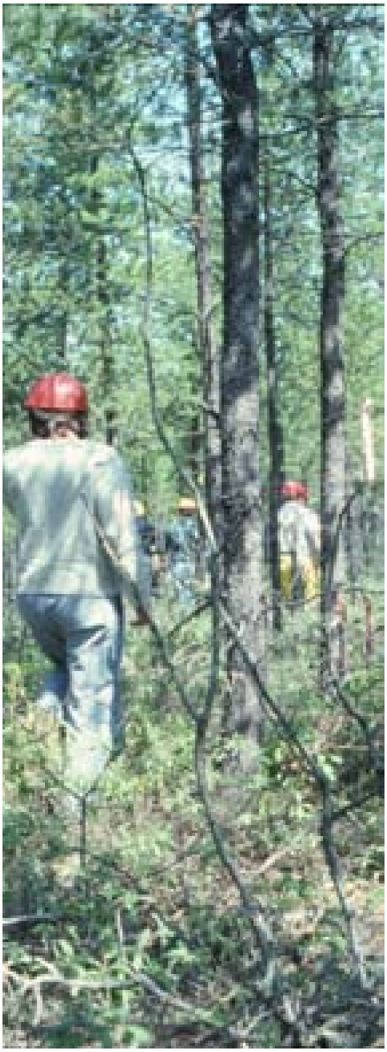

Best Forestry Practices: A Guide for the Boreal Forest in Ontario

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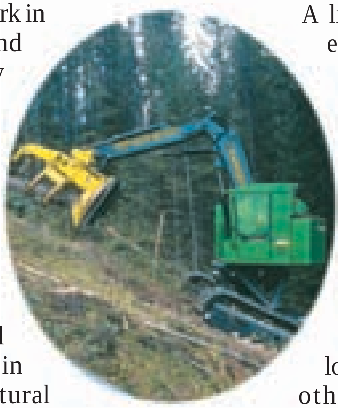
PREFACE

This work is a guide to best management practices in the boreal forests of Ontario, summarizing current methods and recommended procedures for sustainable forest management. It is directed primarily to management foresters, policy makers, and forestry personnel who work in Ontario's boreal forest. Its content and suggestions for applying best forestry practices, however, have relevance in the broader extent of the boreal forest in Canada and the northern hemisphere and to forest practitioners within those confines.



The idea for a guide arose from a group of scientists who were responding to the requirements of the Environmental Assessment for Timber Management in Ontario (Ontario Ministry of Natural Resources 1985, amended 1987). An informal working group was established in 1992 to coordinate the investigations of long-term productivity in boreal ecosystems, primarily related to soil productivity (See Acknowledgments).

Long-term field experiments in black spruce and jack pine ecosystems, with full-tree and tree-length harvesting, and several site treatments including disc trenching, blading, and compaction (Gordon et al. 1993; Jeglum 1994; Tenhagen et al. 1996), are being monitored for effects on soil physical properties (Fleming et al. 1999), nutrient and carbon loss, and cycling (e.g., Foster et al. 1994; Morris 1997; Bhatti et al. 1998; Duckert and Morris 2001), microclimatic changes (e.g., Bhatti et al. 2000), and seedling plantation performance.

Research takes time, and definitive results are not always forthcoming, so the working group decided it was necessary to develop 'interim guidelines' for best management practices.

A literature review (Taylor et al. 1996), expert opinion survey (Kershaw et al. 1996), and six workshops, were completed as background to the present guide. This best management practices guide is the fulfillment of the interim guidelines.

This guide emphasizes the two most important boreal conifers in Ontario, black spruce and jack pine, and the identification of sensitive sites that have low nutrient reserves, or are susceptible in other ways to damage and losses of productivity. However, the whole range of forest sites is included in the general treatment of forest management activities. The guide is not an official management guide book by the Ontario Ministry of Natural Resources (OMNR) and therefore should be used as an additional source of information and not instead of or as a summary of Ontario forest guide information. However, it has undergone review by representatives of the OMNR, of Natural Resources Canada, and forest industry. There is no intent to provide absolute rules or regulations. In managing forests there are no absolutes, and usually there are alternative ways of doing things with a degree of uncertainty about which is best. It is fully expected that as more knowledge of forest ecosystems becomes available, and forest technology and operations improve, best management practices will be revised and improved.

Sustainable forest management, Chapter 1, presents some of the main principles and concepts guiding current-day forestry—sustainable development, sustainable forest management, ecosystem management, sustainable productivity, biodiversity, health, and integrity. In Part I, we present **best management practices — general principles**. This is done with a chapter defining **best management practices** (Chapter 2), followed by chapters dealing with each of the main forestry activities for a rotational cycle: **planning** (Chapter 3), **roads and water crossings** (Chapter 4), **harvesting** (Chapter 5), **site preparation** (Chapter 6), **regeneration** (Chapter 7), and **tending and thinning** (Chapter 8).

In Part II, **best management practices for sensitive sites** are detailed. **Sensitive sites** are defined (Chapter 9), followed by treatments for **shallow-soil landscapes** (Chapter 10); **dry, coarse soil sites** (Chapter 11); **forested wetlands** (Chapter 12); **riparian areas** (Chapter 13); **steep slopes** (Chapter 14); and **other sensitive sites** (Chapter 15).

Finally, Part III takes up **other issues** not dealt with in detail in previous chapters. **Ecological landscape planning** in Chapter 16 includes landscape ecology and planning for biodiversity, key issues in the debate about clearcutting. In Chapter 17 the **socioeconomics** of implementing sustainable forestry—equipment, economics, education, ethics, and long-term ecological research—are considered.

Each chapter refers to a limited number of important references that are particularly relevant to the subject, and these are listed in the **Literature Cited** section at the end of the guide. A **List of Species** referred to in the text, including common and scientific names, has been compiled in Appendix 1. A **Glossary** of the most important terms relevant to sustainable forest management is included in Appendix 2. Terms defined in the glossary are **bolded** in the body of the text the first time they are used. The definitions and uses of terms follow Aird (1994), Natural Resources Canada (1995), Dunster and Dunster (1996), and the Ontario Ministry of Natural Resources (1997) except when noted otherwise.

ACKNOWLEDGMENTS

The original members of the informal working group on sustainable productivity were Neil Foster, John Jeglum, and Ian Morrison from Natural Resources Canada; and Bala Balakrishnan, Al Gordon, and Dave Morris from the Ontario Ministry of Natural Resources. Later Rob Fleming, Paul Hazlett, Maureen Kershaw, Max Tenhagen, and Tom Weldon became involved in the group.

Thanks are extended to all participants at several workshops who contributed to the definition of sensitive sites, sensitivity assessment, and definition of forestry practices appropriate for those site conditions. Literature assistance was provided by Jan Addison, Rob Fleming, Fred Foreman, Neil Foster, Al Gordon, Art Groot, Lorne Johnson, Peter Newton, and Rob Steedman. We are especially grateful for the reviews and helpful comments provided by Rod Gemmell, Heather Barns, and Neil Stocker. All of these individuals with their experience and knowledge of research and forestry practices contributed greatly to this report. Thanks are extended to those individuals who forwarded copies of regional Best Practices. Our thanks also to Mark Primavera for his work in resuscitating many of the figures in this guide and in its layout.

Finally, we gratefully acknowledge all the field foresters, technicians, researchers, and academics whose written material or personal comments we drew upon. The science and art of forestry is built on the knowledge of a large society of practitioners and students, and we acknowledge that we have taken liberally from their practices, ideas, and wisdom.

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BEST MANAGEMENT PRACTICES — INTRODUCTION

Chapter 1. Sustainable Forest Management

Chapter 1.
Sustainable Forest Management

"Our goal is to maintain and enhance the long-term health of our forest ecosystems, for the benefit of all living things both nationally and globally, while providing environmental, economic, social and cultural opportunities for the benefit of future generations."
(Canadian Council of Forest Ministers 1992)

The principle of **sustainable development**, recently brought to prominence by the book "Our Common Future", produced by the World Commission on Environment and Development (1987), has been widely accepted in management of natural resources, including forests. The commission called for a global commitment to undertake economic and social development in such a way as to meet the needs of the world's population "without compromising the ability of future generations to meet their own needs."

In the forestry community, governments, and society in general, there has been continuing debate in the last decades about the impacts of forestry practices on forest land, sustainable forest use, and what constitutes good forestry. In Ontario, this concern has been demonstrated by a lengthy and expensive Class Environmental Assessment (EA) for Timber Management (Ontario Ministry of Natural Resources 1985, revised 1987), and by frequent news media coverage of such topics as:

- clearcutting
- inadequate regeneration
- monocultures and plantation forestry
- environmental impacts
- loss of soil and site fertility
- use of pesticides and biological control
- **biodiversity**
- **old-growth forest**
- rare and endangered species
- climate change

Significant advances have been made towards addressing these concerns in the last decades. Ontario has responded with a new Crown Sustainable Timber Act (Ontario Ministry of Natural Resources 1995b) and several strategic policy statements. The most recent forestry issues revolve around forest land use, namely, how much land to devote to parks, conservation, wilderness, and recreation, and how much for industrial forestry (e.g., "1999 Ontario Forest Accord" and "Ontario Living Legacy", Ontario Ministry of Natural Resources 1999; "Living Legacy" and "Land Use Strategy", Ontario Ministry of Natural Resources 2000).

Sustainable development is in a sense an oxymoron, and many have argued that it is better to speak in terms of **sustainable use**. To sustain something includes the following concepts: to keep in existence, to maintain, to prolong, to supply with necessities or nourishment, to keep from falling or sinking. In forestry there is the long established concept of **sustained yield**. This is the principle of maintaining the useable forest production continuously into the future. In today's forestry this focus on wood fiber is too limited. Nowadays we include a broader range of uses and benefits from the forest in addition to the wood products—e.g., recreation, conservation, spiritual, scientific, food and other products, watershed protection, carbon sequestering, and biodiversity. All these benefits are included in the term **sustainable forest management** (e.g., Canadian Council of Forest Ministers 1995).

Defining sustainable forest management is difficult because it is so comprehensive. A list of key characteristics of sustainable forest management was provided by Johnston (1990):

- long-term maintenance of wood supplies

- long-term maintenance of employment opportunities

- long-term maintenance of supply and quality of water required for human and industrial consumption, and for power generation

- long-term maintenance of genetic resources as a source of future genotypes

- long-term maintenance of intact, unmanaged **ecosystems** as sources of information on the structure and function of forests without the intervention of human activity

In 1992 in the Forest Congress in Ottawa, Canada adopted a National Forest Accord and a National Strategy, which provided a framework for setting objectives and monitoring improvements in forest practices (Canadian Council of Forest Ministers 1992). This led to the Canadian approach to 'Criteria and Indicators' (Canadian Council of Forest Ministers 1995), which has been adopted for reporting in the annual, mandatory Report to Parliament on The State of Canada's Forests. Criteria that have been adopted for use are:

- conserving biological diversity
- maintenance and enhancement of forest ecosystem condition and productivity
- conservation of soil and water resources
- forest ecosystem contributions to global ecological cycles
- multiple benefits to society
- accepting society's responsibility for sustainable development

Ontario has fully embraced the principles of sustainable forest management. In response to concerns expressed at the Class Environmental Assessment for Timber Management in Ontario Hearings (Environmental Assessment Board [Ontario] 1994), Ontario put into effect a new Ontario Crown Forest Sustainability Act (Ontario Ministry of Natural Resources 1995b), which replaced the previous Crown Timber Act. The new Act states that "sustainability" means long term forest **health**, and that sustainability shall be determined in accordance with the Forest Management Planning Manual (Ontario Ministry of Natural Resources 1996b).

Furthermore, it states that the Manual shall provide for determinations of the sustainability of the Crown forests consistent with the following principles:

1) "Large, healthy, diverse and productive Crown forests and their associated ecological processes and biological diversity should be conserved."

2) "The long term health and vigour of Crown forests should be provided for by using 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."

Sustainable forestry must be based upon knowledge of forest ecosystem structure and ecological processes, and how ecosystems are affected and change following various forestry practices. Management of forests based on knowledge of ecosystem structure and processes, and knowledge of the impacts of forestry practices, is termed **ecosystem management** (Boyce and Haney 1994).

Even though we may subscribe to the principle of sustainable forestry, we still do not fully understand the factors controlling **productivity** and the complexity of their interactions.

The ecological factors governing productivity include not only the primary environmental factors—moisture, nutrients, soil aeration, and compaction, heat, and light—but also the complex interconnections among these factors and living organisms. Maintenance of soils for sustained productivity of forest growth, of biodiversity at several levels—genetic, species, ecosystems, and landscapes—and of health and **integrity**, are key elements in achieving sustainable forest management (Kimmins 1997).

Part I.

BEST MANAGEMENT PRACTICES — GENERAL PRINCIPLES

Chapter 2.
What are Best Management Practices?

> "Good resource management is still an art, requiring applied talent, dedication, sensitivity, responsibility, ambition, pride, and a genuine concern for the future…" *(Vogl 1978)*

Best management practices are practices that represent the best current knowledge and methods to achieve sustainable forestry, and to achieve management objectives. In early work towards best practices, there was an emphasis on the maintenance of forest productivity and supply production. In recent work, best practices are defined more broadly to maintain other environmental values, for example, to maintain the biodiversity, health, and integrity of ecosystems at all scales, as well as other nontimber uses and benefits (Figures 2-1 and 2-2).

Figure 2-1. Best management practices are intended to maintain forest production and wood supply. St. Mary's Paper Mill at Sault Ste. Marie, Ontario. (Photo by J. Jeglum.)

Figure 2-2. In addition to forest productivity, best management practices are intended to to maintain environmental values—biodiversity, health, and integrity of the forest. (Photo by M. Kershaw.)

This guide is aimed at the practicing forester, the person in the field who is making the decisions that affect ecosystems. In developing best practices, it is important that they are based upon firm knowledge of individual ecosystems, their structure, function, complexity, interconnectedness, and changes over time. This must also be appreciated at the landscape level. The forester should be an observer of the abilities of various forest ecosystems to maintain their essential characteristics of structure and function under various levels of disturbance, and their ability to recover from the disturbances. Two concepts of change that are particularly important, in the context of forest harvesting and site preparation, are the **stability** of ecosystems, and the **resilience** to and **recovery** from disturbances.

Virtually everyone accepts the principle of sustainable use, and virtually everyone agrees that it is desirable to maintain the productive capacity of the land indefinitely into the future. However, we still do not have enough knowledge about how to achieve this for all the diversity of site types and various main management scenarios. Furthermore, we do not know enough about the impacts of forestry on the functioning of ecosystems, their changes after disturbance, and on biodiversity at all scales of ecosystems, especially the landscape scale. Consequently, best management practices are still based largely on current practices, opinion, and conventional wisdom, augmented by scientific knowledge and recommendations when available.

Best practices may apply at the level of a total landscape, or for particular site types, such as shallow soil sites, dry coarse soils, wetlands, and **riparian** sites. Best practices may also focus on a particular species, such as guides for black spruce, jack pine, important animal species, or particular operations such as road construction and water crossings.

Sustaining site productivity requires that the physical, chemical, and biological nature of the soils are not degraded, and that the ecosystem is able to recover and develop into a similar ecosystem with similar productivity. By maintaining favorable soil conditions, above-ground temperatures, wind regimes, and biodiversity, the growth of the forest is optimized. Boreal conifer ecosystems undergo predictable patterns of succession following disturbances such as wildfire, insect and disease infestations, and **windfall**, varying with the intensity of the disturbance. Best management practices require that forest changes and development patterns owing to management disturbances remain within the historical variations observed for natural disturbances.

Best management practices should aim to achieve the following objectives:

- maintain or enhance forest land productivity
- maintain or enhance nutrient supply
- maintain or enhance favorable soil moisture and temperature regimes
- maintain or enhance normal levels of soil organic matter and rates of turnover
- maintain or enhance favorable soil structure, aeration, and drainage
- maintain or enhance soil micro-organism and invertebrate populations
- minimize impacts to water quality in lakes and streams
- maintain or enhance health, **vitality**, and integrity of ecosystems and landscapes
- maintain or enhance biodiversity at all levels—genetics, species, ecosystems, and landscapes

In this synthesis, we emphasize the best management practices for boreal forests dominated by black spruce and jack pine, but also for some of the related mixedwoods. We deal with general forestry practices for the main forestry activities—planning, roads, harvesting, site preparation, regeneration, and **tending**. Then we identify specific **sensitive sites** that require special treatment. We give guidelines primarily at the site/stand level, but in a later chapter provide some of the recent guidelines used in ecological landscape planning. In the final chapter we deal with several other socio-economic and cultural issues critical to sustainable forest management.

There are many official OMNR guides, codes, and practices already in effect in Ontario (Ontario Ministry of Natural Resources 1983, 1986, 1987, 1988a, 1988b, 1990, 1991a, 1991b, 1997; Archibald et al. 1997). In addition, there are numerous completed or current projects by research groups, science and technology units, and universities that have a direct or indirect bearing on management. These will be referred to throughout the guide.

It is inevitable that there will not be complete agreement in decisions of forest management, with all the different factors involved in making decisions–biological, environmental, and economic. Even among the official OMNR guides there are differences in recommendations (cf. Preface). We emphasize that our recommendations may sometimes vary from the official OMNR guides. Wherever our recommendations vary from these official guides we make note of these differences.

Chapter 3.
Best Management Practices: Planning

> "Any enterprise is built by wise planning, becomes strong through common sense, and profits wonderfully by keeping abreast of the facts."
> *(Proverbs 24:3-4)*

Planning should be conducted in such a way as to maintain or enhance the long-term productivity, biodiversity, health, and integrity of forest ecosystems and landscapes (Figures 3-1 and 3-2). Planning is difficult because of the high degree of uncertainty about the results of various treatments, the need to plan for the long-term as well as the short-term, and the need to change the plans as new research results and knowledge become available. Of course the best laid plans are not worth anything unless they are followed and accomplished.

Planning involves deciding what kind of forest management and silviculture will be conducted—**extensive**, **basic**, or **intensive**—and various mixes of these. This is influenced by the kinds of forests and soil, and their relative productivities, the location of the land and forest types relative to the mills, and decisions about the kinds of forest products for which to manage (e.g., pulp, lumber). The increasing demands for non-timber uses of forest land may force the industry to practice more intensive forestry to make up for loss of forest land base. On the other hand, long-term outlook for product demand and profitability will influence the decisions made, and tactical decisions will have long-term implications. It is difficult to change directions quickly given the long-rotation periods of boreal species, and the long-term capitalization of forestry equipment and mills.

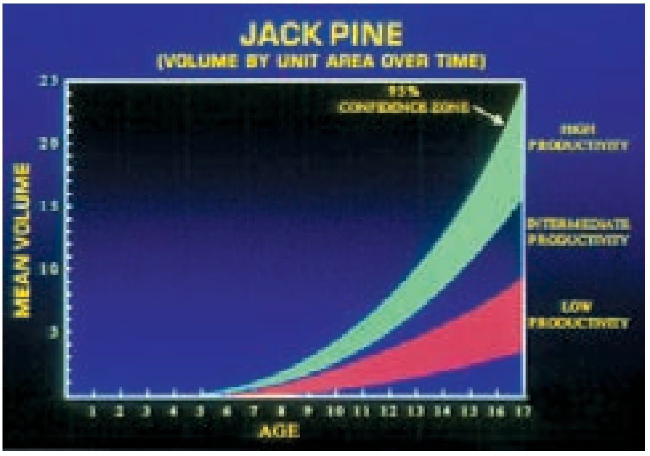

Figure 3-1. Maintenance of productivity is one of the major principles for sustainable forest management. Jack pine productivity classes: high, intermediate, low. For young jack pine plantations (Adapted from MacIver and Karsh 1988).

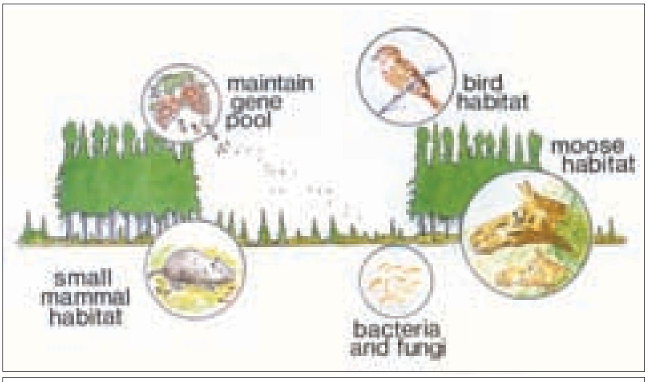

Figure 3-2. Maintenance of biodiversity is the second major principle for sustainable forest management (from Jeglum and Kennington 1993, Figure 19-7).

In planning there must be joint consideration of harvesting and regeneration, including site preparation. Planning for renewal of the forest is more important than planning for removal of the timber. It is especially important to consider the economics of harvesting jointly with renewal, to get a true picture of the cost of a silvicultural system. Without prior planning one may lose opportunites for more economical regeneration consistent with forest management objectives, and there is greater chance for harmful environmental impacts.

Ecological landscape planning and biodiversity questions are dealt with at the planning stage. However, because these are rather special topics, they are dealt with in detail in a later chapter (Chapter 16).

General Principles

- **Employ ecological land classification** — ecozones, ecoregions, ecodistricts, landforms, ecotypes, ecoelements (e.g., Crins and Uhlig In prep.; Figure 3-3). **Ecological land classification** (ELC) provides a framework for sustainable forest management—a basis for analyzing and predicting productivity and environmental changes (Figure 3-4).

- **Employ ecosystem management** (e.g., Boyce and Haney 1994). Knowledge of forest ecosystems at the population, stand, and landscape levels is of primary importance. Forest managers need to continually upgrade their knowledge about the structure, function, and succession of forests.

- **Develop an ecological landscape plan.** The plans for a forest should include the strategy for developing an optimum mosaic of harvested versus unharvested areas; maintenance of variation in structure, composition, and successional stages; designation of buffer zones, corridors, and juxtapositions of ecosystem types; old-growth and interior forests; wildlife habitats; and preserving special habitats.

- **Plan for other forest uses, benefits and values.** The manager should plan for other uses besides production and environmental protection. Hiking and camping; cross-country skiing, snowshoeing, and snowmobiling; hunting and fishing; berry and mushroom picking; and aesthetics are all important elements of modern forest management.

- **Develop a vision for the forest.** Develop a plan for what the forest should look like in the "best of all possible worlds". Assess what are the present and potential values and benefits of the forest, and who uses and benefits from the forest. Develop a scenario of best possible uses for the forest, and develop best forest practices and methods to achieve the vision (e.g., Hunter 1990).

Some Details of Planning

- **Assemble detailed resource information.** This information will consist of general and detailed maps of the geology, landforms and soils, forest inventory, ecological land classifications, streams, drainageways, wetlands, and species-rich and sensitive habitats. Classify forest land into productivity classes. Obtain or conduct **fine-type mapping** of sites and terrain for proposed harvest areas.

- **Stratify forest into areas receiving extensive, basic, and intensive management. Extensive forestry** depends on natural regeneration and protection from fire and insects. **Basic forestry** consists of the current systems of forestry, including extensive and artificial regeneration. **Intensive forestry** consists of basic forest management plus juvenile-stand improvement plus acceleration of growth.

Distance from the mill influences this to some extent. Extensive forestry is done on the poorer sites regardless of distance from the mill. Basic forestry would be considered for good to excellent sites close enough to the mill, e.g., up to 120 km (R. Gemmell, Pers. comm.). Intensive forestry would be considered for good to excellent sites, generally closer to the mill. Models should be developed to address the interactions of site quality, distance from the mill, and economics of different management intensities.

- **Stratify forest into winter versus summer harvesting.** Harvesting areas may be classified into winter vs. summer harvest, matching the winter harvest to the areas with high proportions of sensitive sites, the summer harvest to the less sensitive, resilient sites.

In some companies there can be a third seasonal operating option (Abitibi-Consolilated, Iroquois Falls Forest, R. Gemmell, Pers. comm.) The winter season technically ends when the ability to haul wood from winter roads ends – possibly as early as mid-March.

Figure 3-3. Ecological Land Classification (ELC) is the ecological foundation for planning. The levels of the hierarchy are Ecozone, Ecoprovince, Ecoregion, Ecodistrict, Ecosection, Ecosite, and Ecoelement. Only Ecoregions and Ecodistricts are presented in the model (Drafted by W.J. Crins, December 2000, to be included in Crins and Uhlig In prep.).

However, there is the possibility to operate adjacent to gravel roads from March through May, providing the opportunity to operate on the more sensitive sites while the frost is still in the ground. High-floatation, clam-bunk skidders provide an opportunity to skid long distances to roadside, up to 730m.

- **Prepare management and operational plans.** Forest management plans must follow current regulations and requirements of the 'Forest Management Planning Manual' (Ontario Ministry of Natural Resources 1996b). Plans are made for different time scales, e.g., 5 years and 10 years.

- **Invest in the most productive sites** and rely on good natural regeneration treatments for the less productive sites. The expenditure of money should be described in the 5- or 10-year operating plan and should be a continuous process.

- **Plan for changes in market demands.** In times of constraints on silvicultural dollars, the use of low- and medium-cost regeneration techniques may increase in relation to high-cost plantation forestry. It may be better to wait one to five years for better economic conditions rather than to plant too cheaply. Conversely, in better times, the use of high-cost regeneration techniques may increase in relation to low-cost extensive forestry.

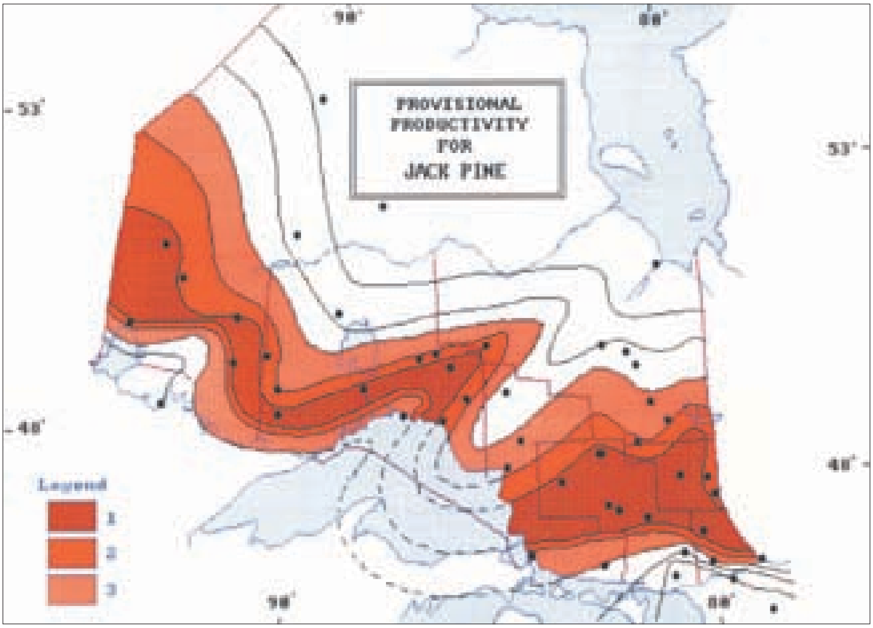

Figure 3-4. Provisional productivity zones for jack pine. Productivity highest to lowest, 1 to 3 (From MacIver 1989).

- **Plan with the time dimension in mind.** Plan for the short-, medium-, and long-term. Think of how the forest composition and structure might evolve over time. This is not only important for production forestry but also for managing for multiple-use forestry.

- **Plan for necessary interventions** that are likely to be needed. This does not mean strict scheduling of treatments, but regular monitoring and implementation of treatments as required. Over time, and with experience, this function will become more reliable and more accurate.

- **Use modern technology in resource management,** e.g., satellite remote sensing, supplementary aerial photography, electronic data collection, geographic information systems (GIS), ground positioning systems (GPS), computer modeling, and so on (Galloway et al. 1987).

- **Plan on an integrated team basis.** Involve expertise and experience in planning the roads, harvesting-regeneration systems, site preparation, regeneration, minimizing soil and water impacts, and promoting wildlife. Technicians and operators should be instructed and trained in essential operating techniques. They should be encouraged to request changes and expect immediate advice on a procedure.

- **Obtain appropriate forest equipment.** Forest equipment should be chosen (or developed) to suit the silvicultural system, site, and stand conditions. More than one set of equipment may be appropriate for different ecosystems. Generally, use equipment with low ground pressure, high operator safety, and high ergonomic efficiency.

- **Employ competent staff and contractors.** Even the best-planned management program will fail if the staff and contractors are incompetent. Training, experience, and motivation for both staff and contractors are all key elements in determining their competencies and capabilities for carrying out the work.

- **Develop contingency plans for large disturbances,** e.g., salvage operations after wild-fire or insect outbreaks, and also for changes in market demands.

- **Develop a monitoring program.** Periodic and systematic monitoring is essential for feedback on the relative success of the program. It minimizes the risk and costs of failure, and provides essential information on the effectiveness of the treatments.

• **Employ knowledge of silvics and ecology.** Productivity is based ultimately on how individual crop species are managed. Use the best available information about species genetics, **ecology**, physiology, nursery practices, and natural regeneration.

• **Employ site-adapted forestry.** Refine prescriptions to particular sites based on experience and research. With increasing knowledge and experience, best management practices should be adapted more and more to specific site conditions (e.g., AssiDomän 1994).

Chapter 4.
Roads and Water Crossings

Road systems are essential for developing a forestry area, maintaining and increasing its productivity, and giving access to other users. They are also critical because of their high potential for harmful environmental impacts.

Roads are essential for forestry operations, to provide access for harvesting, site preparation, regeneration, tending, and protection. For forestry practices to move in the direction of more frequent entries for tending and pest control, site improvements, thinnings, and intensive forestry, more high quality, permanent access roads are required. However, roads have the greatest potential of all the forestry practices for detrimental environmental impacts. Their impacts are much greater than the on-site impacts of harvesting, site preparation, and regeneration (e.g., Kreutzweiser and Capell 2001). Therefore road and water crossing construction warrant serious consideration to minimize environmental impacts like erosion on water quality and aquatic habitats.

Access Roads

Guides for the construction and maintenance of access roads and water crossings are given by the Ontario Ministry of Natural Resources (1983, 1995a). Much information can be obtained from other jurisdictions (e.g., British Columbia Ministry of Forests 1995c; New Brunswick Department of Environment 1994; Finland, Hänninen, et al. 1996), and from the Forest Engineering Research Institute of Canada (e.g., MacDonald 1996; Bradley 1997).

The OMNR's "Environmental Guidelines for Access Roads and Water Crossings" (Ontario Ministry of Natural Resources 1995a) provides a comprehensive collection of mandatory standards, good practice guidelines, and mitigation techniques. Related legislation and mandatory standards set out minimum criteria to prevent unacceptable environmental changes. The key elements of the guidelines are to minimize erosion, slow down water runoff, and minimize impacts on receiving waters.

The most important persons to the successful application of best practices are the field personnel - the surveyors who lay out the roads, the foremen, and the operators of the road- and bridge-building machinery such as bulldozers, excavators, and graders. These persons need to consider the following:

- optimum locations for roads and crossings
- clearing and grubbing of vegetation
- earth and rock grading
- excavations
- construction over wetlands/ peatlands
- material for filling and gravelling
- drainage ditches, water diversions, sedimentation ponds
- crossings – choice of log and brush mats, culverts, or bridges
- road and crossing maintenance
- stabilizing banks
- road abandonment and reclamation

Some key best practices

- **Plan for more than just the harvest.** Consider intermediate entry treatments, protection requirements, and other users throughout the rotation and beyond.

