NATURAL REGENERATION OF WHITE SPRUCE IN WESTERN NORTH AMERICA WITH SPECIFIC REFERENCE TO WESTERN CANADA

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ABSTRACT

The main objective of this report was to provide a review of the information available on the natural regeneration of white spruce in western North America with specific reference to the prairie provinces of Canada. Information was drawn from relevant studies in areas such as Alaska, British Columbia, Ontario and the northwestern United States. The methods used involved standard techniques for research, review and assembly of the literature.

White spruce begins to flower and produce substantial seed at about 30 years of age with abundant crops occurring on trees about 60 years of age. Generally, good cone crops occur every 2 to 6 years and light crops occur in the intervening years. The proportion of sound seed is generally higher in years of heavy production than in years of light production. Seed dispersal distances of 100 meters have been recorded for white spruce with the vast majority of seeds naturally dispersed in the fall and early winter. Spruce regeneration is mostly found on decaying wood or on patches of exposed mineral soil as these areas have more favorable moisture regimes than undisturbed forest soil which has a tendency to dry out readily. Although white spruce can tolerate a considerable range in soil pH, best results occur on soil with a range of 5 to 6. One of the greatest problems in securing successful natural regeneration of white spruce is competition from other vegetation. In addition, optimal environmental conditions required for germination, survival and growth often do not all occur at the same site in the proper time frame for successful regeneration. There are some inconsistent results regarding alternative regeneration systems as well as specific silvicultural-related prescriptions for spruce natural regeneration. In general, however, scarification in combination with some type of shelterwood system along with herbicidal or mechanical control of competing vegetation in establishment years is the most efficient and economical means of spruce natural regeneration according to the. Prescribed burning is not generally supported as a

treatment as this often disrupts soil qualities such as moisture and pH rendering it an unsuitable seedbed for spruce seedlings. Germination and survival are favored on mineral seedbeds and seem reduced on burned areas. Germination delays are also a common consequence of burned sites. In all, white spruce requires specific environmental conditions and requirements for natural regeneration. In order for this effort to be successful, serious reconsideration of the literature and further research efforts must be received before any silvicultural prescriptions be made in the need of white spruce regeneration in the boreal mixedwoods of western North America.

ACKNOWLEDGMENTS

Our most important decisions are discovered, not made, and the knowledge, strength and discipline gained from this project is a tribute to that. Indeed, inspiration comes very slowly and quietly...for the tree, the bountiful, beautiful, incredible tree, is God's choicest gift to man....

I would first like to thank my practicum advisory committee who persevered with me to the very end: Dr. Rick Baydack, Faculty Advisor, Natural Resources Institute for his continued guidance, support and understanding; Dr. Tom Booth, Department of Botany, University of Manitoba for his botanical view and commentary; Dr. Rick Riewe, Department of Zoology, University of Manitoba for his helpful comments with regard to preparing literature reviews; and Mr. Don McDonald, for the opportunity.

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I must gratefully acknowledge the many writers and spruce researchers in Canada and the United States whose cited publications are the main body of this monograph.

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I owe much of the success of this project to my mother and father who have supported me throughout my University career, both financially and more importantly, spiritually. They have given me more than I thought possible, including the faith to believe in myself, now and always.

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Chapter 1: INTRODUCTION

Figure 1-1: Typical young white spruce stand (Kolabinski 1994).

White spruce (*Picea glauca;* see Appendix 2 for further scientific names for botanical terms) is a major component of the boreal forest in the prairie provinces of Canada. The uses and economic importance of this resource have increased dramatically in the last decade, as have more environmentally and economically favorable forestry practices. Natural regeneration of white spruce has been a recognized management concern in Canada for many years and has been studied in-depth for the last 50 years. Yet, there is a need for a consolidated review of this information for managers and field foresters involved with the management of boreal mixedwood forests and the management of white spruce, itself. The focus of this monograph is on Manitoba, Saskatchewan and Alberta, however relevant information is also drawn from other regions such as Alaska, British Columbia, Ontario and the United States where white spruce is also prominent and natural regeneration is emphasized. The text is divided into ten sections, all of which focus on the natural regeneration of white spruce. Approaches to white spruce regeneration and the effect of environmental factors, features of boreal mixedwood stand development, alternative regeneration systems, and silvicultural objectives on the regeneration of white spruce are the main sections that have been reviewed. It must be emphasized, however, that aspects of all these sections must be integrated in order to adequately make informed decisions regarding the management of the species. A summary of knowledge gaps and research needs is also presented.

