- reducing wind damage in released white spruce *after* removal of aspen canopy using the sheltering effect of stands, strips, and windbreaks; and
- combining shelterwood and sheltering effects in one design.

Table 3 lists applicable silvicultural systems with the incremental levels of wind protection, type of wind

Table 3. Silvicultural systems for reducing wind damage in released white spruce understory.

System	Type of protection	Level of protection against wind damage	Level of harvesting difficulty[a]
Clearcut; total removal of aspen canopy	None	None	Easy
Clearcut; total removal of aspen canopy; some clumps of standing balsam poplar (*Populus balsamifera* L.) and aspen	Mutual support of neighbor trees and reduced wind speed within clumps	Low, varies with size and spatial distribution of standing residuals	Easy
Clearcut; removal of the aspen canopy with retained long windbreaks of aspen/balsam poplar	Reduced wind speed on lee side of windbreaks	Medium to high, varies with porosity and distance between windbreaks	Easy
Alternative strip cutting in two passes:	Sheltering effect of stand on windward side	High after first pass, low after second pass, varies with width of strip	
50 m wide			Difficult
100 m wide			Moderate
150 m wide			Moderate
Uniform shelterwood, 50% removal of basal area	Improved stability of understory between first and second passes	Medium	Not compatible with feller-buncher harvesting
Modified uniform shelterwood, one pass	Improved stability of understory and sheltering effect of retained narrow strip	Very high	Moderate
Modified uniform shelterwood, two passes	Improved stability of understory between first and second passes	Very high after the first pass, medium after the second pass	Moderate
Combined shelterwood strip system, two passes	Sheltering effect and improved stability of understory	Medium to high	Moderate to difficult
Combined shelterwood strip system, three passes	Sheltering effect and improved stability of understory	High	Moderate to difficult
Progressive strip clear-cutting	Sheltering effect and height gradient of spruce deflecting wind	High	Moderate to difficult
Wedge strip cutting	Sheltering effect and height gradient of spruce deflecting wind in a wide angle	Very high	Unknown

[a] Feller-buncher felling.

Source: Navratil et al. (1994).

protection, and different harvesting difficulties when using feller-buncher felling. For details of the designs and harvesting layout and harvest sequencing, see the diagrams in Navratil et al. (1994) and Navratil (1995).

Acknowledgments

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The Black Sturgeon Boreal Mixedwood Research Project: ecosystem research in support of integrated resource management

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Abstract

This multidisciplinary, multiagency project seeks to develop a better understanding of the long-term consequences of natural and human disturbances in boreal mixedwood ecosystems. Stand-level studies are concerned with the impacts and ecological responses to different harvesting regimes, prescribed fire, and mechanical site preparation in 55-year-old second-growth spruce–fir–aspen mixedwoods near Thunder Bay, Ontario. Current studies focus upon site impacts, logging damage to residual trees and advance growth, fire behavior, pathological and entomological responses, seed bank dynamics, postdisturbance vegetation succession and stand dynamics, forest renewal, nutrient dynamics, soil invertebrates, and wildlife (songbirds, small mammals, Amphibia).

Résumé

Le présent projet multidisciplinaire, lancé conjointement par plusieurs organismes, vise à mieux comprendre les conséquences à long terme des perturbations naturelles et humaines pour les écosystèmes de la forêt mixte boréale. Près de Thunder Bay, en Ontario, nous avons étudié des peuplements mixtes (épinette, sapin et peuplier faux-tremble) de seconde venue de 55 ans, afin de mesurer les effets de divers régimes d'exploitation, du brûlage dirigé et de la préparation mécanique du terrain ainsi que les réactions écologiques induites par ces traitements. Les études en cours visent l'impact sur les stations, les dégâts causés par l'exploitation aux arbres résiduels et à la régénération préexistante, le comportement des incendies, la réaction des organismes pathogènes et des insectes, la dynamique de la banque de semences, la succession végétale et la dynamique des peuplements après la perturbation, le renouvellement de la forêt, la dynamique des éléments nutritifs et la faune (invertébrés du sol, oiseaux chanteurs, petits mammifères et Amphibia).

Introduction

This long-term, multidisciplinary project was established in 1993 in response to the perceived need for a better understanding of the ecology of boreal mixedwood ecosystems and their response to natural and human disturbances.

In recent years, environmental concerns and public sentiment have forced us to reevaluate our approach to forest management. It began in the 1980s with the debate over the supposed negative environmental and ecological impacts of traditional forestry practices. The result has been a general policy shift away from a focus solely on consumptive timber values to a more comprehensive management concept that recognizes the importance and benefits of a wide range of other forest values. In Ontario, where the term "ecosystem management" reflects this changed outlook, the Ministry of Natural Resources has developed a Policy Framework for Sustainable Forests and a *Crown Forest Sustainability Act* that implement "ecosystem ideas" in forested ecosystems (Euler 1995).

The impact of changing policies and public expectations about how our forests should be managed will perhaps be greater for boreal mixedwoods than for any other forest type in northern Ontario. Because of their diversity, aesthetic appeal, rich flora and fauna, and remoteness, these complex and highly productive ecosystems possess important nontimber values in addition to their value as producers of timber. Consequently, whereas timber-related market forces dictated management approaches in the past, demands for the protection of nontimber values such as wilderness, hunting and fishing, and wildlife are likely to be increasingly influential in shaping the future management of boreal mixedwoods.

If we are to continue to practise economic forestry in boreal mixedwood cover types, it clearly has to be integrated into a more holistic approach to forest management that accommodates the often divergent needs and goals of different interest groups, while protecting ecosystem health. Consequently, integrated resource management, which might be regarded as the operational application of ecosystem management, is likely to play an important role in the future sustainable development of boreal mixedwoods. This creates a need to develop ecologically and operationally sound alternatives for managing these forests, alternatives that are able to satisfy different resource use goals.

Realistically, however, the current ability to apply integrated resource management is severely constrained by our relatively poor knowledge of boreal mixedwood ecosystems. To establish a strong ecological foundation for mixedwood management, we need to develop a much better understanding of these complex ecosystems—their structure and function, their response to disturbance, and the interrelationships among different ecosystem elements (e.g., vegetation, nutrients, wildlife, pests and diseases, etc.). Such knowledge will not come easily or quickly, and it can only be gained through long-term, multidisciplinary research that looks at the forest as a whole.

Meeting the boreal mixedwood challenge

The Black Sturgeon Boreal Mixedwood Research Project attempts to address some of these questions, through fundamental studies that focus on stand-level ecosystem response to disturbance and silvicultural manipulation. At the same time, it incorporates treatments that seek to evaluate the feasibility and impacts of adopting alternative management approaches that avoid clear-cutting. Although the project was established at a semioperational scale, the focus is on understanding ecological processes and relationships rather than on the development of new technologies. The importance of scientific understanding preceding practice cannot be overemphasized when dealing with such complex issues as boreal mixedwood management.

The project is located approximately 120 km northeast of Thunder Bay, Ontario, in an area that has a long history of both mixedwood management and research on spruce budworm (*Choristoneura fumiferana* Clemens) population dynamics. This is a cooperative project of the Canadian Forest Service–Sault Ste. Marie, the Ontario Ministry of Natural Resources, and Avenor Inc. of Thunder Bay. Whereas the Black Sturgeon Boreal Mixedwood Research Project focuses on stand-level issues, a complementary project located at Rinker Lake, some 55 km to the northwest in the Spruce River Forest, deals with landscape-level issues in boreal mixedwood management (Sims and Mackey 1994).

The Black Sturgeon Boreal Mixedwood Research Project is situated in an extensive area of second-growth mixedwood forest, first harvested between 1940 and 1942. For the most part, the soils are fresh, well drained, and fertile. These support stands that fall predominantly within the herb- and shrub-rich mixedwood vegetation types (V-type) of the forest ecosystem classification for northwestern Ontario (V6, V7, V9, V11, V16) (Sims et al. 1989). At the time of the most recent provincial forest resource inventory (1975), stand composition in the project area averaged 50% poplar (*Populus* spp.), 30% balsam fir (*Abies balsamea* [L.] Mill.), 10% black spruce (*Picea mariana* [Mill.] B.S.P.), and 10% white spruce (*Picea glauca* [Moench] Voss), with local admixtures of white birch (*Betula papyrifera* Marsh.) and/or jack pine (*Pinus banksiana* Lamb.). However, 1993 preharvest data demonstrated a significant compositional shift since that inventory, largely because of the depredations of a lengthy spruce budworm epidemic on the balsam fir and white spruce component. Much of the balsam fir in the upper canopy is now either dead or dying.

Despite their relatively young age (approx. 55 years), in the normal course of events these budworm-infested stands would have been clearcut in 1994–1995 to salvage as much of the conifer as possible. This presented an opportunity to explore alternative harvesting and silvicultural strategies within an operational context. The timing is also fortuitous from an ecological perspective, for it coincides with the end of the current spruce budworm epidemic and the period of maximum fire hazard for this forest. Ecologically, this represents the end of one major natural disturbance, the window of opportunity for a second (wildfire), and the beginning of a new cycle of forest succession.

The Black Sturgeon Boreal Mixedwood Research Project currently comprises three multidisciplinary components concerned with ecosystem impacts and responses to different harvesting regimes (*harvesting component*), prescribed fire (*fire ecology component*), and mechanical site preparation (*site preparation component*). The three project components, which are located within a few kilometers of each other, are described below in more detail.

Harvesting component

This component examines shelterwood cutting as an alternative to clear-cutting in second-growth stands. Although the emphasis is on ecosystem response, basic silvicultural questions relating to the application of shelterwood management in boreal mixedwoods are also being addressed (e.g., harvesting impacts upon residual trees, forest renewal issues, etc.).

Six different harvesting treatments, each replicated three times, were carried out in the fall of 1993:

- Clear-cutting:
  1. Conventional feller-buncher and grapple skidder (*full-tree extraction*);
  2. Single-grip harvester (Ultimate 4500) and grapple skidder (*tree-length extraction*);
- Shelterwood cut:
  3. Partial cutting with feller-buncher and grapple skidder (*full-tree extraction*);
  4. Partial cutting with single-grip harvester (Timberjack 1270) and forwarder (*cut-to-length*);
  5. Partial cutting with manual felling and cable skidder (*partially delimbed full-tree extraction*);
- Patch cuts:
  6. Manual felling with cable skidder (*partially delimbed full-tree extraction*);
- Uncut "control."

Both harvested and control blocks have an area of 10 ha, with 100-m-wide uncut buffer strips between the blocks. The shelterwood cuts aimed to remove about two-thirds of the merchantable volume from a block, including all merchantable balsam fir, while retaining a uniform canopy of good-quality trembling aspen (*Populus tremuloides* Michx.) with a scattering of potential white spruce seed trees (2–3/ha). In practice, it was frequently necessary to accept black spruce as a substitute seed tree because of extensive spruce budworm damage to the preferred white spruce.

The harvesting treatments resulted in clear differences in amounts and distribution of logging slash, in site disturbance, in the destruction of balsam fir advance growth and amount of damage to residual trees, and in the residual canopy structure. These translate into differences in successional opportunities, in wildlife habitat, and in biological activity.

The patch cuts were established as a link to related research into white spruce regeneration being conducted in the Chapleau, Ontario, area (Carlson and Groot[1]). The patches are 21-m-diameter clearcuts (equivalent to average stand height) at 50-m center-to-center spacing along 5-m-wide skid trails cut 50 m apart. This removed approximately 20% of the standing volume from each block.

Extensive preharvest sampling of vegetation, soils, and wildlife populations established the baseline conditions that will be used to judge the impacts of harvesting and to monitor long-term changes in the undisturbed forest. With harvesting completed, preharvest research plots were reestablished in the spring of 1994, together with a number of new studies. Current studies focus upon site impacts, logging damage to residual trees and advance growth, pathological and entomological responses, seed bank dynamics, postharvest vegetation succession and structure, forest renewal, stand dynamics, growth and yield, soil nutrient dynamics, soil fauna, and wildlife relationships (songbirds, small mammals, Amphibia). Many of the studies have a long-term outlook, and it is anticipated that the full story of how individual ecosystem elements respond to disturbance will take several years to emerge.

The second phase of research began in 1995 with the initiation of studies that aim to determine the fundamental conditions needed to regenerate spruce successfully under an aspen shelterwood. Site preparation treatments were applied to subplots in partially cut and clear-cut blocks in late summer, including soil mixing, surface organic matter removal, mounding, and herbicide application. Planting and seeding of white spruce and black spruce will follow in the spring of 1996. This phase of the work complements the site preparation component of the project, described below, and will encompass a similar suite of investigations, plus studies on conifer seedling ecophysiology.

Fire ecology component

Fire is a natural phenomenon in the boreal forest, and it has a fundamental role in regulating biotic productivity and in maintaining long-term ecosystem diversity and stability. The boreal forest has been defined as "a fire-dependent system that would lose its character, vigor, and faunal and floral diversity in the absence of fire" (Kelsall et al. 1977).

Fire has been little used as a silvicultural tool in boreal mixedwoods, except to eliminate logging debris. Prescribed fire could potentially play a much more significant role in the management of these ecosystems—for example, to reduce the balsam fir content of conifer regeneration, to control crop/tree competition, to improve wildlife habitat, and to promote increased

[1] Carlson, D.W.; Groot, A. Microclimate of clear-cut, forest interior, and small openings in trembling aspen forest. Agric. For. Meteorol. (In press.)

biodiversity. However, a much better understanding of the impacts of fire on ecosystem-level processes is needed before it can be used as an operational tool.