- **Consider environmental impacts, loss of land base.** Prior planning may help reduce soil disturbance and loss of land base. The road system will depend on the silvicultural system and equipment used, the terrain characteristics (Figure 4-1), and safety requirements. Use of high-flotation, low ground pressure equipment with long skidding/forwarding distances, and carrying large loads, will minimize soil disturbance, reduce loss of land to permanent roads, and reduce costs of construction and maintenance (Figure 4-2).

Figure 4-1. Roads and landings are the leading source of soil erosion, and loss of productive land. Proper road construction, ditching, and water crossings will minimize adverse effects. (Photo by M. Kershaw.)

• **Lay out roads on inventory maps and air photos.** Planning the location of roads should be done by the planning team, photogrammetrist, and road construction staff. It is useful to carry out additional fine-type mapping, to permit better placement of access roads and water crossings, and in designing the harvesting-regeneration systems.

• **Plan access road system in relation to forwarding distances.** Maximize forwarding distances to increase spacings between access roads, thereby reducing total road construction. Take advantage of spring frost adjacent to gravel roads. Longer skid distances are often the objective in winter because there is less disturbance at the **landings**. In the wetter **forested wetlands**, consider two-phase harvesting, summer cuts for the 'front half' of a forwarding run, and winter cuts for the 'back half'.

• **In peatlands use winter roads.** Temporary winter roads, giving access to equipment and hauling trucks, can be constructed by plowing off snow and allowing the peat to freeze. Winter roads are inexpensive, they reduce the need for permanent roads, and site disturbance is minimal. After logging operations, winter roads should be regenerated, and drainage-way blockages opened up.

• **Fit the roads to the terrain.** Locate roads on level to gently sloping deep, well-drained ground. Position roads parallel to or at acute angles to contours to minimize gradients and downcutting of roadside ditches. Avoid locating permanent roads on the shallowest soils, on unstable slopes, and in wetland sites.

• **Consider economics.** Extensive forestry may call for cheaper, temporary roads, whereas intensive forestry warrants more expensive, permanent roads. With wider spacings of roads and fewer landings road construction costs are lower, and environmental impacts may be less. Optimum spacing of roads and landings can be determined to minimize timber harvest cost.

• **Make better roads for basic and intensive forestry.** Basic and intensive forestry call for more permanent, higher quality roads. Both of these include site preparation and planting, and intensive forestry may require more frequent periodic access for forestry operations such as tending and thinnings.

Water Crossings

Water crossings may be considered within four main activities: site selection and design, fords and temporary bridges, construction, and site clean-up.

Some key best practices

• **Plan location of bridges and culverts.** Identify streams and drainageways that will require bridges and culverts (Figure 4-3). Avoid placement of crossings at unstable sites that could be subject to bank slumping, erosion, and sedimentation (Figure 4-4), or sites important as wildlife or fish habitat. Culverts should be placed frequently enough to maintain flows and not cause flooding upslope from the crossing. For permanent crossings, size bridges and culverts for infrequent peak flows of 25-year return periods.

• **Install bridges and culverts correctly.** Choose culverts to maintain the natural morphological features of the watercourse, width, and slope. For fish movement, culvert shapes from best to worst are open bottom, box, pipe arch, stacked culvert, and round culvert. Properly establish and maintain culverts to keep water flowing freely, and to minimize flooding upstream. Set the culvert a minimum of 15 cm below the bed of the stream, and in peatland at least 45 cm below the hollow bottoms, that is, the lowest water table level.

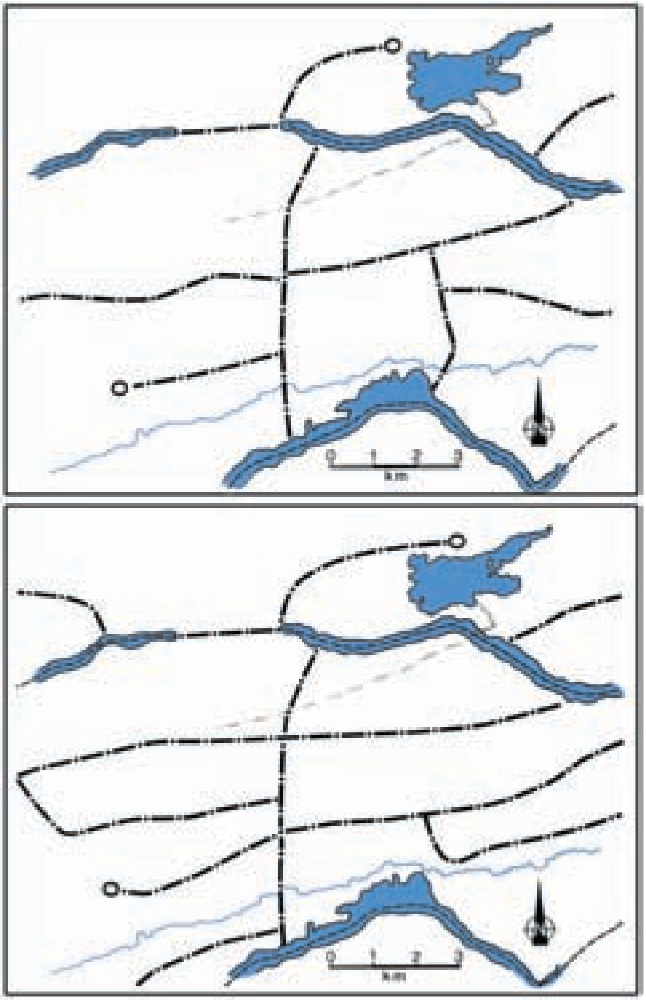

Figure 4-2. Road spacing influences efficiency of operations, costs, and degree of land removal from productive forest growth. These road patterns were developed for deep strip cuts (top) and normal strip cuts (bottom), 366 and 183 m deep, respectively (map courtesy of Domtar Forest Products, Red Rock. From Jeglum and Kennington 1993, Figure 10-3).

• **Install necessary ditches and drains** to manage water flow near roads. Place ditches parallel to roads, on both sides if necessary, to collect and carry water to the culverts, or away from the roads. Establish sedimentation pools to slow water and collect sediment. Construct take-off ditches to divert ditch water before it reaches the stream.

• **Avoid drainage blockage of seepages and drainageways.** Employ temporary crossings such as log fills covered with brush mats. Use moveable metal or wooden tracks, or tire mats (Figure 4-5) to drive over soft, wet spots, drainageways, and ditches. These should permit beneath-road drainage, and should be removed after the harvesting.

Be aware that some of these temporary bridges, such as tire mats, quickly get driven into the wet mineral soil and become a problem to remove (R. Gemmell, Pers. comm.).

• **Take special care in riparian zones and wetlands.** Avoid locating road crossings across wider wetlands or wider riparian floodplains. Attempt to locate crossings at narrows where uplands are close on both sides of the stream and the span will be minimized. Locate landings and borrow pits outside of the riparian areas to minimize disturbance, erosion, and runoff.

Mitigation and Reclamation

Mitigation techniques are considered within several areas: erosion and sediment control, vegetation cover, beaver control problems, fish habitat protection, and aesthetic considerations.

• **Maintain vegetation cover.** Retain existing vegetation where feasible. Minimize the duration of soil exposure. Establish protective vegetative cover with the establishment of graminoids, cattails, sweet gale, willow, and alder (Figure 4-6).

Some key best practices

• **Stabilize slopes and shorelines.** Keep runoff velocities low. Grade disturbed soil to stable angles of repose on steep slopes and shorelines. Divert runoff away from exposed soil. Trap sediment before it can cause damage. Use filter cloth, rip rap (a surface layer of stones), or other stabilizing materials.

• **Control beaver.** Beaver dam cleaning and beaver trapping programs are required to keep the culverts and streams free flowing. The Beaver Handbook by D'Eon et al. (1995) provides guides for understanding and coping with beaver activity. A well-run beaver control program pays big dividends.

Figure 4-3. Permanent or intermittent streams and drainageways require culverts or log underlay brush mats to permit unimpeded water flow beneath the roads. (Photo from files of Canadian Forest Service.)

Figure 4-4. Bridge crossings should be done with care to maintain bank stability and minimize erosion. Crossings should avoid flat wetland areas and unstable, steep banks (Photo by M. Kershaw).

- **Protect fish habitat.** Follow provincial guidelines for fish habitat (Ontario Ministry of Natural Resources 1988a, 1995a) and consult those for other jurisdictions (e.g., British Columbia Ministry of Forests 1998).

- **Carefully use, store, and dispose of fuels, oil, and related materials.** The use, transport, storage, and disposal of fuels and oils must comply with all relevant laws and regulations (Health and Welfare Canada 1986; Ontario Ministry of Environment 1990; Ontario Ministry of Natural Resources 1991b). Clearly define areas for maintaining equipment to confine potential hazards to a few sites (Figure 4-7). Develop a contingency plan for spills and clean-up. Consider the new biodegradable oils.

- **Consider aesthetics.** Steps taken to contour slopes and to revegetate them should take into consideration the beauty and attractiveness of the roadsides and streamsides. Use native species of shrubs and trees that are pleasing, and that grade with increasing height into adjacent forests. Mixtures or patches of conifer and broad-leaf trees may be more desirable than single species.

- **Reclaim roads and landings.** Conduct tilling treatments, soil stabilization, and planting to restore abandoned roads and landings to forest production (e.g., Lawrie et al. 1996; Kosicki et al. 1997).

Figure 4-5. Tire mats used to cross wet spongy sites, drainageways, and ditches. (Photo courtesy of the Swedish forestry magazine Skogen 11/99:8-11, and Skogen 1/00:45.)

Figure 4-6. Stabilize shorelines wherever there are concerns about erosion, bank stability, and quality of runoff water. Filter cloth and the establishment of such plants as graminoids, cattails, sweet gale, red-osier dogwood, willow, and alder, will act to stabilize and filter soil particles and nutrients. (Photo by M. Kershaw.)

Figure 4-7. Regular field maintenance ensures safe and effective use of equipment. The oil being changed in this machine is collected in containers, which will be returned to the shop for proper disposal. Oil spill mats soak up any spills. Biodegradable oils further mitigate environmental impact. (Photos by Meakin Forest Enterprises Inc.)

Chapter 5. Harvesting

> "Two of the most important tasks faced by the logger are to select the best harvesting system and equipment for a given site, and to use the selected equipment in the best way possible." *(MacDonald 1999)*

Harvesting cannot be regarded as a separate activity. It must be regarded as part of a total harvesting-regeneration system that includes site preparation, regeneration, and all the other components of a rotation. A classification of some of the main harvesting-regeneration systems is presented in Table 5-1. The predominant pattern of harvesting (by area, but not by forest type) in Ontario is clearcutting, which is followed by artificial or natural regeneration, or a combination of the two. Partial cutting-regeneration systems are less common, but they have been increasing in use in recent years. These include selection, shelterwood, and **two-storied** systems. Partial harvests may be regenerated naturally, or they may require artificial regeneration after a final cut.

Forests arising after a complete removal of a forest as in clearcutting, or a large scale disturbance such as wildfire, develop **even-aged** (even-sized) forest structures. As well, some types of regeneration cuttings, such as shelterwood, seed tree, and seed tree groups, will give rise to even-aged forests. On the other hand, forests that develop naturally for a long time, and that have smaller internal openings and gaps, may develop **uneven-aged** (uneven-sized) structures. Harvesting-regeneration systems may be developed to promote uneven-aged structures; these include some of the partial cutting options.

Guides to harvesting systems and practices are included in the planning and silvicultural manuals of the Ontario Ministry of Natural Resources (e.g., 1986, 1996a, 1997; Racey et al. 1989). Innovative silviculture systems in boreal forests have been summarized in a symposium (Bamsey 1994). A comprehensive review of harvesting systems and equipment is available for British Columbia (MacDonald 1999).

Reviews of harvesting impacts have recently been published (Archibald et al. 1997; Arnup 1998, 2000). The issue of clearcutting with **full-tree logging** and its effect on removal of nutrients from sites has been, and continues to be, a main concern (e.g., Kimmins 1977). The alternative is **tree-length logging**, which involves delimbing and topping the trees on the site or on the logging trails.

Table 5-1. Some of the main harvesting-regeneration systems.

	Natural Regeneration	**Artificial Regeneration**
Clearcutting	**Careful logging around advance growth (CLAAG)** **Harvesting with regeneration protection (HARP)** Small area clearcuts/ natural seeding—includes strip cutting Seed tree and seed tree groups (technically not a clearcutting system) **Scarification,** seed from cones in slash Suckers or sprouts	Planting, Seeding Fill planting
Partial cutting	Selection thinning - one or more commercial thinnings • low thinning • high thinning • two-storied system Shelterwood Regeneration cut	Underplanting Underseeding **Liber-rich**

Other concerns about clearcutting are impacts of equipment relating to erosion, compaction, accelerated decomposition and loss of organic matter, altered hydrology, rutting, forest structural changes, tree compositional shifts, loss of **advance growth**, and loss of seedbed (e.g., Kershaw et al. 1996; Figure 5-1).

Figure 5-1. Two basic types of clearcutting are full-tree with removal of stems, branches and needles, and tree-length (stem only) with delimbing on site. Residual paper birch and trembling aspen will seed or vegetatively propagate. The manager may accept the tendency to develop towards mixedwoods, or remove the hardwood and favor pure conifer in the next stand. (Photo by M. Kershaw.)

General Principles

- **Base silviculture on knowledge of ecosystem structure and dynamics.** Knowledge of stand structures, forest regeneration, successional pathways, and internal stand dynamics are the bases for understanding and choosing the most efficient methods of management (Kimmins 1997; Gordon et al. 2001).

- **Select an appropriate silvicultural system.** The choice of silvicultural systems will depend on Forest Ecosystem Classification (FEC) site type, the ecosite, choice of species to manage, and kind of forest product desired. The two basic choices of system are clearcutting (Figure 5-2) and partial cutting (Figure 5-3). Clearcutting is used to continue or to create an even-aged forest condition. It lends itself to the efficiencies and rapid extraction associated with larger equipment (Figure 5-4), while partial cutting requires more careful extraction with smaller, maneuverable harvesters and forwarders (Figure 5-5).

- **Consider stand condition, age, and wind stability.** Timber characteristics—tree size, volume per hectare, and timber quality—affect equipment selection (MacDonald 1999). Overmature, dense stands of conifers are subject to windfall when forest edges and narrow strips are exposed (Figure 5-6).

Figure 5-2. Clearcutting exposes the ground, and increases temperature and rainfall reaching the surface. Increased temperatures and wind cause increased drying, which may cause moisture stress to seedlings on drier sites. On lower and wetter sites, there may be problems with water level fluctuations and late frosts. (Photo by F. Foreman.)

Composition and Structure of the Next Stand

- **Select the most appropriate species/ species-groups for sites.** The potential for productivity is determined at the initial stage when the manager decides what species to regenerate or favor in tending. Often there is advance growth present, and this must be taken into account (Figure 5-7).

- **Conserve natural regeneration and advance growth** (e.g., Archibald and Arnup 1993; Ehnes and Sidders 2001). Use harvesting methods and equipment that restrict equipment to parallel trails with maximum distance between trails. This will minimize disturbances to existing advance regeneration, as well as the ground surface and organic mat.

Figure 5-3. Partial cutting practices remove only part of the canopy, and include selection thinning, and shelterwood. This photo shows thinning in peatland, leaving the smaller, non-merchantable trees. (Abitibi-Consolidated Inc. Photo by R. Gemmell.)

Figure 5-4. Large feller-bunchers are extremely efficient in clearcutting. (Photo by J. Scarratt.)

- **Use careful logging around advance growth (CLAAG)** (e.g., Ehnes and Sidders 2001). Careful logging around advance growth is restricting equipment to parallel logging trails, and logging in such a way as to preserve advance growth. It is done especially on black spruce peatlands, but seems to be applied almost everywhere today (Figure 5-8).

- **Use small area clearcuts and strip cuts** (e.g., Jeglum and Kennington 1993; Figure 5-9). These techniques favor regeneration by natural seeding from adjacent forest leave areas. They also reduce exposure, dessication, and runoff; provide diversity of habitats for flora and fauna, and provide landscape diversity.

On the other hand, small area clearcuts and strip cuts may have negative impacts on the forest by contributing to forest fragmentation, smaller stands, and also negative impacts on biodiversity and species dispersal. There are **guidelines** and **standards** in place which address percent of planned clearcuts less than 260 ha and those that are greater in size (Ontario Ministry of Natural Resoures 2001). The objective is to create a more natural landscape pattern.

- **Consider partial harvesting techniques** (Figure 5-3). Partial harvesting maintains some degree of cover on the site, reduces environmental impacts, and provides mixed forest structures, which add to biodiversity. Partial cutting and small area clearcuts are appropriate methods to protect sensitive sites. These practices, however, favor shade tolerant species in comparison to the intolerant species.

- **Avoid creating microclimatic extremes.** Potential damage from frost is associated with basins and lowland flats. Dry sandy and gravelly soils, dune sands, and shallow soils over bedrock may become dessicated by exposure following clearcutting. Partial cutting and small area clearcuts give protection from wind and dessication, and frost.

- **Leave dying trees, snags, and coarse woody debris.** This practice conserves organic matter and nutrients, and maintains biodiversity and ecosystem processes. Old living trees, **snags**, and downed rotting wood provide habitat and food for birds, mammals, insects, soil fauna and flora, and mycorrhizal unions with tree roots (e.g., Figure 5-10).

We recognize that following this recommendation may serve to promote harmful insects and pathogens. As well, by leaving dying trees, one may perpetuate poor quality genotype trees. It may be necessary to limit the number of dying, poor quality trees that are left. (See recommendations by Ontario Ministry of Natural Resources 2001, in Chapter 16.)

Figure 5-5. Medium- to small-size harvesters and forwarders, with low ground pressure, long-reaching booms, and high maneuverability are desirable for partial and selective cutting. (Photo by A. Cameron.)

Figure 5-6. Blowdown is a common occurrence in dense and/or overmature stands of conifer. In such situations, harvesting operations should attempt to minimize forest edges and too narrow strips, which are subject to blowdown. (Photo by M. Kershaw.)

- **Leave living vegetation on the site.** Patches of uncut forest, partial cutting, seed trees or seed tree groups, advance growth, and understory vegetation shade soils and promote rapid recapture evapotranspiration, and maintains root mats. It will promote rapid recovery to the original vegetation.

- **Manage compositional shifts.** If the original species complement is not well suited to the site, the manager may decide to shift to another composition by selective tending or planting. For example, richer and deeper soils with intermediate moisture regimes may be better suited to mixedwoods or pure hardwoods (e.g., Smith and Crook 1996; Figure 5-7). The manager might consider moving towards higher content of trembling aspen, or conversely tending to promote higher content of spruce and less of broadleafs.

- **Manage changes in stand structure.** Careful logging around regeneration may promote uneven-sized structures, which may lead to partial harvesting and promote uneven-sized management in the next rotation. Seed regeneration of jack pine and black spruce together will promote two-storied stand development. Partial harvesting in mixedwoods may move the stand along a number of pathways, depending on how much canopy is removed, and the species that are present (Smith and Crook 1996).

Minimize Windfall Hazard

- **Develop windfall management strategies.** For all harvest operations where there are forest edges, and wherever trees are retained, as in partial cuts and thinning cuts, it is necessary to develop strategies to reduce risk of windfall (e.g., Fleming and Crossfield 1983; Navratil 1995).

- **Reduce windfall risk in partial cuts.** Assessing windfall risk is complex, and depends on many factors including external stability, individual tree stability, and forest stand stability. ‘Slenderness coefficient’ is the ratio of height/DBH. ‘Live crown ratio’ (live crown length/tree height) is sometimes preferred owing to its ease of assessment (Table 5-2).

Table 5-2. Recommended slenderness coefficients and corresponding values of live crown ratios (from Navratil 1995, Table 1).

Age class	Height/DBH	Live crown ratio %
1-20	n/a	100
21-40	<80	75-100
41-60	<85	50-75
61-80	<90	50
80+	<90	full, uninterrupted canopy

Figure 5-7. Mixedwoods with overstory of trembling aspen and understory of black spruce, white spruce, and balsam fir require selection of appropriate crop species. (Domtar Limits. Photo by J. Jeglum.)

- **Reduce windfall risk by planning cut borders.** Use topographic protection and design of logging boundaries to reduce risk. Leave straight boundaries with no sharp corners or indentations.

- **Reduce windfall risk by edge stabilization.** Use treatments such as removing unsound or wind unstable trees, topping and pruning, and edge feathering. (Some of these may require OMNR approval.) Select windfirm trees for retention, such as the following: shorter trees in more open conditions, trees with small open crowns, good root anchorage, no root or butt rot, and relatively large taper, broadleaf species, deep-rooted conifers, and sound snags and well-rooted veterans.

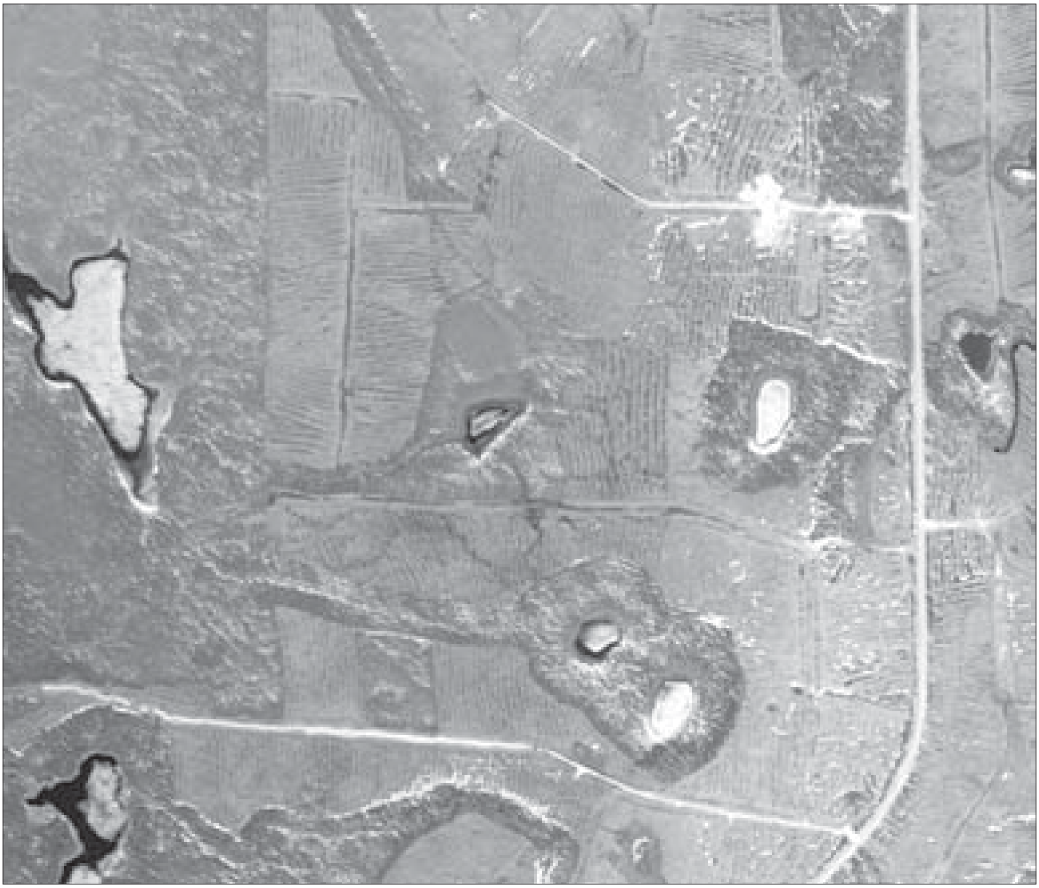

Figure 5-8. Careful logging around advance growth (CLAAG), a common clearcut harvesting method that preserves advance growth by keeping equipment on defined logging trails. (Ontario Clay Belt. Air photo courtesy of Abitibi-Consolidated Inc.)

Figure 5-9. Small and medium area clearcuts, including strip cuts, alternating with leave strips of production forest and no cut forest, reduce the wind speeds, maintain a proportion of forest on watersheds, and promote diversity of habitats. (Domtar Limits, north of Nipigon. Photo by L. Morrow.)

• **Do not remove snags or windfall** from management buffer zones. These provide valuable wildlife habitat and removal may cause more damage. Remove only if the habitat would be improved, or to reduce risk of insects, diseases, or destabilizing stream channels.

Minimize Physical Impacts

• **Carefully plan, establish, and maintain minimum landings.** Limit the number and size of landings, and consider alternative sizes, shapes, and designs. Keep the area of landings and of continuous slash corridors along access roads as low as possible, e.g., to less than 5% of the harvest block. Locate landings as follows:

1. on well-drained sites, preferably level or gently sloping, stable ground;
2. where skidding will not cross drainage-ways and disrupt natural drainage;
3. avoiding poorly drained soils where traffic will lead to excessive compaction, rutting, and puddling;
4. outside and away from riparian zones;
5. outside and away from wetlands, or on wetlands only during frozen conditions and with removal of logs/slash before thaw.

• **Restore landings and slash piles to productive forest** (Figure 5-11). If using full-tree harvest, slash piles should be removed, either by burning, or by chipping for energy or redistribution onto site. Landings should be restored to forest by site preparation, seeding, or planting.

• **Avoid practices that can result in erosion and large scale soil displacement.** These disturbances will result in mass movement and nutrient losses, and degrade stream water quality. Avoid skidding on steep and unstable slopes. Align skid trails along contours to minimize speed of surface water runoff. Minimize long, straight skid trail stretches that will be prone to erosion. Monitor erosion and treat as required to minimize gullies.

• **Avoid soil compaction.** Be particularly careful with very fine sands, silts, and clays. Use low ground pressure (wide) tires or tracks. Use light equipment. Avoid multiple passes on harvesting trails. If there is risk of severe rutting or compaction close to landings, reduce the numbers of passes by shortening the maximum distance of forwarding, or carry out logging in winter on frozen ground or snow.

• **Avoid rutting, churning, and drainage blockage** (Figure 5-12). This is especially relevant in forested wetlands. Use low ground pressure equipment, avoid operations during spring thaw or very wet periods,

Figure 5-10. Downed, rotting logs and standing snags provide habitat for wildlife and microorganisms, and a handy perch for red squirrels to open cones for seed. (Photo by G. Courtin and R. Robitaille.)

and use culverts and temporary bridges over drainageways and wet pockets (e.g., see Figure 4-5). This will reduce the risk of proliferation of sedges, cattails, and other **competition** (Figure 5-13) caused by churning up richer peats and creating muddy surfaces, which are prime seedbeds.

• **Operate equipment on snow or frozen soils** (Figure 5-14). On wet mineral soils and peatlands, operating on snow will reduce soil rutting, churning, drainage blockage, and damage to advance growth. Compacting logging trail snow and allowing frost penetration will allow equipment operation with least damage to the soil. On shallow-soil landscapes and patterned sites with shallow sites alternating with peatlands, operating on snow will give the same benefits, and will reduce damage and physical displacement of the root/organic mat and shallow soil.

• **Consider changes to post-logging water table levels.** Watering-up may occur in peatlands after harvesting. Where **watering-up** is extensive, consideration should be given to remedial drainage ditches to lower water tables, reduce drowning of advance growth, and permit regeneration activities.

Figure 5-11. Top: Full-tree logging with delimbing at roadside. (Photo by J. Scarratt.) Bottom: Slash piles require treatment in order to restore the covered area to productivity. They may be burned, or chipped for energy, or redistributed back onto the site. (Photo by F. Foreman.)

• **Stop logging operations during thaws, spring melt, and excessively wet periods.** Logging should not occur during spring thaw when mineral soils are susceptible to severe rutting and compaction. Use of winter roads during spring thaws can lead to compaction, erosion, slumping, washouts, and sedimentation. As a rule of thumb, operations should stop in the spring when temperatures stay above 0°C for three nights in a row.

As noted previously, however, operating in the spring adjacent to gravel roads when the frost is in the ground minimizes site disturbance. (R. Gemmell, Pers. comm.)

• **Do not use lakes, streams, drainageways, or wetlands for log or brush piles.** For winter logging areas, identify all streams, drainageways, and wetlands. Fine-scale mapping should include this level of detail. Log and brush crossings over streams or drainageways should be removed after harvesting.

• **Keep harvesting equipment out of streams, drainageways, and open wetlands.** Use long reach booms or cables for extraction. See recommendations in Chapter 4 Road-building, Chapter 12 Forested Wetlands, and Chapter 13 Riparian Areas.

Minimize Losses of Nutrients and Organic Matter

Maintain slash on site whenever possible (Figure 5-15). A major concern expressed by ecologists has been that full-tree logging will remove nutrients and reduce the productivity of the next or future rotations. The main method to reduce nutrient losses is to employ tree-length harvesting, leaving slash on site near the stump, or as brush mats on the harvesting trails. There are advantages and disadvantages to leaving slash on site:

Advantages of leaving slash on site:

1. Slash intercepts precipitation and slows runoff;

2. It provides shade for seedlings and possibly limits competition;

3. The foliage and fine branches provide a readily available source of nutrients for uptake by the vegetation and the juvenile stand;

4. Slash provides organic material, which adds to the surface organics, and with decomposition and leaching, particulate and dissolved organic matter is incorporated into the underlying mineral soils;

5. Organic matter in mineral soil is important to hold moisture and nutrients;

6. Organic matter provides substrates for soil micro-organisms and invertebrates, which play a critical role in recycling and making nutrients available;

7. The retention of organic material at the surface protects mineral soils from "weather" effects (e.g., frost heaving, crusting, surface erosion);

8. Reductions in nutrient reserves and organic matter may impair tree nutrition, vigour, and resistance to insects and diseases;

9. When equipment operates on a cushion of slash, soil compaction, soil exposure, and potential for erosion are reduced (Figure 5-15);

10. Disposal of slash is not a problem.

Figure 5-12. Harvesting and site preparation should be different on peatland versus mineral soil upland. Top: The use of wide-tired or tracked, low ground pressure equipment minimizes rutting and compaction on saturated soils. Bottom: Excessive rutting because of summer harvesting with the wrong equipment for peatland. (Photos by M. Kershaw.)

Disadvantages of leaving slash on site:

1. Heavy slash may damage or kill advance regeneration;

2. Heavy slash may present problems for subsequent site preparation and regeneration;

3. Slash may act as a lattice for rapid upward growth of *Sphagnum* in wetlands;

4. Extra costs of introducing an alternate logging system or mixing the logging systems; changes in the system require changes to logging, hauling, and mill handling.

- **Manage the slash so that regeneration can still be accomplished.** On more fertile sites, slash is often more abundant. Here preservation of nutrients and biomass is not critical, and full-tree logging can be used. On sites that are sensitive to nutrient loss, delimbing should take place at the stump leaving the slash there, or delimbing on the logging trails in front of the harvesting machine so that the slash can act as a brush mat to reduce compaction and rutting.

- **Employ tree-length harvesting on sites with low nutrient reserves.** Full-tree harvesting removes more nutrients and organic matter from the site than tree-length. Based on the research available, we recommend the use of tree-length harvest for the sites with the highest potential for losses of nutrients and/or organic matter.

These are the shallow-soil sites and dry coarse-soil sites. However, this must be balanced against the extra costs of having mixed logging systems.

- **Set rotation periods appropriate to rates of replenishment.** The time between harvests should be sufficient to replenish soil organic matter and nutrient supplies lost in biomass removals of the crop. Shortened rotations should definitely not be considered on nutrient-poor soils, and probably not on medium sites either.

- **Plan harvests so that leaves fall off and remain on site.** When possible, harvest in the dormant season and after leaf fall. During the growing season, if possible delay skidding to allow leaves to dry and fall on site. However, this may not be a practical option, because it is expensive to move equipment several times to and from the same site. Allowing trees to dry out may contribute to enhanced fire risk as well.