1.1 OBJECTIVE

In earlier years, surveys (Phelps 1940, Candy 1951) in the Mixedwood Forest Section (Figure 1-2) of the Boreal Forest Region (Rowe 1959) in Manitoba and Saskatchewan revealed that white spruce did not regenerate satisfactorily after logging. Due to the fact that white spruce saw timber has been (Jarvis 1963) and remains one of

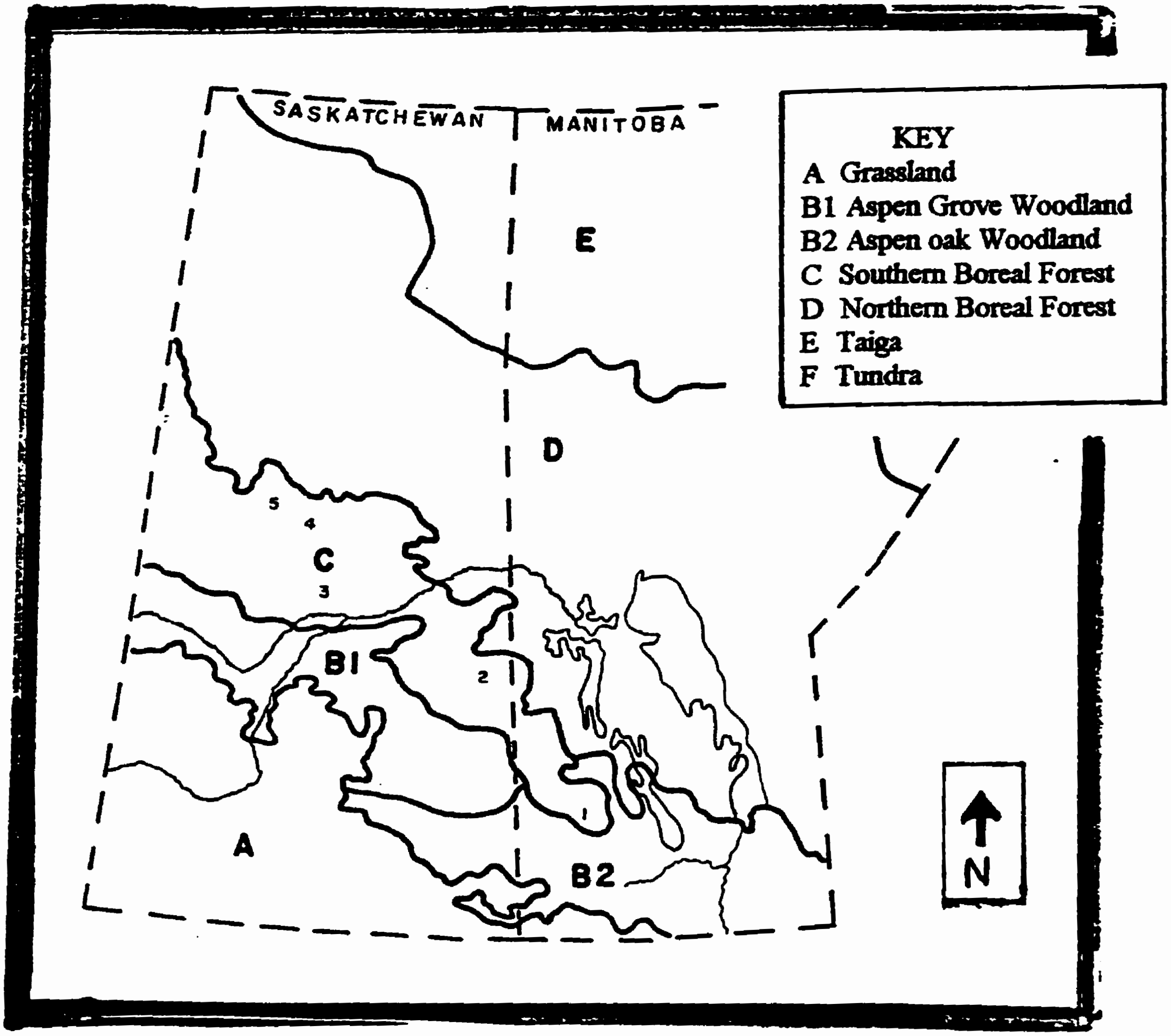

Figure 1-2: Map of Manitoba and Saskatchewan depicting vegetative regions A-F and the Mixedwood forest section in which white spruce inhabits (after Jarvis 1963).

the principal forest products in the Prairies, this lack of regeneration caused much concern among forest industries and various government agencies. Since then, work has been done on developing better silvicultural methods to improve natural regeneration.

Documentation of the natural regeneration of white spruce in western Canada is scattered and sparse, however, thus demonstrating a need to locate and consolidate this information into some usable form. The objective of this report is to summarize information on the natural regeneration of white spruce in western North America with specific reference to the prairie provinces of Canada.