The fire ecology component provides a unique opportunity to investigate the impacts of prescribed fire on vegetation succession and soil nutrient dynamics following large controlled fires of known intensity and to compare the ecological impacts of fire and harvesting on similar sites.

Four harvesting treatments were executed in the fall of 1993:

- full-tree harvest;
- tree-length harvest;
- balsam fir tramped to simulate postbudworm stand breakup; and
- uncut.

Each treatment block (9 ha) was replicated four times, for a total of 16 blocks. Prescribed burning of designated blocks was originally scheduled for the spring and late summer of 1994, but weather conditions and other factors precluded burning in either 1994 or 1995.

It is now planned that burning will take place in early spring of 1996. Eleven blocks will be burned, of which eight will receive no further treatment following the fire in order to document natural responses. The remaining three burned blocks, plus the unburned blocks, will receive various combinations of site preparation and herbicide treatments in 1996.

Current studies, for which extensive preharvest sampling has been carried out, focus on the impacts of prescribed fire on soil chemistry and nutrient cycling, nutrient transfers from biomass to ashbed following burning, seed bank dynamics, vegetation succession, and the relationship between species reestablishment and fire intensity. A broad objective is to integrate soils, vegetation, and seed bank data into a succession model that will enable forest managers to predict the response of boreal mixedwood ecosystems to disturbance by fire.

Site preparation component

Current site preparation practices in boreal mixedwoods typically involve some form of organic layer removal (e.g., screefing or disc trenching), often combined with the use of a herbicide to discourage competing vegetation. However, mechanical site preparation has demonstrated little or, at best, short-term control of competing vegetation. It has also been criticized on the grounds that it promotes nutrient depletion and so threatens long-term sustainability (MacKinnon and McMinn 1988).

High-speed soil mixing is a relatively new site preparation method that has shown the potential to control competing vegetation (McMinn and Hedin 1990) while improving soil conditions, such as aeration and moisture relationships, for conifer regeneration (Örlander et al. 1990).

This component examines the ecological impacts of soil mixing, as well as conventional screefing and herbicide applications, following clear-cutting. It was initiated in 1993 on second-growth mixedwood sites clearcut in 1992 using a conventional cut and skid, full-tree system. Current studies focus on the effects of the different site preparation methods on competing vegetation, the survival and growth response of planted black spruce seedlings, the biodiversity and population levels of soil mycoflora and microfauna, organic matter decomposition and nutrient mobilizations, and the inoculum potential for *Armillaria* root decay. As with the other project components, these are regarded as long-term studies.

Conclusion

The Black Sturgeon Boreal Mixedwood Research Project is an important initiative that will contribute significantly to the knowledge and understanding needed for applying ecosystem-based forest management in this cover type. Much of the research now under way is breaking new ground in the study of boreal mixedwood ecosystems and their response to disturbance. The results will give us a better understanding of the complex ecological relationships within these ecosystems and of the long-term ecological consequences of forestry practices. Such knowledge is essential in order that a strong ecological basis can be established for the sustainable management of boreal mixedwoods to satisfy different resource use goals.

Many of the individual studies within this project (see Annex) are described more fully elsewhere in these proceedings.

Acknowledgments

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Research Institute of Canada–Eastern Division, with contributions toward harvesting costs by Avenor Inc. of Thunder Bay and Sturgeon Timber Ltd. of Dorion, Ontario.

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Annex: Current studies[2]

i. Harvesting component

Harvesting productivities and site impacts.
Jean-François Gingras (FERIC–East, Pointe Claire, PQ)

Logging damage and pathological colonization of residual trees.
Mike Dumas and John McLaughlin (CFS–Sault Ste. Marie, ON)

Logging damage and recovery of advance growth and regeneration.
Jean-Denis Leblanc (CFS–Sault Ste. Marie, ON)

Postharvest vegetation succession and dynamics.
Philippe Nolet and John Scarratt (CFS–Sault Ste. Marie, ON)

Effects of moose browsing on aspen sucker development and vegetation diversity.
John Scarratt (CFS–Sault Ste. Marie, ON)

Seed bank dynamics, seed rain, and tree seedling recruitment.
Meiqin Qi and John Scarratt (CFS–Sault Ste. Marie, ON)

Impacts of harvesting on distribution and cycling of organic matter and elements.
Ian Morrison (CFS–Sault Ste. Marie, ON) and Mark Johnston (OMNR, Centre for Northern Forest Ecosystem Research, Thunder Bay, ON)

Effects of harvest method on canopy development.
Arthur Groot (CFS–Sault Ste. Marie, ON)

Impacts of harvesting practices on boreal forest soil invertebrates.
Jan Addison and Kevin Barber (CFS–Sault Ste. Marie, ON)

Impacts of harvesting practices and fire on the red-backed salamander.
Raymond Guy (Collège Boréal, Sudbury, ON)

Impacts of harvesting practices on small mammal populations.
Arthur Rodgers (OMNR, Centre for Northern Forest Ecosystem Research, Thunder Bay, ON) and Carrie Hutchison (Faculty of Forestry, Lakehead University, Thunder Bay, ON)

[2] FERIC = Forest Engineering Research Institute of Canada; CFS = Canadian Forest Service; OMNR = Ontario Ministry of Natural Resources.

Impacts of harvesting practices on bird populations.
Ken Abraham (OMNR, Southern Terrestrial Ecosystems Research Section, Maple, ON)

Postharvest site preparation and regeneration studies.
Brad Sutherland, Michael Dumas, Ian Morrison, and John Scarratt (CFS–Sault Ste. Marie, ON)

Effects of competition and shelter on establishment of white spruce.
Arthur Groot and Jim Wood (CFS–Sault Ste. Marie, ON)

Growth and yield monitoring in control blocks.
Jim Mackenzie and Mark Roddick (OMNR, Northwest Region Science and Technology, Thunder Bay, ON)

Impacts of spruce budworm and budworm spraying on conifer regeneration.
Chris Sanders (CFS–Sault Ste. Marie, ON), Yves Prévost, Ryan Bichon, and Zhong-Yu Dang (Faculty of Forestry, Lakehead University, Thunder Bay, ON)

ii. Fire ecology component

Fire behavior in boreal mixedwood fuel types.
Terry Curran (OMNR, Atikokan, ON), Doug McRae, and Brian Stocks (CFS–Sault Ste. Marie, ON)

Impacts of burning on ecosystem structure and function.
Mark Johnston (OMNR, Centre for Northern Forest Ecosystem Research, Thunder Bay, ON) and Jim Kayll (Faculty of Forestry, Lakehead University, Thunder Bay, ON)

Monitoring postfire succession using Radarsat imagery.
Eric Kasischke (Duke University, Durham, NC), Mark Johnston and Rob Remple (OMNR, Centre for Northern Forest Ecosystem Research, Thunder Bay, ON), and Brian Stocks (CFS–Sault Ste. Marie, ON)

Soil nutrient cycling following fire.
Mark Johnston (OMNR, Centre for Northern Forest Ecosystem Research, Thunder Bay, ON) and Rob Stronach (Faculty of Forestry, Lakehead University, Thunder Bay, ON)

Plant succession and seed bank dynamics following fire.
Mark Johnston (OMNR, Centre for Northern Forest Ecosystem Research, Thunder Bay, ON) and Tanya Rintoul (Faculty of Forestry, Lakehead University, Thunder Bay, ON)

Impacts of burning on crop tree competition.
Bill Towill (OMNR, Northwest Region Science and Technology, Thunder Bay, ON)

Fire impacts on boreal forest soil invertebrates.
Jan Addison and Kevin Barber (CFS–Sault Ste. Marie, ON)

Impacts of burning on bird populations.
Ken Abraham (OMNR, Southern Terrestrial Ecosystems Research Section, Maple, ON)

iii. Site preparation component

Impacts of site preparation method upon seedling growth and vegetation response.
Brad Sutherland (CFS–Sault Ste Marie, ON)

Impacts of site preparation method on organic matter decomposition and element mobilization.
Ian Morrison (CFS–Sault Ste. Marie, ON)

Impacts of site preparation method on soil fauna abundance and diversity.
Jan Addison (CFS–Sault Ste. Marie, ON)

Impacts of site preparation method on soil microflora and the spread of root decay fungi.
Michael Dumas (CFS–Sault Ste. Marie, ON)

Best practices for maintaining site productivity in boreal mixedwoods

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Abstract

A federal–provincial working group coordinates research and information exchange on the long-term productivity of boreal forest ecosystems. A preliminary workshop was organized to initiate discussion and debate on how best to subdivide boreal mixedwood sites into groups that have similar responses to treatment, with respect to site productivity. Participants developed a selection of preliminary edatopic grids to define primary environmental gradients of significance for boreal mixedwoods. Soil texture, slope, organic matter depth, and presence or absence of calcareous soils were identified as the important characteristics that define mixedwood sites and determine different posttreatment responses. Soil depth may be important, as full-tree trembling aspen (*Populus tremuloides* Michx.) utilization increases on the very shallow sites of northwestern Ontario. One of the primary objectives of the workshop was to identify and share current forestry practices that are effective in sustaining productivity.

Résumé

Un groupe de travail fédéral-provincial coordonne la recherche et l'échange d'information sur la productivité à long terme des écosystèmes de la forêt mixte boréale. Ce groupe s'est d'abord réuni en atelier, pour lancer la discussion et chercher la meilleure façon de classer les stations de la forêt mixte boréale en groupes de stations ayant une réaction semblable au traitement, en matière de productivité. Les participants ont élaboré un certain nombre de matrices visant à définir les principaux gradients environnementaux qui ont une importance pour cette forêt. Ils ont établi que la texture du sol, la pente, la profondeur de la matière organique ainsi que la présence ou l'absence de sols calcaires constituent les principaux paramètres permettant de définir les stations et de prédire les diverses réactions aux traitements. La profondeur du sol pourrait également être importante, car l'exploitation des peupliers-faux-tremble (*Populus tremuloides* Michx.) par arbres entiers s'intensifie dans les stations à sol très mince du nord-ouest de l'Ontario. Un des principaux objectifs de l'atelier était de cerner et de partager les pratiques forestières actuelles qui permettent de maintenir efficacement la productivité.

Introduction

A federal–provincial working group has been established to coordinate research and information exchange on the long-term productivity of boreal forest ecosystems. Owing to the magnitude of the issue, the group initially focused on boreal jack pine (*Pinus banksiana* Lamb.) and black spruce (*Picea mariana* [Mill.] B.S.P.). Shallow, nutrient-poor sandy soils and organic soils were identified as the sites of greatest concern for sustainable forestry of jack pine and black spruce. Field studies are in place on these site types to study and quantify site productivity, nutrient cycling processes, and linkages to forestry practices. The Canadian Forest Service (CFS), a department within Natural Resources Canada, is focusing research activities on jack pine. The Ontario Ministry of Natural Resources (OMNR) is concentrating its research on black spruce.

This year, the working group is branching out to examine the issue of forestry effects on site productivity of boreal mixedwoods. The working group has expanded its membership to include experts in boreal mixedwoods, such as Dr. John Scarratt (CFS project leader for the Black Sturgeon Boreal Mixedwood Research Project), Brad Sutherland (CFS research scientist studying site preparation effects), Dr. Rob Fleming (CFS ecophysiologist and microclimatologist), and Dr. B. MacDonald (boreal mixedwood scientist, OMNR). Field studies that examine the relationship between forestry practices, regeneration, and site productivity in boreal mixedwood forests are currently in place (e.g., Black Sturgeon Boreal Mixedwood Research Project). Data from the field studies will be interpreted over the next decade. In the interim, there is a need to develop "best practices" for less resilient sites, with respect to site productivity.

This workshop was designed to bring together individuals who are working in mixedwood forests to refine the definition of mixedwood sites where current forestry practices should be maintained or modified to minimize effects that may reduce future site productivity.

Approach

The workshop was designed to use an edatopic grid to identify the primary environmental gradients that indicate significant differences in mixedwood sites. For example, the literature indicates that soil texture and soil moisture are important characteristics that define mixedwood sites. The group was divided into four smaller groups, which were each given a range of site/soil/forest cover conditions. Each of these smaller groups was asked to develop or refine an edatopic grid and to rate the risk of susceptibility to losses in site productivity from full-tree clear-cutting. Each group was also asked to fill in a matrix that identified key concerns in boreal mixedwoods, critical management goals, and best practices for maintaining site productivity.

Background

A preliminary literature survey on forestry effects on boreal mixedwood sites has been completed for the Black Sturgeon Boreal Mixedwood Research Project. This information expands on the literature identified in the recently published *Long-term productivity of boreal forest ecosystems: an annotated bibliography* (Taylor et al. 1995). An expert opinion survey of key concerns related to full-tree harvesting effects has also recently been completed.[1] Those surveyed identified stand structure changes and species shifts as key concerns on fresh to moist, deep mineral soils, which often support boreal mixedwood forests.

A second survey of boreal mixedwood research and development needs in Ontario was completed by Weingartner and MacDonald (1994). This provincial survey identified a number of key research needs that confirm that species shifts are one of the key concerns with respect to the effects of current forestry practices on mixedwood forests. Important issues identified in this survey included harvesting effects on residual stand quality, modified cutting to secure natural regeneration, control of species composition, and ecosystem structure and function.