- **Redistribute slash back onto site where nutrients may be limited.** Roadside processing produces piles of branches, bark, twigs, needles, sawdust, etc. that provide poor seedbeds. The land covered with debris should be restored. Woody debris could be chipped, and along with other fine debris, redistributed back onto the site. However, this may not be a practical or economic option. More research is required to demonstrate the benefits.

- **Burn or remove the slash and logging waste.** The Ontario Ministry of Natural Resources (2001) suggests burning roadside slash/chipping waste where it cannot be redistributed. There are other possibilities for slash: leaving as piles on site for erosion protection or biodiversity habitat; as fuel for co-generation plants; and as material for composting.

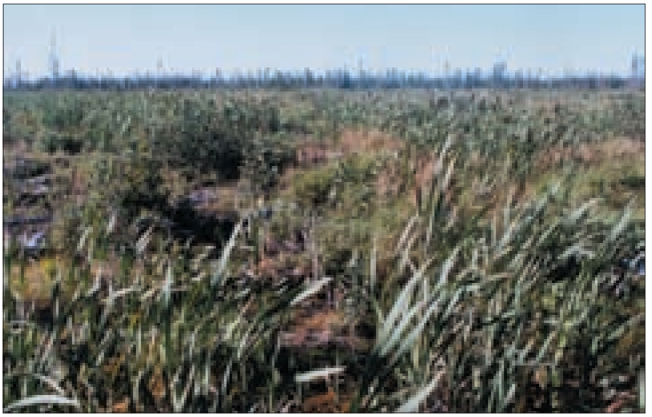

Figure 5-13. Rich peatland and wet mineral sites are easily disturbed and mucked up by summer harvesting, and water tables often rise after cutting. Rapid development of cattails, grasses, sedges, and other competition may ensue, making regeneration difficult. It is important to minimize competition and regenerate promptly. (Photo by M. Kershaw.)

Figure 5-14. Winter harvest on a cushion of snow reduces the risk of compaction and rutting on fine-textured, moist mineral, and organic soils. (Photo by A. Groot.)

Equipment Considerations

- **Use equipment that provides optimal balance between operational and environmental criteria.** Obtain appropriate sets of equipment – harvesters, forwarders – suited to different operational and environmental requirements. Some of the factors that affect equipment selection are:

1. Potential site impacts—ground pressure, rutting likelihood, residual tree damage;

2. Terrain—slope, ground profile, streams, wetlands, gullies, roughness;

Figure 5-15. Brush mat produced by a single-grip harvester in an Abitibi-Consolidated Inc. partial cutting operation, Iroquois Falls Forest, 1994. (Photo by A. Groot.)

3. Soil—texture, moisture content, bearing strength, erodability;

4. Timber characteristics—tree size, volume per hectare, timber quality, windfirmness;

5. Business requirements—worker safety, costs of operating, operating season, log specifications, service, transportation, purchase/rental/lease;

6. Weather and climate—hazardous working conditions, wind, deep snow;

7. Silvicultural systems—equipment maneuverability and size;

8. Legislation, regulations, or permit requirements—stump heights, breakage, forwarding distance, soil disturbance guidelines, other guidelines (e.g., MacDonald 1999).

• **Obtain appropriate equipment for the site and timber.** The general site and timber characteristics must be examined, and the equipment fleet selected to suit those conditions. The time horizon, related to budget and capital amortization, is generally three to five years or longer for major capital purchases. Sometimes the equipment available is limited by budgets or other commitments. Hence, instead of asking "What equipment is suited to this site?" the question becomes, "What site is available to use this equipment?" (MacDonald 1999).

Chapter 6.
Site Preparation

"The most reasonable choice ought to be a site preparation approach which combines acceptable survival and growth with a minimum of site preparation and planting costs, while reducing soil surface disturbance." *(Hallsby 1994)*

Site preparation is done for one or more reasons:

- to prepare receptive seedbed for seed regeneration or planting
- to prepare access for easier planting, ground seeding, aerial seeding, and tending
- to improve the growth of the seedlings by improving the moisture, nutrient and/or temperature conditions
- to discourage competition

There are two extreme approaches to site preparation: 1) deep tillage to mix the organic with mineral soil, to provide optimum soil preparation, and optimum stand growth and productivity, and 2) no site preparation at all, preserve the advance growth, seed on or plant directly into the organic mat. These approaches complement, more or less, the two extreme levels of management intensity – intensive and extensive.

Detailed recommendations for site preparation for the full range of forest ecosystem site types in northern Ontario have been given by Sutherland and Foreman (1995). Several reviews of soil impacts have been published (e.g., Archibald et al. 1997; Arnup 1998, 2000).

General Principles

- **Site preparation should be prescribed for each ecosite type and stand condition.** Objectives for site preparation should be defined on the basis of ecosite and forest stand condition. It is not appropriate to apply one technique universally across the landscape.

- **Select methods that accomplish the objectives with minimum disturbance and cost.** In general, apply just enough disturbance to achieve good survival and growth of seedlings (Hallsby 1994). For extensive or basic management levels, use low to moderate impact mechanical techniques for limited disturbance. For intensive forestry on more fertile sites, higher mineral-organic mixing may be warranted, but watch for rapid vegetational regrowth.

- **Minimize disturbance to minimize competition.** In fertile sites vegetation regrowth can be rapid and luxuriant, and competition with crop trees may be high. Use patch scarification or **mounding** (Holgén and Hånell 2000) to elevate seedlings above competition. Regenerate as soon as possible after harvest, use large nursery stock, apply herbicides or manual tending if necessary.

- **Minimize disturbance to the organic mat (forest floor)**. The overriding principle should be to maintain as much of the forest floor and organic mat on site as possible. This will reduce mineralization and loss of nutrients and organic matter, maintain moisture, and provide habitat for numerous micro-organisms, invertebrates, and fauna. It is advantageous to leave residual trees and living vegetation to maintain living mycorrhizal associations, thereby sustaining nutrient cycling (e.g., Maser 1988; Perry et al. 1989).

Extensive and Basic Forest Management

- **Be aware of potential species shifts.** CLAAG tends to encourage balsam fir and trembling aspen. Balsam fir is not a desirable crop tree, whereas on certain sites and in certain areas, trembling aspen can be. The manager has to decide if site preparation is required to maintain the forest unit in the desired crop species (R. Gemmell, Pers. comm.).

• **Avoid site preparation where there is abundant advance regeneration**. Apply selective site preparation to areas where there is limited advance regeneration. Use specialized hand scarifiers or develop special mobile equipment.

• **Select mechanical scarifiers that provide just enough disturbance for the lowest cost.** Examples are row trenchers and patch scarifiers (Figures 6-1, 6-2, 6-3), which are used to expose mineral soil, and do some mounding and mixing of organic with mineral soils. Soil exposure and mixing will improve soil moisture and temperature, and accelerate rates of decomposition and nutrient release.

• **On sensitive sites, site prepare delicately or not at all.** Site preparation on mineral soils will promote increased exposure and drying, erosion, and/or nutrient losses depending on the site. On wetlands, site preparation should not destroy existing advance growth, and should not go deeply into the surface peat.

• **On sensitive mineral soil sites, prescribe burn at low to moderate intensities or not at all.** Sites include very dry, sandy coarse soils, and shallow soils over bedrock. Prescribed burning will promote exposure, erosion, and nutrient losses. On wetlands, prescribed burning will destroy advance growth, and may start long-lasting peat fires.

Figure 6-2. Top: Disc trencher, powered. (Photo by B. Sutherland.) Bottom: Shallow trenches expose mineral soil, realign slash, and mix surface organic soil with underlying mineral soil to create favorable planting or seeding microsites, and to reduce competition from non-crop species. (Photo by J. Jeglum.)

Figure 6-1. Mould-board plow with trailing row seeder behind small bulldozer. (Photo by L. Riley.)

• **Use the harvesters and forwarders to site prepare.** The manager should take advantage of the harvesting equipment if possible to create good seedbeds for seed germination, or good planting micro-sites. Seeders have been developed that deposit a few seeds at the stump each time a stem is cut by a feller-buncher (Tembec-Spruce Falls).

• **Retain advance growth and vegetation on site.** Advance growth, unmerchantable (but not poor-quality) trees, and understory vegetation should be left on site, to maintain rhizospheres and promote uptake of released nutrients following harvesting and site preparation.

Figure 6-3. Above: Patch scarifier creates lines of patches with similar effects as the disc trencher. Right: An exposed patch of mineral soil. These are preferred microsites for seeding and planting. (Photos by F. Foreman.)

Retention of the organic mat and ground cover also reduces the risk of soil loss on steep or easily eroded soils.

- **Use prescribed burns on intermediate to rich soils with heavy slash or thick organic layers** (Figure 6-4). Prescribed burning may be useful to reduce heavy slash and competition, liberate nutrients, provide warmer soils, create receptive seedbed, and stimulate seedling growth. Burning may reduce competition, and also may reduce disease and insect incidence. On the other hand, burning destroys existing advance regeneration, and there is a danger that the fire can get out of hand and remove too much organic matter, or create long-lasting peat fires (Weber and Taylor 1992). Chemical site preparation may be done to kill or brown vegetation just prior to a prescribed burn (see Chapter 8, herbicide treatments). Use appropriate guides to prescribed burning (e.g., Wearn et al. 1982).

- **Avoid prescribed burning on sensitive sites.** Where site fertility is low, organic matter and nutrients should be conserved on site. Intense prescribed burns may remove high amounts of N, reduce the organic mat, expose mineral soil to erosion, and reduce the productive capacity of the site. Even minor reductions in soil organic matter may reduce soil moisture and nutrient retention in poor sites. However, on slightly less poor sites, jack pine *may* be managed best through appropriate prescribed burning.

Figure 6-4. Prescribed burning of cut-overs on fertile soils improves seedbed conditions without degrading site productivity. (Photo by M. Wiltshire.)

• **Do not blade on sensitive sites** (Figure 6-5). Blading off the organic mat and upper mineral horizons removes stores of organic matter and nutrients, and soil micro-organisms and invertebrates important for nutrient cycling. Exposing the mineral soil increases surface temperatures, mineralization, leaching, and impact of raindrops and soil erosion. Blading may actually promote seedling growth in the early years on some sites, such as coarse to medium soils with sufficient moisture. However, blading of clays, silts, or very fine sands may expose the soil to baking and cracking, reduce growth, and increase frost heaving.

• **Apply shearblading in cutover peatlands and non-stoney, wet to moist soils. Shearblading** is conducted in the winter with a bulldozer equipped with a very sharp horizontal blade, shearing off the tops of mounds, aligning the slash, and creating corridors for planting or seeding. Sites that require this have low amounts of advance growth, or higher amounts of undesirable crop trees (e.g., balsam fir, white birch). With some black spruce regeneration, shearblading lines should be spaced widely; however, they should be more narrowly spaced where there is more fir, birch, and aspen on shallower peats (Figure 6-6).

• **Minimize site preparation on slopes.** The risk of erosion increases with increasing steepness of slopes and with increasing exposure of mineral soil. On steeper terrain, prescribed burning, contour disc trenching, or intermittent patch scarification is preferred. If furrowing up and down slopes, interrupt the furrows to slow runoff and prevent gullying. Use only the minimum site preparation to achieve the regeneration goals. On steeper slopes, consider no site preparation and planting directly into the organic mat.

Figure 6-5. Blading (corridoring) off the organic mat removes a significant proportion of the nutrient and N reserves. This should not be done in coarse, dry sites, but may be acceptable in richer sites where organic reserves in soil are high. Top: Saskatchewan, Smooth Stone Lake. (Photo by D. Beales.) Bottom: Wells Township, Ontario, jack pine trial, blading treatment. (Photo by P. Hazlett.)

Intensive Forest Management

• **Fertilize to replace nutrient losses.** Site fertility may be maintained or improved by amendments and fertilizers (Morrison and Foster 1995). Applications of inorganic fertilizers, chipped slash and needles, wood ash, and sewage water/pellets are all methods to replace lost nutrients and organic matter (when present). However, these intensive solutions may have unexpected side effects and may not be economical. Note that the Class Environmental Assessment by the MNR for Timber Management in Ontario (Environmental Assessment Board [Ontario] 1994) did not endorse the use of fertilizer for forest management. Consequently, this practice may not be freely undertaken within the Province except as part of an approved research project.

• **Employ intensive soil cultivation only to fertile and deep soils.** Intensive site preparation includes blading, deep plowing or tillage, mounding, and bedding. On deep, very fertile soils intensive tillage may improve temperature, nutrient and moisture conditions, soil structure, and plant growth. Mixing surface

Figure 6-6. Top: Shearblading in winter, with heavy bulldozer equipped with very sharp blade. (Photo by J. Jeglum.) Bottom: In this operation, spacing was adjusted according to how much regeneration is showing above snow. With abundant regeneration, either no shearing or widely-spaced lines were placed, while with sparse regeneration shearing lines were closer together. (Air photo courtesy of Abitibi-Consolidated Inc.)

organics with underlying mineral soils distributes soil organisms throughout the upper horizon of soil, and may reduce root decay infections. However, radical scarification is not recommended on poor sites where the nutrient or carbon reserves are low and where slash is a major contributor to the site's total nitrogen.

• **Employ forest drainage in wetlands and peatlands.** Forest drainage is a well established method of site improvement to increase tree growth. The main effect of drainage is to increase the thickness of the surface aerated horizon so that tree roots have access to a greater depth of aerated soil, and more available nutrients (e.g., Jeglum et al. 1983; Jeglum and Overend 1991).

Note that the Class Environmental Assessment by the MNR for Timber Management in Ontario (Environmental Assessment Board [Ontario] 1994) did not endorse the use of drainage for forest management. Consequently, this practice may not be freely undertaken within the Province except as part of an approved research project.

• **Employ mounding in moist mineral soils and rich wetlands.** Mounding is an effective site preparation technique that provides aeration to soils and elevates planted seedlings above competition (Sutton 1991; Holgén and Hånell 2000). Mounding may be conducted on upland and wetlands. In wetlands it may be done simultaneously with drainage, using the spoil from the ditches as mounds (See Chapter 12 Forested Wetlands).

Chapter 7.
Regeneration

> "Regeneration should not be a last minute decision; it should be planned far in advance. Without prior planning, many alternatives will not be available, especially if you wait until after the trees are harvested." *(Ezell 1990)*

The forest manager must consider regeneration as part of a complete system of planning, road building, harvesting, site preparation, regeneration, and tending. Without prior planning and integration, many renewal alternatives will be unavailable, especially if one waits until after the trees are harvested. If early establishment and growth of the seedling plantation is reduced by poor practices or other constraints, this may reduce the growth of the plantation for years or even decades. Unfavorable influences on the early establishment and growth of plantations can reduce the mean annual increment, lengthen the rotation, and reduce the quality of the wood products. A comprehensive treatment on all aspects of regeneration in Ontario has recently been published (Wagner and Colombo 2001).

General Principles

- **Regenerate promptly.** This is done to give seedlings a head start over development of excessive vegetational competition, and to reestablish connections of mycorrhizal fungi with roots before fungal populations diminish too much.

- **Assess regeneration success** in a timely manner. Determine if the regeneration has been successful, if additional regeneration treatment is required, and if spacing or competition control is necessary.

- **Regenerate by planting for basic forestry** when there is significant potential of high competition, good potential site productivity, or sites near the mill. Nursery seedlings grow faster initially and reach rotation faster than seed-origin seedlings.

- **Use natural regeneration for extensive forestry.** Regenerate using advance growth, aerial seeding, mechanical row seeding, seed spotting, or scarification/seed-from-slash. These seeding methods are appropriate for sites with low potential for competition, and sites far from the mill.

- **Take tree silvics and ecology into account.** It is essential to understand the silvics and ecology and choose the right species for the site. One must consider the responses and tolerances of species to primary environmental regimes, their rooting habits, rates of growth, susceptibility to frost, insects, and diseases, etc.

- **Match species to site.** As a general rule, replace the stands being harvested with similar stands. However, changes in working group may be warranted if certain species are better adapted than the previous dominant. For example, one may shift towards jack pine for poor, coarse-soil sites, and towards black spruce for organic soils and wet mineral soils. Species with more demanding nutritional requirements, such as white spruce, trembling aspen and white birch, should be favored on more fertile sites.

Natural Regeneration and Seeding

"…alternatives to high cost systems require planning and effort from the forest manager prior to harvest — not just after the timber is cut." (Ezell 1990)

Natural regeneration and seeding are cheaper than planting, but they are not free. There is increased managerial effort in evaluation, planning, and supervision. There are also other costs such as **weeding**, **spacing**, and **thinning**, a possible need for fill planting or a second regeneration operation, and longer rotations. Finally, with natural regeneration one foregoes the opportunity to use genetically improved seedlings or better stock types than those naturally occurring.

Archibald and Arnup (1993) have given guides on the management of black spruce advance growth in northeastern Ontario. Groot et al. (2001) have summarized natural regeneration by advance growth and natural seeding in Ontario, and Groot (2001) has made a comparison of natural and artificial regeneration methods. A guide on artificial regeneration by seeding, emphasizing black spruce and jack pine, is nearing completion (Adams et al. In prep.)

- **Use natural regenerative forces** to minimize costs for raising, planting, and tending seedlings. If the regeneration comes naturally, it makes sense to use it.

- **Utilize advance growth for regeneration whenever possible.** Careful logging around advance growth is an acknowledged technique in peatland forests where there is abundant advance regeneration (Figure 7-1). Preservation of existing seedlings and unmerchantable trees is desirable for providing some or all of the next rotation individuals. This will also maintain existing genetic stock on the site.

- **Match silvicultural system to species.** For natural regeneration, the harvesting-regeneration system should be selected to fit the species that are chosen for management. Table 7-1 shows preferences for species for some natural regeneration systems, as related especially to shade tolerance.

- **Use small area clearcuts including strip cuts** for natural regeneration by seed (Jeglum and Kennington 1993; Figure 7-2). Natural seeding by black spruce and other species is a large regenerative force that should not be ignored. By using small area clearcuts, the seeding in from adjacent forests is used, and the small areas provide protection from exposure and increased probability of seed germination and establishment.

Table 7-1. Natural reproduction methods for Ontario conifers (Groot et al. 2001). Symbols: N = not feasible; F = feasible; R = recommended. Note that applicability of any one system is highly dependent upon site and stand conditions.

Species	Selection	Shelterwood	Harvesting with regeneration protection	Seed-tree clearcut	Small-tree clearcut[a]	Seed-in-place
Balsam fir	F	F	R	N	F	N
Red spruce	F	R	F	N	N	N
Black spruce	F	F	R	F	R	N
White spruce	N	F	N	F	F	N
White cedar	F	F	F	N	F	N
White pine	N	R	N	F	F	N
Red pine	N	N	N	F	F	N
Jack pine	N	N	N	F	N	R
Tamarack	N	N	N	F	F	N

[a] Stand edges provide the seed source.

Figure 7-1. Advance growth regeneration release after clearcutting. Advance growth responds to improved light, temperature, nutrient and moisture conditions, and recovers to grow very well. (Photo by D. Morris.)

- **Site prepare as soon as possible after harvesting** to provide receptive seedbed. Provide enough receptive seedbed to achieve fully acceptable stocking levels. It is important to take advantage of the natural seedfall as early as possible to provide a head start for seedlings.

- **Use the scarification, seed-from-cones-in-slash method for jack pine.** If stem-only harvesting is done with delimbing on the site, cone-containing slash is left on site. This is followed by site preparation to provide seedbed for seeds coming from cones. However, if there is heavy slash it can interfere with site preparation. Manual redistribution of cone-bearing branches onto scarified surfaces can improve the catch of seedlings. The method is not recommended for black spruce, because dense cone-bearing tops directly on the ground often tend to smother and inhibit seed germination. (However, manual placement of individual cones on receptive seedbeds may be effective [e.g., Figure 7-2].)

- **Use seed from residual trees and seed-tree groups**. Circular seed-tree groups of black spruce, about 10 to 15 m in diameter and 100 m apart, can be left to provide seed. However, the regeneration gain from the seed trees is probably small (e.g., 5-10%), and the technique is regarded as only supplemental to the main regeneration technique being used, such as careful logging or direct seeding. If advance growth is mimimal, site preparation should be conducted around the seed tree groups.

- **Use direct seeding techniques.** Direct seeding, if conducted with the right techniques, can be an excellent, cost-effective method to regenerate jack pine (Adams et al. In prep.). Direct seeding of black spruce gives variable results. Some have suggested mixing black spruce and jack pine seed, and managing the resulting stand with two-storied management.

- **Monitor the establishment of seedlings.** Seedbeds 'mature' and become less receptive with time. If adequate levels of seed-origin regeneration are not achieved by year five, probably little additional natural regeneration will take place.

- **Conduct selective spot seeding/fill planting.** If adequate regeneration is not achieved, with too many unregenerated gaps, steps must be taken to seed or fill plant in the gaps, or to conduct a full regeneration operation again.

Regeneration by Planting

"…without active regeneration efforts, we have no control over what species will occupy the site or how long it may take for trees to cover the site." (Ezell 1990)

By planting, the manager has control over the species, stock type and quality, and spacing, and provides the seedlings a head-start over competition with potentially shorter rotation. As well, the manager has the option to use improved stock. Sutton (e.g., 1990, 1991) has conducted extensive research into both **stock quality** and planting methods. A symposium on seedling quality and grading was held in Ontario (Colombo and Noland 1997). A major compilation on regeneration in Ontario, including all aspects of growing and planting seedlings, has recently been published (e.g., Wagner and Colombo 2001).

- **Regenerate as soon as possible after harvesting and site preparation** to utilize the nutrient release effects, mimimize the influence of competition, and shorten the rotation. When heavy competition is anticipated, as on richer FEC types, plant large stock, especially for black spruce and white spruce. Smaller stock may be sufficient on medium to poor sites (Figure 7-3).

Figure 7-2. Top: Groups of seed trees for supplemental natural regeneration. (Photo by F. Foreman.) Bottom: Seedlings of black spruce on receptive seedbed, originating from cones in slash on ground. (Photo by D. Mossa.)

Figure 7-3. Plantation of 5-year-old jack pine from jack pine biomass removal experiment. Organic mat removed, soil compacted, and herbicided. (Photo by P. Hazlett.)

- **Plant seedlings as soon as possible** after they are lifted from the nursery or taken from cold storage (Paterson et al. 2001). Allowing seedlings to sit for days or weeks before planting is poor practice, owing to problems with too early flushing of buds and root development, and possible dessication.

- **Plant quality stock in good physiological condition.** Evaluation of stock quality is a key component of any planting program (IUFRO 1980; Sutton 1990). Seedlings should be in good physiological condition when they are planted, e.g., with high "root growth capacity" (Sutton 1991), good moisture contents, and appropriate "nutrient loadings" (Timmer 1997).

- **Plant into optimum seedbeds that are conducive to seedling establishment.** Optimum seedbeds will minimize moisture stress, and optimize temperature, nutrient supply, soil aeration, and organic-mineral mixing. A large body of literature deals with creating optimum seedbeds and correct placement of seedlings (e.g., Sutton 1991; Sutherland and Foreman 1995).

- **Consider planting into duff with no site preparation.** Some studies in mid-boreal conditions in northern Sweden, for example, have shown that planting directly into the duff, with no site preparation, gives good survival and growth (Hagner and Molin 1998). Terminal shoot lengths of Norway spruce 3 years after planting were not significantly different among treatments—no treatment, humus over mineral, humus-mineral mix, and mineral (Hallsby 1994).

- **Select the right provinance.** Follow the best knowledge and practices for selecting seed from the correct seed zone (e.g., Joyce and White 2002, Seed Zones of Ontario Web Site). Genetic diversity and provenance (locality of origin) of trees will influence seedling performance and ultimately forest productivity.

• **Use improved trees, but also maintain natural genetic diversity.** Black spruce is highly variable and tree improvement programs in Ontario have produced superior seed and clonal stock. At the same time consideration should be given to maintaining genetic diversity, possibly by designating certain forests for natural regeneration systems within ecoregions and ecodistricts (e.g., Joyce 1994).

• **Maintain broadleaf content.** When partial harvesting is conducted, or when advance growth is being used, some broadleaf trees, such as aspen and birch, could be maintained to keep full stocking. In addition, maintaining some broadleaf content will promote biodiversity of other organisms that use broadleaf trees.

• **Consider alternating broadleaf and conifer crops**. The broadleaf trees will improve the nutrition of the site by one or more factors: 1) the pumping effect of Ca and other cations owing to deeper penetrating roots; 2) enrichment of the litterfall by the broad leaves which have higher concentrations of nutrients than spruce and pine; 3) the greater penetration of light and heat to the forest floor, which will promote higher nutrient cycling rates and higher productivity (e.g., Figure 7-4).

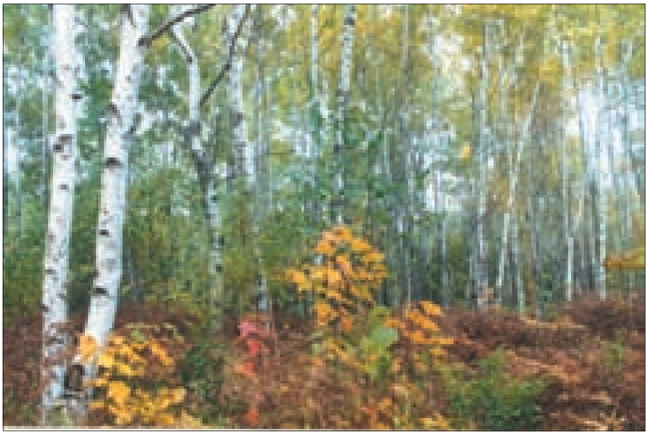

Figure 7-4. Paper birch stand. Broadleaf species such as birch and trembling aspen have deeper roots than conifers, and act as a "cation pump" bringing Ca, Mg, and other elements from deep soil layers and redepositing them in litterfall on the ground surface. Broadleaf litter is higher in cations and pH than that of conifers. (Photo by M. Kershaw.)

Chapter 8. Thinning and Tending

"Thinning, based on sound silvicultural principles, is the most natural, most effective and — probably — the cheapest method of maintaining a high level of production or promoting the productive capacity of forests." *(Vuokila 1976)*

Tending and thinning operations are intended to increase the size and quality of the stems, by regulating the density and degree of intra- and interspecific competition. The tending and thinning operations are weeding and spacing, precommercial thinning, commercial thinning, and pest management measures.

Weeding, Spacing, and Precommercial Thinning

- **Conduct weeding operations.** Delays in control of competition can result in reduced seedling growth and significant volume slowdowns early in the stand development, but this depends on how dense the young stand is. Herbicide applications, motorized brush saws, and brush axes are used to remove competition and to select and space good quality crop trees.

- **Conduct spacing or precommercial thinning**. Depending on the value of and demand for sawlogs, and the site quality, the manager may decide to conduct a precommercial thinning in juvenile stands that are too dense (Figure 8-1). Regenerating areas should be assessed for density and clumping of the crop trees. Some crowding may be good for early stand development, to lengthen internodes, reduce branch size, and promote self-pruning.

With jack pine, developing appropriate spacing and thinning guides involves questions of desired wood quality and intended product, e.g., lumber versus pulpwood. Barbour et al. (1994) found that as spacing increased from 1.7 to 2.6 to 3.4 m, the density of the wood decreased. In addition, branches became larger, knots increased, and trees tended to develop poorer forms. Barbour (1991) cited studies suggesting that the best stem quality resulted from natural regeneration or direct seeding followed by precommercial thinning, and that delaying thinning until after crown closure minimizes branch size in the lower stem.

- **Leave some protection against frost.** In lowlands and potential frost pockets, leave some taller sheltering trees or broadleaf saplings for protection of seedlings from late spring frost. This is most important for white spruce.

Figure 8-1. Pre-commercial thinning provides soil warming, nutrients, moisture, and light for the remaining crop trees. Pre-commercial thinning should be done before the tree growth is reduced by crowding. Photo shows thinned (left) and unthinned condition in 37-year-old jack pine stand 15 years after treatment at age 22 years. (Photo by R. Smith.)

• **Follow literature and guides that are available** (e.g., Smith and Brown 1984; Haavisto et al. 1991; Newton 1997; Ontario Ministry of Natural Resources 1998).

Vegetation Management

• **Apply knowledge from the literature and recommendations from guides** (e.g., Ontario Weed Committee 1995; Wagner and Thomson 1998). Reduce potential for competition by canopy maintenance, low disturbance of forest floor and soil. Consult experts in environmental effects and best practices for application.

• **Apply herbicides to control competition** (Figure 8-2). Herbicides are most often required on fertile deep soils where vegetational regrowth is luxuriant after harvesting and/or site preparation. Broadcast methods should be applied with care and constraint. Selective treatment of target competitors is preferred. Seven herbicide chemicals and 21 herbicide products are registered for forestry use in Ontario (Campbell 1991; McLaughlan et al. 1996). Table 8-1 provides brief descriptions of the five main chemicals. (The other two registered chemicals, picloram and dichlorprop, are used in formulations with 2,4-D.)

Figure 8-2. Application of herbicide on speckled alder overstory to release black spruce. (Tembec-Spruce Falls. Photo by J. Jeglum.)

• **Apply herbicides prior to prescribed burn or mechanical site preparation.** This guideline is applicable to backlog or failure sites where competition has gotten out of control, which emphasizes the need for prompt regeneration operations.

• **Handle chemicals and fertilizers carefully to avoid pollution.** Do not store, mix, or rinse containers with these substances below the high-water mark of adjacent water bodies. The following practices should apply:

1. know and comply with regulations governing hazardous substances;

2. do not transport, handle, store, load, apply, or dispose of any hazardous substance in lakes, streams or other water bodies;

3. develop an emergency clean-up plan for hazardous substance spills.

• **Do not apply herbicides near human settlements, recreation areas, or water sources.** Take into account the potential movements of herbicides and pesticides in the environment. Consider runoff into streams, deep leaching into aquifers, berry and mushroom collecting areas, camping areas, etc.

• **Follow all relevant precautions and regulations** regarding safe handling and spill management (Health and Welfare Canada 1986; Ontario Ministry of Enviroment 1990; Ontario Ministry of Natural Resources 1991b).

Commercial Thinning and Density Management

• **Conduct commercial thinning and manage stand density.** To increase site productivity use thinning and **density management** guides for the major crop species (e.g., Haavisto et al. 1991; Smith 1996; Newton 1997; Ontario Ministry of Natural Resources 1998; Figure 8-3). Selective thinning and low thinning are used for producing sawlogs. For black spruce, selective thinnings from above and uneven-aged management might be appropriate for producing pulpwood (MacDonell and Groot 1996; Groot 1997).

Table 8-1. Main herbicide chemicals, target species, and selected advantages and limitations (from McLaughlan et al. 1996).