1.2 SCOPE

This monograph focuses on a review of research done in the last five decades in relation to the natural regeneration of white spruce in western North America. There is some review of the ecology of the species and approaches to natural regeneration. Most emphasis, however, is on the factors, both biological and environmental, which affect the natural regeneration of white spruce, and the features of boreal mixedwoods which also affect white spruce in this manner. Alternative regeneration systems as well as a discussion of boreal mixedwood management with specific reference to white spruce is also included.

1.3 METHODS AND INFORMATION SOURCES

Within this study, several main methods were essential to producing a white spruce monograph. Since the project was mainly a literature review, the main focus was on the methods of conducting the research. These main methods consisted of: a library search including a database search for relevant articles related to the natural regeneration of white spruce in western Canada, a book search for books that contained relevant information on this subject, and a search for government documents related to white spruce. Networking searches were also done to connect with specialists in the field as well as uncover useful information on white spruce worldwide. Finally, consulting the experts and conducting informal interviews was an important part of the research and consisted of travel to certain Forestry Centers to converse with experts in the field as well as accessing other universities to best explore the field of white spruce and natural regeneration.

1.4 REPORT ORGANIZATION

The terms of the contract for this study consisted of a review of literature on natural regeneration of white spruce and the preparation, review, and editing of a monograph on the natural regeneration of white spruce in boreal mixedwood forests in Western North America.

The report consists of 12 chapters and 4 appendices (a glossary, list of abbreviated forms and complete titles of journals used, list of scientific botanical names, list of scientific mammalian names, and imperial conversions for metric units found in the text) as well as a bibliography. The introduction describes the objective and scope of the report and identifies methods used. The background section consists of general information about the spruces graduating to a more specific description of the white spruce to generalize the reader with the tree under study. Since information surrounding the ecology of the white spruce greatly influences natural regeneration success, a complete section is devoted to the ecology of the white spruce, followed by information on its reproductive cycle and life history, aiding in the understanding of the process of regeneration and how certain factors may affect its success.

Chapter 5 is dedicated solely to the natural regeneration process. This chapter defines natural regeneration and examines historical and present approaches to this method of regeneration. With the basic information regarding white spruce and natural regeneration, more specific topics are then discussed, starting with a review of environmental factors affecting natural regeneration of white spruce in Chapter 6.

In chapters 7 through 10, natural regeneration is explored with chapters becoming increasingly more specific with regard to natural regeneration of white spruce and finally to prescriptions and decision-making in boreal forest management. The reader is first introduced to natural regeneration in chapter 5. With this information in mind, alternative regeneration systems are then presented in chapter 7 to give a full picture of the many ways white spruce is regenerated and to give a frame of reference to the process of natural regeneration. With more direct prescriptions in mind, specific silvicultural objectives relating to the natural regeneration of white spruce are examined in chapter 8. Other factors which affect the natural regeneration of white spruce--such as those features of mixedwood stands--are identified in chapter 9.

Chapters 10 through 12 deal with more administrative issues surrounding the regeneration of white spruce. Decision making in boreal mixed wood management is examined in Chapter 10, based on the information previously presented. Chapter 11 consists of a summary and conclusions followed by recommendations regarding knowledge gaps and research needs for the future in the final chapter of the document.

Chapter 2:
BACKGROUND

In order to understand completely the aspects of natural regeneration and how different elements affect the natural regeneration of white spruce, it is essential to gain some general knowledge about the spruces. The following section is dedicated to exploring the characteristics of the spruces, and particularly white spruce.

2.1 ABOUT THE SPRUCES

2.1.1 GENERAL

About 40 species of spruce have been named, and 5 of these 40 are found in Canada. Several varieties have been reported in different parts of Canada and hybrids are common among the individuals of sitka spruce, white spruce and Engelmann sprucewhere ranges overlap. There are no records of cross-breeding between white spruce and black spruce nor are there records of cross-breeding between white spruce and red spruce.

2.1.2 DESCRIPTION

The spruces have long straight trunks with scaly bark, and dense narrow crowns of many pliable branches that often extend to the ground--particularly on open-grown trees. In dense stands, the older trees may be clear of their branches for half of their height, but spruce, being tolerant of shade, is not considered to be self-pruning and often retains some live branches below the upper crown. Additional characteristics include a shallow root system and susceptibility to windthrow (Hosie 1979).