An earlier study of research needs in boreal mixedwood forests of Ontario (Weingartner and Basham[2]) also identified concerns with the effects of forest practices on wildlife, fisheries, and recreation. This 1979 report suggested that mechanical site preparation could have negative impacts on nutrient cycling and soil moisture regimes. It also emphasized the need to quantify site quality and to identify what site factors affect growth and yield. *A report on the status of forest regeneration*, by Hearnden et al. (1992), confirmed that past forestry practices have led to a decline in the conifer component of boreal mixedwood sites.

Results

The workshop participants generally identified erosion (sheet erosion), disruption of lateral water flow, loss of surface organic matter, compaction, rutting, and loss of nutrient capital as the key forestry impacts on boreal mixedwood sites. Objectives were established to minimize soil and surface organic matter loss and to maintain the nutrient capital on site. Best practices were designed to meet these objectives, including winter harvesting, use of equipment with low ground pressure, delimbing and processing at the stump, harvesting hardwoods during the leaf-free period, minimizing mechanical scarification, and adopting partial harvesting systems on slopes greater than 10%. Maximizing road spacing, reducing slash pile area through burning, and minimizing the area dedicated to landings were also identified as best practices. The tables prepared by one group for fresh to moist, coarse loam soils and for fresh to moist, deep fine-textured soils are presented here as Tables 1 and 2, respectively.

An example of a matrix developed by one group to subdivide boreal mixedwood sites into site conditions of low to high risk for losses in site productivity following harvesting is presented in Table 3. Percent slope, organic matter depth, and presence or absence of calcareous soils are identified as key factors that influence risk for productivity losses. Soil texture and soil depth were selected as other controlling factors. The groups emphasized that forest ecosystem classification groups were not necessarily the most appropriate framework for defining boreal mixedwood susceptibility to forestry practices.

[1] Kershaw, H.M.; Jeglum, J.K.; Morris, D.M. Long-term productivity of boreal forest ecosystems. II. Expert opinion on the impact of forestry practices. Nat. Resour. Can., Can. For. Serv.–Sault Ste. Marie, Sault Ste. Marie, ON. NODA/NFP Tech. Rep. TR-23. (In prep.)

[2] Weingartner, D.H.; Basham, J.T., eds. 1979. Forest management and research needs in the boreal mixedwood forest of Ontario. The Spruce–Fir–Aspen Research Committee. Unpublished report. 90 p.

Table 1. Key concerns, goals, and best practices for fresh to moist, coarse loam soils in boreal mixedwood stands.

Key concerns	Goals	Best practices
Compaction/rutting	Minimize rutting and compaction	High flotation equipment Frozen ground operation Shut down operations when excessive precipitation occurs Minimize number of passes on skid trails
Productive land losses	Minimize reduction in productivity of site	Maximize road spacing (balance with skid distance) Retain productive land area Slash pile burning Minimize landing

Table 2. Key concerns, goals, and best practices for fresh to moist, fine-textured soils in boreal mixedwood stands.

Key concerns	Goals	Best practices
Loss of organic matter	Maintain root mat	Low ground pressure Chip at stump Patch site preparation
Compaction/rutting	Minimize surface drainage Minimize depth of rut and area of rutting	Good site layout Winter harvest Low ground pressure
Nutrient capital (on coarse loam to sand with no free carbonates)	Retain foliage and fine branches on site	Delimb at stump Full-tree harvest during winter only

Table 3. Susceptibility of mixedwood sites to losses in site productivity caused by full-tree clear-cutting.

Site factor	Shallow silty sand to silt loam	Moderately deep to deep, very dry to fresh coarse sand	Moderately deep to deep, fresh to very fresh coarse loam	Moderately deep to deep, fresh to very fresh fine loam	Deep, very fresh to moist silty loam/ clay loam	Peaty-phase mineral soils with fluctuating water table
Slope						
≤10%	M				M	H
>10%	H	M	M	H	H	H
Organic matter depth						
≥10 cm		M	L	L		H
<10 cm	H	H	M	H	H	H
Calcareous						
Yes			L	L		
No	H	M	M	M		

Gradient of nutrient concerns

Most concern .... Least concern

Note: Level of risk: H = high, M = moderate, L = low.

Discussion

There is a need to define and identify key concerns for the least resilient sites. With the recent introduction of a number of industries that will utilize trembling aspen (*Populus tremuloides* Michx.), there is an immediate need to identify risks associated with full-tree clear-cutting of aspen on different sites. Deeper, fertile soils are expected to be very resilient to changes in site productivity following current harvesting practices; however, sensitivity varies with slope, moisture, texture, and depth of organic matter. The effect on very shallow soils is less clear.

The impact of forestry practices on the land in the boreal forest varies with the nature and timing of the activity, site conditions, and cumulative effects of adjacent land uses. Forestry activities can have both a positive and negative effect on tree growth. The effects will vary with soil conditions, plant cover, local climate, and forestry practices.

Conclusions

The development of "best practices" for the maintenance of forest site productivity in the boreal forest would provide interim measures, pending the outcome of scientific studies that quantify the effects of forestry practices on site productivity. "Best practices" would not replace the need for "on-site" evaluation, the use of professional judgment, or the need to comply with other management objectives, including biodiversity, fisheries, wildlife, or tourism values. This workshop provided a forum for exchanging ideas on critical concerns with respect to boreal mixedwood management. Participants were able to expand their thinking beyond the traditional focus on regeneration.

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Taylor, M.E.; Kershaw, H.M.; Nixon, D.N. 1995. Long-term productivity of boreal forest ecosystems: an annotated bibliography. Can. For. Serv. and Ont. Min. Nat. Resour., Sault Ste. Marie, ON. Can. For. Serv. NODA Note No. 8. 6 p. + diskette.

Weingartner, D.H.; MacDonald, G.B. 1994. A survey of mixedwood research and development needs in Ontario. Ont. Min. Nat. Resour., Sault Ste. Marie, ON. For. Res. Inf. Pap. No. 118. 17 p.

An eastern spruce budworm hazard rating system for the forests of northern Ontario

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Abstract

The Ontario Ministry of Natural Resources and the forest industry have spent millions of dollars responding to spruce budworm (*Choristoneura fumiferana* Clemens) infestations and damage. Studies have demonstrated that stands differ in their vulnerability to spruce budworm and therefore require different management strategies. Effective management requires a predictive capability to forecast stand development and damage in the presence of budworm. The objective of this project is to develop a decision support tool that will integrate the impacts of a major pest into forest management.

Résumé

Le ministère des Ressources naturelles de l'Ontario et l'industrie forestière de cette province ont dépensé des millions de dollars pour réagir aux infestations de tordeuse des bourgeons de l'épinette (*Choristoneura fumiferana* Clemens) et aux dommages causés par cet insecte. Des études ont cependant montré que les peuplements varient quant à leur vulnérabilité et nécessitent donc des stratégies de lutte différentes. Pour qu'une telle stratégie soit efficace, il faut qu'on puisse prédire l'évolution du peuplement et les dégâts qui surviendront en cas d'infestation. Le présent projet vise à élaborer un outil d'aide à la décision permettant d'intégrer à la gestion forestière les impacts d'un ravageur important.

Introduction

The eastern spruce budworm (*Choristoneura fumiferana* Clemens) is the most destructive insect pest in the forests of Ontario. Gross et al. (1992) estimated that between 1982 and 1987, average losses in Ontario attributable to the budworm were over 8.7 million cubic meters annually. In 1995, budworm-associated tree mortality was observed over an area of more than 8 million hectares in northern Ontario. There are three major host species of the eastern spruce budworm in Ontario: balsam fir (*Abies balsamea* [L.] Mill.), white spruce (*Picea glauca* [Moench] Voss), and black spruce (*Picea mariana* [Mill.] B.S.P.). These species also represent major components of the Boreal Mixedwood Forest.

Since the 1960s, the Ontario Ministry of Natural Resources (OMNR) has conducted annual control programs against this pest, and industry has modified harvest schedules and road construction in response to local outbreaks. In 1989, OMNR produced its Spruce Budworm Management Strategy for Ontario. It was recommended that susceptibility and vulnerability rating systems be developed to facilitate protection and harvest planning. In 1990, at the environmental assessment hearings in Thunder Bay, the Ontario Lumberman's Association and the Ontario Forest Industries Association (OFIA) stated that a vulnerability rating system was a fundamental requirement for the successful implementation of the Spruce Budworm Management Strategy.

The hazard rating literature contains several terms, such as risk, hazard, susceptibility, and vulnerability, that are often confused and used inappropriately. The terms "susceptibility" and "vulnerability" are used in this report and were first differentiated by Mott (1963). Susceptibility refers to the probability that a tree or forest will be attacked. Vulnerability refers to the probability that a tree or forest will suffer damage or mortality resulting from the attack. Any spruce–fir stand or host tree in Ontario is susceptible to attack by the budworm, and, during a budworm outbreak, stands may be repeatedly attacked over a 5- to 10-year period. Host impacts can often be detected in the first year, and stand deterioration may occur over a 15-year period (Table 1). However, studies have demonstrated that different stand conditions result in differential vulnerability to the budworm and require different management prescriptions during a budworm outbreak (MacLean 1982). Effective management requires a predictive capability to forecast stand development and damage. It is the objective of a hazard rating system to predict how a stand will be affected by an insect outbreak both in the short and in the long term.

Table 1. General deterioration of stands affected by spruce budworm.

Severe defoliation (yr)	Impacts
1	Growth loss, upper crown
2–3	Radial growth loss, height, top mortality
4–6	Mortality: understory and overmature
7–15	Tree mortality

Source: Montgomery et al. (1982).

Many hazard rating systems have been developed to address a wide variety of forest insect pests (Hedden et al. 1980). Most hazard rating systems are empirical or based on correlation, rather than mechanistic, and based on causal relationships between the insect pest, host, and environment. Studies have shown that stands vulnerable to spruce budworm are typically >50% balsam fir and white spruce, >50 years old, water stressed (wet or dry), downwind of high budworm populations, and closely spaced (Westveld 1945; Batzer 1969; van Raalte 1972; MacLean 1982; Witter 1985).

In 1992, with funding from the Northern Ontario Development Agreement (NODA), the Forest Insect and Disease Survey (FIDS) of the Canadian Forest Service (CFS) began a three-year project to develop a spruce budworm hazard rating system to assist forest managers in assessing the susceptibility and vulnerability of the forests in northern Ontario. Specifically, the objectives were to develop budworm susceptibility and vulnerability maps using the forest inventory data base and to construct first-generation predictive vulnerability models using field data collected from a permanent plot network and historical records. Collaborators on this project included the OMNR and the OFIA.

Susceptibility and vulnerability maps

Both susceptibility and vulnerability maps of northern Ontario were produced using geographic information system technology and provincial forest inventory data. Susceptibility and vulnerability indices were calculated at the mapsheet level (Ontario basemap, township, or Forest Resources Inventory [FRI] basemap). The susceptibility map was based on the presence and abundance of balsam fir within each mapsheet. Methodology developed for Quebec, New Brunswick, Nova Scotia, and Newfoundland was used to produce a first-generation budworm vulnerability map that incorporated balsam fir and white spruce volumes, age, black spruce volumes, and climate into the development of a vulnerability rating for each mapsheet (MacLean 1982).

Impact plot network

In 1993 and 1994, a permanent plot system was established throughout northern Ontario to monitor budworm populations and assess impact. Selection criteria for plots included balsam fir/white spruce composition (10–30%, 31–60%, >60%), balsam fir age (20–40, 41–60, >60), and site class (1, 2, 3+4). In total, 225 plots were established (Figure 1). At each location, 5–8 prism plots were established to assess basal area, stand composition, balsam fir age, crown class, diameter at breast height, live/dead status, tree condition, tree height, crown length, top condition, defoliation history, crown density, budworm egg mass density, and protection history. Information gathered from these plots will be used to generate predictive models and to refine the susceptibility and vulnerability maps.

Historical review

FIDS budworm defoliation maps from 1941 to the present were digitized (PC ARC/INFO) and will be used to produce a historically based budworm hazard map of northern Ontario. Overlays of each major outbreak during this period will be produced and analyzed to identify areas of greater or lesser hazard based on frequency of budworm attack. These maps will be compared with the FRI-based susceptibility and vulnerability maps.

Support for this study through NODA's Sustainable Forestry Development Program ends in 1996. However, if a credible hazard rating system is to be developed, there will need to be a long-term commitment by the CFS and the project collaborators to ensure that the first-generation maps and models produced during the current effort are continuously refined and improved.