Active Ingredient	Target Species	Advantages	Limitations
Glyphosate	Selective, broad spectrum, controls most annual, perennial and woody species. Very effective on deep-rooted perennials, and biennial grasses and sedges.	Conifers are resistant once buds have set and foliage has hardened. Completely biodegradeable, does not leach, and cannot accumulate in the food chain.	Strictly foliage active, no residual soil activity. Actively growing conifers subject to injury. Not effective against all species in a given area.
2,4-D	Controls many broadleaf weeds and woody species.	Available in several formulations for different applications. Economical. Allows removal of shrub and tree species while maintaining grass cover on right-of-ways.	Ester formulation can vaporize and drift out of target area. Will not control grasses or sedges. Resprouting is a problem and retreatments may be required.
Hexazinone	Broad spectrum of annual, perennial, and woody plants.	Liquid formulation acts as both a foliar and soil active herbicide. Can be applied at almost any time of year, including in light rain. Residual activity reduces germination of species with windborne seed and seed banking species. Granular formulation can penetrate multi-canopied vegetation and be effective on all strata.	Tendency to move downslope and out of target area. Not to be used on frozen ground. Rapid leaching on coarse soils. A site- and soil sensitive herbicide, need for careful prescription. Has some residual activity and may affect crop species planted too soon after treatment.
Triclopyr	Auxin type, selective, controls many woody, annual, and perennial broadleaf weeds.	Allows removal of shrub and tree species while maintaining grass cover on right-of-ways. Can be applied in dormant season using basal stem and bark treatments. Fast acting, good candidate for brown and burn treatments.	Basal bark treatment prevented by deep snow. Grass is tolerant. Jack pine more sensitive than other conifers.
Simazine	Selective herbicide to control grasses and broadleaf weeds. Mainly used in Christmas tree plantations, seed orchards, and for afforestation of abandoned fields.	Has residual soil activity and can reduce sprouting of certain species. Limited leaching capacity reduces risk of off-target movements.	Limited to applications in spring and fall. Residues cannot persist in soil for more than one season. Resistant species may invade site. Efficacy greatly reduced on sites with a surface organic layer.

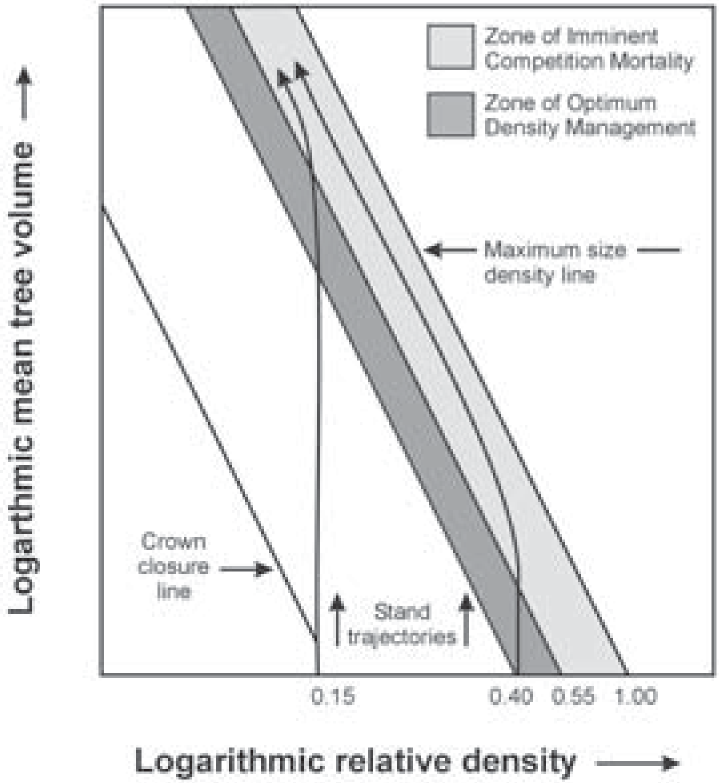

Figure 8-3. Stand Density Management Diagrams are average stand-level models that show the relationships between yield, density, and mortality at all stages of stand development. They are used to derive density control schedules through application of thinning interventions in the Zone of Optimum Density Management. (Adapted from Smith 1996, Figure 1d; cf. Newton 1997.)

- **Conduct thinnings so as to minimize disturbances and maintain wind stability.** To minimize potential for windfall, crown thinning with low amounts of removal may be most appropriate. This practice may be most relevant to sensitive sites for which uneven-aged management and **continuous cover forestry** would give protection and stability. Remove no more than 30% of the stand basal area per cut, uniformly distributed within the stand.

Pest Management Measures

- **Monitor plantations for potential insect and disease infestations.** The Great Lakes Forestry Centre Forest Health Monitoring Unit (Canadian Forest Service) and the Ontario Ministry of Natural Resources have monitored forest tree pests for many years and accumulated a large knowledge base (e.g., Whitney 1988; Myren and Laflamme 1994; Armstrong and Ives 1995).

- **Apply chemical or biological controls for insect outbreaks.** The main spraying programs are for eastern spruce budworm (balsam fir and white spruce) and jack pine budworm. Other significant insect pests are gypsy moth and forest tent caterpillar. Follow provincial spraying guides and practices (Ontario Ministry of Natural Resources 1991b) or contact the Forest Health and Silviculture Section, OMNR, for detailed information.

Part II.

BEST MANAGEMENT PRACTICES — SENSITIVE SITES

Chapter 9.
What Are Sensitive Sites?

The term sensitive site refers to areas that may easily be impaired, damaged or changed regarding productivity, biodiversity, health, or integrity. *(cf. 'Sensitive zones', MacDonald 1999)*

Sensitive sites are those that are readily changed or displaced from a condition of stability by forestry operations or any other natural or man-made disturbances. They are often not resilient, do not recover easily or rapidly to the previous condition of stability, may change into another kind of ecosystem with different structure and function, and often lose values compared to the original condition.

Recent literature reviews and guides have been completed for the impacts of forestry on soils and the physical environment (Archibald et al. 1997; Arnup 1998, 2000). The intensity of forestry impacts varies depending on the specific site conditions. Generally sites with deeper soils, medium to fine textures, intermediate moisture levels, and level to moderate slopes (e.g., Figure 9-1) are less susceptible to damage and are more resilient. On the other hand, sites that have extremes of one or more of these factors, or that are close to streams or wetlands, are sensitive to damage, and are less resilient. The sensitive sites in boreal Ontario are as follows (e.g., Figure 9-2):

1) shallow-soiled sites (Chapter 10);
2) dry, nutrient-poor coarse soil sites (Chapter 11);
3) forested wetlands (Chapter 12);
4) riparian zones (Chapter 13);
5) steep slopes (Chapter 14); and
6) other sensitive sites (Chapter 15).

The first three of these sensitive sites are included in the framework of Forest Ecosystem Classifications (FEC) for the boreal forest in Ontario (e.g., Jones et al. 1983; Heikurinen and Kershaw 1986; Sims et al. 1989; McCarthy et al. 1994; Harris et al. 1996; Racey et al. 1996; Taylor et al. 2000). The last three are sensitive site conditions that are often not specifically identified in the FECs, but should be recognized because of their particular instability, risks for damage, and values that could be lost. These are included under the riparian, steep slopes, and other sensitive sites chapters.

Figure 9-1. Moderately deep to deep, fresh to moist, and intermediate textured soils. These sites support optimum tree growth and are relatively resilient to disturbance. (Photo by M. Kershaw.)

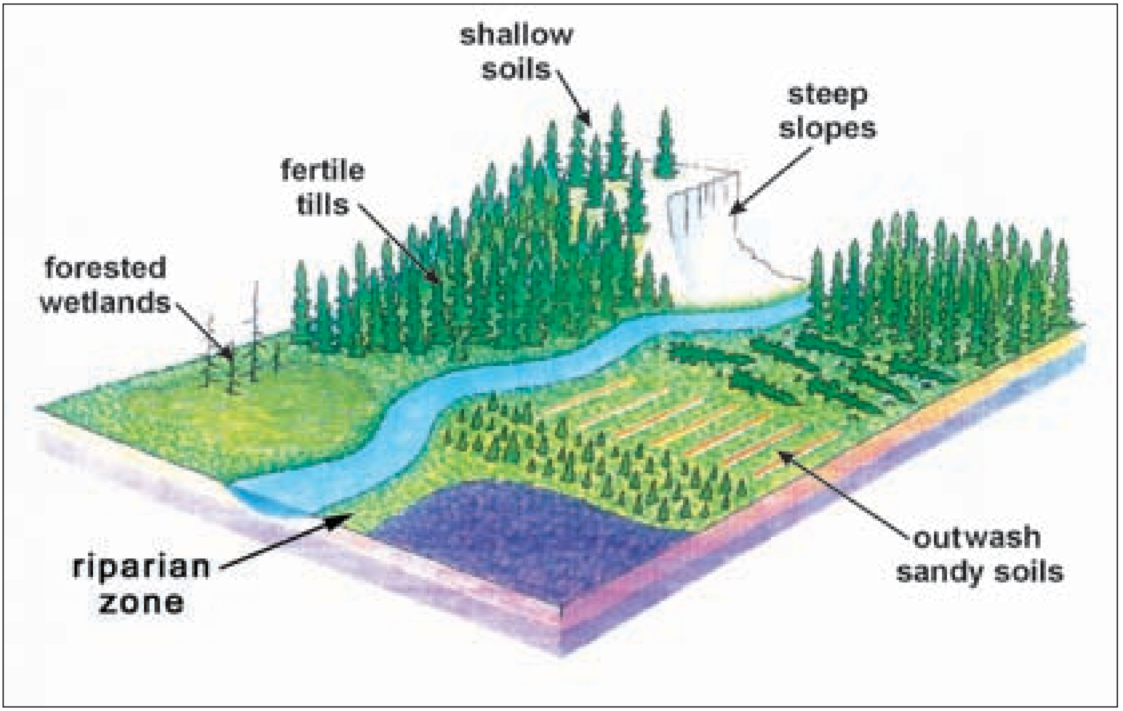

Figure 9-2. Some of the main sensitive sites: shallow soils; dry, coarse soils; forested wetlands; riparian zones; and steep slopes. These are all sensitive to losses in productivity and soil damage. (Illustration by S. Kennington.)

Chapter 10.
Shallow-soil Landscapes

Shallow-soil landscapes are areas where the average soil depth is less than 100 cm over bedrock. In actual forestry practice, mineral soils deeper than 40 to 60 cm are not usually recognized as "shallow". *(cf. Sims and Towill 1988; Ontario Centre for Soil Resource Evaluation 1993)*

On the Precambrian Shield in Ontario the underlying bedrock often controls the general topography, and shallow soils are common. Shallow soils are irregular complexes of bedrock covered by thin glacial tills and sand deposits. They often contain wet, peaty deposits in waterlogged basins and drainageways. The upland portions are dominated by black spruce, jack pine, or black spruce-jack pine mixtures; the peatlands are dominated by black spruce, white cedar, or tamarack.

The following references provide further information on management of shallow soils: Anon. (1987-88); Jeglum and Kennington (1993); Heikurinen and Kershaw (1986); Racey et al. (1989); Ontario Ministry of Natural Resources (1997).

Variation in Sites and Productivity

An edaphic model of the above variation is presented in Figure 10-1. This model is based on the classification of shallow soils in NW Ontario by Sims et al. (1989, SS1 to SS7). We regard 'sensitive' shallow-soil landscapes as the 'very shallow soil' types SS1, SS2, SS3, and SS4 as defined by Sims et al. (1989). These soil types are included in ecosites ES11 and ES12 in the NW Ontario FEC (Racey et al. 1996), and in ST1 (McCarthy et al. 1994) and ES1p and ES1r (Taylor et al. 2000) in the NE Ontario FECs. We note that the depth of mineral soil separating shallow from very shallow is 20 cm in NW Ontario, but 30 cm in NE Ontario. We recognize a very dry shallow site type that crosses all soil depth classes. Wet, organic sites may be found as a component in shallow soil landscapes.

There is a wide range of depths of accumulated organic mat over bedrock or mineral soil, from 0 to over 40 cm, dependent on moisture regime (more organic on moist and wet sites), and time since last fire (e.g., Figures 10-2 through 10-5). The shallow soil site types are as follows:

Very Dry Shallow Sites

Very dry moisture regimes may occur in all soil depth classes. These sites are usually dominated by jack pine, other pines, or broadleafs. The extreme dryness is indicated by the shallow organic mat, and such indicators as reindeer lichens, club and cup lichens, and xerophytic graminoids.

Boulder Pavement (SS4)

This type of site consists of very shallow-soil areas with variable depths of organic mat over a layer of cobbles, stones or boulders mixed with sands, gravels or tills (Figure 10-2). They may have subsurface seepage and moisture accessible to roots, in which case they may support moderately productive forests of black spruce and jack pine, and sometimes white cedar and white spruce.

Extremely Shallow (SS1 + SS2)

Theses are sites with average soil depths of less than 5 cm of mineral soil over bedrock, and variable depths of organic layers (Figure 10-3). These areas are generally poorly stocked with low to very low productivity. On air photos they are areas 4 hectares or larger with greater than 75% visible bedrock.

	Mineral Soil Depth				
Soil Moisture Regime and Depth of Organic Mat	Very Shallow on Boulder Pavement, <20 cm (SS4)	Extremely Shallow, <5 cm mineral (SS1 + SS2)	Very Shallow, <20 cm (SS3)	Shallow, 20-60 cm, on various textures (SS5, SS6, and SS7 in part)	Moderately Deep, 60-100 cm, on various textures (SS5, SS6, and SS7 in part)
Dry θ (<4 cm LFH)	4	4	3	2	2
Dry 0 (4-9 cm LFH)	3-4	4	3	1-2	1
Fresh 1-3 (10-19 cm organic mat)	2-4	3-4	2-3	1-2	1
Moist 4-6 (20-39 cm organic mat)	2-4	3-4	2-3	1-2	1
Wet 7-9 (=>40 cm organic, poor to rich)	2-4	2-4	2-4	1-4	1-4

Classification: Dark Gray = Very dry, shallow organic; Blue = Boulder Pavement; Light Gray = LFH over Bedrock; Yellow = Very Shallow; Light Green = Shallow; Dark Green = Moderately Deep; Red = Wetland and Peatland. **Productivity ratings:** 1= High, 2= Moderate, 3 = Low, 4 = Very low.

Figure 10-1. Two-dimensional model of shallow-soiled sites, with subjective productivity ratings.

Very Shallow (SS3)

Bedrock is encountered within 20 cm of the mineral soil surface. For air photo recognition, these are areas with 50 to 75% visible bedrock (Figure 10-4). The complexes often include some extremely shallow bedrock, and some shallow and moderately deep soil sites.

Shallow (SS5, SS6, and SS7 in part)

Sims et al. (1989) defined SS5, SS6, and SS7 as areas where average mineral soil depths range between 20 and 100 cm. SS5 has very fine to coarse sandy soils, whereas SS6 and SS7 have coarse loamy and fine loamy-clayey soils, respectively. Here we recognize 'Shallow' as those sites with 20-59 cm mineral soil over bedrock (Figure 10-5), with variable depths of organic layer. These areas are interpreted from aerial photographs as units with 20–50% exposed bedrock.

Moderately Deep (SS5, SS6, and SS7 in part)

These are areas of SS5, SS6, and SS7 where the average depth of mineral soil over bedrock ranges from 60–100 cm (cf. Figure 9-1) with variable textures and depths of organic mat. These have less than 20% exposed bedrock and are the least sensitive of the shallow soils.

Figure 10-2. Boulder pavement sites are where cobbles, stones or boulders are at the surface and create difficult conditions for forestry. (Photo by M. Kershaw.)

Figure 10-3. Extremely shallow soils, or 'rocklands', areas where average mineral soil depth is less than 5 cm. These have low resilience to clearcut harvesting. Vegetation cover is often discontinuous, found in areas where there are patches of soil or water. (Photo by M. Kershaw.)

Wet Peaty Sites

Organic depths greater than 40 cm characterize the wet, peaty sites, which are often included as a part of shallow-soil complexes.

Subjective productivity ratings are superimposed in Figure 10-1. For simplicity we have generalized the productivity ratings for black spruce and jack pine combined. The lowest productivities, and least nutrient reserves, are in the driest and shallowest of sites. The highest productivities and highest nutrient reserves are in the fresh to moist, moderately deep sites.

The greatest range of possible productivity ratings is given for the boulder pavement and wet sites. Categories of boulder pavement are variable because of the variation in quality of the finer matrix around and under the boulders and stones, and the amount of subsurface or surface water movement that is influencing tree roots. Categories of wet sites are variable in fertility, from poor to rich, depending on the richness of parent material and bedrock, depth of peat, and how much poorly decomposed **fibric** peat has accumulated. Hence productivity for wetlands varies from low (poor treed bog and poor swamp) to high (rich swamp). Generally the larger the peatland area the deeper the peat and the lower the productivity.

The risks of productivity loss are inversely related to productivity ratings, highest for boulder pavement and very shallow soil over bedrock, decreasing as soils become deeper. For the shallow to moderately deep soils, especially richer tills, another risk to growth of seedlings and saplings is competition from graminoids, herbs, shrubs, and broadleaf trees.

Concerns and Goals

Concerns for productivity loss for shallow-soil landscapes focus on nutrient losses, changes in soil moisture and temperature, soil erosion and runoff, compositional shifts, and competition (Table 10-1). The concerns are addressed with a number of goals that are intended to minimize changes.

Best Practices

Tables 10-2 and 10-3 present the best silvicultural practices for establishing black spruce and jack pine, respectively, on the 'very shallow soil' sites of the FEC classifications. We have drawn upon the silvicultural guides of the Ontario Ministry of Natural Resources (1997). We have chosen the recommendations for the most representative 'very shallow soil' site types: ES12 in NW Ontario (ibid. Book II), and ST1 in NE Ontario (ibid. Book III).

The recommendations for NW and NE Ontario do not always agree (Tables 10-2, 10-3). These differences may be a result of the drier conditions in

Table 10-1. Concerns and goals for management of shallow-soil landscapes.

Concerns	Goals
Nutrient losses	Keep nutrients and organic matter on site. Reduce rates of organic decomposition, organic and nutrient runoff, and leaching. Promote biotic capture of nutrients. An opposite view is to promote decomposition to make nutrients available to seedling growth. However, this may promote net nutrient loss from the site.
Soil moisture and temperature extremes	Soil too dry: minimize moisture loss, reduce exposure. Soil too hot: reduce soil temperatures, reduce exposure. Soil too cold: increase temperatures, increase exposure. Exposure of fine textures (clays, silts) causes baking, sealing, and frost heaving: minimize exposure of fine textures.
Soil erosion and runoff	Minimize physical displacement of soils. Minimize exposure of mineral soil. Minimize runoff
Compositional shifts	Minimize shifts of species, maintain black spruce and jack pine.
Competition	Control competition if required. Treatment generally not required on the very shallow sites, but may be required on the shallow to moderately shallow.

the west, with greater moisture stress on regeneration, and to different practices that have developed in the two regions. In the tables, we provide our recommendations for the two most sensitive subtypes of shallow soil—extremely shallow soil (SS1, SS2), and boulder pavement (SS4). Sometimes these recommendations are more restrictive than the ones given for the general class 'very shallow', owing to the more extreme conditions of these sites.

Some Additional Recommendations

- **Set a consistent Provincial definition of limits between shallow soils and very shallow soils.** The limit should correspond to the limit between full-tree logging and tree-length logging.

The FEC guides and OMNR guides (Ontario Ministry of Natural Resources 1997) are not consistent about the limits between shallow soils and very shallow soils. Sims et al. (1989) use 20 cm of mineral soil over bedrock as the limit between very shallow and shallow, whereas the classifications in NE Ontario (McCarthy et al. 1994; Ontario Ministry of Natural Resources 1997; Taylor et al. 2000) use 30 cm.

The OMNR guide for NW Ontario (1997, Book II) deviates from both of these and sets 20 cm of mineral *plus* surface organic depth as a limit below which full-tree logging is not recommended. We prefer the 'safer' limit of 30 cm of mineral soil, but more work is required to define this limit.

- **Use natural regeneration techniques whenever possible.** Supplement with direct seeding, or plant/fill-plant. Low-cost regeneration methods are appropriate for low productivity shallow soils.

- **Choosing crop species.** Black spruce is preferred on wet and moist sites, jack pine on the fresh and dry. In site complexes, direct seeding could be done with mixtures of both species. Species of broadleaf, and more nutrient-demanding conifers, may regenerate naturally. These should not be accepted on very shallow soils, but can be accepted on shallow and moderately deep if the parent material is moderately rich to rich.

- **Consider partial harvesting and continuous cover forestry,** if the stand structures and species ecology permit. Very shallow soils often warrant

Table 10-2. Silvicultural interpretations for black spruce on 'very shallow soils' (from the Ontario Ministry of Natural Resources 1997). Our recommendations for extremely shallow soil (SS1, SS2) and boulder pavement (SS4), and our additional recommendations and comments are italicized.

Silvicultural System	Boulder Pavement SS4	Extremely Shallow SS1, SS2	Very Shallow (SS1-SS4) NW, NE	Comments (only for NE Ontario, ST1)
Harvest Method				Portions of these sites may be classified as 'Protection Forest'.
• Clearcut				
-Conventional	*R*	*R*	R, R	*Use CLAAG to minimize site damage and protect advance growth.*
-Strip/Block	*CR*	*CR*	CR, CR	Strips must be no wider than the height of the trees as this is a dry sensitive site. Patch size width must not be wider than one and a half times the height of the trees as this is a dry sensitive site. Cuts should be oriented to minimize the effects of prevailing winds. This cutting technique may be prescribed to meet other management objectives.
-Patch	*CR*	*CR*	CR, R	See Conventional comment.
-Seed-tree	*CR*	*CR*	NR, CR	Group seed tree. Potential for seasonal drought will limit success of this treatment. Windfall may be a hazard on site.
-HARP (cf. 'selection from above' see Glossary)	*CR*	*CR*	**, NR	HARP applies to peatland black spruce stands only. *HARP can be used when there is an uneven-sized structure and sufficient advance growth. It could lead to 'continuous cover forestry' (see Glossary).*
• Shelterwood	*NR*	*NR*	NR, NR	High probability of windfall.
• Selection	*CR*	*CR*	NR, NR	Promotes shift in species composition to balsam fir and/or white cedar. *Selection from below is inappropriate for black spruce, because of windfall risk, and high cost compared to return of quality sawlogs. 'Selection from above' for uneven-aged management (see HARP above).*
Logging Method				Harvest on frozen ground or use high flotation equipment.
• Full-tree	*NR*	*NR*	CR, CR	Avoid this technique on the dry phase of this site (i.e., black spruce, jack pine only in overstory). See Logging Method comment. *We do not recommend full-tree on extremely shallow or on boulder pavement sites. Full-tree harvest might be used in the extremely shallow or boulder pavement sites if the logging slash is heavy enough to smother advance growth or impede further regeneration.*
• Tree-length	*R*	*R*	R, CR	See Logging Method comment.
• Cut-to-length/ Shortwood	*R*	*R*	R, CR	See Logging Method comment. *This method leaves slash on site, which can be used to create a root mat on logging trails.*
Site Preparation				Very low competition on this site.
• Mechanical	*CR*	*CR*	CR, CR	*For very shallow soil*, use light site preparation due to thin LFH layer. *Mechanical SIP should not extend through wet peaty parts of a shallow soil complex (see Chapter 12, Forested Wetlands).*
• Chemical	*R*	*R*	R, R	
• Prescribed Burn	*CR*	*CR*	CR, CR	Low severity fires on this site (average depth of burn should not remove more than 20% of organic matter). *On extremely shallow sites, we do not recommend prescribed burn. On boulder pavement it may be the only way to site prepare if there are large boulders and deep organic accumulations.*

Table 10-2. Continued

Regeneration				
• Natural				
-Advance Growth	*R*	*R*	R, R	*CLAAG and HARP can utilize this*
-Seed	*R*	*R*	R, R	*Natural seed from seed-tree groups, strips/blocks, patches, and distant forest edges*
-Vegetative (coppice)	*NR*	*NR*	NR, NR	This species does not regenerate by coppice.
• Blended*	*R*	*R*	**, R	
• Artificial				
-Planting	*CR*	*CR*	R, R	*Planting may not be cost effective on low productive sites, and there may be low success on extremely shallow sites.*
-Seeding	*CR*	*CR*	NR, R	*Direct seeding may be successful if one applies limited SIP for very shallow soil sites. We conditionally recommend (CR) mechanical SIP PB (see SIP guides above).*
-Scarification	*NR*	*NR*	NR, R	*Scarification regeneration probably will not be successful with black spruce on very shallow soil sites in the NW, but may have a better chance in the NE. It would require SIP, which we conditionally recommend (CR) for boulder pavement and extremely shallow.*
Tending Treatments				
• Cleaning				
-Manual	*R*	*R*	R, R	Treatment generally not required.
-Mechanical	*R*	*R*	R, R	Treatment generally not required.
-Chemical, Ground	*R*	*R*	R, R	Treatment generally not required.
-Chemical, Aerial	*R*	*R*	R, R	Treatment generally not required.
• Spacing	*CR*	*CR*	R, R	*Sites may not grow sawlogs, treatment probably not economical. May be more nutrient loss with spacing.*

R = Recommended, CR = Conditionally recommended, NR = Not recommended. * = Category used in NE but not NW Ontario guides. **= Not rated in NW Ontario.

extensive forestry options. We believe there are certain sites where selection cutting may be employed for black spruce. In boulder pavement and extremely shallow sites where there are uneven-sized structures and abundant advance growth, one could apply selection thinning from above to minimize windfall risk and to obtain regeneration. Continuous cover forestry may be the best way to regenerate these sensitive sites, maintain forest productivity, and maintain the protective and other non-timber production values.

- **For partial harvesting, use small to medium-size equipment,** maneuverable harvesters and forwarders, not skidders. Maintenance of the thin **LFH** and living, organism-rich organic mat is an important goal. Obtain or contract out such machinery for the instances where selection thinning and continuous cover forestry are used.

- **Avoid short-rotation forestry.** We recommend that short-rotation forestry, which is an intensive forestry method that will draw higher quantities of nutrients than basic forestry, be used on the deeper of the shallow soils, the moderately deep, and preferably richer soils.

- **Use the extremely shallow soils and boulder pavement sites as part of a system of protection forests.** Shallow soil areas offer an opportunity to provide patches or larger areas of no-cut, protection forest, which are beneficial for biodiversity, wildlife, and watershed protection.

Site-adapted Best Practices

Very Dry Shallow Sites

These sites should be dealt with very carefully, because with removal of forest and vegetation cover they may become so dry that they are hard to regenerate. As well, the organic mat, containing nutrients and soil organisms, should be protected as much as possible.

These sites can be full-tree harvested, tree-length harvested, partially harvested, or reserved as protection forest, depending on the depth of soil and potential risk of drying and nutrient loss. There may be light site preparation, or no site preparation for the shallower sites, and no prescribed burning. Maintain organic mat and live vegetation for both nutrient and moisture conservation. Regenerate to jack pine by planting, or scarification and/or direct seeding in block cuts as soon as possible after harvest. Maintain shading for protection against drying. Tend if required, and space using density management.

Boulder Pavement (SS4)

These sites are unstable for trees, and easily subject to disruption of the organic mats. They should be reserved as protection forest, or partially harvested with high thinning, or tree-length harvested, depending on fragility of the site. Keep machinery off boulder pavement if possible to preserve organic mats, harvest from edge of site with long reaching boom and cutting head, or manual ground cutting and careful extraction (e.g., high line, or cable). Do not site prepare. Linear site preparation (e.g., disk trencher) can canalize surface root development, and deep roots are impeded by boulders; therefore tree stability is compromised. Prescribed burning can remove too much duff, and kill advance growth. Move stand in direction of uneven-age and continuous cover forestry, fill plant to maintain stocking.

Extremely Shallow (SS1 + SS2)

Recommendations are the same as for boulder pavement.

Very Shallow (SS3)

The OMNR guide for the NW (1997, Book II) does not recommend full-tree harvesting where total soil depth (mineral and surface organic) is less than 20 cm. Full-tree harvest is permitted on sites where total soil depth exceeds 20 cm provided that a winter harvest is employed or when other measures such as high flotation equipment are used to minimize disturbance of the organic layer. The OMNR guide for the NE (1997, Book III) conditionally recommends full-tree, but advises to avoid it on the dry phase of the type. Very shallow soils are less than 30 cm mineral in the NE.

The depth criteria cited above are best guesses, and further work is required to determine how depth, soil parent material, and moisture regimes influence nutrient loss with full-tree and tree-length harvesting. A program has been established in the NW to monitor nutrient deficiencies where a not-recommended practice is used.

We conditionally recommend strip cutting or block cuts but owing to the dryness of the site, openings should be quite narrow, up to 20 m for dry (up to 40 m for fresh, moist and wet). The sites will require light site preparation to provide receptive

Table 10-3. Silvicultural interpretations for jack pine on 'very shallow soils' (from the Ontario Ministry of Natural Resources 1997). Our recommendations for extremely shallow soil (SS1, SS2) and boulder pavement (SS4), and our additional comments are italicized.

Silvicultural System	Boulder Pavement SS4	Extremely Shallow SS1, SS2	Very Shallow (SS1-SS4) NW, NE	Comments (only for NW Ontario, ES12)
Harvest Method				Portions of these sites may be classified as 'Protection Forest'.
• Clearcut				
-Conventional	*CR*	*CR*	R, R	*Use CLAAG to minimize site damage and protect advance growth.*
-Strip/Block	*CR*	*CR*	R, CR	Residual stand may not contribute seed of sufficient quantity *or genetic quality*. However, this cutting technique is preferred for site protection *and other management objectives. Orient cuts to minimize effects of windfall.*
-Patch	*CR*	*CR*	R, R	See Strip/Block comments.
-Seed-tree	*NR*	*NR*	NR, CR	Jack pine seed tree systems are used in conjunction with prescribed fire. Prescribed fire is not recommended due to potential loss of nutrient capital on these shallow sites. *Normally seed-tree is not recommended because of the serotinous cones (requiring heat to open and shed seed). Also windfall may be a hazard.*
-HARP	*NR*	*NR*	**, NR	Biologically inappropriate.
• Shelterwood	*NR*	*NR*	NR, NR	Jack pine is shade intolerant and generally not suited to this silvicultural system.
• Selection	*CR*	*CR*	NR, NR	See Shelterwood comments. *Selection thinning from below could be applied (CR), leaving trees with low windfall risk, and dense enough to maintain good tree form and self-pruning. Site quality should be high enough to potentially produce sawlogs.*
Logging Method				Harvest on frozen ground or use high flotation equipment.
• Full-tree	*NR*	*NR*	CR, CR	Full-tree is not recommended (NR) where total soil depth (mineral and surface organic) is less than 20 cm. Full-tree is permitted on sites where total soil depth exceeds 20 cm provided that a winter harvest is employed or when other measures such as high flotation equipment are used to minimize disturbance of the organic layer. *NOTE: The depth of shallow soil in NE Ontario is 30 cm mineral soil over bedrock.*
• Tree-length	*R*	*R*	R, CR	
• Cut-to-length/ Shortwood	*R*	*R*	R, CR	
Site Preparation				Very low competition on this site.
• Mechanical	*NR*	*NR*	CR, CR	Sufficient seedbed may be created as a result of the harvest. Apply techniques that maintain a high percentage of intact forest floor to limit the loss of nutrients. *For boulder pavement and extremely shallow soil, we do not recommend site preparation.*

Table 10-3. Continued

• Chemical	*R*	*R*	R, R	Shrub and herb poor. Chemical site preparation is generally not required.
• Prescribed Burn	*CR*	*NR*	CR, CR	Prescribed fire is conditionally recommended due to potential loss of organic matter and nutrients. Low severity fires that remove ≤ 20% of surface organic material are permissible. *On extremely shallow sites we do not recommend prescribed burn. On boulder pavement it may be the only way to site prepare if there are large boulders and deep organic accumulations.*
Regeneration				
• Natural				
-Advance Growth	*R*	*R*	NR, NR	Jack pine does not regenerate under a closed canopy.
-Seed	*R*	*R*	R, CR	Moderate to high levels of ingress. Supplemental artificial regeneration may be required.
-Vegetative (coppice)	*NR*	*NR*	NR, NR	Jack pine does not coppice.
• Blended*	*R*	*R*	**, R	
• Artificial				
-Planting	*CR*	*CR*	R, R	The number of plantable spots will be limited by soil depth. Natural seed and/or seeding are preferred options, as natural ingress will override density and distribution control objectives associated with planting. *Planting is a high cost activity and it may be more economical to opt for natural, supplemented by fill plant.*
-Seeding	*CR*	*CR*	R, R	Good distribution of mineral soil seedbeds will contribute to success. This site is prone to seasonal drought which will influence the success of this treatment. *Direct seeding may work well if there is not much of the extreme dry phase.*
-Scarification	*CR*	*CR*	R, CR	Insufficient data exist. Site conditions imply high levels of ingress. *Jack pine cone scattering has worked well on these sites in the NE.*
Tending Treatments				
• Cleaning				Very low competition, cleaning is generally not required.
-Manual	*R*	*R*	R, R	Treatment generally not required.
-Mechanical	*R*	*R*	R, R	Treatment generally not required.
-Chemical, Ground	*R*	*R*	R, R	Treatment generally not required.
-Chemical, Aerial	*R*	*R*	R, R	Treatment generally not required.
• Spacing	*CR*	*CR*	R, R	Spacing is usually not necessary since jack pine natural regeneration is well distributed. *In addition, jack pine thins itself well, spacing delays or stops self-pruning (lowering wood quality), and spacing may result in larger branches and poor stem form.*

R = Recommended, CR = Conditionally recommended, NR = Not recommended. * = Category used in NE but not NW Ontario guides. **= Not rated in NW Ontario.