Leaves of all species of spruce are evergreen and remain on the tree for at least five years. In general, they are less than 2.5 centimeters (see Appendix 4 for Imperial conversion factors) long, stiff, narrow and needle-shaped. They are singly and spirally arranged on wooden peg-like bases which remain on the branchlets when the leaves are shed. The leaves are four-sided in cross-section and generally roll easily between the thumb and the forefinger (Collingwood and Brush 1955).

The twigs of the spruces are slender, tough, whitish to dark greyish brown with conical, pointed, scaly buds which are usually shorter than 0.5 cm and are sometimes resinous (Peattie 1963).

2.1.3 USES

The wood of the different species of spruces is similar in its properties, being light in weight, soft, moderately strong and without a distinct heartwood. Spruce wood is of great commercial importance. In fact, in volume of production of sawn lumber, spruce is first among the timber producers. It is used for general construction, mill work, interior finishing, plywood, boxes and crating. It is also the preferred material for food containers because it is almost tasteless and odorless. The spruce is also the foremost species in the world for the production of pulpwood due to its naturally light color, its low resin content and its formidable fibre characteristics (Hosie 1979).

2.2 WHITE SPRUCE

The white spruce belongs to the family Pinaceae and is a conifer. White spruce is also known as Canadian spruce, skunk spruce, cat spruce, Black Hills spruce, western white spruce, Alberta white spruce and porsild spruce. White spruce is tolerant of considerable shade and recovers from suppression well. Its growth is slow but faster than that of black spruce. It naturally attains an age of 250 to 300 years. Reproduction is abundant on moist sites and it possesses a shallow, spreading rooting system (Harlow and Harrar 1958) but the tree has only moderate resistance to windthrow (Hosie 1979). This tree is adapted to many different edaphic and climatic conditions in the Northern Coniferous Forest. The wood of white spruce, which is used for pulpwood and as lumber for general construction, is light, straight grained, and resilient (Preston 1976, Hosie 1979, Nienstaedt and Zasada 1990).

2.2.1 DESCRIPTION

White spruce is a medium to large-sized (averaging 17 m high, up to 28 m), evergreen conifer with a fairly symmetrical, conical crown, a tapered bole and thin, scaly bark, branches which spread and droop slightly and a regular branching pattern that often extends to the ground (Figure 2-1). Being tolerant of shade (Hosie 1969), the tree retains its leaves and branches low on the trunk but gradually sheds its branches in dense stands where there is little light. It is in these conditions that the tree develops a long, slightly tapering trunk that is almost free of branches and which has a crown which occupies about half of the tree's height. White spruce is a transcontinental species found mainly in mixed stands. It rarely grows in pure stands. It occurs mostly on moist soils and is commonly associated with balsam fir, trembling aspen, and black spruce (Steill 1976; Anon. 1980; Arnup et al. 1988).

2.2.2. HABITAT

White spruce is a typical species in the Boreal Forest region, although it can be found almost everywhere in Canada. With such wide distribution, it is evident that it grows in a variety of different soils and climates. Best examples of the tree have been found in mixed stands on well-drained but moist, silty soils. The most common trees found associated with the white spruce include trembling aspen and balsam fir though it does grow in mixtures with other conifers and broad-leaved trees (Nienstaedt 1957).

2.2.2.1. Native Range

White spruce has a transcontinental distribution ranging all across northern North America (Figure 2-2). It grows naturally from Newfoundland and Labrador west across Canada along the northern limit of trees to Hudson Bay, Northwest Territories, Yukon and northwestern Alaska, where it almost reaches the Arctic Ocean in the District of Mackenzie in the Northwest Territories (Sutton 1969b.). In British Columbia it is found