If sustainable forestry is to be achieved in northern Ontario, then it is essential that we begin to integrate the effects of spruce budworm outbreaks into forestry planning and management. An effective hazard rating system will be quantitative and will utilize parameters normally assessed and available from forest inventory data. It should predict host mortality and growth loss within reasonable confidence limits and should integrate the effects of protection programs. The economic benefits of a hazard rating system will be realized in the effective management of budworm-susceptible stands between and during outbreaks. It will enable the forest manager to more precisely monitor pest populations, adjust harvest schedules, carry out silvicultural

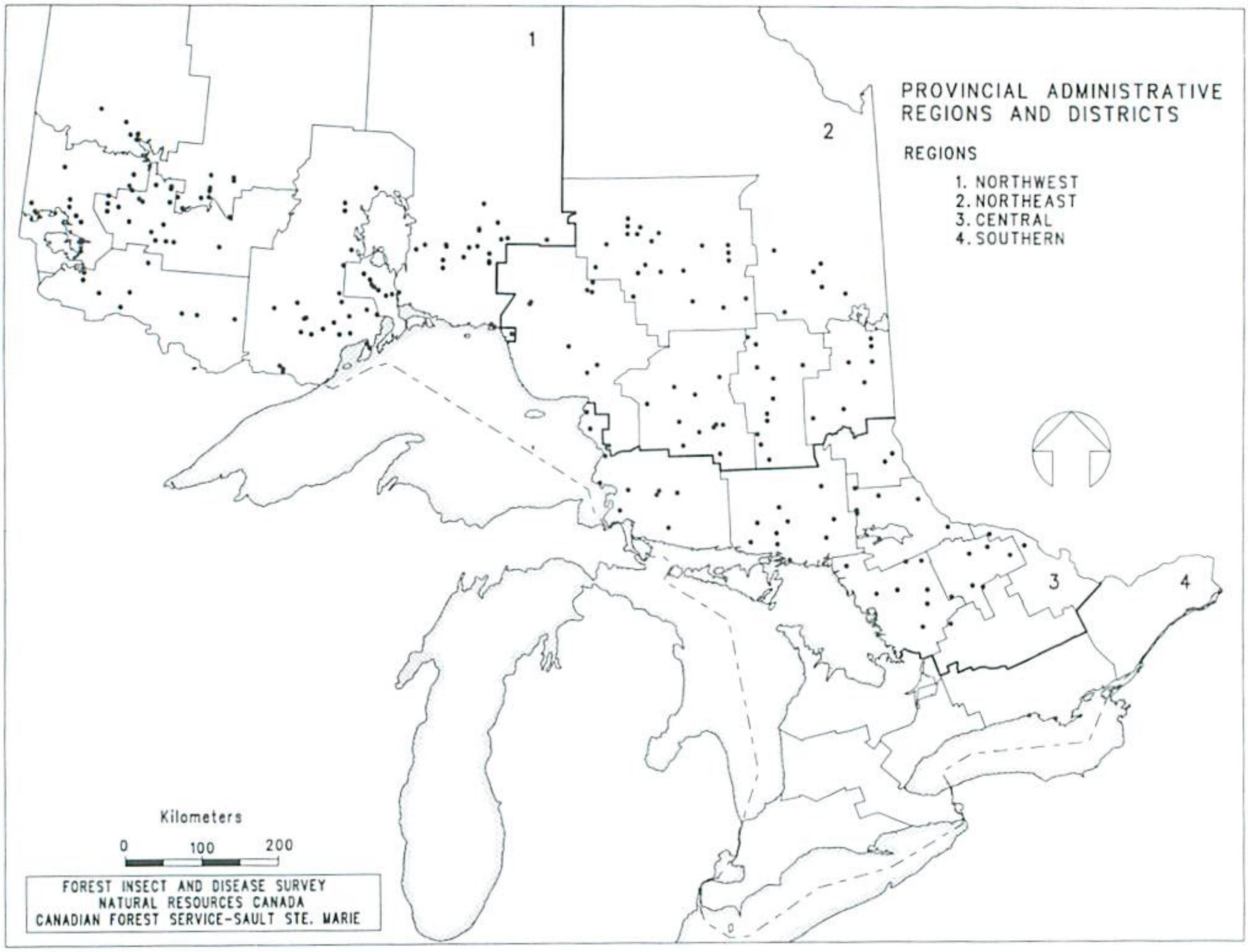

Figure 1. Spruce budworm NODA plot locations.

operations, delimit budworm control operations, and select species for reforestation.

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WORKSHOP CONCLUDING REMARKS

Observations, reflections, and challenges

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Abstract

Much good research on boreal mixedwoods has been carried out in Ontario over the past couple of decades, and much has been learned about these complex ecosystems. Forest policy now in place through Ontario's *Crown Forest Sustainability Act* must be protected and strengthened to ensure that the mixedwood forests are not managed by default on a single-species basis, as they are in other jurisdictions. This paper provides a brief overview of the approaches that have been taken and that are now being taken. Forest managers must be cognizant of the many challenges that lie ahead, and research programs should be designed with the following points in mind:

1. The benefits of establishing large ecological study areas are many: they afford the opportunity to obtain data on responses to forest practices over the long term, thus allowing the interpretation of ecosystem responses that short-duration studies do not. Sufficient long-term funding must be allocated to ensure the security of these areas.
2. Synergism can be achieved among scientists and practitioners if efforts are taken to establish intraprovincial and interprovincial networks, to share and critically evaluate information, to establish an effective means of communication, and to demonstrate the successes and failures wherever mixedwood management is practised.
3. While there are the beginnings of decision support systems for mixedwood management, the development of these systems should receive greater attention and should provide for the integration of information from other jurisdictions.
4. It is recognized that the mixedwood forests of Ontario and across Canada are extremely productive, but attention is often focused on solving immediate management problems without considering matters of a global nature. The challenge that we are now obliged to face is to determine the role that Ontario's and Canada's mixedwood forests should play in meeting world demands for wood in the face of rapid population growth.

Résumé

En Ontario, il se fait depuis une vingtaine d'années beaucoup de recherche de qualité sur les peuplements mixtes de la forêt boréale, et on connaît aujourd'hui mieux ces écosystèmes complexes. De nouvelles politiques forestières viennent d'être établies en vertu de la *Loi sur la durabilité des forêts de la Couronne*, mais elles doivent être protégées et renforcées afin que les peuplements mixtes ne soient pas gérés par défaut, en fonction d'une seule essence, comme elles le sont dans d'autres provinces. Le présent article décrit brièvement les démarches qui ont été adoptées, ou sont en train de l'être, à cet égard. Il faut que les responsables de la gestion forestière soient conscients des nombreux défis à venir et que les concepteurs des programmes de recherche gardent à l'esprit les points suivants.

1. Les études écologiques portant sur de vastes secteurs présentent de nombreux avantages. Elles produisent des données sur les effets à long terme des pratiques forestières et permettent d'élucider certaines réactions des écosystèmes, contrairement aux études de courte durée. Il faut qu'un financement à long terme suffisant permette de protéger les secteurs étudiés.
2. On peut réaliser une synergie entre chercheurs et gestionnaires en établissant des réseaux intraprovinciaux et interprovinciaux assurant un partage et une évaluation critique de l'information, un moyen de communication efficace et une occasion de mettre en évidence les réussites et les échecs de tout programme de gestion de la forêt mixte.
3. On commence à élaborer des systèmes d'aide à la décision pour la gestion de la forêt mixte, mais il faut accorder plus d'attention au développement de ces systèmes et prévoir l'intégration de données provenant d'autres provinces ou États.
4. Il est reconnu que les forêts mixtes de l'Ontario et des autres provinces sont extrêmement productives, mais on se contente souvent de trouver des solutions aux problèmes de gestion immédiats, sans tenir compte des facteurs d'envergure planétaire. Il est aujourd'hui essentiel que nous cherchions à déterminer le rôle que pourraient jouer ces forêts quant aux besoins en bois d'une population mondiale en croissance rapide.

The sustainable management of any renewable resource requires an in-depth understanding of what the resource is, how it functions, and how it responds to ecological pressures, which must include the activities of humans. Without this understanding, we can only hope that changes to the landscape wrought by harvesting will not become permanent, but that the landscape will eventually recover to become a productive ecosystem. Ecosystems range dramatically in their complexity (e.g., single-species vs. multispecies stands), requiring a myriad of complex, ecologically based information to implement sound resource management decisions.

For the past two days, we have been exposed to the current status of mixedwood research in Ontario, embodied in 44 presentations and 32 posters. The scope of the research presented clearly indicates that we are cognizant of our need for information that will allow us to manage mixedwood forests by design rather than by default. This need, interestingly, begins with being able to define the mixedwood forest in terms of its extent, composition, and contribution to the total provincial growing stock. We need to know what it is we are managing, we need to know where what we are managing is, and we need to have an appreciation of the values of the forest that we are managing. Taken in sum, mixedwood forests are resiliently complex multispecies ecosystems that occur on a variety of sites that are generally more productive than average and contribute significantly to the overall growing stock of the province (45–49%).

Although I have been charged with the task of providing a wrap-up to this workshop, I prefer instead to offer a few reflections and observations and conclude with a few challenges. I suppose by having worked in northern Ontario for 17 years in the area of mixedwood research before moving to British Columbia in 1990, I find that I am in a unique position to remark on progress that has been made over the past five years. In a few words, progress has been remarkable.

Progress just doesn't happen; it takes vision of what ought to be, recognition of needs, determination, and a willingness to risk failure in meeting the many challenges. I believe that these attributes were and are characteristic of the forest scientists and technicians that have ventured into the realm of mixedwood management. Inasmuch as the success achieved in any field of science can be thought of as an extension of previous work of others, it would be fruitful to consider briefly some earlier work that laid the foundation for the mixedwood research that we have been privileged to listen to at this workshop.

Much of our effort today in mixedwood research and evidence of silvicultural success had its impetus provided by a number of provincial research foresters in the late 1940s and early 1950s, namely Cedric Larson and Frank Lyon. While operating in northern Ontario, they consistently observed that stands whose preharvest composition typically included aspen (*Populus tremuloides* Michx.), black spruce (*Picea mariana* [Mill.] B.S.P.), white spruce (*Picea glauca* [Moench] Voss), balsam fir (*Abies balsamea* [L.] Mill.), and birch (*Betula* spp.) reverted to stands whose composition shifted dramatically to aspen, balsam fir, and birch. The spruce component was greatly reduced, and what remained was advanced regeneration that escaped damage from logging. Much of the change was attributable to residual composition as well as the ability of balsam fir to respond rapidly to release with the removal of the overstory. Early establishment of spruce was suppressed, if not totally excluded, because of competition from resilient vegetation, insufficient soil disturbance, and removal of the seed source. The many years of regeneration surveys conducted by Cedric Larson and the monitoring of semipermanent site-specific transects by Frank Lyon in the Black Sturgeon area confirmed these disturbing successional trends.

Lyon[1] presented a summary of his observations in a paper entitled "The future forest" at a Lakehead University symposium. His paper described successional changes wrought by selective harvesting (high-grading) for spruce and the rapid response of balsam fir and intolerant hardwoods. This transition was perceived to have many implications for forest management—e.g., increase in fire risk, increased vulnerability to insect and disease, volume loss, decline in future yields, etc. These early concerns soon became shared concerns of the forest industry. American Can of Canada Limited is worthy of mention because of its lengthy commitment to monitoring successional changes on its limits between 1954 and 1980. From its efforts in this regard, management strategies were proposed, one that emphasized the early control of balsam fir and aspen to favor the establishment of spruce, and the second, to accept the fir and aspen along with subsequent high protection costs to control spruce budworm (*Choristoneura fumiferana* Clemens) and bring the spruce component to maturity (Yang and Fry 1981).

The surge in concern on the matter of biased succession on mixedwood sites became the focus of northern forest research conducted by provincial scientists.

[1] Lyon, N.F. 1978. The future forest. Paper presented at a symposium. School of Forestry, Lakehead University, Thunder Bay, ON.

Current thinking at the time led forest scientists to consider the possibility of understanding the mechanics of the mixedwood forest by first studying the individual species that comprised it, with the expectation that this knowledge could be later integrated and approaches to managing the mixedwood forest achieved. Unfortunately, the desired result was not achieved. It became abundantly clear that in order to understand the dynamics of the mixedwood forest, the mixedwood forest had to be studied as a complete forest ecosystem. In recognition of this need, the Spruce–Fir–Aspen Research Committee (a subcommittee of the now-defunct Canada–Ontario Forest Research Committee) prepared a report detailing the forest management and research needs of the boreal mixedwood forests of Ontario (Weingartner and Basham[2]).

This report, although a synthesis of the current management perspectives and recommendations of forest scientists, was largely ignored by head office forest management. Nevertheless, many of the 75 recommendations presented in this report are as pertinent today as they were 16 years ago. Judging from the research that was reported in the course of the presentations and posters at this workshop, it appears that many of the recommendations of this report are being addressed as well as many other important considerations for the thoughtful management of mixedwood forests. I say thoughtful because now, unlike in the past, when the timber industry was driven by the need for timber, we must be concerned with all products and values of the forest. This bestows considerably more responsibility on resource managers, as they must now be concerned with recreation, visual quality, water quality, wildlife, biodiversity, and spiritual values, in addition to the flow of timber to the mill.

Very clearly, the management of mixedwood forests will require the combined effort of multidisciplinary teams looking for creative solutions. Our solutions, however, must now be considered in a framework that takes into account changes in social values as noted above and what is economically viable for future generations. As Ontario strives to practise sustainable forest management in all Crown forests, which we are assured by the *Crown Forest Sustainability Act* includes mixedwood forests, it must do so with the two above considerations in mind.

[2] Weingartner, D.H.; Basham, J.T. 1979. Forest management and research needs in the boreal mixedwood forest of Ontario. Unpublished file report prepared by the Spruce–Fir–Aspen Forest Research Committee, Canada–Ontario Forest Research Committee. 90 p.