Figure 10-4. Very shallow soils, areas where average mineral soil depth ranges from 5 to 20 cm with scattered patches of exposed bedrock. Site productivity is often half of that on equivalent soils of deeper depth. (Photo by M. Kershaw.)

Figure 10-5. Shallow soils, areas where average mineral soil depth ranges from 20 to 60 cm in depth. They are difficult to predict from the air and on the ground. These sites are more resilient to biomass removals than shallower soils. (Photo by D. Morris.)

seedbed, and tree-length harvest. CLAAG or HARP may be conducted if advance growth and/or small trees are abundant enough. In this case, winter harvesting and full-tree may be preferable to avoid smothering regeneration, and of course no site preparation. Do not use prescribed burning. Plant or fill-plant if necessary.

Shallow (SS5, SS6, and SS7 in part)

Best practices are conventional clearcutting, and small area clearcuts, such as strip/block and patch cuts. Logging method may be full-tree, tree-length, or cut-to-length/shortwood. Use light to moderate mechanical site preparation. If there is abundant advance growth, do not site prepare and do not prescribe burn, employ natural regeneration from advance growth or natural seeding, and fill plant as required. If there is little advance growth, use light to moderate mechanical site preparation, and regenerate by scarification, direct seeding, or planting. Prescribed burning is acceptable on fresh, moist and wet sites, but not on dry sites. Apply **zig-zag screefing** for natural regeneration of black spruce on moist sites. Apply tending if required. Apply precommercial and commercial thinning to favor sawlogs. Monitor developing stands on the shallower soils of this type for nutrient deficiencies.

Moderately Deep (SS5, SS6, and SS7 in part)

The management practices are more or less the same as those of deep mineral soils. If original stands are mixedwoods, decide whether to manage for the same proportions of conifer to hardwood, or to move the stands either to more conifer or more hardwood. Base this decision on soil conditions and distance to product mills.

Wet Peaty Sites

Moist to wet soils are subject to rutting and soil disturbances. Harvest on snow or when soil is frozen, or use low ground pressure equipment (e.g., Figure 5-14). Harvesting may be conventional clearcut, strip/block cut, or patch cuts. Use careful logging around regeneration. In the context of the shallow-soil landscape mosaic, consider moving the wetlands towards uneven-aged management, with continuous cover forestry. Do not site prepare or prescribe burn if advance growth is within acceptable stocking levels. Often it may be better to not site prepare and to regenerate by natural regeneration and fill-planting. If the areas are large enough to warrant a separate harvesting operation (e.g., 20 to 40 ha) they should be handled as forested wetlands (see Chapter 12).

Managing Complexes of Types

The main difficulty with shallow soil landscapes is that they consist of complexes or mosaics of different site types. Often one or two of these site types are dominant, and they determine what best management practices to use. It is desirable that the management methods are modified and adapted to suit the site variation.

For example, a shallow-soil complex may include all of the site types mentioned in this chapter:

- moderately deep to shallow soils that can be conventionally full-tree harvested and planted;

- very shallow sites that are tree-length harvested using small area clearcuts; and

- extremely shallow, boulder pavement; and forested wetlands that are partially harvested and managed for continuous cover, or left unharvested.

When on-site inspection allows one to separate out the shallow soil sites – SS1 to SS4 – best practices should apply to a buffer zone at least one tree height beyond the exposed bedrock areas. If there are high proportions of very sensitive sites in the mosaic, such as extremely shallow soil and/or boulder pavement, the whole area could be assigned protection forest, with harvesting being restricted to the outer edges of the area.

It is a challenge to the forest manager to develop variable, **site-adapted** best practices for the complex shallow-soil conditions to maintain their productivity and integrity.

Chapter 11.
Coarse Soil Sites

Sites that are dry or moderately dry, with textures that are gravels or cobble, very coarse and coarse sands, and loamy very coarse and coarse sands.

Coarse sandy to gravelly soils are common in the boreal forest of Ontario. Some of the associated landform types are glacial outwash, deltas, eskers, kames, beaches, dunes, and ground moraine (till). The usual dominant tree species is jack pine, which is well adapted to the low moisture and poor nutrient conditions of coarse soils, and to frequent wildfires. Black spruce may be codominant with jack pine on fresher soils, and dominant on moister soils. Several other broadleaf and conifer species with higher nutrient requirements become more important on soils having finer textures or lenses of finer material in a coarse matrix.

Figure 11-1. Dry, coarse soils often consist of glaciofluvial sand and gravel deposits. (Photo by M. Kershaw.)

Management of dry, coarse soils has not been dealt with as a featured site type, but is included in the context of several OMNR management guides (Heikurinen and Kershaw 1986; Racey et al. 1989; Ontario Ministry of Natural Resources 1997).

Variation in Sites and Productivity

Dry, coarse, to moderately fresh, medium textured sites are shown in Figures 11-1, 11-3 and 11-4. The sensitive site concept of 'dry and coarse' is not recognized specifically in the FEC site types and furthermore there is no consistency of treatment in the NW and NE Ontario FEC classifications (see footnote). The relationship of NE Ontario FEC Site Types (McCarthy et al. 1994) to soil textural types is shown in Table 11-1. Jack pine and black spruce are the dominants on the coarsest-textured soils, while mixed-woods and hardwood are more common on the medium-textured soils.

Footnote: In NW Ontario, the concept of dry and coarse is largely equivalent to the S1 soil type (dry/coarse sandy) defined by Sims et al. (1989), but is included as dry and coarse sites within several Ecosites of the OMNR guide (Ontario Ministry of Natural Resources 1997 - ES13 jack pine-conifer: dry-moderately fresh, sandy soil; ES14 pine-spruce mixedwood: sandy soil; ES15 red pine-white pine: sandy soil; and ES16 hardwood-fir-spruce mixedwood: sandy soil). In NE Ontario the dry and coarse sites are included in two soil types described by McCarthy et al. (1994 - S2 dry-fresh, non-calcareous sandy and S3 dry-fresh calcareous sandy), and in several Site Types defined by the OMNR (Ontario Ministry of Natural Resources 1997 – ST2a jack pine: coarse soil; ST2b jack pine: very coarse soil; ST3b mixedwood: coarse soil; ST4 jack pine: black spruce: coarse soil; and ST6c: hardwood mixedwood: coarse soil).

Table 11-1. Relationships of NE Ontario FEC Site Types to soil texture (McCarthy et al. 1994) and risk of productivity loss.

	Decreasing Coarseness of Textures →		
Decreasing Risk of Productivity Loss ↓	Very Coarse	Coarse	Medium
	Jack Pine-Very Coarse (ST 2b)	Jack Pine-Very Coarse (ST 2b)	
		Jack Pine-Very Coarse (ST 2b) Jack Pine-Very Coarse (ST 2a) Mixedwood-Coarse (ST 3b) Jack Pine - Black Spruce-Coarse (ST 4) Hardwood Mixedwood-Coarse (ST 6c)	
			Mixedwood-Medium (ST 3a) Black Spruce-Medium (ST 5b) Conifer Mixedwood-Medium (ST6b) Hardwood-Medium (ST 7b)

A two-dimensional model of soil variation is presented in Figure 11-2. The model was taken from the Ontario Soil Moisture Regime System (Ontario Centre for Soil Resource Evaluation 1993), which is used in all of the FEC classifications in the Province. In the scheme we include the 'medium' soil texture and 'moderately fresh' moisture class to show how the 'dry, coarse' soils relate to adjacent, less sensitive soils. The Ontario Moisture Regime model (ibid.) does not recognize certain combinations of texture and moisture regimes. These are the grey cells in Figure 11-2. However, these textural-moisture combinations may exist, and we have given them productivity classes that would logically apply.

Productivity is controlled primarily by nutrient regime and moisture regime. Nutrient regime is represented primarily by texture, increasing from cobble and gravel > 2mm, to very coarse and coarse, to medium sand (0.5 to 0.25 mm). Moisture regime influences the availability of the nutrients by the amounts of nutrients in soil solution, and rates of weathering. Depth of organic matter generally increases with increasing moisture regime.

The risks of productivity loss are interpreted to be highest with lowest productivity ratings, and vice versa (Figure 11-2). Generally, the coarser and drier the soils, the less organic mat develops, and the more rapid is decomposition and leaching of nutrients.

Concerns and Goals

Concerns and goals for best practices on dry, coarse sites are summarized in Table 11-2. Five major concerns are nutrient losses, maintaining soil moisture, compaction, composition shifts, and competition. Goals address these concerns.

	Mineral Soil Texture (uncompacted parent material)		
Soil Moisture Regime and Depth of Organic Mat	All material > 2 mm	Very coarse and coarse sands: loamy very coarse and coarse sands	Medium sand: loamy medium sand
Dry θ (< 4cm)	1 all slopes VR	1	2
Moderately Dry 0 (4-9 cm)	1	2 all slopes R/VR	3 all slopes R/VR 3
Moderately Fresh 1 (10-19 cm)	2	3 g: 100-180 or G: 150-200 R/VR	4 g: 100-180 or G: 180-240 R/VR

Productivity ratings: 1 = Very low, 2 = Low, 3 = Moderate, 4 = High. R = rapid drainage; VR = very rapid drainage.

Figure 11-2. Two-dimensional model for dry, coarse soil sites and adjacent medium-textured and fresh sites. Management-oriented site types are shown in red, yellow, and green. These represent increasing nutrient supply and productivity potential, jointly influenced by texture and moisture.

Best Practices

Here we consider silvicultural interpretations for black spruce and jack pine on dry, coarse soils (Tables 11-3, 11-4). The FEC types that are closest to our dry, coarse sensitive site are ES13 and ST2b (NW and NE Ontario, Ontario Ministry of Natural Resources 1997, Books II and III). However, our dry, coarse soils are the drier and coarser phases of these types, and consequently we sometimes give more restrictive interpretations in the table. The interpretations for dry, coarse are often similar to the drier, shallow soil sites (cf., Tables 10-2, 10-3).

Some Additional Recommendations

- **Employ selection thinning, low thinning, and density management,** to favor development of larger stems and higher proportions of quality sawlogs in later entries.

Jack pine presents a good opportunity for increasing productivity and sawlogs by selection thinning and density management. We do not know if this will provide economic returns in the dry, coarse soils, or what the nutrient loss implications are. However, we conditionally recommend selection, commercial thinning for this site type. More research is needed to determine thinning strategies to achieve desired wood product types (sawlogs, wood density, etc.).

- **Maintain understory vegetation, forest floor, and root mat**. As much as possible, maintain vegetation and forest floor to act as a protective mulch. On these sites, significant competition is unlikely. Control programs for marginal levels of competition could be more deleterious than beneficial.

- **With full-tree harvesting** redistribute slash and debris evenly back onto site. This could be combined with low intensity, linear site preparation, and placement of cones on scarified microsites.

- **Reduce exposure and wind-speeds**, by reducing size of clearcut areas, and providing windbreaks. Take windfall into account in establishing small area clearcuts.

- **Use low ground pressure equipment**, minimize passes on logging trails, especially for medium-textured soils where compaction may occur. If compaction has occurred, plant appropriate fast-growing soil decompacting plants, and/or introduce appropriate decompacting soil fauna, if possible.

Figure 11-3. Dry, coarse soils often support jack pine forests of low basal area with a sparse understory of reindeer lichens and other xeric plants. These soils are often nutrient poor, and are likely to lose productivity with whole-tree logging. (Photo by J. Jeglum.)

- **Do not employ short rotation forestry** on these dry, coarse sites, unless accompanied by fertilization or redistribution of slash back onto site. Further research on nutrient supply and loss is required for this specific site.

- **Avoid blading scarification.** This exposes large areas, removes the vital organic mat, and exposes the mineral soil to extremes of temperature and moisture.

- **Species to favor.** Maintain jack pine, or combine with red or white pine, on this dry, coarse site. Red pine may perform best in the southern boreal fringe. Black spruce will not do well on these dry, coarse sites, although on coarse but moderately fresh soils it should do well in mixture with jack pine. Paper birch requires richer, moister sites for optimum growth, but it could be used as a nurse crop or soil improver that will not be overly competitive with the pines. Avoid trembling aspen, this site is not optimum for it, but it may establish itself and cause competition problems with the pines.

Site-adapted Best Practices

Very low productive sites

These sites have the coarsest sands and gravels, and are quite dry. Indicators are reindeer lichens, club and cup lichens, xerophytic graminoids, and very shallow forest floors. The soil organic matter and nutrient reserves are limited. There is a high risk for nutrient loss and excessive drying. Very coarse sites grade into boulder pavement type (See Chapter 10).

The stands have low densities and open canopies owing to low moisture and nutrients. They need to be managed carefully to avoid dessication and loss of nutrients and organic matter. We recommend no cut, or light density crown thinning. One could also apply narrow strip cutting, thinning in leave strips, and planting in cut strips. Apply no or light scarification, and no prescribed burning.

Table 11-2. Concerns and goals for management of dry, coarse soils.

Concerns	Goals
Nutrient losses	Conserve organic matter, C and N reserves. Minimize the rate of organic decomposition and leaching.
Soil moisture	Conserve moisture in soil. Reduce extreme temperatures.
Compaction	Minimize compaction.
Changes in composition	Maintain dominance by jack pine on the very low to low productive sites. Accept mixes of jack pine and black spruce, and some broadleaf content, on the moderate to high productive sites.
Competition	Control competition if required.

Table 11-3. Silvicultural interpretations for black spruce: dry, coarse soil (Ontario Ministry of Natural Resources 1997: Book II, NW Ontario). Our recommendations and comments are italicized.

Silvicultural System	Dry, Coarse	ES13 NW, *	Comments (from NW Ontario guide)
Harvest Method			Portions of this site may be classified as 'Protection Forest'.
• Clearcut			
-Conventional	*CR*	R	*Use CLAAG to minimize site damage and protect any advance growth that is present*
-Strip/Block	*CR*	CR	An assessment of seedbed quality and the quality and quantity of black spruce parent trees in the leave strip is necessary to determine potential of this treatment. Strip width should be less than 40 m due to soil moisture regime. This cutting technique may also be prescribed to meet other management objectives.
-Patch	*CR*	CR	An assessment of seedbed quality and the quality and quantity of black spruce parent trees in the leave strip is necessary to determine potential of this treatment. Careful consideration must be given to the size and configuration of patches due to soil moisture regime. This cutting technique may also be prescribed to meet other management objectives.
-Seed-tree	*NR*	NR	Potential for seasonal drought will limit success of this treatment.
-HARP	*NR*	*NR*	Biologically inappropriate.
• Shelterwood	*NR*	NR	Black spruce is mid-tolerant and susceptible to windfall after thinning of closed canopy stands.
• Selection	*CR*	NR	See Shelterwood comment.
Logging Method			
• Full-tree	*NR*	CR	Full-tree logging is conditionally recommended provided that "best practices" are used to minimize disturbance of the surface organic layer. Where surface organic thickness averages < 5 cm, winter harvest and/or use of high flotation equipment should be considered to maintain the integrity of the surface organic layer. *We do not recommend full-tree on this dry site, but it may be acceptable on fresh sites that have more nutrient reserves.*
• Tree-length	*R*	R	Slash remaining on the site may reduce the effectiveness of mechanical site preparation and seedbed/plantable spot availability.
• Cut-to-length/ Shortwood	*R*	R	See Tree-length comment.
Site Preparation			Very low competition on this site.
• Mechanical	*NR*	R	Sufficient seedbed may be created as a result of the harvest. Apply techniques that maintain a high percentage of intact forest floor to limit the loss of nutrients. *For boulder pavement and extremely shallow soil, we do not recommend site preparation.*
• Chemical	*R*	R	
• Prescribed Burn	*NR*	CR	Prescribed fire is conditionally recommended due to potential loss of organic matter and nutrients. Low to moderate severity fire which removes $\leq$ 50% of the surface organic layer is permissible and will result in the creation of suitable seedbed/plantable spots. *On the dry, coarse sites we do not recommend prescribed burn.*

Table 11-3. Continued

Regeneration			
• Natural			
-Advance Growth	*NR*	NR	Black spruce advance growth is not of sufficient quantity or distribution to regenerate the site.
-Seed	*NR*	NR	Low levels of black spruce ingress.
-Vegetative (coppice)	*NR*	NR	Black spruce does not coppice, *but regeneration by layering is very common.*
• Artifical			
-Planting	*NR*	R	*Planting has a high cost and there may be low success on dry, coarse sites. Jack pine or red pine are better choices (see Table 11-4.)*
-Seeding	*NR*	NR	Seeding success is reduced on sandy soils. Xeric to dry moisure regimes will further limit success. *Jack pine or red pine are better choices (see Table 11-4.)*
-Scarification	*NR*	NR	Limited cone supply. The quantity, distribution and retention of suitable microsites limits the success of this treatment. Low levels of black spruce ingress. *This method is intended for jack pine (see Table 11-4).*
Tending Treatments			
• Cleaning			Low competition, cleaning is generally not required.
-Manual	*R*	R	
-Mechanical	*R*	R	
-Chemical, Ground	*R*	R	
-Chemical, Aerial	*R*	R	
• Spacing	*CR*	R	Spacing of black spruce is usually not necessary, but may be required where levels of jack pine ingress are high.

R = Recommended, CR = Conditionally recommended, NR = Not recommended. * = Black spruce not rated in ST2b, NE Ontario.

Low productive sites

These are similar sites to the previous type, but less extreme with more moisture and nutrients. They have feathermoss-dominated shallow forest floors with rather few herbs and shrubs. There is not as much potential for nutrient and moisture loss as the previous type, and there is better growth and generally denser tree canopies.

These sites still need to be managed carefully by harvesting in small area block cuts or strip cuts, with tree-length, stem-only harvest. Site preparation should be light mechanical, and prescribed burning at low burning indices. They may be planted, or use scarification with seed-from-slash, or direct seeding. These sites may lend themselves to selective low thinning, and management for sawlogs. Avoid short-rotation forestry. Monitor for seedling moisture stress and nutrient stress. Competition and pest control may be necessary.

Table 11-4. Silvicultural interpretations for jack pine: dry, coarse soil (Ontario Ministry of Natural Resources 1997: Book II NW Ontario, Book III NE Ontario). Our recommendations and comments are italicized.

Silvicultural System	Dry, Coarse	ES13 NW, ST2b NE	Comments (NW Ontario)
Harvest Method			
• Clearcut			
-Conventional	*CR*	R, R	*We recommend small area clearcuts.*
-Strip/Block	*CR*	R, CR	Residual stand will not *(may not)* contribute seed of sufficient quantity or genetic quality. However, this cutting technique may be prescribed to meet other management objectives.
-Patch	*CR*	R, R	See Strip/Block comment.
-Seed-tree	*NR*	CR, CR	Use prescribed fires of low to moderate severity to open cones and prepare a receptive seedbed. *We are concerned there may not be enough seed in the scattered seed trees. We are also concerned that prescribed fire on this 'dry, coarse' site may burn off too much of the LFH and cause nutrient loss.*
-HARP*	*NR*	*, NR	Biologically *(and silviculturally)* inappropriate.
• Shelterwood	*NR*	NR, NR	Jack pine is shade intolerant and is generally not suited to this silvicultural system.
• Selection	*CR*	NR, NR	See Shelterwood comment. *Commercial thinning using density management can produce larger trees, and more of sawlog size. However, it is not known if this technique is profitable on dry, coarse soils.*
Logging Method			
• Full-tree	*NR*	CR, R	Full-tree harvesting is conditionally recommended provided that 'best practices' are used to minimize disturbance of the surface organic layer. Where surface organic thickness averages < 5 cm, winter harvest and/or use of high flotation equipment should be considered to maintain the integrity of the surface organic layer. *We do not recommend full-tree on dry, coarse sites, but it may be acceptable on moderately fresh sites that have more nutrient reserves. Scarification with slash redistribution and cone placement may be an option.*
• Tree-length	*R*	R, R	Tree length is the preferred logging method. Leaving cone-bearing tops on site will contribute to success of natural seeding/scarification treatments for jack pine. See Cut-to-length/Shortwood comment.
• Cut-to-length/ Shortwood	*R*	R, R	Slash remaining on the site may reduce the effectiveness of mechanical site preparation and seedbed/plantable spot availability.
Site Preparation			
• Mechanical	*CR*	CR, CR	Apply techniques that maintain a high percentage of intact forest floor to limit the loss of nutrients. A good distribution of mineral soil seedbeds created by mechanical site preparation will contribute to successful natural and/or direct seeding. *Avoid intensive area treatments, e.g., raking and blading, in favor of linear or patch scarification.*

Table 11-4. Continued

• Chemical	*R*	R, R	Shrub and herb poor. Chemical site preparation is generally not required.
• Prescribed Burn	*NR*	CR, CR	Prescribed fire is conditionally recommended due to potential loss of organic matter and nutrients. Low to moderate severity fire, which removes ≤ 50% of the surface organic layer is permissible and will result in the creation of suitable seedbed/plantable spots. *On dry, coarse sites we do not recommend prescribed burn.*
Regeneration			
• Natural			
-Advance Growth	*CR*	NR, NR	Jack pine does not regenerate under a closed canopy. *Some stands on dry, coarse sites have open canopies, with advance growth in the openings. These sites could be carefully harvested around the regeneration to provide some of the regeneration.*
-Seed	*CR*	R, CR	High level of jack pine ingress. Mineral soil exposure is required for successful treatment. Potential for seasonal drought may limit success of this treatment.
-Vegetative (coppice)	*NR*	NR, NR	Jack pine does not coppice.
• Blended *	*R*	*, R	*This could involve combinations of CLAAG, scarification, direct seeding, and fill planting.*
• Artificial			
-Planting	*R*	R, R	Natural seed and/or seeding are preferred options. Ingress will override density and distribution control objectives associated with planting.
-Seeding	*R*	R, CR	This technique is successful with adequate distribution of receptive seedbeds. Precision/direct seeding will assist in density regulation. This site is prone to seasonal drought which will influence the success of this treatment. *Direct seeding could be complemented by fill planting.*
-Scarification	*R*	R, CR	Good distribution of mineral soil seedbeds will contribute to regeneration success from cone scattering. This site is prone to seasonal drought which will influence the success of this treatment. *Scarification could be complemented by direct seeding or fill planting.*
Tending Treatments			
• Cleaning			
-Manual	*R*	R, R	Low competition on this site, cleaning is generally not required.
-Mechanical	*R*	R, R	
-Chemical, Ground	*R*	R, R	
-Chemical, Aerial	*R*	R, R	
• Spacing	*R*	R, R	Spacing may be required when using natural or artificial seeding techniques.

R = Recommended, CR = Conditionally recommended, NR = Not recommended, * = Category used in NE but not NW Ontario guides.

Moderately productive sites

These sites have moderately good moisture and nutrient supply, and deeper forest floors. They have moderate development of herbs and shrubs. Because of the deeper organic mats (see Figure 11-2) and fresh moisture conditions these sites have better moisture buffering and nutrient cycling.

Figure 11-4. Dry coarse soils grade into fresh coarse and fresh medium sands, which may also be nutrient poor, but not as limiting (Photo by M. Kershaw.)

Employ small area block cuts or clearcuts to preserve the organic mats, provide edge effect, enhance natural regeneration, and reduce fire spread risk. Use tree-length harvesting. Apply moderate site preparation, and prescribed burning. Regenerate by planting, or scarification/seed-from-slash, or direct seeding. Employ CLAAG if there is sufficient advance growth to justify saving. Use selective low thinning to produce sawlogs. Employ intensive forestry, fertilization, and short-rotation forestry. Monitor for seedling moisture stress, and nutrient stress in mid-rotation. Competition and pest control may be necessary.

Highly productive sites

These sites have good moisture and nutrients. They are indicated by herb-rich, shrub-rich conditions, and moderate to deep forest floors. The main risk is moisture stress in very dry conditions, and vegetational competition. If dominated by jack pine or black spruce, apply full-tree or tree-length clearcutting, site prepare, plant and tend. Prescribed burning can be applied to discourage hardwood and balsam fir and prepare for planting. Apply precommercial or commercial thinning to produce high quality sawlogs in subsequent harvests.

If the site is mixedwood, decide whether to maintain the original composition and structure, or to move either towards more conifer or more hardwood (e.g., Smith and Crook 1996). Managing for conifer requires planting with large stock, and will probably require chemical control of competition.

Managing for hardwood is another option. If there is 30% or more original composition of trembling aspen, allow the stand to go to more trembling aspen by sucker regeneration. This will avoid herbiciding, but may still require tending and fill planting with conifer. It will also result in a two-story stand comprising an aspen overstory over a black spruce, white spruce, and/or balsam fir understory, which may require two-story management, and may present future problems with spruce budworm.

Chapter 12.
Forested Wetlands

> "In Canada, forested wetlands and thicketed wetlands are usually termed swamps. Sparsely treed wetlands with somewhat more open canopies are termed either treed bog or treed fen, depending on whether they are ombrotrophic or minerotrophic." *(Jeglum and He 1995)*

In Canada, five main types of wetlands are recognized – shallow open water, **marsh, fen, swamp,** and **bog**. The large majority of Ontario's wetlands and peatlands are classified as forested or treed, and black spruce wetlands provide a high proportion of the black spruce harvested annually. Management of black spruce has been a topic of research by the Canadian Forest Service for over 30 years, and much of the work dealt with black spruce on peatlands. This research has been summarized in a black spruce compendium (Crook and Cameron 1995), and several management summaries and guides relevant to black spruce have been published (e.g., Jeglum et al. 1983; Arnup et al. 1988; Ontario Ministry of Natural Resources 1997). An intensive experiment on forest drainage of black spruce peatland was conducted at Wally Creek in NE Ontario from 1983 to 1994 (Jeglum and Overend 1991).

Variation in Sites and Productivity

There is a large amount of variation in forested wetlands (Figures 12-1 to 12-3). Figure 12-4 presents a classification of forested wetlands and adjacent site types in Ontario. For management purposes, the main ecosystem types are: treed bog, poor conifer swamp, intermediate conifer swamp, rich conifer swamp, hardwood swamp, thicket swamp, and treed fen. Adjacent site types, moist forests (peat < 40 cm) and open wetlands, are included for orientation. The main FEC wetland site types that are managed for forestry are Site Types ST 11, 12, 13, and 14, the latter type only infrequently harvested owing to its small trees. This is the FEC classification for NE Ontario,after McCarthy et al. (1994), the basis for the OMNR silvicultural guide in NE Ontario (Ontario Ministry of Natural Resources 1997, Book III, NE Ontario).

Figure 12-1. Forested wetland dominated by black spruce with Labrador-tea beneath. (Photo by D. Morris.)

A recent revision of the NE Ontario FEC has been done by Taylor et al. (2000) in which the term Ecosites (ESs) replaces Site Types (STs) and some finer subdivisions of types are recognized.

Productivity in forested wetlands is controlled largely by nutrient and moisture regime. Nutrient regime

Figure 12-2. Black spruce/speckled alder with typical pits and channels. These sites are especially at risk to soil rutting and churning and should be harvested in winter. (Photo by J. Jeglum.)

Intermediate Conifer Swamp (ST 12: Black Spruce – Speckled Alder): Black spruce and speckled alder, medium number of shrubs, herb poor. On wet, organic soils with thick surface fibric horizons. Abundant, moderately high hummocks of *Sphagnum* and feathermoss, with sparse patches of litter. Small water-filled depressions common on sites with strong groundwater flow, sparse on sites with weak flow.

Rich Conifer Swamp (ST 13: Conifer – Speckled Alder): Black spruce, cedar and larch stands with speckled alder, shrub, herb and moss rich. On wet, well-decomposed organic soils with thin surface fibric horizons. High hummocks of *Sphagnum* and feathermoss with sparse patches of litter and abundant small water-filled depressions.

increases from **oligotrophic** to **mesotrophic** to **eutrophic** (see oligotrophic in Glossary). This gradient is related to 1) increasing pH and calcium content of the peat and water, 2) decreasing thickness of surface fibric peat, 3) increasing humification of peat, and 4) increasing species richness. Moisture regime is related to depth to water, and better tree growth is related to deeper water tables (e.g., Jeglum 1991; Jeglum and He 1995).

Brief descriptions of the main FEC-STs are as follows:

Treed Bog and Extremely Poor Conifer Swamp (ST 14: Black Spruce – Leatherleaf): Stunted black spruce stands, abundant leatherleaf with a medium number of other ericaceous shrubs, herb poor. On wet, poorly decomposed organic soils with a deep fibric horizon. Low to moderate hummocks of *Sphagnum*, with sparse water-filled depressions. **Ombrotrophic** or weakly **minerotrophic.**

Poor Conifer Swamp (ST 11: Black Spruce – Labrador-tea): Black spruce stands with abundant Labrador-tea, medium number of ericaceous shrubs, herb poor. On moderately decomposed organic soils with thick surface fibric horizons. Abundant moderately high hummocks of *Sphagnum* and feathermoss, with sparse, small, water-filled depressions.

The risk classes 1 to 5 are related to the bearing capacity of the soils, i.e., the thickness and continuity of the fibric peat, the continuity and strength of the root mat, and the proportion of low wet pockets and channels. In the model (Figure 12-4) in each row of types with the same moisture regime, the highest risk of physical damage is to the right in the richer types, and this decreases to the left in the poorer types. The risk ratings also increase as the moisture regimes become wetter. The same gradients of risk apply to competition, which is related to degree of damage by

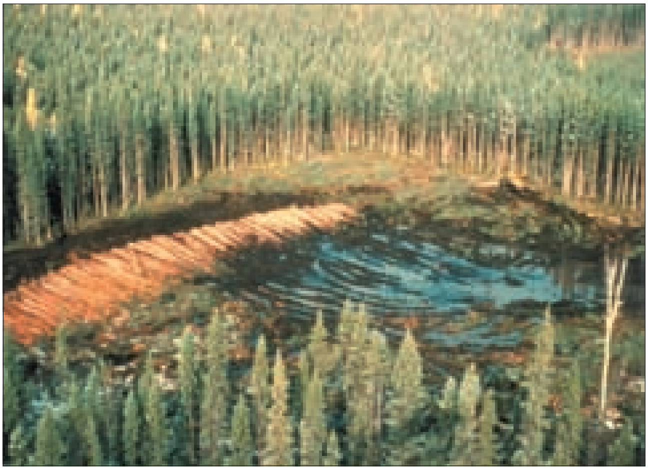

Figure 12-3. Severe rutting and mucking-up near log landing. This degree of damage is uncommon nowadays, but should be guarded against by careful logging and forwarding methods, and winter harvesting. Note narrow-tired skidder at upper right of clearing. (Photo by V. Sleep.)