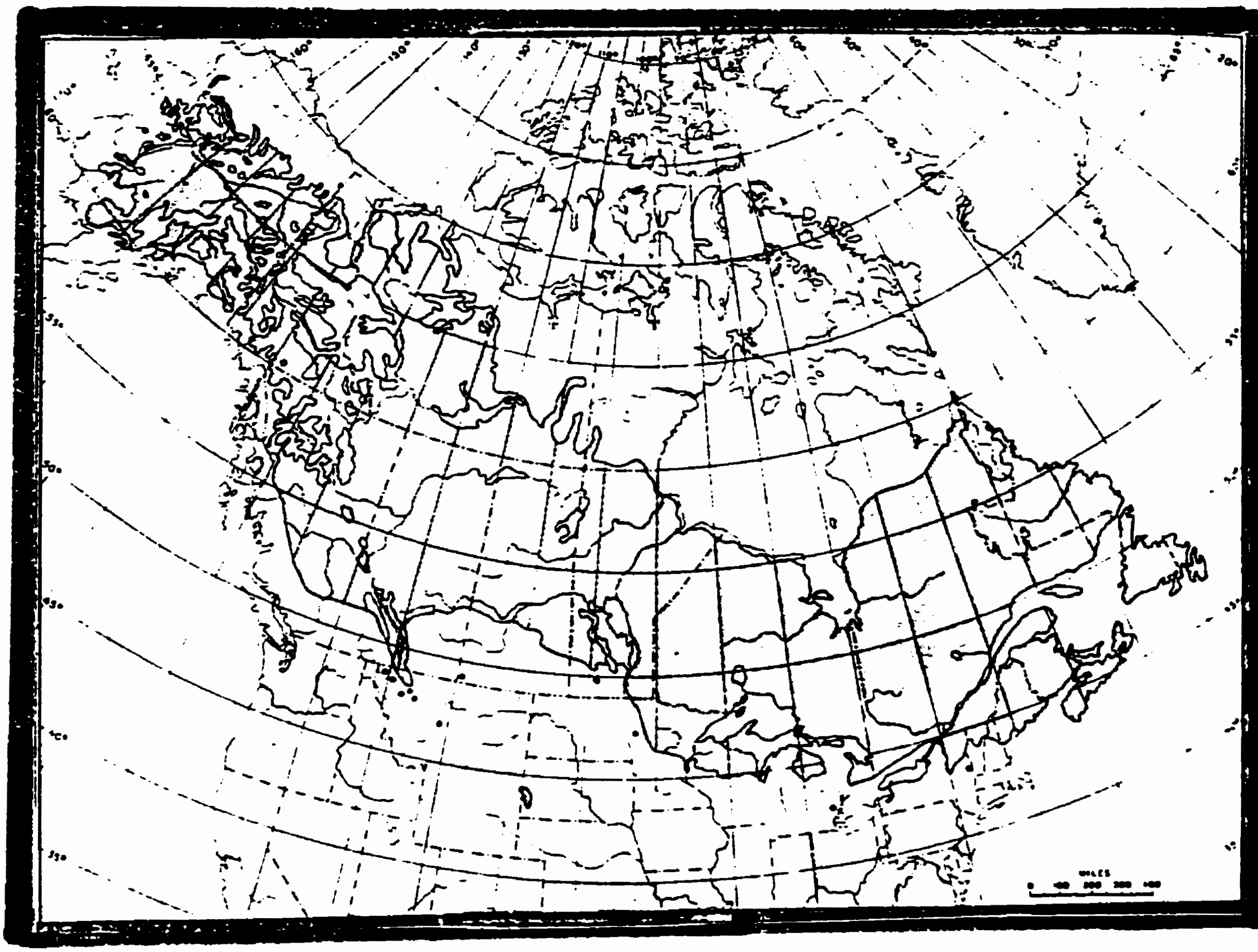

Figure 2-2: The range of white spruce (after Nienstaedt and Zasada 1990).

The northern limit for the species of white spruce is associated with the tree line. In turn, the position of the tree line has been correlated with a variety of climatic factors including the 10° C isotherm for mean July temperature, cumulative summer degree days, position of the Arctic front in July, mean net radiation and low light intensities (Elliott 1979). None of these factors strictly define the northern limit of white spruce and with the mountainous topography in northern Alaska, it is difficult to determine controlling factors (Densmore 1980). As well, there exist other biotic and abiotic variables which affect the northern distribution of white spruce. These include the lack of soil, low fertility, low soil temperature, fire, insects, disease. human impact, soil stability and others (Elliott 1979, Van Cleve et al. 1986, Viereck 1987).

The southern limit of white spruce is generally in correlation with the 18° C July isotherm. The limit is defined by the southernmost area in which white spruce forms more than 60 percent of the total stand. This is northeast of Lake Superior in the east and just north of the isotherm in the Prairie Provinces (Nienstaedt and Zasada 1990).

In all, climatic extremes are significant. White spruce can survive in Alaska and parts of Canada in a climate where recorded extremes for one study area were -54° C in January and 34° C in July (Maini 1966, Van Cleve et al. 1986). A mean daily January temperature of -29° C for January has been recorded throughout most northern parts of its range. Mean daily July temperatures range form 21° C in the most southeastern area of range to 13° C throughout much of Alaska and Canada. In Manitoba, a maximum temperature of 43° C has been recorded.

Precipitation ranges are extreme as well. Mean annual precipitations vary from 1270 mm in Nova Scotia and Newfoundland to 250 mm throughout the Northwest Territories, the Yukon and parts of Alaska. It is found, though, that conditions are most severe along the southern edges of Manitoba, Saskatchewan and Alberta where a mean annual precipitation of 380 to 510 mm coincides with a mean July daily temperature maxima of 24° C or more.