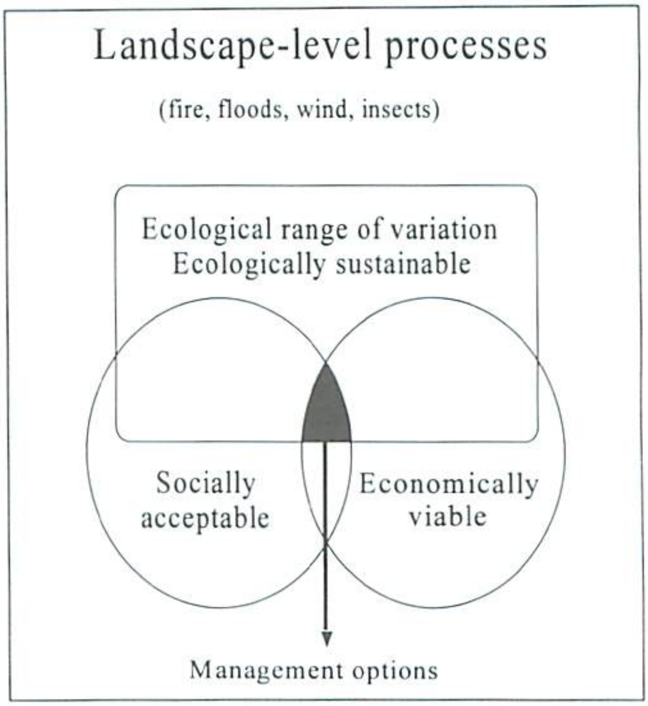

Figure 1. Framework for the McGregor Model Forest. Only where choices are socially acceptable and economically viable, within a framework of ecological sustainability, can management options be considered.

Indeed, it is in everyone's best interest to manage for forests that are healthy, productive, and sustainable for future generations. In order to do this, we must recognize and appreciate that forests are complex and dynamic ecosystems that are sustained in nature by various renewal and disturbance regimes. Knowledge of these multileveled processes is crucial if we choose to adapt our management procedures so that we work with, rather than against, the natural processes that sustain healthy and productive forests.

Figure 1 illustrates the three basic components determining acceptable management options (The McGregor Model Forest Association 1994). If we operate beyond the boundary of ecological variability (outside the perimeter of the square) by, for example, excessive harvesting without ensuring renewal, causing soil erosion, etc., the productive forest cannot be sustained, nor will it be socially acceptable or economically viable for future generations. Now that we need to consider practices that are both economically viable and socially acceptable, there is only a small area within the realm of ecological variability where certain management options can be considered. Our efforts must be directed at defining this area of acceptable management options.

With all things considered, this is an immense task, and current research activities that have been reported upon at this meeting suggest that the task will be addressed not by lone scientists acting on isolated problems, but by teams of motivated individuals in an integrated approach that will allow for the ecosystem to be evaluated as a system. On this point, I wish to make note of two important initiatives. The first is the Black Sturgeon Boreal Mixedwood Research Project, led by Dr. John Scarratt, and the second, the provincial Mixedwood Silviculture Project AT9507, led by Dr. Blake MacDonald.

These two projects exemplify the qualities of valuable long-term research projects; they are collaborative efforts involving various interest groups; they cover typical mixedwood forest sites; they include different harvesting and renewal regimes; and they include long-term plans for monitoring and reporting. These projects also differ in other respects, but, taken together, they will jointly provide a solid foundation for many opportunities to explore the function and dynamics of mixedwood forests that are so vital for the management of these forests on a sustainable basis.

Concluding, I wish to commend the organizers for their judgment in hosting this workshop at this time, because in one sense they were taking a risk. Managers are constantly faced with having to make decisions based on information that they do not have. Scientists, on the other hand, typically wish only to communicate their results after they have analyzed data and are reasonably confident of the trends and relationships. After all, their reputation is at stake. This workshop has succeeded in bridging the gap between the demand for information (incomplete as it is) and the supply of information (limited as it is). I suspect researchers are more aware of the need for their work to provide functional results for practitioners, and, likewise, I suspect that practitioners appreciate that they must provide feedback to the scientists, a process that will allow for fine-tuning of their recommendations.

But while we congratulate ourselves, we must be cognizant of the many challenges that lie ahead of us. I perceive that some of these challenges are as follows:

1. Forest policy that is in place through the *Crown Forest Sustainability Act* must be protected and strengthened to ensure that the mixedwood forests are not managed by default on a single-species basis, as they are in other jurisdictions.

2. The benefits of establishing large ecological study areas are many: they afford the opportunity to obtain data on responses to forest practices on the long term, which allows the interpretation of ecosystem response that short-duration studies do not. Sufficient long-term funding must be allocated to ensure the security of these areas.

3. Synergism can be achieved among scientists and practitioners if efforts are taken to establish intraprovincial and interprovincial networks, to share and critically evaluate information, to establish an effective means of communication, and to demonstrate the successes and failures wherever mixedwood management is practised.

4. Although there are the beginnings of decision support systems for mixedwood management, the development of these systems should receive greater attention and should provide for the integration of information from other jurisdictions.

5. While we recognize that the mixedwood forests of Ontario and, indeed, across Canada are extremely productive, we often focus much of our attention on the solving of immediate management problems around us, without considering other matters of a global nature. For example, the world's population is estimated to be 5.4 billion and is expected to increase to 8–9 billion in 30 years. Along with the increase in the world population will be greater demands for wood products from a diminishing forested land base. The challenge that we are obligated to face is to determine the role that Ontario's and Canada's mixedwood forests should play in meeting world demands for wood. Decisions on this matter will be difficult, but they will have to be made.

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Corporate display and technical poster titles

Corporate displays

Boreal mixedwood notes
A.I. Aleksa

Integrated ecosystem studies in the Rinker Lake Research Area, northwestern Ontario
K.A. Baldwin, R.A. Sims, and K.M. Lawrence

The Ontario Forest Research Institute: sustaining forest ecosystems
L. Buse and J. Watt

Demonstration forests: the Black Sturgeon Boreal Mixedwood Forest
D.A. Cameron

The Fallingsnow Ecosystem Project: comparing conifer release alternatives (year three)
R.A. Lautenschlager, F.W. Bell, and R.G. Wagner

The Black Sturgeon Boreal Mixedwood Research Project
J.B. Scarratt

Technical posters

Mixing, screefing, and chemical site preparation: impacts on forest soil and implications for vegetation control and biodiversity
J. Addison, M. Dumas, I. Morrison, and B. Sutherland

Impact of spruce budworm on conifer regeneration
R. Bichon

Ingress of naturals
C. Bowling

Effects of glyphosate spraying on moose browse
H.G. Cumming, C. Kelly, and S. Thapa

Correlation between FEC treatment units and their susceptibility to *Armillaria* root decay
M.T. Dumas, A.M. Weinsczyk, and R.W. Irwin

Understanding reproductive fitness in boreal mixedwood tree species
I.R.H. Ho

Six steps to developing silvicultural decision keys
C. Hollstedt

Concurrent harvesting and stump herbicide application to reduce unwanted hardwood regeneration—Phase I
C. Hollstedt and P. Bastarache

Monitoring forest health in the boreal forest: the Acid Rain National Early Warning System
A.A. Hopkin and I.K. Morrison

Spatial analysis of spruce budworm pheromone trap data
D.B. Lyons, C.J. Sanders, A.M. Liebhold, B.G. Pierce, and P.S. Robertson

Maintaining conifers in harvested mixedwood stands
G.B. MacDonald

Preliminary spatial predictions of aspen productivity in Ontario
D. McKenney, Y. Wang, R. Sims, and B. Mackey

Refining prescribed burning procedures for Ontario
D.J. McRae

Are things warming up? How climate change in Ontario will affect red pine plantations established on sandy soils
C.S. Papadopol

Effects of seedbed quality on white spruce: the role of *Polytrichum* moss in natural regeneration
W.C. Parker, D.W. Cairns, and S.R. Watson

FEXPERT: an expert system for forest ecosystem classification
B. Payandeh and D. Dukes

Variable stocking yield functions and tables for the boreal mixedwood in Ontario
B. Payandeh, Y. Yang, and P. Papadopol

Effects of harvest method on seed bank dynamics in boreal mixedwood forest
M. Qi and J.B. Scarratt

Variation in the canopy, understory, nonvascular plant, and vertebrate communities among three successional stages of aspen-dominated boreal mixedwood forests in Alberta
J. Schieck, S. Crites, P. Lee, L.D. Roy, and J.B. Stelfox

Stand dynamics of mixedwood forests of Ontario
D.J. Smith

Principles and impacts of site preparation in boreal mixedwoods
B. Sutherland

Mixedwood site types of northeastern Ontario
K. Taylor

Ecosystem classification and inventory in Ontario
P.W.C. Uhlig and S.C. McMurray

Early succession in boreal mixedwoods in the Rinker Lake Research Area, northwestern Ontario
S. Walsh, K. Baldwin, and R. Sims

Management considerations for aspen thinning
D.H. Weingartner

Predicting the effects of postplanting forest vegetation management
J.E. Wood, R.A. Fleming, E.G. Mitchell, and T.R. Burns

Appendix 1: Poster abstracts

A. Corporate displays

BOREAL MIXEDWOOD NOTES

A.I. Aleksa

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The silvicultural guides are a summary of best practices for growing Ontario's forests. The guides are used during the development of silvicultural ground rules for all Crown forest management plans in Ontario. Foresters choose options from the guides, which provide direction for silvicultural operations such as harvesting, regeneration, tending, and protection. There is a silvicultural guide for each of the following tree species working groups: jack pine, poplar, spruce, white pine and red pine, and the tolerant hardwoods. A tree-marking guide has also been developed for the tolerant hardwoods.

The guides are developed by scientists and resource managers and stress leading-edge silvicultural options. They are revised periodically to incorporate changes in information, technology, and the results of monitoring field practices. All guides are currently being reviewed to ensure that the contents direct forest management toward ecological sustainability.

Boreal Mixedwood Notes is the most recent addition to the series. It is a note series designed to give quick access to concise, accurate information about managing Ontario's boreal mixedwoods. The first release of notes is scheduled for February 1996. An annual release of notes is expected thereafter. Silvicultural guides are also being developed for species in southern Ontario. The silvicultural guides project supports training, workshops, and demonstration areas for resource managers.

INTEGRATED ECOSYSTEM STUDIES IN THE RINKER LAKE RESEARCH AREA, NORTHWESTERN ONTARIO

K.A. Baldwin, R.A. Sims, and K.M. Lawrence

Canadian Forest Service–Sault Ste. Marie, Natural Resources Canada, 1219 Queen Street East, P.O. Box 490, Sault Ste. Marie, ON P6A 5M7

In spring 1992, a five-year multidisciplinary and multiagency research project was initiated in the Rinker Lake Research Area, northwestern Ontario. A principal goal of this collection of studies has been to assimilate and integrate findings of various researchers into static and predictive models that can be applied to resource management planning at mainly an "operational" forest scale (i.e., suitable for management planning at a scale of about 1:15 000 to 1:20 000).

Located about 110 km north of Thunder Bay, Ontario, the 900-km^2 (i.e., 30 x 30 km) Rinker Lake Research Area (center: 49°10'N, 89°20'W) comprises nine Ontario Base Map (OBM) mapsheets at 1:20 000 scale. The area is located in the Spruce River Forest, under Forest Management Agreement licence to Abitibi-Price Inc. The forest cover conditions include predominantly spruce and mixedwood forests; past and current harvesting operations have resulted in the development of a range of cut-overs and young postharvest stands throughout the research area.

Spatially based ecosystem models in the research area are being developed using geographic information systems technology. This work has involved a combination of field and laboratory data. In the field, forest plots have been intensively studied for a range of attributes, including percent forest cover, tree growth and development, forest floor and soil chemistry, site moisture status, and seasonal use by forest-nesting bird species. A detailed digital elevation model constructed at a 20-m resolution has been used in concert with the assembled data bases, which include surficial geology, terrain features, vegetation cover and Forest Resources Inventory polygons, derived climate features, and interpreted air photo and remote sensing imagery.

THE ONTARIO FOREST RESEARCH INSTITUTE: SUSTAINING FOREST ECOSYSTEMS

Lisa Buse and Jocelyn Watt

Ontario Forest Research Institute, Ontario Ministry of Natural Resources, 1235 Queen Street East, P.O. Box 969, Sault Ste. Marie, ON P6A 5N5

Over the last 50 years, provincial forestry research has shed new light on forestry and forest ecosystems. Pioneering soil and site classification systems, establishing seed zones, developing the Brohme aerial seeder, improving regeneration techniques for yellow birch, and developing sophisticated tests for evaluating seedling health are just a few of the accomplishments.

Today, the Ontario Forest Research Institute (OFRI) is a state-of-the-art research facility in Sault Ste. Marie that houses laboratories, greenhouses, growth rooms, and growth chambers. In addition, a 95-ha arboretum provides local outdoor study opportunities. Researchers conduct projects here and across the province, focusing on everything from seedlings to landscapes. Some examples are as follows:

- developing stock quality assessment techniques that ensure only healthy seedlings are planted;
- determining the best conditions for natural regeneration of white pine and white spruce;
- searching for alternatives to herbicides;
- developing new pest management techniques;
- protecting the genetic diversity of Ontario's tree species;
- improving management practices for mixedwood and hardwood forests;
- monitoring and modeling how forests grow over time;
- developing a provincial ecological land classification system that includes wetlands;
- using satellite imagery and geographic information systems to help forest managers conserve biodiversity, manage old-growth red and white pine, and predict fire and pest problems; and
- improving our understanding of ecosystems.

The results of OFRI's research are used to provide resource managers with new techniques and tools for managing Ontario's forest resources and to help government and industry leaders set policies that will sustain forest ecosystems, biodiversity, and multiple uses of the forest.