	Trophic (Species Richness) Gradient				
Soil Moisture Regime and Depth to Water Table	Ombrotrophic-Oligotrophic	Minerotrophic-Oligotrophic	Mesotrophic	Eutrophic	Flooding and Riparian
Peat <40 cm MR 6 (Moist) DWT >40 cm	ST8 Black spruce- Feathermoss-*Sphagnum* 1		ST9 Conifer-Moist Soil 2		ST10 Hardwood-Moist Soil 3
Peat >= 40 cm MR 7-8 (Wet) DWT 20-39 cm	ST14(cf. ES34) 2 Treed Bog (high density)	ST11 (cf. ES35) 2 Poor Conifer Swamp	ST12 (cf. ES36) 3 Intermediate Conifer Swamp	ST13 (cf. ES37) 3 Rich Conifer Swamp	ES38 3 Hardwood Swamp
MR 9 (V. wet) DWT 10-19 cm	ST14(cf. ES34) 3 Treed Bog (low density)	ES40 3 Poor Treed fen	ES40 4 Intermediate Treed fen	ES40 4 Rich Treed fen	ES44 4 Thicket Swamp
DWT < 10 cm	Open Bog 5	Open Wetlands 5 Fen Marsh-Meadow			

Risk classes: 1 (Dark Green)= Very low risk of damage; 2 (Light Green)= Moderate risk of damage, utilize low ground pressure equipment, summer or winter harvest; 3 (Yellow)= High risk of damage, use low ground pressure equipment, preferably winter harvest; 4 (Violet)= Very high risk of damage, use low ground pressure equipment, only winter harvest, take great care; 5 (Red)= Keep equipment and operations out of these sites.

Figure 12-4. Classification of forested wetlands, and risk to losses in site productivity owing to soil damage and altered hydrology. MR = moisture regime. DWT = depth to water table. STs are after McCarthy et al. (1994) and Ontario Ministry of Natural Resources (1997 Book III, NE Ontario), and ESs are after Racey et al. (1996) and the Ontario Ministry of Natural Resources (1997 Book II, NW Ontario).

soil rutting and churning, as well as trophic status (highest in eutrophic).

In forested peatlands there may be deficiencies of N, P and/or K, as well as micronutrients. Nutrients such as N and P may be abundant in total amounts, but are bound (in different proportions) in organic forms and unavailable to trees. Nutrients are most limiting in oligotrophic, less so in mesotrophic and eutrophic. The removal of nutrients by full-tree harvesting represents a potential loss of tree productivity.

Concerns and Goals

The key concerns and corresponding goals for forested wetlands are in Table 12-1. Soil damage (rutting, mucking, and compaction), and altered hydrology (drainage blockage and watering-up) are the main concerns. In addition, competition, advance growth damage, and stand structural changes are moderately important. Nutrient deficiencies and loss are least important of the concerns, although if wetlands were to become intensively managed the importance of nutrients would increase greatly.

Best Practices

Table 12-2 presents the best practices for silvicultural practices for establishing black spruce. We draw upon the recommendations of the OMNR for NE Ontario (Ontario Ministry of Natural Resources1997 Book III) because NE Ontario has the greatest activity in peatland forestry.

Silvicultural guidelines are quite similar among the STs (Table 12-2). However, some differences arise owing to the gradient of nutrient regime from poor to rich in the sequence ST 14, ST 11, ST 12, and ST 13. Because there is increasing richness and increasing potential for graminoid and shrub development, as well as potential for soil churning, several recommendations relate to avoiding competition or soil disturbance in the richer types ST 12 and ST 13.

Two special harvesting and regeneration methods for peatland black spruce have evolved in this region. The older one is careful logging around advance growth, CLAAG, and a more recent one is harvesting with regeneration protection, HARP. The first is aimed at clearcutting of even-sized stands where most trees are large enough to harvest, but there is an abundant lower layer of advance growth seedlings and saplings. The second is aimed at harvesting uneven-sized stands where there is a more mixed structure of sizes. Here one may use a diameter limit for harvesting, and logging is conducted with smaller equipment in such a way as to conserve the regeneration and small trees. Both of these techniques aim to conserve advanced growth and smaller trees so that they make up a proportion of the next stand. **Blended** regeneration is an application of two or more methods, natural and/or artificial, to achieve acceptable stocking and quality of regeneration.

Some Additional Recommendations

- **Stratify operational areas into winter only, and summer or winter harvest areas**. ST13, treed fens, hardwood swamps, and thicket swamps would normally be designated winter only.

- **Keep number of machine passes low** to minimize rutting and churning.

- **Employ adequate culverts and bridges** on permanent roads to avoid road damming.

- **Employ temporary crossings of log/brush mat, or tire mats** for machines to cross drainageways and wet, sensitive spots (e.g., Figure 4-5).

- **Do not leave brush piles in streams or drainageways**. Clear streams and drainageways of blockages after harvesting.

- **Apply selection thinning from below** on richer sites to obtain larger pulpwood and sawlogs. Use density management guides (e.g., Newton 1997; Ontario Ministry of Natural Resources 1998).

- **Apply HARP on sites with uneven-sized structures.** Consider moving toward uneven-sized management (Groot 1997; Ehnes and Sidders 2001), and continuous cover forestry (Mason et al. 1999).

- **Employ strip cutting** where there is insufficient advance regeneration, and/or distance to the mill is great. Also use it to maintain landscape diversity, along streams where stream water protection and moose corridors are desirable, and where peatlands are intermixed with shallow-soiled sites (e.g., Jeglum and Kennington 1993).

- **Plan for new equipment for partial cutting.** With increasing areas of stands with uneven-sized structures, it may be necessary to obtain single-grip harvesters and medium-sized forwarders to conserve advance growth and residual trees.

- **Plan for protection from frost.** In lowlands and frost pockets, leave some protection trees, saplings, or tall shrubs for shelter of seedlings from late frost. This is especially critical for richer moist and wet sites with white spruce (e.g., Groot and Carlson 1996; cf. Norway spruce, Holgén and Hånell 2000).

- **Avoid especially sensitive wetlands,** such as riparian wetlands, groundwater discharge seeps, springs, etc. Do not cut, or use very careful and

Table 12-1. Concerns and goals for forested wetlands.

Concerns	Goals
Soil damage: Rutting, mucking-up, compaction, and loss of seedbed	Minimize compaction, and soil disturbance (rutting and churning of the peat). Maintain living ground cover, and root mat ground surface mosses. Minimize compaction of wet mineral soils.
Altered hydrology	Avoid drainage blockage. Minimize watering-up by maintaining interception and evapotranspiration.
Competition	Minimize development of cattails, sedges, grasses, alder, and ericaceous shrubs.
Advance growth damage, structural changes	Preserve advance growth. OR Prepare receptive seedbeds.
Nutrient losses	Reduce losses of nutrients.

Table 12-2. Silvicultural interpretations for black spruce: forested wetlands (Ontario Ministry of Natural Resources 1997: Book III NE Ontario). Our additional recommendations and comments are italicized.

Silvicultural System	ST11 NE	ST12 NE	ST13 NE	Comments (NE Ontario**)
Harvest Method				
• Clearcut	R	R	R	*Use CLAAG to minimize site damage and protect any advance growth that is present.*
-Conventional	R	R	R	
-Strip/Block	CR	CR	CR	ST11, 12 and 13: Strips should be from 70 to 100 m wide. This technique may be prescribed to meet other management objectives.
-Patch	R	R	R	
-Seed-tree	CR	CR	CR	ST11, 12 and 13: Group seed tree. This technique may be prescribed to meet other management objectives.
-HARP*	CR	CR	CR	ST11, 12 and 13: HARP may be used for overmature black spruce stands. Must identify lower diameter limit and maintain a semi-contiguous crown cover. *It could lead to 'continuous cover forestry' (see Glossary).*
• Shelterwood	NR	NR	NR	ST11, 12 and 13: High probability of windfall.
• Selection	NR	NR	NR	*'Selection from below' is inappropriate for black spruce, because of windfall risk, and high cost compared to return of quality sawlogs. 'Selection from above' could be used for uneven-aged management (see HARP above).*
Logging Method				ST11 and ST12: Harvest on frozen ground or use high flotation equipment during the frost-free season. ST13: Harvest on frozen ground.
• Full-tree	CR	CR	CR	ST11, 12, and 13: See Logging Method comment. ST13: Winter logging will reduce nutrient loss.
• Tree-length	CR	CR	CR	ST11, 12 and 13: See Logging Method comment.
• Cut-to-length/ Shortwood	CR	CR	CR	ST11, 12 and 13: See Logging Method comment.
Site Preparation				
• Mechanical	CR	CR	CR	ST11 and ST12: This activity should only be done on frozen ground. ST13: Mechanical site preparation on these sites promotes heavy competition. *Mechanical site preparation here refers to 'shearblading'.*
• Chemical	R	R	R	*Chemical treatment may be necessary if speckled alder or graminoids become a problem.*
• Prescribed Burn	R	NR	NR	ST11: Low severity fires on this site (average depth of burn should not remove more than 20% of organic matter). ST12 and ST13: Promotes grass growth on moist, nutrient-rich sites.
Regeneration				
• Natural				*Use CLAAG to minimize site damage and protect any advance growth that is present.*
-Advance Growth	R	R	R	
-Seed	R	R	R	*This refers to seed coming by wind transport from adjacent uncut forests or uncut groups of seed trees.*
-Vegetative (coppice)	NR	NR	NR	ST11, 12 and 13: This species does not regenerate by coppice.

Table 12-2. Continued

• Blended*	R	R	R	*Advance growth natural regeneration along with seeding and/or fill planting will be cheaper than planting, and accomplish regeneration goals.*
• Artifical				
-Planting	R, *CR*	R	R	*Planting has a high cost, and it may not be economical on the poorer forested wetlands. Advance growth regeneration may be sufficient.*
-Seeding	R	R	R	*Direct seeding may be part of a Blended regeneration effort.*
-Scarification	CR	CR	CR	ST11, 12 and 13: See Mechanical Site Preparation comment. *'Scarification' is a term that refers to jack pine regeneration by seed from cones on site prepared surfaces. The effectiveness of this method has not been proven for black spruce.*
Tending Treatments				
• Cleaning				
-Manual	R	CR	CR	ST12 and ST13: Cutting may stimulate stem sprouting and/or root suckering of competition.
-Mechanical	CR	CR	CR	ST11: Site sensitive to rutting. Ground pressure of equipment should be less than 10 psi. Can also damage seedlings. ST12 and ST13: See Manual Cleaning comment.
-Chemical, Ground	CR	CR	CR	ST11, 12 and 13: Ground pressure of equipment should be under 10 psi.
-Chemical, Aerial	R	R	R	Treatment generally not required.
• Spacing	R, *NR*	R, *NR*	R, *CR*	*Spacing is not recommended as this species produces mainly pulpwood. Could be economical on ST13.*

R = Recommended, CR = Conditionally recommended, NR = Not recommended.
* = Category used in NE but not in NW Ontario guides.
** = We provide comments only for NE Ontario.
psi = pounds per square inch

light high selection thinning, do not allow equipment in sensitive areas, reach with long booms from outside, or hand-felling, and horse or cable extraction. Winter harvest.

• **Stop logging operations during thaws, spring melt, and excessively wet periods** (See Chapter 5 Harvesting).

• **Avoid prescribed burning** to avoid destroying advance growth unless there is abundant slash or balsam fir and alder to remove. Avoid burning during dry weather and times of high fire risk to avoid deep burning peat fires.

• **Do not block or impede drainage** with shear-blading or raking. Residues from shearing or raking operations should be kept out of drainageways, streams, and wetlands.

• **Consider drainage and fertilization** to increase productivity of intermediate to rich swamps and treed fens (e.g., Jeglum and Overend 1991). This could be close to the mill where transportation costs are low. (Note: These practices have not been endorsed by the Class Environmental Assessment for Timber Management.)

• **Use natural regeneration from advance growth.** This will result from careful logging around advance growth.

• **Use artificial regeneration when required.** Sites with less advance growth may require regeneration.

Fill planting or fill seeding on the harvest trails may be used.

- **Apply variable shearblade spacing** for sites with variable advance growth—narrow spacing when advance growth is sparse, wider spacing when advance growth is more abundant (e.g., Figure 6-4). Avoid shearblading where advance growth is very abundant.

- **Consider mounding and planting.** On rich wetlands with potentially heavy competition, mounds could be created with backhoe, planting large stock for rapid growth (Holgén and Hånell 2000).

Site-adapted Best Practices

Treed Bog and Extremely Poor Conifer Swamp (ST 14)

These very poor sites normally do not have enough merchantable timber to justify harvest. However, there is a thick, continuous fibric layer, and well-developed root mat, which give good bearing strength for low ground pressure equipment. If harvesting is done, we recommend light partial harvesting with careful logging, or selection thinning. Keep equipment to trails, and delimb on trails to create a brush mat. Harvest high density treed bog (drier) in the summer with low ground pressure equipment, and low density treed bog (wetter) in winter. Preserve advance growth, and do not site prepare.

Poor Conifer Swamp (ST 11)

These sites also have a rather continuous fibric layer and well-developed root mat.We recommend light partial harvesting with careful logging or strip cutting, or selection thinning. Keep equipment to trails, and delimb on trails to create a brush mat. Harvest poor swamp preferably in the winter, or in the summer with low ground pressure equipment. Preserve advance growth, and do not site prepare.

Intermediate Conifer Swamp (ST 12)

These sites have a higher proportion of wet pockets and channels in a continuous matrix of hummocks. Harvest with careful logging, tree-length. Strip cutting or selection thinning is also recommended. Winter is the best time to harvest; in the summer use low ground pressure equipment. Keep equipment to trails, and delimb on trails to create a brush mat. With abundant advance growth do not site prepare. With sparse advance growth, shearblade on frozen ground or snow, and fill plant or direct seed if required. Control competition. For intensive forestry, drain and fertilize. (Note: Drainage and fertilization have not been endorsed by the Class Environmental Assessment for Timber Management.)

Rich Conifer Swamp (ST 13)

These sites are characterized by black spruce/ alder/ herb-rich vegetation. *Sphagnum* and feathermoss are dominant on hummock level surfaces. There are more numerous wet windows and channels than in intermediate conifer swamp, and these are underlain by minerotrophic peat, as indicated by numerous minerotrophic indicator plants. Best management practices are the same as for intermediate conifer swamp, except that we recommend winter harvesting only, owing to the higher risks of soil mucking up, drainage disruption, and high vegetational competition.

Rich Hardwood Swamp (ES 38)

These sites may be dominated by black ash, balsam poplar, balsam fir, white spruce, and tall shrubs with numerous herbs and low shrubs present. The soil may be **mesic** to **humic** (see **fibric** definition in Glossary) organic, or organic-rich mineral. Ground surfaces are flat to hummocky, and fallen, moss-covered logs are common. These sites are seasonally flooded or flushed with base-rich water. There is high potential productivity, but the sites are highly sensitive to damage and intense competition. These sites should be harvested in winter, with careful logging or partial harvesting. Hardwood regeneration by suckering/ sprouting is likely, and underplanting may be necessary. Competition control and spacing may be required. This is a rich site type that warrants high silvicultural investment. Could be drained and fertilized (Note: Drainage and fertilization have not been endorsed by the Class Environmental Assessment for Timber Management.)

Thicket Swamp (ES 44)

These sites may be dominated by willow, speckled alder, and red-osier dogwood, and are moderately to very herb-rich. They occur naturally in the landscape between meadow-marsh on the wetter side, and rich hardwood swamp or conifer swamp on the drier side. If *Alnus* is present in understory of swamps, after harvesting the site may develop into a long-lived *Alnus* successional stage. The sites are seasonally flooded, and water tables are relatively high. N-fixing nodules on the roots of *Alnus* can provide a fertilization effect. This is an intermediate to rich type, and warrants high silvicultural investment. To reforest, site prepare by herbiciding, prescribed burning, and/or shearblading, followed by artificial regeneration. Leave buffer strips along streams, drainageways; do not apply herbicide in streams. Shearblading should not remove hummocks, which are the most desirable microsites for planting. Could be drained and fertilized. (Note: Drainage and fertilization have not been endorsed by the Class Environmental Assessment for Timber Management.)

Treed Fen (ES 40)

Downslope from the conifer swamps in wetter conditions are the treed fens, generally sparsely treed, non-merchantable, dominated by black spruce-tamarack on organic soils. There are two main ground surface levels, hummock level (groundwater $\geq$ 20 cm below surface) supporting tree development, and intermediate level (groundwater 5 to 20 cm below the surface). Small pools and depressions may be frequent. The site type includes a range of nutrient regimes-poor, intermediate, and rich. The potential for competition increases from poor to rich. Harvest only in the winter using careful logging or partial selective harvesting. Use natural regeneration by advance growth and natural seeding. We recommend leaving 30% canopy cover (> 2.5 cm dbh) on site to reduce watering-up. Intermediate to rich type, could warrant high silvicultural investment. The intermediate to rich treed fens could be drained and fertilized. (Note: Drainage and fertilization have not been endorsed by the Class Environmental Assessment for Timber Management.)

Moist mineral soils

On moist mineral soils upslope from the peatlands, with organic mat depths of 20 to 39 cm, are a range of trophic classes of sites from poor to rich – ST 8, ST 9, and ST 10 – comparable to the sequence poor swamp – intermediate swamp – rich swamp. These types may be present in complexes with forested wetlands, and may be subject to rutting and mucking impacts and compaction, especially on finer soils, and where there is groundwater discharge or periodically wet conditions. ST 8 can be handled with conventional clearcutting, full-tree or tree-length, site prepare, and plant. ST 9 should be handled more carefully, and is similar to the rich and intermediate conifer swamps. ST 10 on moist mineral soil should be handled like hardwood swamp.

Chapter 13. Riparian Areas

Riparian areas are zones next to lakes, rivers, streams, drainageways, and wetlands. They include the immediate water's edge, and adjacent uplands which influence, and are influenced by, the water body. *(cf. Stevens et al. 1995; Dunster and Dunster 1996)*

Riparian areas include some of the most productive sites for tree growth, owing to the supply of moisture and, in some cases, enrichment by flood-water deposits. However, riparian areas also contain many of the highest non-timber values in the natural forest. Thus, management of riparian areas must be a balance between production and environmental goals.

'Riparian management areas' (RMAs) are the areas delimited along water bodies for specific management practices. They consist of a **riparian management zone** in which certain constraints apply to forestry operations and harvesting, and sometimes also a **riparian reserve zone** in which forestry is not permitted. Inclusion of a reserve zone is based on judgement of the relative sensitivity of the streamside to erosion and slumping, and biodiversity considerations.

Relevant Ontario management guides are the ones for riparian areas (Ontario Ministry of Natural Resources 1991a), for roads and water crossings (Ontario Ministry of Natural Resources 1990), and for fish habitat Ontario Ministry of Natural Resources 1988a). Other relevant guides are available from other jurisdictions (e.g., New Brunswick Department of Environment 1994 [watercourses]; Stathers et al. 1994 [windfall]; British Columbia Ministry of Forests 1995a [gullies], 1995b [riparian]; Hänninen et al. 1996 [watercourses]).

Functions of Riparian Areas

Riparian areas provide several important functions in the landscape (e.g., Stevens et al. 1995; Haycock et al. 1996). Two of the main functions relate to bank and water protection and biodiversity. Water protection refers to minimizing erosion and nutrient loss off the upland, as well as maintaining water quality and water storage functions, and reducing water level fluctuations and flooding (Figure 13-1). Biodiversity is high in riparian areas because they may encompass such a large variety of habitats, from terrestrial to aquatic, with high variation in soil textures and nutrient regimes. Biodiversity is also favored by new habitats and substrates, created by fluctuating water levels, deposition of sediments, channel relocation, etc. Although most of these benefits of riparian areas are undoubtedly true, more research is required to better quantify their real physical and biological relationships (e.g., Steedman et al. 1998).

Figure 13-1. The tree roots, vegetation, and often thick surface organic mats act as a filter and absorptive zone between land and water for sediment and nutrients. (Photo by M. Kershaw.)

Stabilize shorelines

Riparian zones may contain steep banks, or unstable parent materials, and there may be potential problems of erosion and slumping. Vegetation along streambanks and shorelines reduces the impact of rain, slows surface runoff, and binds the soil with living root systems. In wet riparian habitats, organic matter tends to accumulate, stabilizing the soils and reducing erosion. **Coarse woody debris** (e.g., fallen trees) helps to stabilize banks through structural support, acts as physical barriers to sediment in overland runoff, reduces the erosive potential of flood water, and provides habitat for many life forms.

Filter sediments and nutrients

The vegetation and soils can act to filter sediments and absorb compounds of N, P, and other elements, thus minimizing losses from the land to adjacent waters. This may be important in the case of wild-fire or clearcuts, where there can be significant increases in ion mineralization and mobility, particularly of nitrates and mobile cations. On the other hand, some studies have shown that clearcutting with no treed riparian buffer does not significantly increase nutrient losses into the adjacent waters (e.g., Kreutzweiser and Capell 2001).

Hydrologic buffers

Riparian zones can be important as hydrological buffers (Haycock et al. 1997). They can be sites of groundwater discharge from the upland, and also as sources of recharge into streams or wetlands. They can act to store and slowly release water, thus moderating fluctuations of water level in streams, reducing maximum peak water levels during wet periods, and prolonging flow during droughts. Wetlands may occur in basins or zones along streams and lakes, and frequently are found as headwater wetlands that form the source of primary streams. The integrity and buffering capacity of these headwater wetlands and riparian zones should be maintained.

Habitats and food

The character and complexity of habitats of streams and rivers is determined by vegetation, but also by the local topography, geology, and parent materials. Soil materials, nutrients, vegetational debris, and organisms are flushed or fall into streams from adjacent vegetation. Much of the organic food in streams comes from bordering vegetation. Streamside tree roots and plunge pools created by log dams provide shelter and feeding areas for fish. Increases of silt and organic sediments in water may cover sand and gravel spawning beds for trout and other fish. Streamside vegetation can shade and reduce stream and lake temperatures, causing cooling and lower diurnal fluctuations, but these changes may be small in comparison to influences of regional air temperatures (e.g., Steedman et al. 1998). Many birds, small and large mammals, reptiles, amphibians, and invertebrates use riparian zones for foraging, nesting, resting, or to gain access to water (Figure 13-2).

Ecological linkages and corridors

Riparian areas maintain ecological linkages throughout the forest landscape, connecting terrestrial habitats to streams, and upper headwaters to lower valley bottoms. No other landscape feature provides as much linkage in the landscape. Riparian areas are important as migration or travel corridors for plants, birds, mammals, and invertebrates. When upland areas are disturbed by fire or logging, vegetation in adjacent riparian areas can provide refuge for species, which then spread onto the disturbed areas (Figure 13-3). Narrow strip cuts through the riparian zones from upland to water can provide moose and other animals, including humans, access corridors to water (Figure 13-4).

Figure 13-2. Riparian buffer zone acting as forest habitat, and corridor for travel and dispersal of wildlife species. Removal of riparian buffers could have adverse effects on quality of aquatic resources as well as wildlife populations. (Photo by M. Kershaw.)

Figure 13-3. Fires often burn through riparian zones leaving standing timber, stimulating rapid regrowth, and leading to temporary increases in fluxes of water, sediments, and nutrients. (Photo by M. Kershaw.)

Figure 13-4. Very narrow strip cuts between an upland area and a stream left as protection and travel corridors for moose. (Photo by V. Keenan, Abitibi-Consolidated, Pine Falls, Manitoba.)

Concerns and Goals

Key concerns and corresponding goals for management of riparian areas are summarized in Table 13-1. The major concerns are loss of stabilizing functions, and losses of sediments and nutrients by erosion and leaching. There are also concerns about loss or reduction of storage and recharge functions, loss of habitat for biodiversity, and loss of dispersal corridors for species and genes.

Best Practices

- **Establish Riparian Management Areas.** A diagrammatic portrayal of the riparian management area, riparian management zone, and riparian reserve zone is presented in Figure 13-5.

Various widths of riparian management areas, RMAs, have been recommended in different jurisdictions, from no riparian buffer to 100 m or more (e.g., Westland Resource Group 1995). Many jurisdictions have very flexible reserve requirements, and may leave it to the judgement of the local forest manager and/or designated environmental agency to determine on a site-by-site basis. Sometimes there are explicit riparian site entry and/or extraction options (Gary Bull and Associates 1999).

In Ontario, the code of practice for riparian management (Ontario Ministry of Natural Resources 1991a) applies to all lakes and streams. Currently, a narrow machine exclusion of about 3 m of undisturbed forest floor or vegetation (not necessarily with trees) is to be left on the banks of water bodies, except for stream crossings. Revisions to this code are currently being made, along with revisions to access roads and water crossings, and fish habitat protection guides (Ontario Ministry of Natural Resources 1988a.) Currently, fish habitat protection guidelines apply at 30 to 90 m from the high water mark. Widths vary depending on shoreline slope, and timber operations must be modified or restricted within areas of concern on both sides of the water body and associated riparian zone.

In Quebec, a 20-m buffer is required for non-salmon streams. Only 33% of the basal area can be removed in the buffers. Timber may only be hand felled, and no heavy machinery is allowed in the riparian buffer zones (Gary Bull and Associates 1999).

Riparian management areas vary in width depending on the type of river and channel width and wetland classification (Figure 13-6). As an example we draw upon the recommendations from the British Columbia Riparian Management Area Guidebook (British Columbia Ministry of Forests 1995b; Table 13-2). Widths are variable, from 20 m to over 100 m. Total widths of riparian management areas for wetlands range from 30 to 50 m, and for lakes from 10 to 30 m. Not all classes of streams or wetlands include recommendations for reserve zones within the management areas (ibid.).

Table 13-1. Concerns and goals for management of riparian areas.

Concerns	Goals
Loss of stabilizing function of shorelines	Minimize disturbances from road crossings. Maintain some canopy cover, understory vegetation, and ground cover. Minimize the disturbance of banks, soils, and root mats.
Loss of sediments and nutrients	Minimize erosion, hold soil in place. Minimize leaching, retain nutrients. Slow water movements through zone.
Reduction of storage and recharge functions	Avoid damage to soil water storage and flow capacities.
Loss of habitats for biodiversity, and loss of dispersal corridors	Establish riparian areas wide enough to promote biodiversity, and to maintain quality fish and aquatic habitat.
Loss of ecological linkages, corridors, dispersal routes	Use riparian areas to promote landscape connectivity and dispersal of species and genes.

• **Riparian management areas may not always require trees.** We know that wildfires can burn forests to the water's edge (see Figure 13-3). If treed riparian areas are applied everywhere, important components of natural landscape diversity, habitats, and juxtapositionings may be inadvertently lost or reduced, such as open ground, and various successional stages next to open water and wetlands.

Researchers are currently studying the riparian zones in relation to impacts on sediment and nutrient losses, temperature, biodiversity, dispersion of flora and fauna, and wildfire disturbances. New OMNR guidelines on aquatic and fish habitats, and riparian zones, are being formulated (R. Steedman, Pers. comm.), and new guidelines have been published dealing with natural disturbance pattern emulation, especially wildfire patterns in relation to clear-cut configurations and sizes (McNicol 2001; Ontario Ministry of Natural Resources 2001).

There may be valid reasons for harvesting to the water's edge, thus creating gaps or breaks in the RMAs. One of these may be to provide easier access to the water for fishermen, hunters, and wildlife (e.g., moose). However, such gaps should be used sparingly to minimize impacts on other functions of the RMAs, such as wildlife dispersal corridors, wildlife habitat, and water quality protection.

Wetlands

• **Define RMAs for wetlands.** Include wetlands in the RMAs of the streams and lakes (e.g., Figure 13-2). Individual wetlands and wetland complexes also should have riparian management areas. Open wetlands, shrubby wetlands, and sparsely treed wetlands will require different guidelines than for well-forested riparian wetlands.

Roads and Crossings (see also Chapter 4, Roads and Water Crossings)

• **Avoid locating roads in riparian areas**. Establishment of tertiary roads within RMAs is permitted only in exceptional cases where there is no reasonable alternative. Roads should be located well back from the banks of streams and lakes, and should have minimum size and impact. Deactivate temporary and spur roads when harvesting is completed within RMA.

• **Keep temporary stream crossings to a minimum.** Make crossings where banks are relatively stable, and avoid instream, stable coarse woody debris. Use box culverts to avoid damage to streambanks. Remove temporary structures when operations are completed. Where streambank disturbance occurs, bank stabilizing structures and streamside vegetation must be established.

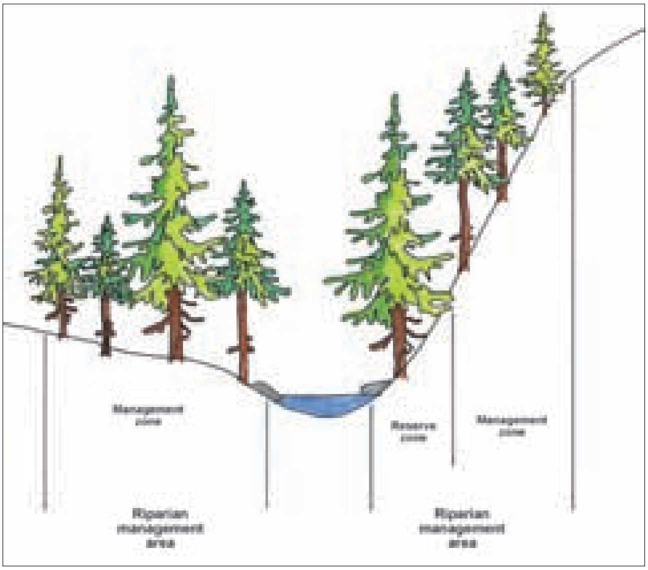

Figure 13.5. Diagrammatic portrayal of the riparian management area, riparian management zone, and riparian reserve zone (from MacDonald 1999, Figure 14-6).

Harvesting, Regeneration, and Tending

- **No harvesting in the riparian reserve zone.** There may be exceptions in the case of windfall cleanup, to reduce windfall hazard, and to maintain forest and bank stability.

- **Partial harvesting is preferred in riparian management zones** to maintain maximum streambank and water protection, and biodiversity functions. A preferred goal is to establish continuous cover forestry. However, systems in management zones may vary from clearcutting at one extreme to selection thinning at the other.

- **Reduce risk of erosion and destabilizing banks** by avoiding use of heavy equipment and preferably hand-felling, carefully selecting harvest and skid trails, moving equipment along slope contours when safe, avoiding repeated use of same trail, and using extra-long winch cables or boom and grapple.

- **Do not damage fish habitat or create blockages to fish passage.** This includes small channels that provide access to fisheries-sensitive zones. Each channel should be adequately culverted; do not create artificial channels to reduce number of culverts required.

- **For permanent crossings, install correct culvert sizes.** On active floodplains install oversize culverts. On floodplains minimize height of fill construction, install extra culverts beneath road fill, protect fill from erosion.

Stream Activity

- **Employ careful instream clean-out methods** to remove excess debris. Avoid large machinery, or use by reaching from well back of the bank. Hand clean when necessary. Use helicopter yarding in gullies or confined streams.

- **Leave stable, instream, coarse woody debris in place.** It has become a stabilizing part of the stream system, and creates fish habitat.

- **Leave logging debris above the high-water mark**, and in such a way that it will not enter the stream. Slash piling may be desirable for minor gully protection, to promote natural regeneration, or as wildlife habitat. Consult wildlife biologists regarding slash.

- **Reduce windfall hazard when logging in RMAs.** In partial cutting, leave trees that are lower, tapered, and with smaller canopies. Use high thinning, topping, pruning, and edge tapering to lower trees to reduce windfall risks. Consult windfall guides and the literature (e.g., Stathers et al. 1994; Navratil 1995).