The growing season of the white spruce varies from approximately 180 days in parts of Maine to as little as 20 or 25 days in parts of northern Canada. Generally speaking, however, white spruce grows best in regions where the growing season is about 60 days long (Canada Department of Transport 1954, Canada Department of Transport 1956, Nienstaedt 1965a). Yet, it is essential to point out that a considerable part of the species' range falls within the permafrost zone of northern Canada.

Photoperiod varies continuously over the range of the species from approximately 17 hours at summer solstice along the southern edge of the species' range to 24 hours north of the Arctic Circle in Alaska and parts of northern Canada (Nienstaedt and Zasada 1990).

2.2.2.3 Soils and Topography

White spruce grows on a wide variety of soil types including those of glacial, lacustrine, marine or alluvial origin. White spruce can survive on more extreme sites than aspen and is able to establish itself successfully on exposed mineral soil as well as invading and replacing native prairie vegetation on gravely kames, eskers, old beach ridges and deltaic deposits. It can also survive in wet areas, growing successfully on fen or muck soils at the edges of rivers, creeks and sloughs (Rowe 1956). Substrata represent the geologic eras from the Precambrian to Cenozoic and include a great variety of rock formations including granites, gneisses, Silurian sedimentaries, slates, shales, schists and conglomerates (Halliday 1937, Rowe 1972, Van Cleve et al. 1986). While some bedrocks, such as the granites, are acidic, others are basic dolomites and limestones.

Best growth of white spruce often occurs along streams and lakes where moisture and nutrients are not limiting. It achieves good growth on fresh sandy loams, calcareous silts and silt loams and other silt rich soils. In the north, mature white spruce stands usually have well-developed moss layers. These moss layers significantly affect the mineral soil as well as increase the depth of the organic layer. In areas with adequate moisture conditions, the layers are more highly developed and are often dominated by feather mosses such as stair-step moss, Schreber's moss, knight's plume and the broom mosses as opposed to the Sphagnum species (La Roi and Stringer 1976). Where white spruce inhabits the far north, the total depth of live moss-organic layers frequently 25 to 46 cm or more. Development of this moss, however, is regulated by flooding and stand composition and mixed stands tend to possess a shallower and more discontinuous moss layer. The moss layer in these circumstances acts not only as an insulator, reducing temperature in the rooting zone, but also acts as a strong competitor for nutrients. Temperature reduction, though, varies with both latitude and climatic regime and even reaches lows at which permafrost is developed and maintained such as in Alaska, Yukon and the Northwest Territories (Gill 1975, Van Cleve et al. 1986, Viereck 1970b.).

A number of different soils occur throughout the range of the species. Soils range from heavy clays in the Upper Peninsula of Michigan to the alluvial plains along the Peace River in Wood Buffalo National Park, Alberta, where white spruce reaches peak development (Place 1955). Generally, though, white spruce inhabits brunisolic, luvisolic, gleysolic, regosolic and podzolic soils. According to Nygaard et al. (1952), white spruce is considered very important on the gray wooded soils and the brown forest soils but on the sandy podzols, white spruce is usually a minor species. It is known to reach its best development on the podzolized gamma gley loams and on the strongly podzolized clays, which are most prevalent over the range of the species. It is also common on sandy flats and other coarse-textured soils. In Saskatchewan, it grows on shallow mesic organic soils and in the central Yukon on organic soils along with black spruce (Van Cleve et al. 1986, Sutton 1969b.).

Although white spruce is able to grow on a variety of very different sites, to achieve its best success, it is generally more demanding than its counterparts. White spruce is found to be exacting with respect to its habitat conditions (particularly in the boreal forest in Canada) as opposed to its associated conifers--balsam fir, black spruce, jack pine, and tamarack (Nienstaedt 1959). As one moves northward in the species' range, climate becomes more severe and the range of sites supporting the species becomes more limited (Sutton 1969b).

The white spruce is known to be a major component of the stands on the calcareous podzol loams and clays in the Algoma district of Ontario and is found to develop exceptionally well on melanized loams and clays (Wilde et al. 1954). In Saskatchewan, white spruce does best on the moderately well-drained clay loams (Kabzems 1971). White spruce of the Alberta Mixedwoods develops best on well-drained lacustrine soils (Heger 1971). In northern Canada and Alaska, exceptionally productive stands are found on moist alluvial soils along rivers (Jeffrey 1961, 1964, Lacate et al. 1965, Viereck 1973) and on south-facing upland sites (Farr 1967, Van Cleve et al. 1986). Alpha gley soils produce poor white spruce stands yet productivity increases with an increasing depth into the gley horizon (Wilde 1940).