DEMONSTRATION FORESTS: THE BLACK STURGEON BOREAL MIXEDWOOD FOREST

D. Allan Cameron

Canadian Forest Service–Sault Ste. Marie, Natural Resources Canada, 1219 Queen Street East, P.O. Box 490, Sault Ste. Marie, ON P6A 5M7

A sign kiosk has been established at 46.5 km of the Black Sturgeon Lake Road north of Highway 17W and Hurkett, Ontario, for public information and education. It houses a selection of photo-anodized aluminum bilingual signs describing the boreal mixedwood resource in terms of its composition, extent, and value to the economy; gives a history of the area's development, including logging, past and present, and the natural agencies (i.e., pests and fires) that have caused the second-growth boreal mixedwood forest that viewers see before them; and describes the ongoing multidisciplinary, multiagency research under way at this site.

Several harvesting patterns, prescribed burning, and site preparation treatments that underlie the Black Sturgeon Boreal Mixedwood Research Project allow researchers to monitor and record responses from a wide range of components in this system. Soil fauna, soil fertility and water relationships, insects, diseases, small vertebrates, developing plant communities, birds and animals, tree species composition, and performance are some of the areas being studied. The objective is to understand the complex interrelationships between and among the various contributors to such a forest and to develop integrated resource management techniques that consider all aspects of resource usage in the quest for sustainable forestry practices.

THE FALLINGSNOW ECOSYSTEM PROJECT: COMPARING CONIFER RELEASE ALTERNATIVES (YEAR THREE)

R.A. Lautenschlager, F.W. Bell, and R.G. Wagner

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Forest managers need data comparing the effects of alternative conifer release methods on ecosystems. This integrated study documents ecosystem (abiotic and biotic) responses, production capabilities, and associated costs. A Randomized Complete Block design was used to quantify treatment effects, with four 25- to 55-ha blocks and the following treatments: 1) brush saws; 2) Silvana Selective/Ford Versatile: 3) Release® (triclopyr) herbicide; 4) Vision® (glyphosate) herbicide; and 5) control (no treatment). Each treatment block also has an adjacent unharvested aspen/spruce stand that environmental cooperators study.

Environmental variables being examined are 1) soil solution nutrients, soil biodiversity, and nitrogen mineralization; 2) belowground soil temperature/moisture and aboveground air temperature, relative humidity, and photosynthetically active radiation; 3) vegetation (trees, shrubs, herbs, lichens, liverworts, mosses, fungi) species composition, abundance and pattern, and changes in foliar nutrient content (spruce and aspen); 4) below- and aboveground insects; 5) terrestrial gastropods; 6) amphibians and reptiles; 7) small mammals; 8) songbirds; and 9) moose area use and forage production.

First- and second-year posttreatment data were collected in 1994 and 1995. Pretreatment (1993) differences in several environmental variables were found among blocks, but few differences among treatment plots within blocks were identified. One growing season posttreatment, control plots tended to have consistently larger, more diverse populations of the biotic components examined. Cooperators have identified, however, few dramatic differences attributable to the alternative conifer release treatments used. In 1995, cooperators began actively testing integrated hypotheses.

THE BLACK STURGEON BOREAL MIXEDWOOD RESEARCH PROJECT

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Boreal mixedwood forests are estimated to occupy at least 50% of productive forestland in northern Ontario. Although their timber yield is a major contributor to the provincial economy, these complex and dynamic ecosystems pose a multifaceted challenge for the forest manager. Because of their diversity, aesthetic appeal, and rich flora and fauna, they have important nontimber values that increasingly must be taken into account in decisions relating to mixedwood management. Consequently, integrated resource management (IRM), including the appropriate application of alternative harvesting and silvicultural practices, is likely to play a critical role in the future sustainable development of these forests.

To establish a strong ecological foundation for IRM in boreal mixedwoods, a much better understanding of these ecosystems is needed—their structure and dynamics, their response to disturbance and manipulation, and the interrelationships among different ecosystem elements. The Black Sturgeon Boreal Mixedwood Research Project attempts to address some of these questions, through long-term studies that focus upon stand-level ecosystem processes.

This multidisciplinary, multiagency project was initiated in 1993. It seeks to develop a better understanding of the long-term impacts and ecological responses to different harvesting regimes, prescribed fire, and mechanical site preparation in 55-year-old second-growth spruce–fir–aspen mixedwoods near Thunder Bay, Ontario. Current studies focus upon site impacts, logging damage to residual trees and advance growth, fire behavior, pathological and entomological responses, seed bank dynamics, postdisturbance vegetation succession and stand dynamics, site preparation, forest renewal, nutrient dynamics, soil invertebrates, and wildlife (songbirds, small mammals, Amphibia).

B. Technical posters

MIXING, SCREEFING, AND CHEMICAL SITE PREPARATION: IMPACTS ON FOREST SOIL AND IMPLICATIONS FOR VEGETATION CONTROL AND BIODIVERSITY

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Current site preparation practices in boreal mixedwoods typically involve some form of organic layer removal (e.g., screefing or disc trenching), often combined with use of herbicide to discourage competing vegetation. However, mechanical site preparation has demonstrated little or, at best, short-term control of competing vegetation and, in addition, has been criticized on the grounds that it promotes nutrient depletion and so threatens long-term sustainability.

High-speed soil mixing is a relatively new site preparation method that has shown the potential to control competing vegetation and to improve soil conditions, such as aeration and moisture relationships, for conifer regeneration. A brief description is provided of the single-row prototype of a rototiller developed by the Forest Engineering Research Institute of Canada.

An interdisciplinary study to investigate the impacts of soil mixing, as well as conventional screefing and herbicide applications, was initiated in 1992 on a boreal mixedwood site near Nipigon, Ontario. The effects of these site preparation methods were determined for competing vegetation, the response of black spruce tree seedlings, biodiversity and populations of soil mycoflora and microfauna, organic decomposition and nutrient mobilizations, and the inoculum potential for *Armillaria* root decay. Preliminary results are provided.

IMPACT OF SPRUCE BUDWORM ON CONIFER REGENERATION

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The spruce budworm (*Choristoneura fumiferana* Clemens) is well-known as a canopy-level defoliator of balsam fir (*Abies balsamea* L.), white spruce (*Picea glauca* [Moench] Voss), and black spruce (*Picea mariana* [Mill.] B.S.P.) in Ontario. At epidemic levels, the spruce budworm regularly consumes all or most of the current year's foliage on host trees and then disperses to the understory in search of additional food. The new foliage of established host-tree seedlings provides a suitable food source. The impact of this understory feeding by late-instar larvae is not well-known and remains a topic of some debate.

Fieldwork was conducted over a two-year period in a boreal mixedwood forest near Black Sturgeon Lake, located about 120 km north and east of Thunder Bay. An outbreak of the spruce budworm began in this area about 1980 and was still under way at the time of this study in 1993 and 1994. Fieldwork conducted during the summer of 1993 examined budworm-caused damage to regeneration under natural stand conditions. Water traps were set out to capture late-instar larvae as they dispersed to the understory. Despite substantial numbers of larvae being caught, feeding damage to regeneration was not severe enough to cause any mortality among seedlings.

Operational harvesting treatments were applied in late fall of 1993. Treatments consisted of an uncut control, a partial cut in which mature spruce were left standing as seed trees, and a strip clearcut in which all trees were removed. Budworm dispersal and understory feeding were monitored in the treated areas during the summer of 1994. Understory damage in the uncut control was again low. The partial-cut treatment did not have any influence on the number of larvae dispersing from white or black spruce, but it may have been too soon after treatment application to detect any real differences. Water traps set in the strip clearcut caught no larvae, indicating that late instars do not disperse laterally into open areas. Regeneration in the partial-cut and strip clear-cut areas was almost completely destroyed by heavy equipment during harvesting, and what little regeneration remained was not damaged by budworm larvae. It appears that harvesting rather than the spruce budworm results in major losses to established regeneration. If forest product companies wish to rely on natural conifer regeneration, harvesting practices that preserve established seedlings will have to be adopted.

INGRESS OF NATURALS

Colin Bowling

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A survey of 71 full-tree logged and 85 tree-length logged sites was completed between 1990 and 1993 in northwestern Ontario. Data were collected on the abundance and rate of ingress of both softwood and hardwood natural regeneration by species and seedbed condition. The age of the cutovers ranged from 6 to 19 growing seasons after harvest.

Results indicate that, in most cases, the species composition of the natural regeneration is closely associated with the preharvest vegetation community. For both harvesting methods, upland hardwood/mixedwood stands (treatment unit [TU] B) naturally regenerated to young stands composed mostly of hardwoods. Similarly, jack pine/feathermoss communities (TU F) were dominated by jack pine naturals. In contrast, upland black spruce mixedwoods (TU E) naturally regenerated to young stands dominated by jack pine and/or trembling aspen in the overstory, with black spruce in the understory.

On the full-tree logged sites, most natural regeneration was complete within six growing seasons after harvest. In addition, there was no significant difference in rates of ingress for any TUs studied. On the tree-length logged sites, ingress was complete after seven growing seasons for most sites, seedbed, and species combinations.

EFFECTS OF GLYPHOSATE SPRAYING ON MOOSE BROWSE

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Aerial applications of glyphosate herbicide (Vision®) at 0.8, 1.06, and 1.6 kg/ha active ingredient reduced hardwood competition, i.e., moose browse, by up to 75% in the numbers of stems per hectare by the third year after spraying. In contrast, untreated control areas sustained as many as 37 000 stems/ha. Reductions of this magnitude have implications for the number of moose that might be sustained on a given area after such spraying. This study and previous research concluded that aerial application of glyphosate herbicide for silvicultural purposes such as vegetation control can greatly reduce the quantity of available moose browse on local areas.

However, these results did not address the question: What effect does glyphosate have on nutrient quality of available moose browse? A new study was initiated by collecting winter twigs and summer leaves of trembling aspen, beaked hazel, willow, and raspberry. These samples were submitted to a local laboratory for analysis of crude protein, from which digestible protein and digestible dry matter could be calculated. Four and eight years after spraying, these analyses showed statistically similar nutrient levels in browse and leaf samples from treated areas and unsprayed controls. Thus, any significant differences in nutrients following glyphosate spraying are probably short term. This finding suggests that the quantitative differences in browse availability after spraying, reported from the earlier surveys, adequately represent the impacts of spraying on these moose foods. Models based on quantitative results should be valid.

CORRELATION BETWEEN FEC TREATMENT UNITS AND THEIR SUSCEPTIBILITY TO *ARMILLARIA* ROOT DECAY

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Five- to 15-year-old black spruce (*Picea mariana* [Mill.] B.S.P.) plantations, within forest ecosystem classification (FEC) Treatment Units (TUs) B, C, D, E, and F, were sampled for the incidence of *Armillaria* root decay. Plantations in TU F had the highest infection and cumulative mortality levels, whereas plantations in TU B had the lowest infection and cumulative mortality levels. For all TUs, the average ratio of infected living trees to infected dead trees was 3.28:1. Traplogs were not a good indicator to use to predict the infection levels in trees. The use of color and relative shoot growth was only moderately effective in identifying trees infected with *Armillaria*. Data were also collected on stock type, competition index, soil texture, moisture regime, pH, and nutrient levels, as well as the basal areas and numbers of infected and noninfected stumps. A significant nonlinear relationship was observed between tree age and infection levels. The logistic or logit function (the nonlinear model used in the analysis) indicated that the dummy variables for TUs B and D, stock type, total basal area of all stumps, percent clay in the C horizon, and phosphorus levels in the A horizon were significant environmental predictable factors in determining the relative susceptibility of a stand to *Armillaria* infections.

UNDERSTANDING REPRODUCTIVE FITNESS IN BOREAL MIXEDWOOD TREE SPECIES

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Early surveys in mixedwood stands after harvesting and wildfire disturbances indicated that natural regeneration of white spruce was insufficient to form well-stocked stands. A recent survey in Ontario has shown that a shift in forest composition occurs from softwoods to mixedwoods and from softwood-dominated mixedwoods to hardwoods following clear-cutting, site preparation, and seeding or planting. These treatments have failed to reestablish the valuable spruce on productive boreal mixedwood sites. This challenge will remain unsolved unless all factors influencing spruce establishment are well understood. The factors include both biotic and abiotic factors and their correlations. This proposal focuses on the biotic by studying sexual reproduction and reproductive relationships of major mixedwood tree species in relation to different types of logging practices. The effects of stocking, regeneration, seed dispersal, canopy manipulation, and site preparation on seed germination and the effects of some abiotic factors on reproduction will be included in the study. The study is a component of a proposed collaborative research initiative addressing integrated resource management on an operational scale in northern Ontario.

SIX STEPS TO DEVELOPING SILVICULTURAL DECISION KEYS

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An active process for developing silvicultural decision keys to support integrated vegetation management is presented in an easy-to-use format. The problem-solving approach takes into consideration specific biological, operational, and financial constraints and guides resource managers through the six steps to developing decision keys for silvicultural prescriptions.

The six steps are as follows:

- defining the problem;
- identifying pertinent management objectives and strategies;
- gathering background information;
- developing keys and checklists;
- identifying the assumptions and limitations of the keys; and
- field testing and revising.

A technical note, "Development of silvicultural keys to support integrated vegetation management decision making in forest renewal" (Street et al. 1994[1]), has been produced by Northwest Region Science and Technology and will be made available for distribution. This note defines the decision-making process and provides a case study in which decision keys have been put into practice.

[1] Street, P.W.; Arlidge, C.J.; Hollstedt, C.; Bell, F.W.; Towill, W.D. 1994. Development of silvicultural keys to support integrated vegetation management decision making in forest renewal. Ont. Min. Nat. Resour. Northwest Reg. Sci. Technol. Tech. Note 28. 16 p.