- **Keep equipment away from banks**. Tracks and wheels of ground-based equipment should not be operated within 5 m of any stream, lake, or wetland. If trees are removed to the water, maintain a filter strip of undisturbed forest floor and vegetation at least 3 m wide on the banks of water bodies.

- **Keep equipment out of steams, water bodies, and wetlands**.

- **No site preparation, no prescribed burning.** The objective is to limit soil exposure to protect water quality, and to maintain the forest floor and understory vegetation.

- **Employ mechanical or manual tending.** Chemical tending is not recommended in riparian zones. However, it may be acceptable with the proper chemicals and methods. Pesticide specialists should be consulted.

Table 13-2. Delineating stream and wetland riparian management areas (from British Columbia Ministry of Forests 1995b, Figure 11).

Stream riparian class	Average channel width (m)	Reserve zone width (m)	Management zone width (m)	Total riparian management area width (m)
S1 large rivers	≥100	0	100	100
S1 (except for large rivers	>20	50	20	70
S2	> 5≤20	30	20	50
S3	1.5≤5	20	20	40
S4	<1.5	0	30	30
S5	>3	0	30	30
S6	≤3	0	20	20

Shaded = Fish stream or community watershed.
Unshaded = Not fish stream and not in community watershed.

- **Keep toxic and polluting materials out of riparian areas.** Do not refuel or lubricate in riparian areas. Do not store gasoline, oil, or pesticide chemicals in riparian management areas. Follow guidelines for handling toxic and hazardous materials.

Felling and Yarding

- **Minimize cross-stream yarding** (where the tree or log touches the bank, channel, or vegetation). Undertake only where banks are stable, and in such a way as to minimize damage to bank, channel, residual trees, vegetation, and root mats.

- **Fell away from the channel.** Fell across channel only if the stem will span stream and stem can be lifted without doing damage. When yarding will cause undue damage to banks, channels, or stable coarse woody debris, leave the stem spanning the stream, providing it does not obstruct streamflow or fish passage.

- **Take care when felling uphill.** Worker safety is paramount. If felling away from stream is uphill, consider felling across channel and leaving part of log for coarse woody debris.

- **Minimize slash and debris in channels.** Fell away from the channel and use yarding methods that minimize breakage and debris falling into streams.

- **Establish zones of harvesting exclusion around wildlife trees**. Felling near **wildlife trees** and snags may be dangerous to workers.

Gullies

These are steep-sided and deep channels or streams that require special management considerations to guard against erosion, debris flows, and debris floods. They are generally not fish streams but may influence fish and wildlife habitat further downstream.

Best management practices require selection of harvesting equipment and systems that can extract trees very carefully, causing minimum damage to residual trees and gully sidewalls (e.g., British Columbia Ministry of Forests 1995a; MacDonald 1999). Try to reach timber from outside the RMA. Minimize the amount of logging debris entering the gully.

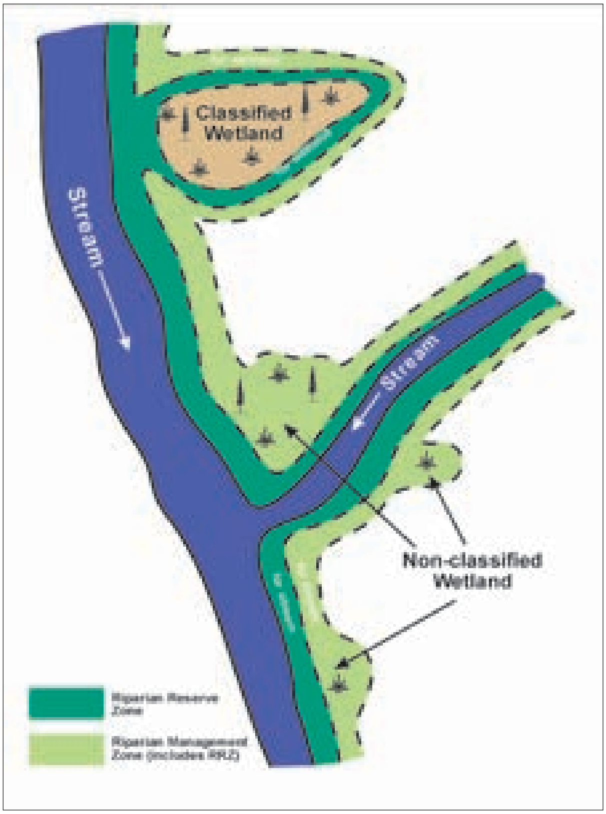

Figure 13-6. Delimiting stream and wetland riparian areas (adapted from British Columbia Ministry of Forests 1995b).

Chapter 14. Steep Slopes

Steep slopes are those that present risks of erosion or mass slumping of underlying materials, or unsafe working conditions.

Forestry on steep slopes and unstable materials involves risk of erosion and mass slumping (Figures 14-1 to 14-3). Erosion increases as slopes become steeper. Heavy clays are generally least susceptible, loams and tills, and clays with more silt are more susceptible, and silts and very fine sands are most susceptible to erosion. On steep ground, the tracks caused by dragging the logs on the ground can become pathways for water flow. Level to moderately sloping clays, and medium- to coarse-textured loams and tills, are less susceptible to erosion. Risks of erosion are greater on longer slopes, regardless of soil texture and ecosite type.

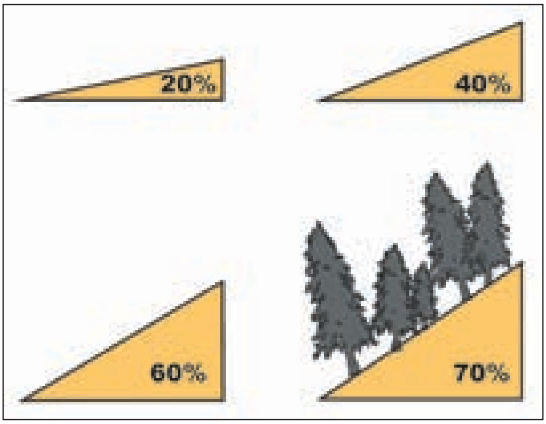

Figure 14-1. Slope percentages used in the terrain stability classes. These slopes are not intended to be absolute cut levels of terrain stability, but rather general guides. (adapted from Terrain Stability Classes, British Columbia Ministry of Forests 1999.)

Use recommended guidelines to prevent erosion (e.g., Ontario Ministry of Natural Resources 1983, 1990, 1991a; Minnesota Department of Natural Resources and Minnesota Pollution Control Agency 1994; British Columbia Ministry of Forests 1999, 2001; MacDonald 1999).

Terrain Stability Classes

Terrain stability is a term combining the condition of slope steepness with the relative resistance of the parent material to erosion or slumping. The following are classes of terrain stability based on slope and relative stability of underlying materials (modified from the Terrain Stability Classes, British Columbia Ministry of Forests 1999). The slopes are portrayed in the simple diagram in Figure 14-1. The slopes and material types are not intended as absolutes, but rather as guides to be used with caution and modified as required for different areas.

Figure 14-2. Steep slopes should be harvested with small harvesters, or with cable yarding techniques. Partial cutting practices are preferred to maintain slope stability. (Photo courtesy of Timberjack™.)

Very High

- Plains and level to undulating areas.
- Most terrain with slopes <20%.
- Heavy clay in glacial lakebeds.

High

- Gently sloping (5 to 20%), erodable soils (silts, sands), imperfectly to poorly drained.
- Moderately sloping (20-40%) with somewhat more stable materials (mixed glacial tills, clays) well to rapidly drained surficial deposits.

Moderate

- Moderately sloping (20-40%), erodable materials imperfectly to poorly drained.
- Moderately sloping (40-60%), with somewhat more stable materials (mixed glacial tills, clays) well to rapidly drained surficial deposits.

Low

- Moderately sloping (40-60%), erodable materials imperfectly to poorly drained.
- Steeply sloping (>60%), with somewhat more stable materials (mixed glacial tills, clays) well to rapidly drained surficial deposits.
- Gullied surficial deposits.

Very low

- Any areas where deep gullies or natural landslide scars are visible on air photos or in the field.
- Very steeply sloping (>70%), imperfectly or poorly drained, deeply gullied, surficial deposits.
- Thin surface deposits over bedrock, with slopes greater than 20%.

Concerns and Goals

Concerns, goals, and best practices for terrain stability are summarized in Table 14-1. Steep slopes and unstable terrain are susceptible to soil erosion, mass movements, and slumping. All forestry activity should be carried out without disrupting the stability of the soil, and by maintaining some protective cover of trees, understory and ground vegetation, and root mats.

Best Practices

Roads

- Build roads on slopes of high to moderate terrain stability. Risks increase with slopes greater than 20%.

Harvesting, Regeneration, and Tending

- **Designate no cut reserves on slopes greater than 70%**, and on less steep slopes that are inherently unstable, and subject to erosion and mass slumping.

- **Employ partial cutting on terrain that has low and very low stability.** Aim to establish uneven-sized management and continuous cover forestry. Use stem-only harvesting, leave slash on site.

- **Use clearcut harvest, stem-only slash-on-site on moderate slopes**. Use slash piles to stabilize ruts, potential erosion paths, and small gullies (see Chapter 13, Riparian

Table 14-1. Concerns and goals for management of terrain stability.

Concerns	Goals
Soil stability	Maintain soil in place. Minimize runoff water movements. Promote biotic capture of nutrients. Prevent establishment of erosion rills and gullies.
Vegetation stability and continuity	Maintain partial tree cover. Aim toward continuous cover forestry. Maintain advance growth, field, and ground layer vegetation. Maintain root mats.

Figure 14-3. Steep slopes are subject to erosion, especially on sandy and silty soils. Use care when harvesting, leaving trees, vegetation, and organic mat cover, and avoiding exposure of mineral soil. (Photo by M. Kershaw.)

Areas). Full-tree logging with slash removal may be preferred on moderate slopes to prevent debris slides into gullies, or to minimize smothering of advance regeneration.

- **Employ special equipment and methods** such as manual cutting, walking harvesters (e.g., Kaiser, Menzi Muck, Allied), low centers of gravity, and low ground pressures. Employ low impact extraction—e.g., light forwarders, cable extraction or high line yarding.

- **Conduct operations along contours.** Avoid operations that create paths or channels up and down slopes.

- **Do not use mechanical site preparation or prescribed burning.** Regenerate or fill-plant into the organic mat.

Site-adapted Best Practices

Very High Stability

Practice conventional forestry, and take normal precautions.

High Stability

Practice conventional forestry, take normal care not to damage the vegetation or root mats, and not to expose mineral soils excessively, or create opportunities for erosion paths.

Moderate Stability

These conditions have moderate erosion risk. Conventional logging practices can be conducted, but with some precautions to maintain soil stability. Clearcutting should be done with tree-length or full-tree, depending on requirements for regeneration. Winter operations are preferable, but summer operations may be done. We recommend low ground pressure equipment and equipment with low centers of gravity and stabilizing legs.

Low Stability

These conditions have a high risk of erosion. Conventional logging practices can be conducted, but with great care and precautions to maintain soil stability. Clearcutting may be done using CLAAG if there is enough regeneration to warrant this, while maintaining logging trails along contours if possible. Tree-length cutting in the winter is preferable, with brush mats in front of harvesters. Extraction should be with light and maneuverable forwarders, or cable yarding systems. Manual or mechanical slash piling can be done to stabilize potential erosion tracks.

Very Low Stability

These conditions have the highest erosion risk. Modified logging practices may be used, but with great care and precautions to maintain soil stability. It is recommended to do selection cutting using manual cutting with chain saws, leaving at least 50% canopy (>5 m tall individuals), and conserving advance growth. The goal should be to maintain as much as possible of the advance growth, vegetation, forest floor and root mat. If possible, move towards uneven-sized management and continuous cover forestry. No cutting should be done where slopes exceed 70%, or on shallow soil over bedrock where slopes exceed 20-40%, unless to salvage windfall, or stablize a slope where risk of windfall is high. Some of those sites with less steep slopes will nonetheless have high risks, and should not be cut. Protection forest on low and very low stability sites should be incorporated into the plan for reserves and corridors for the whole forest area.

Chapter 15. Other Sensitive Sites

There are other special sensitive sites and features that may be easily disturbed and changed.

Other sensitive sites, areas, and features will be encountered during harvesting operations, and decisions need to be made about how to treat them, often on the spot by the field staff and operators. Some of these may be partially harvested with constraints. Usually the decision will be whether to use some light partial cutting, or no cutting at all. The goal is of course to protect the site or feature, and leave it as undisturbed as possible.

Racey et al. (1996) list a number of special, non-forested terrestrial sites, and Harris et al. (1996) have considered the whole range of wetlands, which often are sensitive sites. More research is required to identify the sensitive **biotopes** in Ontario (e.g., AssiDomän 1994). Field staff and operators should be trained to recognize and handle the sensitive sites and **small sensitive areas**. In this chapter we highlight a few of the most important, sensitive sites that should be handled with extreme care when encountered.

Beaches, Bars, and Dunes

Beaches and bars are sandy materials, variable in texture, laid down along present or past lakes, rivers, and streams. When coarse, these are the same as the dry, coarse sensitive sites (Chapter 11). When beaches are sandy or silty, they are susceptible to reworking by wind, and may develop into dunes with irregular mound and swale topography. Dunes may become covered by trees, but when harvested the plant cover, forest floor, and root mat are easily disturbed, opened up to wind, and become easily eroded (see Figure 14-3). Silvicultural solutions to minimize excessive exposure to high winds, to minimize widespread exposure of mineral soil, and to ensure rapid revegetation are critical on these sites.

Very Fine Sand and Silt Soils

In some places in glacial lakebeds and alluvial sites, very fine sand and silt deposits can be quite susceptible to erosion or compaction. Drainage ditches in these materials, even with low gradients, may move large quantities of sediment, with creation of large gullies and mud slides on the one hand, and plugging of ditches and erosion fans on the other (Figure 15-1). When organic mats are removed to expose the mineral soil, it may bake, crack, and seal when dry, giving very poor growing conditions (Figure 15-2). Seed-

Figure 15-1. Very fine sands and silts are washed down from eroding roadway and landing. Even low gradients may move large quantities of materials. (Photo by J. Jeglum.)

Figure 15-2. Fine sands and silts are subject to surface baking, cracking, and frost heaving of seedlings. Owing to high soil fertility, heavy competition from graminoids and shrubs may develop. (See Figure 5-13.) The goal should be to maintain organic mat cover and not reach this stage. (Photo by M. Kershaw.)

lings planted in such soils may be subject to high moisture, poor aeration (related to compaction), and frost heaving.

Groundwater Discharge, Seepages and Springs

These sites have seepage or outflow of groundwater (Figure 15-3). These are found at the bottoms of slopes, the 'toe' of the slope, and often beside esker or outwash deposits where the groundwater is emerging over an impermeable layer such as clay or bedrock. They can be extremely difficult to operate on with machinery, and should be handled very carefully, perhaps in the winter on deep snow, or set aside as reserves and not harvested.

Kettle Holes and Frost Pockets

Kettle hole topography gives rise to kettle lakes or basins that are particularly susceptible to cold air drainage and summer frost occurrence. These pockets have become forested over time, but when the trees are removed, it may be extremely difficult to reforest owing to recurring frost damage and kill. Other low positions in the landscape may also be subject to frosts. This is particularly critical to white spruce (Groot and Carlson 1996).

Small Sensitive Areas

Small sensitive areas are areas or features, usually a few hectares in size or less, that have some special diversity, habitat, or cultural heritage value. Examples are a grove of old-growth; a population of trees with unique phenotype and possibly also genotype; an area that is species rich or contains rare species, a wildlife tree, den, or nesting area; a unique hydrologic or landform feature (e.g., rich fen, prairie). We include also archeological sites such as old native campsites, villages, and burial sites (cf. AssiDomän 1994).

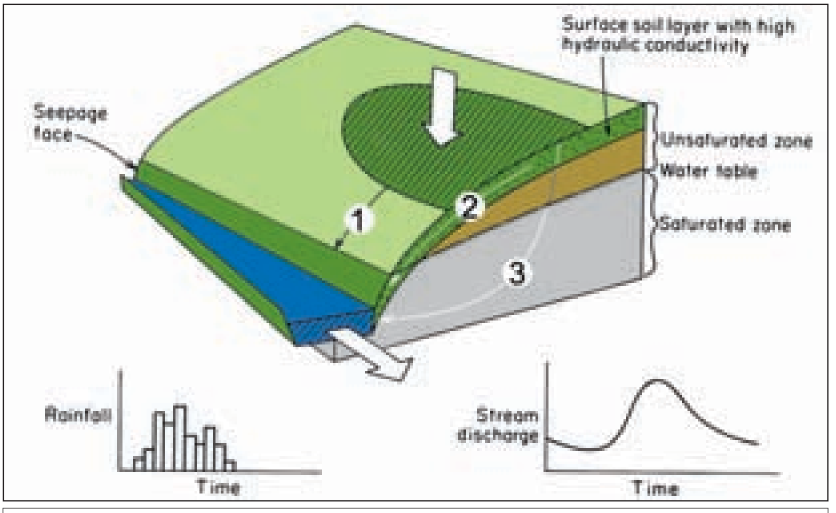

Figure 15-3. Groundwater discharge occurs at the bases of slopes and creates springs, springy meadow marshes, or tellaric swamps. They may also feed directly into stream or lake waters. (Adapted from Freeze and Cherry 1979, Figure 6-17.)

Part III.

BEST MANAGEMENT PRACTICES — OTHER ISSUES

Chapter 16.
Ecological Landscape Planning

"Understanding the spatial structure is fundamental to understanding landscape functioning, and to date we have astonishingly few structural studies or concepts to guide us in studying function in landscape ecology." *(Forman and Godron 1986)*

In the boreal forest, disturbances caused by fire, insects, disease, and windfall (Figures 16-1,16-2, 5-6), superimposed on the variations in relief and surficial deposits, create a mosaic of stands with different compositions, structures, and ages. With every forestry operation, foresters are redesigning the forest landscape—the forest cover types, sizes and patterns of stands, and distribution of stands of various ages. The mosaic resulting from forestry operations, regeneration, and tending will yield a forest landscape that is different from the original one.

Figure 16-1. Wildfire is still an important natural disturbance in the boreal forest. It occurs at shorter intervals on drier sites, and longer intervals on peatlands. (Photo by M. Kershaw.)

Some of the practices currently used to maintain landscape diversity include leaving single trees, small groups of trees (Figure 16-3), forest reserves, corridors, riparian buffer strips (see Figure 13-2), and sensitive sites. These practices may be done for a number of reasons—maintenance of biodiversity in general, and protection of soils, water bodies, wetlands, and sensitive habitats.

There are no absolute rules for how to redesign the forest for optimum sustainable use. Some ecologists have suggested that the forest landscape should be modeled after the original (pre-European settler) forest with its mix of stand types, ages, and patch sizes (Figure 16-4). Forest management that allows natural disturbance regimes, in particular wildfire, may be the safest approach to sustaining biodiversity. Some limited amount of natural disturbances should be accepted, or even imposed, to maintain disturbance structures (Kimmins 1997).

Biodiversity at the Landscape Level

- **Develop a landscape perspective.** Forest managers need to develop a landscape view, one that takes into account not only the stand being harvested, but the total complex of forest and other ecosystems in his/her district, and in a broader regional context. An ecological land classification is an essential tool for organizing information and placing a forest in ecological context (Ecological Stratification Working Group 1995; Crins and Uhlig In prep.).

- **Maintain diversity at the landscape level.** This involves the maintenance of a mosaic pattern of different ecosystems, with different compositions, structures, ages, successional stages, disturbance conditions, sensitive habitats, and dispersal paths for plants and animals (e.g., Figure 16-5).

Figure 16-2. Spruce budworm population explosions kill large amounts of balsam fir and white spruce. (Photo from Forest Insect and Disease Survey, CFS.)

• **Employ multiple-objective landscape planning.** The objectives of such planning include timber production, maintenance of biodiversity, and other environmental and social values. It is possible to analyze the ecological and economic outcomes from a range of landscape planning scenarios.

• **Maintain compositional and structural diversity in the forest**. Composition refers to tree composition of pure to mixed forests of conifers and hardwoods. Structural diversity includes the diversity of forest types, with different ages and development (successional) stages, even-sized versus uneven-sized, gaps versus closed canopies, coarse woody debris, snags, and wildlife trees (see recommendations of Ontario Ministry of Natural Resources 1996a and 2001, some ecological landscape planning information from this guide is listed in Chapter 16), and disturbance structures like windfall mounds.

• **Maintain old growth in the forest.** How much old growth and where? There are no absolute answers. The amount could be 5% to 10% or more. The location will depend on where the forest holding is in relation to the ecological land classification, and what is thought to be adequate for each district and region.

• **Include both large and small area clearcuts.** There has been a trend to reduce maximum sizes of clearcut blocks. Larger clearcuts may provide conditions similar (but not the same) to large wildfires, i.e., large tracts of even-aged forests. Interior forest species, such as woodland caribou, pine marten, and certain song birds require larger areas of interior forest. The safest approach is to make variable sizes of clearcuts.

• **Employ partial cutting to protect sensitive sites and aquatic habitats.** Aim to establish uneven-sized management and continuous cover forestry. Use stem-only harvest, delimb-on-site whenever possible.

• **Maintain connectivity of forests.** Plan to leave forest areas for return harvest, no-cut reserves, riparian buffer strips, and corridors. Identify no-cut sensitive sites and special habitats that contain rare species, or that are species rich.

• **Employ islands and fragments.** In the past 'edge' was highly desirable, but recently it has been suggested that a lot of edge may also represent a high degree of fragmentation with low forest interior area. As well, windfall incidence increases and predation is higher along edges. The recent OMNR

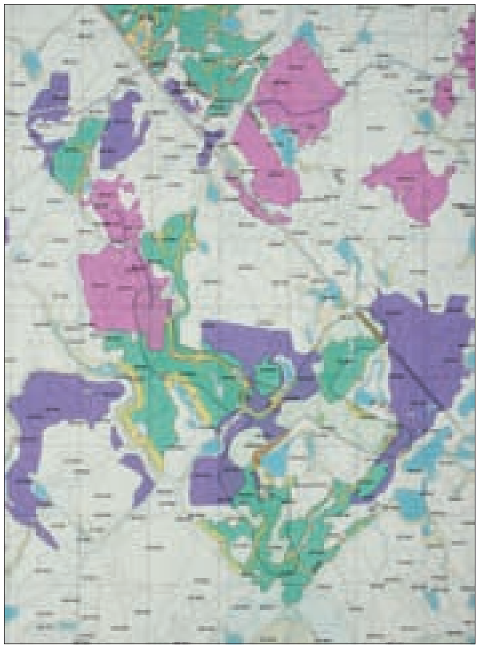

Figure 16-3. Ecological landscape planning includes clearcutting, partial cutting, reserves and buffers, riparian management areas, harvest timing restrictions, road allowances, and water crossings. Forest management planning map courtesy of Clergue Forest Management Inc.

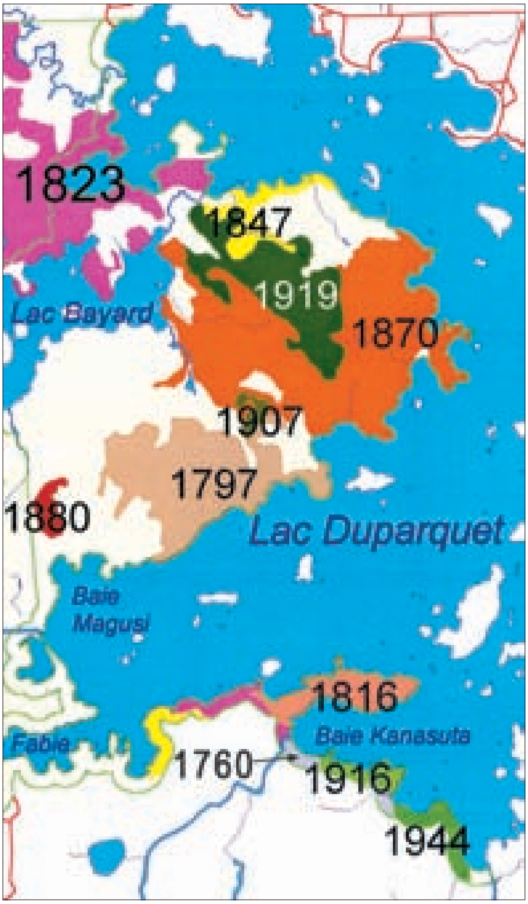

Figure 16-4. History demonstrates the strong relationship that exists between the boreal forest landscape and wildfire. Eight major fire episodes, from 1760 to 1944, around Lake Duparquet, western Quebec are shown here (Illustration provided by B. Harvey, adapted from Bergeron and Harvey 1997).

guide for natural disturbance pattern emulation (Ontario Ministry of Natural Resources 2001), among other things, gives a number of guidelines and standards for residual tree patches, individuals, and downed woody debris. A summary of two types of residual tree patches (islands and peninsulas) follows:

Islands of tree patches

1. Maintain a range of 2-8% of the clearcut area in islands of residual tree patches (guideline).

2. Minimum patch sizes of tree islands is 0.25 ha.

3. Residual patches should be well distributed within the cutover (standard).

Peninsular residual tree patches

1. Maintain a range of 8-28% of the clearcut area in peninsular residual patches (guideline).

2. Residual patches should be well distributed within the cutover (standard).

3. 50 % of peninsular residual patch area is available for subsequent harvest after 3 metre 'Free-to-Grow' green-up (standard).

4. Alternatively, a one-pass harvest may include the removal of 50% of the volume in 50% of the exterior edge of the peninsular area leaving the core area unharvested (standard).

- **Plan for nature conservation.** Conserve rare species habitats; wildlife resting, nesting and foraging areas; special landforms; sensitive sites; and cultural heritage sites. Special attention should be given to migrating species, and wildlife feeding and overwintering areas.

- **Use an integrated approach on terrestrial and aquatic ecosystems.** The key to wise management of aquatic ecosystems is wise management of watersheds and landscapes (Likens and Bormann 1974). Watersheds are a useful unit for management (perhaps at the ecosection level) in cases where the uses and benefits of rivers, streams, and lakes are of high importance (e.g., Figure 16-6).

- **Mimimize impacts on streams and watersheds.** Planning should take into account how harvesting influences runoff, peak flows, and flooding. Whole watersheds should not be clearcut all at once. It has been suggested to maintain on the order of 50% forest cover for each watershed (at the second or third order level). This would include younger and older stages of forests. Riparian management is a critical component of maintaining healthy, diverse aquatic ecosystems, as well as maintaining landscape connectivity.

- **Maintain disturbances.** Disturbances are an integral part of boreal ecosystems, and disturbance structures support a multitude of habitats and creatures. Allow or impose sufficient disturbance to maintain the disturbance-related ecology.

- **Obtain proper equipment for different sites, forest conditions, and systems.** Forest sites are variable, and forest structures range from monodominant to mixed, from even-aged (uneven-sized) to uneven-aged (uneven-sized). Harvesting and regeneration equipment and systems need to be sought out or developed to re-create the range of forest types that are naturally found.

• **Plan for aesthetics and tourism.** Beauty and aesthetics are important to humans. Take into account skylines, views from lookouts, visibility of cutovers from highways and canoe rivers. Use the Ontario Ministry of Natural Resources (1987) management guides for protection of tourism.

Biodiversity at the Site Level

• Accept some broadleaf regeneration. It is recommended to maintain some broadleaf component if it serves to fill unregenerated holes, or if the site can support a mixedwood forest and forest management. The natural successional trend on rich, deep soils with intermediate moisture is to mixedwood. It is probably the best, in terms of economics and site productivity, to work with natural succession on such sites (e.g., Smith and Crook 1996).

Figure 16-5. Best practices should strive to maintain diversity at the landscape level. This means maintaining different ecosystems, compositions, forest structures, ages, successional stages, disturbance structures, sensitive habitats, and dispersal paths for plants and animals. (Photo by M. Kershaw.)

• **Leave living vegetation.** "New forestry" (Franklin 1989) is a term coined for maintaining some portions of the forest on site during a clearcut. This may be single trees or groups of trees, advance growth, and unmerchantable and dying trees and snags during a clearcut. These serve as refuges and protection for wildlife and invertebrates, and as centres of biodiversity from which recolonization occurs.

• **Leave wildlife trees.** A wildlife tree is a standing live or dead tree, 'snag', that provides valuable habitat for a diversity of wildlife. They are often dangerous to work around, and a no harvest zone (1 or 2 tree lengths) should be established around them, both for safety, and for wildlife values. If wildlife trees are missing, consider creating them by felling some poor quality trees at 3 m to create 'stubs'. The Ontario Ministry of Natural Resources (2001) suggests retaining 25 well-spaced trees per hectare including at least 6 large high-quality cavity trees (standard).

• **Leave coarse woody debris.** At the site level, leave logs on the ground, and slash piles. To minimize the potential for smothering of advance growth and difficulties for regeneration, decomposing slash and woody debris could be accumulated in piles, as brush mats on logging trails, etc.

The Ontario Ministry of Natural Resources (2001) suggests providing coarse downed woody debris through:

1. using cut-to-length or tree-length harvest systems;

2. individual tree and snag retention;

3. leaving unmerchantable logs on site; and

4. avoid windrowing of coarse woody debris during mechanical site preparation (guideline).

• **Manage slash, fine woody debris, and needles.** The Ontario Ministry of Natural Resources (2001) suggests the following:

1. redistribution of roadside slash/chipping waste;

2. provide fine woody debris on shallow or very shallow, or very coarse-textured soils through avoiding full-tree harvesting on these sites;

3. redistribution of logging slash after roadside delimbing or chipping (guideline); and

4. burn roadside slash/chipping waste where it cannot be redistributed (guideline).

There may be situations where slash piles should be left on site, for instance, to fill gullies or erosion channels, or to provide habitat for wildlife or biodiversity.

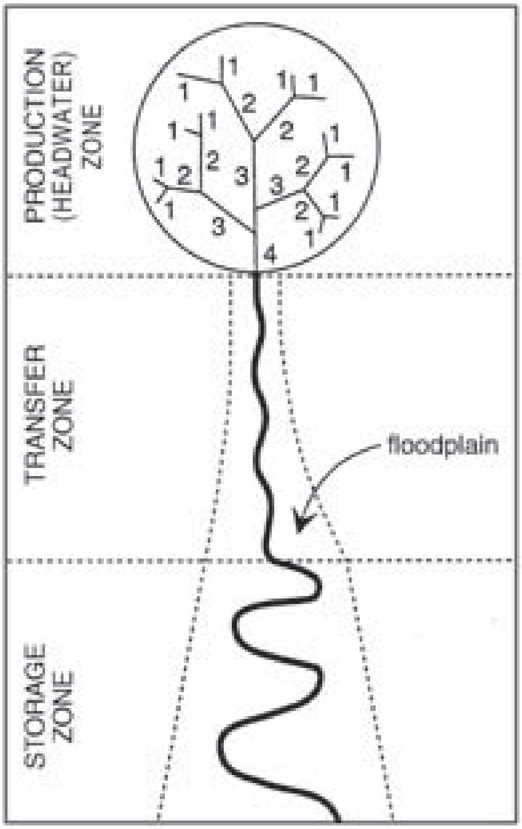

Figure 16-6. Fluvial systems are useful units for management. The diagram shows three primary zones: production (headwater) zone with 1st to 3rd order streams; transfer zone with less hill slope and more floodplain input; and storage zone where floodplain and channel are most significant. (From Burt 1997, Figure 1.)