A variety of other factors also affect the success of white spruce. Depth to ground water, permeability of surface layers, presence of hardpans or claypans, and minerological composition of parent material are other soil factors that must be carefully considered.

White spruce stand development can also affect the soil itself--forest floor composition, biomass and mineral soil physical and chemical properties are all affected by the environment and stand conditions of the site. As well, the magnitude of these effects is dependent upon the site and its history of disturbance. A good example of this are sites in Alaska in which organic layers accumulate to greater depths in mature white spruce stands than in hardwood stands of similar site characteristics. As a result of the deeper organic layers, soil temperatures decrease and permafrost may even develop in extreme cases (Viereck 1970b, Viereck et al. 1983). Mineral soil in spruce plantations established on abandoned Ontario farmland showed a decreased acidity by 1.2 pH units over a period of 46 years. Soil conditions also differed significantly in 40-year-old white spruce as compared to those of aspen, red pine and jack pine growing on similar soil types (Alden and Loopstra 1987).

Although the species will tolerate a wide range of moisture conditions, it performs poorly on dry or poorly drained soils. Good growth requires a dependable supply of well-aerated water but white spruce will grow on dry but fertile sites. Stagnant water inhibits the growth of white spruce as this condition reduces the rooting volume.

It is important to note that soil fertility, soil moisture and physical properties are all interrelated. Without adequate fertility, or optimum soil structure, moisture alone will not improve yields. For example, a study comparing tree growth on two different sites in Riding Mountain, Manitoba (Jameson 1963) found that lower yields on moist sites were attributed to a higher clay content and massive structure when wet as opposed to a columnar structure in dry conditions.

2.2.2.4. Associated Forest Cover

White spruce can grow in association with all other tree species over a wide range of sites and its presence can be expected in most forest types except only black spruce stands on deep peats and jack pine stands on the driest sand soils (Rowe 1956). White spruce is found to be a principal species in four eastern forest types and two western forest types. It is a minor species in 11 eastern and 2 western types listed in Table 1.

White spruce is also found to be a pioneer species in abandoned fields in the New England states, forming pure stands. White spruce also forms pure stands in western North America. Five of the eight recognized forest regions of Canada contain white spruce with it being particularly prevalent in the Boreal Forest Region (Nienstaedt 1959). In British Columbia, two additional types of white spruce have been recognized according to Raup (1945). One type is the white spruce-lodgepole pine-aspen type which forms the transition between the pioneer lodgepole pine and aspen stands and the climax white spruce stands. The second type is an association of black spruce, white spruce and lodgepole pine. White spruce is also considered a major forest cover type in both the eastern and western forests of North America. The Eastern Forest consists of forests in New England and the Maritime Provinces as well as Quebec and Labrador. In the Western Forest, which includes Alaska, the Northwest Territories, British Columbia and the Prairie Provinces, white spruce appears as a major component in three tree cover types. These are the White Spruce (Type 201), White Spruce-Aspen (Type 251), and White Spruce-Paper Birch (Type 202) .

Pure white spruce forest is the main forest type in the west. In areas such as Alaska and the Northwest Territories, the white spruce type is largely confined to stream bottoms, river floodplains and terraces and warm, south-facing upland sites (Figure 2-3). In British Columbia and Alberta, its distribution is broader--from as low as 760 m to 1520 m.

White spruce in this type varies little and mostly comprises closed stands. There are a variety of spruce-plant communities in interior Alaska (Dyrness et al. 1988, Foote 1983, Hegyi et al. 1979) but only two main communities are common in northwestern Canada and in Alaska. These are: (1) white spruce / willow / buffaloberry / northern goldenrod / crowberry and (2) white spruce / willow / buffaloberry / huckleberry /dewberry /paevine.

The White Spruce-Aspen forest type requires that each species listed in the name make up at least 20 percent of the total basal area. Either white spruce or aspen may be dominant in this forest; black spruce and paper birch are commonly associates in the Alaskan forests. Canadian stands also include balsam fir and lodgepole pine along with black spruce and paper birch. This forest type is common throughout all of western Canada as well as Alaska, especially at lower elevations. Associated shrubs in Alaska are American green alder, willows, common bearberry, soapberry, highbush cranberry or

Table 1 Table of associated trees and shrubs of the white spruce listed by type number and forest type (after Nienstaedt 1957).