CONCURRENT HARVESTING AND STUMP HERBICIDE APPLICATION TO REDUCE UNWANTED HARDWOOD REGENERATION—PHASE I

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In 1992, Canadian Pacific Forest Products, Ltd. (now AVENOR Inc.), the Northwest Science and Technology Unit (now Northwest Region Science and Technology), Monsanto Canada, Inc., DowElanco Canada, Inc., and DuPont Canada, Inc. cooperated to develop and test a herbicide application device to be attached to a feller-buncher saw head for herbicide stump treatment. The purpose of the applicator is to treat hardwood stumps during harvest operations to decrease the 1) use of broadcast aerial herbicide spray, 2) total amount of herbicide used, and 3) cost of herbicide application.

The specific objectives of this Phase I trial were to 1) test the durability and efficiency of the herbicide applicator and 2) compare the ability of Vision®, Release®, Tordon® 101, and Velpar® L to control trembling aspen sprouting following harvest. Herbicide products were applied in an undiluted form.

Results of the field test showed that the applicator was very durable, breaking down only once owing to a crimped hydraulic hose, and was able to distribute herbicide to the cambial area on the stump. One year after treatment, control of aspen sprouting ranged from 33 to 68%, with Vision providing the most control, Release and Tordon relatively equal, and Velpar L the least control.

Two years after treatment, the herbicide-treated blocks still have fewer aspen stems per treated stump than the control block. Vision-treated blocks had 63% fewer suckers per treated stem than the control, whereas the results for the Release-, Tordon-, and Velpar-treated blocks were 54, 54, and 36%, respectively.

Final assessment and a report are planned for 1996. For more information on the project, contact Chris Hollstedt or Paul Bastarache at (807)939-3101.

MONITORING FOREST HEALTH IN THE BOREAL FOREST: THE ACID RAIN NATIONAL EARLY WARNING SYSTEM

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The Acid Rain National Early Warning System (ARNEWS) is composed of 150 plots located in all ecoregions of Canada. In Ontario, 38 plots have been established to date, of which 25 are situated in the boreal forest, and which include all major boreal tree species. These plots are monitored on an annual basis to detect damage to forest trees not attributable to natural causes; long-term changes in ground vegetation and forest type; and the presence, fluctuation, and diversity of biotic factors affecting forest condition. In addition, plots are assessed every five years for mensurational purposes and are also intensively monitored to detect changes in soils and foliage chemistry.

SPATIAL ANALYSIS OF SPRUCE BUDWORM PHEROMONE TRAP DATA

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Each year, pheromone-baited traps are distributed throughout the range of the spruce budworm in North America by cooperating agencies, and the number of male moths captured is determined. However, these point data cannot be used to analyze spatial patterns in a geographic information system (GIS). A series of software tools that convert the point data into contour maps for GIS use has been developed and incorporated into a user-friendly graphic user interface (GUI). Opening the data base module from the GUI allows the user to add, edit, or delete trap catch and related data. In the geostatistical module, for a subset of the data (i.e., by year and region), the spatial relationship between point data is described using a variogram model, and data between points are interpolated using a technique known as kriging. IDRISI®, an inexpensive, fully functional, raster-based GIS, is used to display, manipulate. and analyze the kriged output data. The resulting maps have contour intervals showing estimated areas of equal moth densities or "isomoths." CorelDRAW!, the vector-based structured drawing program, is used to prepare high-quality maps for reporting trap catch results.

As the first step in developing a logistic regression model for predicting spruce budworm defoliation, individual annual defoliation maps (1977–1993) provided by the Forest Insect and Disease Survey Unit were summed in the GIS to produce a probability map showing proportion of years defoliated. The frequency of defoliation map was combined with individual defoliation maps and interpolated pheromone maps (1986–1993) to create a logistic regression model. To predict defoliation for a given year, the logistic regression model was solved using the previous year's defoliation map and the previous year's pheromone catch as input variables. The resulting map depicts the probability of defoliation for Ontario.

MAINTAINING CONIFERS IN HARVESTED MIXEDWOOD STANDS

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The maintenance of spruce and pine in Ontario's boreal mixedwood forests is an important management challenge. This study tested the effects of different careful logging treatments (clearcut and shelterwood) on the performance of natural hardwood regeneration and underplanted white spruce and jack pine in an aspen-dominated mixedwood stand.

There were no differences in machine productivity between the cutting intensities. Basal area reduction figures overestimated canopy cover reduction, because of understory vegetation. Windthrow loss was high for residual trees larger than 10 cm diameter at breast height (DBH), especially on clear-cut areas.

After one growing season, spruce and pine exhibited high survival and height growth in the clear-cut and shelterwood treatments. Performance was much poorer in the uncut control. As the diameter of jack pine progressively decreased with increasing residual overstory, underplanting may not be appropriate for this species. The best growth of hardwood regeneration occurred on the clear-cut blocks.

It is concluded that modified harvesting is an economically feasible technique for maintaining conifers in mixedwood stands. In shelterwood cuts, a maximum of 50% basal area removal is recommended to minimize windthrow losses. For white spruce enrichment, underplanting should follow shelterwood cutting. Planting density should be high enough to form a continuous stratum under the regenerating hardwoods. For jack pine enrichment, interplanting should follow clear-cutting in stands with minimal windthrow risk to the conifer understory. A low planting density with spot weeding is recommended to produce a pine–aspen overstory. Underplanting uncut stands with either conifer species is not recommended.

PRELIMINARY SPATIAL PREDICTIONS OF ASPEN PRODUCTIVITY IN ONTARIO

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Regardless of what definition is given to boreal mixedwoods, trembling aspen (*Populus tremuloides* Michx.) is an important component of any such stand. Aspen is, in fact, the most widely distributed tree species in North America. The development of a predictive capability of the variation in aspen productivity across landscapes would be a useful tool for forest planners. However, this is not a simple task. Two things are required: 1) a comprehensive forest plot network so that statistical analysis of the site data can occur, and 2) a spatial data base of the independent variables so that the predictions can be made.

Currently, one of the most extensive forest ecology data sets in Ontario is derived from the forest ecosystem classification (FEC) network of approximately 4100 plots. Site index for aspen was estimated on 555 FEC plots where this species occurred as a dominant feature in the overstory. Correlations were derived between site index and numerous climatic variables, such as growing season length, precipitation during the growing season, and others. Gridded estimates of these variables are now available through the work of the Bio-environmental Indices Project, a Canadian Forest Service-led initiative. These data enable spatial predictions to be made on a 1-km grid across the entire province. Statistical models that were tested on the data resulted in estimated errors (i.e., predicted site index minus the observed one) that ranged from –12 to +12 m, although most (>70%) were in the range of –2 to 2 m.

Considerable effort is required to validate spatial predictions such as these, as there does not appear to be any available benchmark for comparisons. Future work will also attempt to incorporate other site and soil variables as the required data bases become available at selected locations in the province.

REFINING PRESCRIBED BURNING PROCEDURES FOR ONTARIO

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On-ground documentation of prescribed fire behavior has been difficult owing to safety considerations pertaining to the large burn size and the mass-fire ignition techniques usually employed. In addition, smoke obscures any possibility of monitoring these burns from the air. Documentation of fire behavior is necessary for the improvement of boreal mixedwood fire models that ultimately are used to improve prescribed burning guidelines. Fire documentation is also important for later use in interpreting fire effects. In the past, small electronic timers, triggered by the passage of the fire front, could help interpret fire spread in small areas of the prescribed burn where complex fire behavior was not present (e.g., junction zones). However, these timers did not allow full documentation of the entire prescribed fire.

The Canadian Forest Service, using a Barr and Stroud IR-18 imager, has developed a methodology to document large prescribed fires using infrared technology. Infrared, which can penetrate through smoke, allows the fire to be videotaped on a continuous basis from a hovering helicopter platform. Selected frames from the video can be digitized for later computer analyses. Analytical computer packages have been designed to estimate the fire's temperatures and energy release rates on a pixel basis. Calibration of the imager using a black-body calibrator is the key in this data acquisition. In addition, selected frames can be superimposed on each other in a geographical information system approach to determine the fire's rate of spread. High-temperature reference points located on the ground allow the frames to be easily superimposed.

ARE THINGS WARMING UP? HOW CLIMATE CHANGE IN ONTARIO WILL AFFECT RED PINE PLANTATIONS ESTABLISHED ON SANDY SOILS

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Long-term (110 years of continuous records) weather information from northern Ontario, analyzed at the Ontario Forest Research Institute (OFRI), has detected a clear warming trend of about 1°C per century. The primary ecological consequence of this trend is a significant increase in the atmospheric demand for evaporation. In future, we may expect that the growing season will be longer and that the climate in the forested zone of Ontario will gradually become more arid. The effects of increased aridity on forest vegetation will appear first on the most permeable soils, those that lose water to a greater extent through infiltration rather than consumptive use. In the past, based on the belief that red pine can withstand long droughty intervals, but ignoring its shallow rooting, large expanses of sandy soils were planted to this species.

A comprehensive project to determine the influences of climate change on the ecological stability of forest plantations has been funded by OFRI. It is based on high-resolution monitoring of environmental parameters and tree reactions. In this research, considerable emphasis was placed on soil moisture, which is continuously monitored during the growing season on a background of thinning treatments. In parallel, microclimatic studies are focused on evapotranspiration, light, and interception. The project started in 1993.

Analysis of the material collected to date has shown that in the intervals between major rainfalls, a mature red pine plantation, established in 1928 in the Kirkwood forest, has to withstand great variations in the soil water content, owing mostly to the properties of the local sandy soil. The greater the rain event, the more water is lost through infiltration in the following 24 hours. In the last days of an interval between rainfalls, the plantations usually suffer severe water stress. On top of the current level of water stress that occurs, accentuation of the atmosphere's demand for evapotranspiration owing to climate change is sure to result in growth reduction and even dieback.

Thinning red pine plantations has a significant impact on soil water availability. Thus, a limited resource, soil water, is divided among fewer consumers, and the intensity of stress is diminished. The continuation of monitoring in the course of this research will accumulate valuable data and provide an indication of the silvicultural measures that are necessary to secure the stability and productivity of red pine plantations on marginal soils.

EFFECTS OF SEEDBED QUALITY ON WHITE SPRUCE: THE ROLE OF *POLYTRICHUM* MOSS IN NATURAL REGENERATION

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Greenhouse and field studies were undertaken to examine the role of *Polytrichum* moss in natural regeneration of white spruce (*Picea glauca* [Moench] Voss). Germination, survival, and seedling morphology were measured on mineral soil, undisturbed duff, burned duff, and *Polytrichum* moss seedbeds in a greenhouse. Percent germination was significantly greater in mineral soil, with no differences among the other seedbeds. Differences in germination were not related to surface temperature or soil moisture status. Days until 50% germination and percent survival did not differ. Seedlings grown on moss were tall and thin, with a small percentage of total stem length occupied by foliage. Vertical penetration of seedling root systems was significantly greater for seedlings grown on moss. The above- and belowground biomass of herbaceous competition formed on moss seedbed was less than 5% of that on duff and burned seedbeds. A field study of white spruce natural regeneration and percent cover of *Polytrichum* moss established the first growing season after scarification revealed no correlation between the presence of spruce and moss. Both species colonized mineral soil microsites, with moss often forming carpets surrounding spruce germinants that prevented the establishment of herbaceous competition. Moss is good seedbed for germination and establishment of white spruce, provided it is not too tall. Thereafter, exclusion of competition likely results in increased resource availability for seedlings. When good seed years do not coincide with scarification for natural regeneration, invasion of mineral soil by *Polytrichum* may temporarily retain a proportion of the scarified area in receptive seedbed.

FEXPERT: AN EXPERT SYSTEM FOR FOREST ECOSYSTEM CLASSIFICATION

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"FEXPERT" is a rule-based computer program developed to facilitate the application of the forest ecosystem classification (FEC) for northwestern Ontario. It provides the essential information contained in the "field guides," thus replacing such manuals. At each plot, the program guides the user through a decision process in order to classify that stand into one of 38 vegetation types and one of 22 soil types. At any point during the classification process, one or more of the previous decisions may be revised to examine the effect on the final classification for that stand. The factsheet for various soil or vegetation types can be retrieved from FEXPERT's extensive help system. The most important feature of FEXPERT is its help system, which incorporates nearly all of the information contained in the field guides as Hypertext documents. This eliminates the users' need for flipping through the manuals to find descriptions or illustrations of soil profiles and plants or to find definitions of classification terms. Help on virtually any topic relating to the classification is available by using the search utility, clicking a mouse button on a question in the classification, or following the Hyperlinks within the documents. FEXPERT is written in PDC-PROLOG and runs on MS DOS computers. A copy of the program and its users' manual may be obtained from the authors.

VARIABLE STOCKING YIELD FUNCTIONS AND TABLES FOR THE BOREAL MIXEDWOOD IN ONTARIO

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Variable stocking yield functions were developed based on 197 permanent sample plots from the boreal mixedwood of north-central Ontario. The resulting yield equations compare favorably with previous ones but are more appropriate for the boreal mixedwood. The basic improvement in mixedwood yield estimation via basal area index, however, should have broad applications for other stand types, particularly for the disturbed hardwoods of southern Ontario and those in the eastern United States.