Biodiversity at the Genotype-Population Level

The genetic preservation program of the Ontario Forest Research Institute is: to develop species management plans for tree species (Joyce 1994). These are based on two principles: 1) natural species populations adaptively differentiate in different climatic conditions, and 2) retention of evolutionary potential requires large effective population sizes (at least 1000 individuals). A genecological research project has been initiated to identify adaptive strategies of priority species, and studies are in progress for black spruce, white spruce, jack pine, and red oak. Some best practices are:

- **Employ a climatically based system of ecological regions** (see Figure 3-1). The basis of species management plans should be the recent versions of ecological land classification and Site Regions for Ontario (e.g., Crins and Uhlig In prep.). The new seed zone map and climate model for Ontario should be consulted (Joyce and White 2002).

- **Identify local races or populations of species** by variations in phenotype, phenology, cold hardiness, and growth characteristics. Inform forest geneticists of any unusual races or forms.

- **Make plans to maintain genetic diversity of local races.** Maintenance of local gene pools may include establishing local reserves, using natural regeneration, and planting or seeding with material from the same area (district, or section) from which seed was obtained.

- **Beware of the pitfalls of breeding for homogeneity.** Endeavor to select and maintain seed orchard material from a wide range of regions, districts, and sections, and from different environments such as uplands versus wetlands.

Chapter 17. Socioeconomics

Forestry is both an economic and social undertaking. We must learn how to interact with the forest and the land so that we gain benefits and values while sustaining its ecological functions and complexity.

Equipment

Environmentally sound forestry depends on having the right machines for the jobs and skilled, knowledgeable operators to run them. The economically right machines for large clearcut operations may not be silviculturally correct for selection cutting. Keep up-to-date with new developments in harvesting and forwarding equipment. Machinery is continually changing to operate on the land with minimum soil disturbance, greater maneuverability, and longer booms in order to reduce damage to both site and advance regeneration (Figure 17-1). Similarly, site preparation and tending equipment continues to be refined to meet specific objectives on different site conditions. Equipment should be developed for the site conditions and the trees to be harvested. Forest managers with different kinds of sites and silvicultural systems should ideally have different kinds of equipment to suit the job. Contracting out special logging operations could be an option if it is not economical to invest in special equipment.

Figure 17-1. Equipment development, and operator skills and knowledge, will reduce the impacts of forestry practices on the forests and land. (Photo courtesy of Timberjack™.)

Economics

In sustainable forest management, there is often a conflict between economic and ecological goals. Economic analyses and market-driven forces usually do not take into account all of the costs and benefits of the forest, or the ecological constraints. A workshop in 1992 in Stockholm addressed the theme of sustainable management with a new cross-disciplinary approach to sustainability called **ecological economics** (Jansson et al. 1994). The main conclusions were that economic systems are a subset of the global ecosystem, fundamental uncertainty is large and irreducible and certain processes are irreversible, and there are limits to biophysical throughput through the economic system. Therefore, we need to conserve natural capital, or maintain adequate stocks, keep our options open to avoid irreversibilities and create opportunities, and include a broader range of values such as ethics, equity, and intergenerational concerns.

Whenever a new practice is undertaken, costs should be determined and compared to existing systems. In calculating total cost/benefits, at least the combined costs of harvesting with regeneration should be calculated. Preferably, the total costs and benefits should be accounted for, roads, harvesting, regeneration, and tending costs should be balanced against the benefits of wood products and other non-timber values.

When we manage forests to maintain sustainable productivity, minimize environmental impacts, maintain biodiversity, and obtain other non-timber benefits, extra costs of forest management will be incurred. Issues of safety and health must also be an important part of employee training. Even when a modified silvicultural system is not as economical as a conventional system, other societal values may weigh in favor of the modified practice.

Education and Safety

In the training curricula for foresters, technicians, and equipment operators it is essential to include a firm grounding in environmental issues and forest ecology (Figure 17-2). Foresters need to continually upgrade their knowledge of forest ecology by subscribing to journals, belonging to forestry organizations, and taking relevant courses for continuing education.

When a new operation or procedure is used, the manager should set aside control areas to compare with the operational treatment. Permanent plots or observation points could be established and monitored for the changes and impacts to the regeneration, vegetation, and soils. The manager should make use of all available resources including researchers, for information and advice.

Equipment operators should be well educated about impacts of machinery on soils, water, and vegetation. They should have knowledge to make decisions about roads, harvesting, site preparation, regeneration, and ways to avoid soil and vegetation damage. They should be informed about the goals and requirements of different silvicultural systems. There should be regular short courses, training sessions, and operator skill requirements in operating equipment properly (e.g., AssiDomän 1994).

It is necessary to develop more significant programs of socially responsible forestry. An excellent example of this is the “Greener Forests” study campaign in Sweden (Swedish National Board of Forestry 1999). The campaign was set up to provide better basic knowledge for the forest owners, others dealing with the forest, and the public.

Long-term Ecological Research

Effects of intensive harvesting on productivity are best assessed by long-term experiments designed explicitly for that purpose (e.g., Figure 17-3). Ontario has a rich legacy of long-term research areas established by provincial and federal research agencies, and universities. Several long-term silvicultural experiments have been established in Ontario to quantify the ecological impacts of forestry practices, and to understand processes and cycling (e.g., Gordon et al. 1993; Tenhagen et al. 1996; Cameron et al. 1999; Morrison et al. 1999; Duckert and Morris 2001).

Most of these long-term experiments emphasize productivity at the stand and site levels of concern. However, we realize that there are broader issues at the landscape level that need to be considered. Landscape function, optimum patterns of cover types and developmental stages, impacts of forestry on watersheds, and impacts of forestry on wildlife productivity and biodiversity, are all important issues.

Figure 17-2. Education and extension programs are required for best management practice. (Photo by A. Cameron.)

Figure 17-3. Neutron meter and access tubes used to measure volumetric soil water content. From the jack pine biomass removal experiment, near Chapleau, Ontario. (Photo by R.L. Fleming.)

Ethics

"…quit thinking about decent land-use as solely an economic problem. Examine each question in terms of what is ethically and esthetically right, as well as what is economically expedient. A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise." (Leopold 1949)

The landscape that we live in—climate, landforms, forests, rivers, lakes, wetlands, and wildlife—shapes our cultural identity. Much of Canada is clothed in forests, which are a major source of raw material, wildlife, and wilderness. Indeed our basic underpinning as a forest nation is symbolized by the maple leaf flag. As Leopold (1949) so eloquently postulated, in order to maintain the productive capacity, health and diversity of the forest, the most important element is to develop an ethical responsibility towards the forest and the land. This ethical-moral sense is an essential requirement for achieving sustainable forest management (e.g., Maser 1988; Botkin 1990; Kimmins 1997).

EPILOGUE

> "Nature in the twenty-first century will be a nature that we make; the question is the degree to which this molding will be intentional or unintentional, desirable or undesirable." *(Botkin 1990)*

Forestry and silvicultural practices in Ontario have changed dramatically in the last few decades, with many improvements in harvesting and regeneration systems, and reductions in environmental impacts. Operational practices are still changing to become more environmentally sound, but it is clear that more changes are still required. One of the major problems in forestry is how to manage forests and ecosystems that are continually changing, and for which we have no absolute 'true' or 'best' goals to aim to achieve.

This guide has presented a large number of recommendations to achieve sustainable forest management. We certainly do not have all the answers, and many actions are best guesses from limited evidence and common sense. However, some of the key components that should be considered in sustainable forest management are:

1. Protection and enhancement of ecosystem integrity, function, and productivity;

2. Maintenance and enhancement of biodiversity;

3. Maintenance of landscape integrity, including connectivity, avoidance of fragmentation, protection of waterways, and identification and protection of sensitive habitats;

4. Representation of older stands, along with the development of structural traits resembling old-growth;

5. Maintenance of a flow of energy with continual renewal of complex organic molecules (**primary productivity**), which counteracts the tendency of the system to "wear down", and maintains a high level of resilience within the system (Morris 1997).

Best management practices should meet local, regional, and international expectations for environmentally sound forestry. With the need for 'eco-labelling' and 'certification', site-specific, site-adapted best practices will help industry and private landowners develop environmentally sound and socially acceptable forestry. The world is becoming ever more interconnected, and new knowledge about standards and best practices will continue to improve and evolve at an international level.

The best way to minimize mistakes is to plan and base decisions as much as possible on factual information. Most of the negative effects of forestry practices can be avoided through knowledge, good planning, modified practices, and continuing site-adaptive forestry. The most important information relates to ecosystem structure, function, and change under different management regimes and for different impacts. We urgently require information about landscape level ecology, and about soil ecology.

Best management practices for maintaining site productivity will continue to evolve as results from research and new technological developments become available to land owners and forest managers (e.g., Galloway et al. 1987). All available information should be considered, then integrated with professional judgement combined with a sense of responsibility to society and forests. For guidance in making judgements, the forester must balance biological feasibility, environmental acceptability, economic realities, and societal values. The measures of success are long-term sustainable productivity, and maintenance of biodiversity, health, and integrity of forests.

APPENDIX 1. LIST OF SPECIES

Alder, speckled	*Alnus rugosa* (Du Roi) Spreng.
Ash, black	*Fraxinus nigra* Marsh.
Aspen, trembling	*Populus tremuloides* Michx.
Birch, paper or white	*Betula papyrifera* Marsh.
Budworm, spruce	*Choristoneura fumiferana*
Budworm, jack pine	*Choristoneura pinus pinus*
Caribou, woodland	*Rangifer tarandus*
Caterpillar, forest tent	*Malacosoma disstria*
Cattail	*Typha latifolia*
Cedar, eastern white	*Thuja occidentalis* L.
Dogwood, red-osier	*Cornus stolonifera*
Ericaceous	Shrubs in the heath (*Ericaceae*) family, including leatherleaf, and Labrador-tea.
Feathermoss	includes *Pleurozium schreberi*, *Hylobium splendens* and *Ptilium crista-castrensis*
Fir, balsam	*Abies balsamea* (L.) Mill.
Graminoid	refers to *Gramineae*, *Cyperaceae*, *Juncaceae*, and *Typhaceae* families
Leatherleaf	*Chamaedaphne calyculata*
Labrador-tea	*Ledum groenlandicum*
Lichen, reindeer	*Cladina* spp.
Lichen, club and cup	*Cladina* spp.
Marten, pine	*Martes americana*
Moose	*Alces alces*
Moth, gypsy	*Lymantria dispar*
Oak, red	*Quercus rubra* L.
Pine, jack	*Pinus banksiana* Lamb.
Pine, red	*P. resinosa* Ait.
Pine, white	*P. strobus* L.
Poplar, balsam	*Populus balsamifera* L.
Sedge	*Cyperaceae* family
Spruce, black	*Picea mariana* (Mill.) B.S.P.
Spruce, Norway	*P. abies* (L.) Karst.
Spruce, red	*P. rubens* Sarg.
Spruce, white	*P. glauca* (Moench) Voss
Squirrel, red	*Tamiasciurus hudsonicus*
Sweet gale	*Myrica gale*
Tamarack	*Larix laricina* (Du Roi) Koch
Trout	*Salmo* and *Salvelinus* spp.
Willow	*Salix* spp.

APPENDIX 2. GLOSSARY

The definitions and meanings of terms follow Aird (1994), Natural Resources Canada (1995), Dunster and Dunster (1996), and the Ontario Ministry of Natural Resources (1997), except when noted otherwise.

Advance growth, cf. Advance regeneration: Seedlings, saplings or young trees under existing stands capable of becoming the next crop. Regeneration established before logging that has survived the logging operation.

Basic forest management: Extensive forest management plus artificial regeneration where necessary. Basic silviculture includes all the silvicultural practices required to achieve free-growing (or established) regeneration of desired species at specified densities and stocking (Natural Resources Canada 1995).

Best management practices: Practices that represent the best methods to achieve sustainable forestry and to achieve management objectives. Best practices include both timber-production forestry and non-timber production uses and values.

Biodiversity: The diversity of plants, animals, and other living organisms in all their forms and levels of organization, including genes, species, and ecosystems, and the evolutionary and functional processes that link them.

Biotope: "The smallest geographical unit of land or habitat in which environmental conditions (soil and climate), and the associated organisms dwelling there, are uniform." (Dunster and Dunster 1996).

Blended regeneration: Blended regeneration involves a combination of natural and artificial regeneration for establishing black spruce and jack pine stands. Usually this involves seeding or planting to compliment advanced growth.

Bog: Peatland with water table at or near the surface, peat usually > 40 cm. Surface often raised above surrounding terrain, not influenced by mineral soil water, nourished only by rainfall i.e., 'ombrotophic'. 'Minerotrophic' indicators absent. *Sphagnum* usually dominant in bottom layer, other species of sedges, ericaceous shrubs, and small trees may be abundant (cf. National Wetlands Working Group [Canada] 1988; Harris et al. 1996).

CLAAG, Careful logging around advance growth: Full-tree harvesting operation in which overstory is removed while protecting understory advance growth. Feller bunchers harvest along parallel trails, cutting in the trails and also in the intervening strips. Bunches of trees are laid down diagonally to the trails in the intervening strips. Clam bunk or grapple skidders follow the harvesters and extract the full trees carefully, minimizing damage to the remaining advance growth. The trails are as wide as the operating width of the machines, e.g., 4 to 6 m. The intervening strips are 6 to 9 m wide. Another name applied to the system is 'corridor selection harvesting', which describes the pattern of parallel trails alternating with carefully logged strips (Kliewer 1997). See HARP.

Coarse woody debris: Includes snags, logs, large pieces of wood (from disintegration of larger snags and logs), large branches, and coarse roots. Harmon et al. (1986), in their review, used 2.5 cm as the minimum diameter, but other studies have used larger minimums, up to 15 cm.

Competition: Refers to the competition by vegetation for resources —moisture, nutrients, and light. Especially used in relation to the unfavorable influences of other vegetation on planted and naturally regenerated crop tree species.

Continuous cover forestry: Continuous cover forestry, a popular silvicultural movement in the UK, proposes to maintain tree cover continuously on site. It promotes lower impact silvicultural systems in windfirm conifer plantations, and management for high diversity of species and forest structures, to provide for multiple use objectives. Silvicultural systems that can be used to achieve these goals are single tree selection, group selection, shelterwood or underplanting, and area clearcuts (Mason et al. 1999). Not suited for shade intolerant tree species.

Density Management: This is the management of the density of a forest stand throughout its rotation for the optimum production of products defined in objectives for the stand, e.g., wood fiber or solid wood. Density management diagrams are being developed for the main crop species to help foresters determine initial regeneration and subsequent tree densities throughout the stand development (e.g., Newton 1997; Ontario Ministry of Natural Resources 1998).

Ecological economics: A transdisciplinary field of study that addresses the relationships between ecosystems and economic systems in a broad and comprehensive way. It seeks to address the issues related to sustainable development, viz., how to achieve a balance between growth of human populations, economic development, and ecological constraints (e.g., Jansson et al. 1994).

Ecological land classification: A hierarchical classification of land at different scales, from broad regional to fine site levels. Units of the Ecological Land Classification (ELC) include Ecozone, Ecoprovince, Ecoregion, Ecodistrict, Ecosection, Ecosite, and Ecoelement (Ecological Stratification Working Group 1995; Crins and Uhlig In prep.).

Ecology: A branch of science concerned with the interrelationships of living organisms with each other and with their environment. There are many different kinds of ecology, autecology (single organisms), synecology (communities), forest ecology, wetland ecology, soil ecology, process ecology, human ecology, and so on.

Ecosystem: Any complex of living organisms with their environment, that we isolate for purposes of study. An ecological system exhibits five criteria: structure, function, complexity, interconnectedness, and change over time (Kimmins 1997).

Ecosystem management (of forest ecosystems): Management of forests as ecosystems based on knowledge of ecology, structure and function, and knowledge of the ecological impacts of forestry practices (e.g., Boyce and Haney 1994).

Even-aged: Of a forest, stand, or forest type in which relatively small age differences exist between individual trees. The differences in age permitted are usually 10 to 20 years; if the stand will not be harvested until it is 100 or 200 years old, larger differences up to 25% of the rotation age may be allowed.

Even-aged system: Silvicultural systems in which stands have an even-aged structure, e.g., clearcutting methods, coppice methods, seed-tree methods, and some shelterwood methods.

Extensive forest management: Protection from fire and insects; reliance on natural regeneration.

Fen: Peatland with water table at or near the surface, peat usually > 40 cm deep. Influenced by mineral soil water, as indicated by presence of minerotrophic indicator plants. Sometimes floating mat. Vegetation dominated by sedges, brown mosses, and/or *Sphagnum* mosses, sometimes shrubs, and sometimes sparse tree layer (cf. National Wetlands Working Group [Canada] 1988; Harris et al. 1996).

Fibric: Refers to peat that is undecomposed to very weakly decomposed. It includes von Post humification classes H1 to H3. Other classes of decomposition are mesic (weakly to strongly decomposed, H4 to H6), and humic (strongly to completely decomposed, H7 to H10).

Fine-type mapping: Mapping at finer scales than the traditional 1:15,840 (1:20,000) to provide more details of ecosites, terrain features, sensitive sites, and wildlife habitats. Scales such as 1:5000 or 1:2000.

Forested wetland: These are wetlands that have tree or tall shrub development and tall woody canopy cover that exceeds roughly 25 to 30%. These sites are often called swamp or swamp forest, and consist of conifer swamp, hardwood swamp, and thicket swamp. The conifer and hardwood swamps are mostly merchantable, production forests.

Full-tree harvest: Removing the complete tree above the stump, including stem and branches, off site to roadside, then delimbing and detopping. Some authors use the term **whole-tree harvest** to mean the same as full-tree, but others define whole-tree as removing the complete tree including stump and major roots. See tree-length harvest.

Guideline: In OMNR Forest Management Guides (e.g., Ontario Ministry of Natural Resources 2001), this term is used to indicate a component of a guide that provides mandatory direction, but requires professional judgement for it to be applied appropriately at the local level.

HARP, Harvesting with regeneration protection: A harvesting operation similar to CLAAG. HARP is currently used to refer to harvesting of uneven-aged (-sized) stands where it is possible with careful harvesting to save some of the larger saplings and small trees. The HARP retains stems below a set diameter limit, e.g., 10 to 12 cm. In both CLAAG and HARP, the already established regeneration creates the next stand, and it may be possible to reduce rotation age to 60 or 80 years instead of the more typical 100 to 120 years for black spruce on peatland sites. Another general term applied to this system and to CLAAG (see definition) is 'corridor selection harvesting', which describes the pattern of parallel harvest trails alternating with carefully logged strips (Kliewer 1997).

HARP is related to uneven-aged harvesting systems (see definition), in which selective harvesting and higher diameter limits (e.g., 15 to18 cm) result in a higher proportion of merchantable trees remaining on the site after a harvest (MacDonell and Groot 1996).

Health (stand-level): 1) The traditional view of health is forest production oriented, a healthy forest is vigorously growing and productive, there is rapid nutrient cycling, the successional development is normal for that particular seral stage. Traditional concerns are about impacts of insects and diseases, atmospheric pollution, acid rain, and climate change. 2) The modern view of health is ecosystem-oriented and emphasizes ecological processes. Ecosystems are healthy when the ecosystem structure, function, conditions, species composition, and processes are all within or close to the historical range of the seral stage that the forest is in, or for which it is being managed. Healthy ecosystems demonstrate constant interactions among plants, animals, micro-organisms, soil, water, and air. These processes form soils, recycle nutrients, store carbon, recycle and clean water, and fulfill other functions essential to life (Kimmins 1997).

Health (landscape-level): 1) When the landscape pattern of forest ages, ecological conditions, and seral stages is within or close to the range of these characteristics for that landscape; and 2) When the scale, severity, pattern, and frequency of disturbances do not impair the landscape-level processes that provide a sustained supply of values desired from that landscape (Kimmins 1997).

Integrity: 1) When the structure and species composition, rate of its ecological processes, and ability to resist change from disturbance or stress, or to recover from disturbance, are within the range exhibited historically by that ecosystem; and 2) when the ecosystem is at a late seral stage, or is developing by vegetational succession processes toward a later stage at rates and by pathways characteristic of that ecosystem (Kimmins 1997).

Intensive forest management: Basic forest management plus juvenile-stand improvement plus acceleration of artificial regeneration (Natural Resources Canada 1995). In Ontario, **intensive silviculture** may be considered to include plantation establishment, e.g., using genetically improved planting stock; intensive site preparation, such as spraying herbicides to reduce competing vegetation before mechanical preparation; and manual weeding of plantations at early stages. Highly intensive silviculture includes commercial thinnings, fertilization, drainage, intensive soil cultivation, and short-rotation forestry.

Landings: Places at roadside where the trees are piled. Sometimes these can be almost continuous piles at roadside where the forwarding distances and numbers of trees accumulated per forwarding trail are large; these may be called 'skidways' (R. Gemmell Pers. comm.). At the landings, branch removal and stem cutting may occur, leaving slash piles. The logs are then transported and accumulated in large piles either in the field or in the mill yard. In some cases, trees may be chipped whole into chip vans, with accumulation of piles of bark, sawdust and needles on site.

LFH: Litter, fermentation, and humus layers of the organic mat (forest floor) over mineral soil or bedrock.

Liber-rich: Silvicultural system in which the largest, most valuable trees are selected for harvest, which opens the canopy and liberates advance growth. At the same time, improvement thinning is done. The gaps and openings that are not filled by advance growth are enriched by underplanting with genetically improved nursery stock (Hagner and Molin 1998).

Marsh: Ecosystems at the margins of open water bodies, permanently or frequently flooded, and with high water level fluctuations. Vegetation consists of submerged, floating, or emergent plants. Nutrient-rich water generally remains within rooting zone for most of growing season. Substrate is mineral soil, well-decomposed aquatic sediments, or early stages of peat, often held together with a root mat (cf. National Wetlands Working Group [Canada] 1988; Harris et al.1996).

Minerotrophic: The groundwater contains nutrients derived directly from underlying mineral soil, or flowing into the site by flooding or subsurface water movement. Marshes, fens, and swamps are minerotrophic.

Mounding: Creation of elevated mounds on which seedlings are planted (Sutton 1991). Low mounds are created with equipment such as patch scarifier-mounders and disc trenchers (ibid.). In Scandinavia, higher mounds are created with a digger backhoe on highly productive shallow peatlands and planted with Norway spruce (Holgén and Hånell 2000). It is often done in combination with shelterwood cutting to reduce the risk of frost. The technique may be used in combination with shallow ditching, using the material from the ditches to create the mounds (e.g., see Figure 15-1).

Old-growth forest: A forest dominated by old, usually large, trees that have originated naturally from those endemic to the forest or its surrounds, in which the genetic, species and structural diversity have not been significantly changed by human activity. Gaps created by windfall are filled with understory vegetation and tree seedlings, saplings, and young trees. Coarse woody debris, consisting of snags and downed logs, is common. There are numerous old-growth forest types, corresponding to the several forest types and ecotypes in a region.

Oligotrophic: The poorest class of wetlands and peatlands in a three-part system of nutrient regime. The other classes are **mesotrophic** (intermediate) and **eutrophic** (rich). Oligotrophic is roughly equivalent to ombrotrophic and poor minerotrophic (see Jeglum 1991).

Ombrotrophic: Surface groundwater containing nutrients derived only from rainfall and dust. Indicated by the absence of indicator plants that are sensitive indicators of minerotrophy (see Jeglum 1991).

Primary productivity: The rate at which energy is stored by photosynthetic and chemosynthetic activity of producer organisms (chiefly green plants) in the form of organic substances. This can be estimated for an ecosystem, community, or parts thereof, such as the tree component of a forest stand. Often expressed as biomass produced for a given area and unit of time, e.g., kg/ha/year. Net primary productivity is the rate of storage of organic matter in plant tissues in excess of the respiratory utilization by the plants during the period of measurement.

Productivity: The rate of production of wood of given specifications, by volume or weight, for a given area. (Cf. site capability).

Resilience: The speed with which a system returns to its equilibrium after a change or disturbance. Recovery is a similar concept, referring to the ability of a system to return to an earlier state after being changed. Large disturbance in the inherent structure and function of an ecosystem may lead to an irreversible change to another ecosystem (e.g., Holling 1986).

Riparian: Riparian areas are zones next to lakes, rivers, streams, drainageways, and wetlands. They include the immediate water's edge, and adjacent uplands which influence, and are influenced by, the water body. (Cf. Stevens et al. 1995).

Riparian management areas (RMAs) are the areas delimited along water bodies for specific management practices. They consist of a **riparian management zone** in which certain constraints to forestry operations and harvesting apply, and sometimes also have a **riparian reserve zone** adjacent to the water body (British Columbia Ministry of Forests 1995b).

Scarification: Loosening the topsoil of open areas or breaking up the forest floor to create better seedbed and tree growing conditions, or to prepare receptive seedbed for natural or artificial seeding. It is also used in a more restricted sense as a regeneration method for jack pine in which a tree-length operation is followed by mechanical site preparation, possibly with further redistribution and placement of cone-bearing slash onto seedbeds. Some research has been done with slash placement or cone scattering on receptive seedbeds for black spruce, but the method has not been proven.

Selection cutting: Periodic cutting of trees chosen individually or by groups, in an uneven-aged stand. Cuts are usually a mix of regeneration cuts and improvement cuts. ‘Selection from above’ is cutting mostly taller, canopy individuals, while ‘selection from below’ is cutting mostly below canopy individuals.

Sensitive site: Site that is easily damaged, is not resilient, and may be changed to a quite different ecosystem with too much disturbance. Sensitivity may be to erosion, nutrient loss, organic matter loss, soil compaction, soil rutting, drainage disruption, watering up, species and structural shifts, and development of excessive vegetative competition.

Shearblading: A mechanical site preparation method using a large bulldozer with sharpened blade positioned to shear off the top layers of *Sphagnum* moss hummocks and competing woody vegetation. It is done in winter on sites with minimal advance growth. Twenty-five percent seedbed exposure is recommended.

Site-adapted forestry: Each harvesting area has numerous sites with widely differing biological and growth characteristics. Each area is cut and reforested with those methods that are best suited to maintain the natural yield capacity of that site. Harvesting and regeneration are treated as one package within site-adapted forestry (AssiDomän 1994).

Small sensitive area: Special sites, areas, or features, usually smaller than a few hectares in size, but can be larger. Usually warrant complete protection, or minimal disturbance. May be unique ecosystems, areas of rare species, high species diversity, and sites valuable to wildlife (dens or nests; wildlife trees; feeding, overwintering, breeding, or migration sites). Also includes areas of special tree stands or specimens of trees, landform features, hydrological phenomena, archeological sites, and historical/cultural features (old homesteads, campsites, burial sites, rock paintings, spiritual sites) (cf. AssiDomän 1994; Swedish National Board of Forestry 1999).

Spacing: 1) The distance between trees in a plantation, a thinned stand, or a natural origin stand. 2) The act of altering the distance between adjacent stems (usually) of the same desired species by increasing (planting) or decreasing (thinning) the number of stems per hectare (Natural Resources Canada 1995; Dunster and Dunster 1996).

Stability: The propensity of a system to attain or retain an equilibrium condition of steady state or stable oscillation. Systems of high stability resist any departure from that condition and, if perturbed, return rapidly to it with the least fluctuation. An ecosystem with high stability may have either low or high resilience to external disturbance (e.g., Holling 1986).

Standard: In OMNR Forest Management Guides (e.g., Ontario Ministry of Natural Resources 2001), this term indicates a component of the guide that provides mandatory direction.

Stock Quality: The quality of planting stock is the degree to which that stock realizes the objectives of management (to the end of the rotation or achievement of specified sought benefits) at minimum cost. Quality is fitness for purpose (IUFRO 1980).

Sustainability: “The ability of an ecosystem to maintain ecological processes and functions, biological diversity, and productivity over time.” (Dunster and Dunster 1996).

Sustainable development: Development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It implies meeting the basic needs of all, in particular the world’s poor, and the idea of limitations imposed by the state of technology and social organization on the environment’s ability to meet present and future needs (World Commission on Environment and Development 1987).

Sustainable forest management: Management regimes applied to forest land that maintain the productive and renewal capacities as well as the genetic, species and ecological diversity of forest ecosystems. Sustainable forest management is required to achieve sustainable forest development (e.g., Canadian Council of Forest Ministers 1995).

Sustainable use: Use of renewable or recyclable resources at a rate that does not exceed their capacities for renewal.

Sustainable yield: The yield of defined forest products of specific quality and in projected quantity that a forest can provide continuously at a given intensity of management. **Sustained yield management** implies management to achieve at the earliest practical time a balance between increment and harvest. **Potentially sustainable forest productivity** has been defined as that rate which results from the primary input and output flows of N, P, K, Ca and Mg [and other nutrients] at the stand level, in reference to the indefinite continuation of the existing forest type, and within the context of a specific disturbance regime (various harvest levels, recurring forest fire), and existing site and climate conditions (Bhatti et al. 1998).

Swamp: Forested or thicketed wetland or peatland. Minerotrophic indicators present, water may move laterally below the surface. Pits and channels with open water pools. The substrate is often a mixture of woody peat, *Sphagnum*, other mosses, herbs, and sedges. The hummock phase is dominant, and the surface peat is aerated deeply enough to support the roots of tall woody growth (cf. National Wetlands Working Group [Canada] 1988; Harris et al. 1996).

Tending: Any operation carried out for the benefit of a forest crop or an individual thereof, at any stage after establishment; includes operations both on the crop itself, e.g., pruning, thinnings, and improvement cuttings, and on competing vegetation, e.g., weeding, cleaning, and girdling of unwanted growth.

Terrain stability: The inherent ability of a sloping terrain with its underlying glacial deposits to maintain itself in place against the forces of rain, runoff, wind, and landslides (cf. British Columbia Ministry of Forests 1999).

Thinning: A cutting made in an immature crop or stand to salvage potential mortality, accelerate diameter increment, and improve the average form and/or quality of the trees that remain. There are many kinds of thinnings - e.g., chemical, commercial, crown, free, high, low, mechanical, precommercial, row, selection, and spacing. **Thinning cycle** is the time interval between thinnings in the same stand.

Tree-length harvest: Delimbing and detopping on the site, and extracting only the stem from the site. Cf. 'stem-only harvest'. This is the only system used in Scandinavian forestry, although sometimes the branches are collected from the site after harvest to be used as fuel in co-generation plants. See full-tree harvest.

Two-storied system: A system in which a tall stratum of one species exists over a shorter stratum of another species, where the two crops may be harvested together, or the upper one before the lower one. Such structures may develop after fire where two or more species establish at the same time, but one overtops the other, for example, jack pine over black spruce, or trembling apen over black and white spruce. Such structures may also develop by natural succession, such as white spruce and balsam fir beneath trembling aspen or paper birch.

Uneven-aged (cf. uneven-sized) system: Silvicultural system in which stands have an uneven-aged (uneven-sized) structure. Stand is managed by high thinnings, or a combination of high and intermediate level thinnings, and regenerated by continuing development in the understory of natural regeneration, sometimes supplemented by underplantings. See even-aged system.

Vitality: The relative level of physical/ biological energy within an organism or ecosystem.

Watering-up: A rise in groundwater that often occurs after cutting, owing to the abrupt break in evapotranspiration of the forest, and possibly combined with logging impacts of pooling owing to drainage blockage or compaction.

Weeding: A release treatment in stands during the seedling stage that eliminates or suppresses undesirable vegetation regardless of crown position.

Wildlife tree: A dying or dead, decaying, deteriorating, or other designated tree that provides present or future critical habitat for the maintenance or enhancement of wildlife. Cf. **snag**, which is a standing dead tree.

Windfall: A tree, trees, or area of trees thrown down, or with their stems broken off, or other parts blown down by the wind.

Zig-zag screefing: Using a bulldozer or other mechanical implement to remove the surface vegetation and duff layers, and expose the mineral soil, by going right and left in a zig-zag pattern.

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