EFFECTS OF HARVEST METHOD ON SEED BANK DYNAMICS IN BOREAL MIXEDWOOD FOREST

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To understand the effects of clear-cutting and partial cutting on seed bank dynamics in boreal mixedwood forests, seed rain, seed distribution in the soil, and changes in species composition in understory vegetation and seed bank were investigated. Fourteen 10-ha blocks were harvested and subjected to clear-cut or partial-cut treatments. Samples for seed bank and seed rain studies were collected in each of the harvest blocks plus three uncut blocks in fall 1994. Results from the first postharvest year indicate that partial cutting increased species diversity in seed input. Seed rain had very few conifer seeds, and there were no persistent conifers in the soil seed bank in all treatments. Some herbs and most graminoids can persist for many years in the seed bank, as their seeds were deeply buried in the mineral soil. Harvest methods had little effect on immediate postharvest understory vegetation or the seed bank. The present study indicates that low conifer seed frequency in both seed rain and seed banks will negatively affect natural restocking. The high density of trembling aspen and white birch in the seed bank indicates that predominantly hardwood stands will develop unless supplementary regeneration treatments (seeding or planting) are applied to reestablish conifers.

VARIATION IN THE CANOPY, UNDERSTORY, NONVASCULAR PLANT, AND VERTEBRATE COMMUNITIES AMONG THREE SUCCESSIONAL STAGES OF ASPEN-DOMINATED BOREAL MIXEDWOOD FORESTS IN ALBERTA

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Live and dead trees, shrubs, herbs, grass, moss, nonvascular plants, birds, mammals, and amphibians were surveyed in young (25–30 years old), mature (50–65 years old), and old (>120 years old) aspen-dominated mixedwood forests in Alberta to evaluate changes in biological communities during the first 150 years of succession. Canopy height increased and density of canopy trees decreased throughout succession. Young forests, however, had many residual snags (standing dead trees) and abundant down woody materials (DWM) remaining from the prefire forest, and those residual materials created similarities between young and old aspen forests that otherwise would not have been present. Most large snags had fallen and most DWM was in late stages of decay by the time the forests reached maturity. Most species of plants and animals were observed in all three successional stages, although abundance differed among stages for many species. Old aspen forests had the highest diversity and abundance of nonvascular plants, although nonvascular communities were more highly associated with degree of rot in DWM than with forest successional stage. Two-thirds of the bird species had their highest abundance in old forests, possibly due to the presence of large live trees, large snags, abundant DWM, and abundant shrubs and grass under canopy gaps that were found there. About half of the mammal species had their highest abundance in old forests, although young forests with their abundant shrubs, grasses, and DWM may have been more important for this class of vertebrates than they were for birds. Both amphibian species had their highest abundance in mature forests.

STAND DYNAMICS OF MIXEDWOOD FORESTS OF ONTARIO

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Two decision support tools that would assist the forester and wildlife biologist in planning management strategies for mixedwood stands are a stand growth and development model and two related size–density mortality models. Four mixedwood stand types were considered:

- black spruce–balsam fir (*Picea mariana* [Mill.] B.S.P.–*Abies balsamea* [L.] Mill.);
- black spruce–jack pine (*P. mariana–Pinus banksiana* Lamb.);
- black spruce–trembling aspen (*P. mariana–Populus tremuloides* Michx.); and
- hardwood–softwood (generic).

For the *stand growth and development model*, exponential and polynomial models were fitted to model height and volume growth and the changes of species composition (by basal area) over time. A simplified stand growth and development model was presented for three mixedwood stand types (generic hardwood–softwood stand type excluded).

Two related *size–density mortality model* types were considered: the density management diagram (DMD) and the size–density response surface model. The DMD is based on the –3/2 self-thinning rule that relates tree size to stand density. The surface model illustrated the relationship between tree size and density for varying proportions of species within a stand.

The models predict average stand development, and the broad long-term dynamics of population development are well reflected. For the forest manager, the DMD, surface model, and stand growth model offer potential stand development pathways. For the wildlife biologist, the models aid in the identification of a desired habitat structure.

Funding for this project has come from a Northern Ontario Development Agreement (NODA) contract, NODA Project #4223. Reports and technical notes are available from the Canadian Forest Service–Sault Ste. Marie.

PRINCIPLES AND IMPACTS OF SITE PREPARATION IN BOREAL MIXEDWOODS

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Two interdisciplinary studies of mechanical and chemical site preparation have been established as part of the Black Sturgeon Boreal Mixedwood Research Project. One, initiated in 1992, compares high-speed soil mixing with more conventional screefing and herbicide application following conventional, clear-cut harvesting. The second, initiated in 1995, compares soil mixing, screefing, mounding, and herbicide site preparation under partially cut versus clear-cut harvest conditions. Preliminary results and interpretation of seedling and vegetation response for the 1992 study are provided.

MIXEDWOOD SITE TYPES OF NORTHEASTERN ONTARIO

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The forest ecosystem classification for northeastern Ontario recognizes five ecosites as being boreal mixedwoods (ST 3a, ST 3b, ST 6a, ST 6b, and ST 6c). One definition includes four additional ecosites (ST 7a, ST 7b, ST 9, and ST 10) as mixedwoods. These communities are found on loamy medium sands to clay soils and in moisture regimes ranging from 0 to 5. The most common humus form is a fibrimor, but mulls and moders are also found. Mixedwood sites are within the environmental range of many species because of the availability of nutrients, coupled with moderate amounts of moisture. The large number of species capable of thriving in these areas means that prediction of the effects of management impacts is difficult and requires further investigation.

ECOSYSTEM CLASSIFICATION AND INVENTORY IN ONTARIO

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Ecosystem classes, at a variety of spatial scales, are useful diagnostic units that resource professionals can employ during planning, implementation, and monitoring of management practices. As basic building blocks, the ecosystem classes facilitate fully integrated resource management.

Ontario is currently conducting a comprehensive, province-wide program of ecosystem land classification (ELC) and inventory. Components and current status of the provincial ELC are presented. Work under way includes classification of forested and wetland ecosystems, examination of classification approaches for other nonforested and early successional ecosystem types, the development of successional trajectories, multiscale inventory approaches, and the development of management interpretations, applications, and decision support tools. A wide variety of publications and technical reports outlining program products and applications will be highlighted and on display.

EARLY SUCCESSION IN BOREAL MIXEDWOODS IN THE RINKER LAKE RESEARCH AREA, NORTHWESTERN ONTARIO

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In the summer of 1994, more than 70 plots were sampled in a study of postharvest vegetation development. The work took place in the Rinker Lake Research Area, a 30 x 30 km area of actively managed boreal forest located approximately 100 km north of Thunder Bay, Ontario. Sampling locations had to meet three main criteria: 1) they occurred on a till deposit (deep or moderately deep mineral soils); 2) the precut stand composition was mixedwood (i.e., having both hardwood and conifer components), with black spruce as the main conifer component; and 3) harvesting took place within the previous 10 years.

Preliminary site selection employed a geographic information system to combine spatially attributes from three digital map layers, each of which characterized one of the selection criteria. Site selections were finalized in the field. At each sampling location, a plot (2 x 2 m or 4 x 4 m in size) was established within which all vegetation species were identified and their abundances (percent cover) recorded. Several soil and site features were also recorded for each plot. Each plot was accurately georeferenced using a geographic positioning system (GPS) unit.

Results of data analyses highlight, for each of the hardwood- and conifer-dominated groups, differences between plots in three age-classes, particularly with respect to vegetation composition and abundance. Detrended correspondence analysis and canonical correspondence analysis showed that groups of plots can be distinguished because they have different vegetational compositions that are related primarily to the age of the site postharvest. Within age-class groups, vegetation development is weakly related to measured soil and site variables.

MANAGEMENT CONSIDERATIONS FOR ASPEN THINNING

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The risks of thinning aspen are primarily increased incidence of Hypoxylon canker (*Hypoxylon mammatum*) and wind breakage. Hypoxylon incidence appears to be related to the intensity of thinning and the genetic susceptibility of the individual clone. Wind damage appears to be related to hilly terrain and localized to small areas (<0.1 ha), but it could be larger in an operational situation.

Thinning may aid in the establishment of conifers or release established conifers in mixedwood stands.

Browse production increases dramatically following thinning, as aspen and a variety of shrubs sprout or sucker. In moose feeding areas, this helps maintain browse production, particularly as the stand matures; in nonfeeding areas, regrowth provides bedding cover for cows and calves. For grouse, the regrowth provides cover for nesting and chicks.

Our limited data suggest that trees in the unthinned stand will surpass the thinned stands by age 70.

Generally, the potential for more rapid merchantable volume production must be balanced against the potential of increased incidence of Hypoxylon canker. Thinning older stands (i.e., 20 years old) and thinning to a 2-m spacing appear to be the safest tactics; however, thinning at age 5 or 6 has the greatest potential for maximizing merchantable volume.

PREDICTING THE EFFECTS OF POSTPLANTING FOREST VEGETATION MANAGEMENT

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To study the long-term growth response of black spruce (*Picea mariana* [Mill.] B.S.P.) to weed control, individual outplants were sampled at intervals up to 11 years after planting. The experiment was located in northeastern Ontario on an upland mixedwood herb-rich site in the boreal forest region. Experimental treatments included two weed controls (with and without), stock type (bareroot and paperpot), and planting season (spring and fall). Regression analysis showed that reduction of weed competition almost always had a beneficial effect on crop growth. This benefit was evident in the volume in all six planting treatments examined (and in the basal diameter of four of these treatments). However, even eight years after weed control, tree height and survival showed little discernible response to weed control. Where weed control effects were evident, the models used in the analysis indicated that these effects increased with time.

Appendix II: Workshop evaluation

Introduction

Short interviews were conducted by Greg Crook and Guy Smith to poll the opinion of three types of participants: speakers, poster presenters, and general participants. A sample of about 10% of each of these three subgroups was taken. An effort was made to interview from a cross-section of employers. Numbers in parentheses refer to the number of responses received.

Speakers (sample of 6)

Facility, equipment, schedule

- all but one reported that the facility was good. One said the room was too small. He suggested it would have been better to orient the seating so that the entrance door was to the back of the room rather than the side (this modification was not possible, as a chandelier would block projections)
- equipment good, moderators good
- general satisfaction with the schedule was expressed. One speaker complained because his talk was switched to a different time slot

Notable strengths

- event was well organized (2)
- good interaction with practitioners in miniworkshops (1)
- excellent breadth of topics, which generated important questions (1)

Notable weaknesses

- no time for questions during sessions (1)
- poor room layout, too crowded during concurrent sessions (2)
- not enough "results-oriented" material for practitioners (1)
- there were competing presentations at certain times during concurrent sessions (1)

Poster presenters (sample of 6)

Facility, equipment, schedule

- poster room was inadequate (reference to narrow Algoma East room; his display included video, but the aisle was too narrow to allow people to gather for easy viewing) (1)
- poster rooms were fine (5)
- equipment provided was excellent (3)
- equipment provided was good (3)
- schedule was good (6)

Notable strengths

- standardized poster panels (1)
- spacious Brulé room (1)
- good electrical outlet service (1)
- provision of audiovisual equipment (1)
- lunch in poster room guaranteed attendance (1)
- quantity and variety of posters (1)

Notable weaknesses

- school tours did not mix with coffee breaks; too distracting and crowded (1)
- Brulé room too far away, especially at coffee breaks (2)
- posters should all be in same room (3)

General participants (sample of 20)

Why did you attend? Did the event meet your expectations?

One of the main reasons given for attending was because participants work with mixedwoods and/or wanted to receive current knowledge and research information. Three respondents said the event did not meet their expectations because the talks were too vague, with insufficient practical information.

Notable strengths

- broad spectrum of speakers; diverse topics (5)
- good scheduling and flow; well organized (5)
- short talks (3)
- concurrent sessions (2)
- quality of speakers (1)
- topics very timely and important to a global view of ecosystem management (1)

Notable weaknesses

- few results; too inconclusive; vague; few take-home messages; no recommendations (9)
- concurrent sessions—cannot attend all presentations; miss some interesting talks; some talks of competing interest at same time (6)
- no time for questions (2)
- lack of focus on mixedwoods in some presentations (1)

Other remarks

- informal discussions during breaks valuable
- buffet lunch a good idea, but chairs (at least) and tables are needed to be able to eat and talk in a relaxed way
- schoolchildren attendance is good for the profession
- a panel discussion after each half-day session would have been valuable to provide an opportunity for dialogue with presenters

Conclusions

The survey indicates that *Advancing Boreal Mixedwood Management in Ontario* satisfied the expectations of 85% of participants. Furthermore, 80% of participants identified notable strengths of the workshop (i.e., ways in which the workshop was exceptional, compared with similar events).

The survey revealed that the event was very well organized. Efficient scheduling was frequently mentioned. Smooth organization, coupled with the excellent diversity of topics (another frequently noted strength), provided a favorable experience for participants.

The responses identified some weak areas. One was the tendency by speakers to dwell on methodology rather than results and practical implications. This problem may have partly been the result of time limitations but in general seemed more to do with speakers not having fully followed the preworkshop instructions. Also, the moderators present during each session could have played a more active role in helping speakers keep on time and on topic. Had more time been available for questions, speakers may have provided conclusions and tentative recommendations.

A problem cited with concurrent sessions is that participants are unable to take in all the presentations that interest them. This is largely unavoidable, as many respondents noted when they offered the comment. Nobody said concurrent sessions are a mistake and should not be used. The key is to use them effectively by balancing concurrent sessions to appeal to different audiences and by running on a rigid schedule to permit people to move between sessions.

G.K.M. Smith and G.W. Crook
October 27, 1995