Principal Species--EASTERN FOREST TYPE

Type Number	*Forest Type*
2	Black Spruce - White Spruce
4	White Spruce - Balsam Fir
9	White Spruce - Balsam Fir - Aspen
36	White Spruce - Balsam Fir - Paper Birch

Minor Species--EASTERN FOREST TYPE

Type Number	*Forest Type*
1	Jack Pine
3	Jack Pine - Paper Birch
5	Balsam Fir
7	Black Spruce - Balsam Fir
8	Jack Pine - Aspen
10	Black Spruce - Aspen
12	Black Spruce
18	Paper Birch
25	Sugar Maple - Beech - Yellow Birch
30	Red Spruce - Yellow Birch
33	Red Spruce - Balsam Fir

Principal Species--WESTERN FOREST TYPE

Type Number	*Forest Type*
201	White Spruce
202	White Spruce - Birch

Minor Species--WESTERN FOREST TYPE

Type Number	*Forest Type*
203	Poplar - Birch
217	Aspen

Figure 2-3: Shelterwood of 170-year-old white spruce located on an upland site in Alaska (Courtesy Forestry Program, U of A IN Zasada 1990).

squashberry, and mountain cranberry. Associated shrubs in the Prairie Provinces are common snowberry, red-osier dogwood, western serviceberry, and western chokecherry (Nienstaedt and Zasada 1990).

The definition of the White Spruce-Paper Birch type forest is similar to that of White Spruce-Aspen in that either of the species may be dominant with the requirement that each species make up at least 20 percent of the total basal area of the forest. This forest type is common in Western Canada and in Alaska from the Arctic Circle to the Kenai Peninsula and associated species are aspen, lodgepole pine, subalpine fir and black spruce. Undergrowth species include willow, Amercian green alder, highbush cranberry, prickly rose, mountain cranberry, bunchberry, and Labrador-tea (Nienstaedt and Zasada 1990).

White Spruce-Aspen and White Spruce-Paper Birch are successional stages which lead to the pure White Spruce type. However, near the altitudinal and northern tree line, the Black Spruce-White Spruce forest type may be a climax forest. It has also been suggested that white spruce may be being replaced by black spruce on some intermediate sites on older river terraces (Viereck 1970). Black Spruce-White Spruce is the lichen-woodland type that is found along the treeline from Hudson Bay to northwestern Alaska. It is also found in open stands at alpine treeline sites in interior Alaska and northwestern Canada as well as on sites intermediate to the two species such as older terraces above the floodplain. Species which may be found within the stands include paper birch, tamarack, balsam poplar, aspen and balsam fir. Ground or dwarf birch, alder and willows may form a continuous shrub cover in open stands near the treeline. In drier sites, mats of feathermosses and lichens may replace the continuous shrub cover. Other common shrubs in the Black Spruce-White Spruce forest type include Labrador-tea, alpine blueberry, mountain cranberry, and black crowberry (Nienstaedt and Zasada 1990).

White spruce is an associate with other Western forest cover types in addition to the three forest cover types in which it is a major component. White spruce is an associate with Balsam Poplar, Black Spruce, Engelmann Spruce-Subalpine Fir, Aspen, Lodgepole Pine, Interior Ponderosa Pine, Paper Birch, and Black Spruce-Paper Birch.

Some of these forest types are intermediate in succession and eventually may advance to pure White Spruce, albeit slowly. For example, Balsam Poplar is eventually overtopped and replaced by White Spruce. Spruce and fir are more tolerant and aspen often precedes the overtaking of these species. In northern latitides, lodgepole pine may be replaced by white spruce.

White spruce also associates with a variety of other trees not mentioned in Table 1. Red maple, American basswood, eastern hemlock, northern red oak, white ash, black cherry, sweet birch, American or white elm, rock elm, and eastern hophornbeam or ironwood (in the most eastern part of its range) are some species that occur with white spruce (Ninestaedt and Zasada 1990).

Understory shrubs that occur with white spruce in the northern part of its range mainly include those of the genera *Betula*, *Vaccinium* and *Kalmia* according to Hare (1954). The eastern portion of the range of white spruce also includes mountain and striped maples (Vincent 1955) and in Ontario, understory shrubs include the American cranberrybush viburnum, alder buckthorn, mountain maple, beaked hazel and American fly honeysuckle (Wilde et al. 1954).

The Canadian boreal spruce-fir forest is another notable forest type. In this forest, American green alder is the most common tall shrub. Littletree willow, gray willow, and Bebb willow are important in the western range. In the East, Mountain maple, showy mountain ash, and American mountain ash are important associates. The most common medium to low shrubs are highbush cranberry, red currant, prickly rose, and raspberry. The most wide-ranging members of the herb-dwarf shrub stratum are fireweed, one-sided wintergreen, one-flowered wintergreen, northern twinflower, naked bishops-cap, bunchberry, dwarf rattlesnake-plantain, stiff clubmoss and horsetail (La Roi 1967).

In Canadian white spruce stands, there are an average of 24 bryophytes. Of these 24 bryophytes, 17 are mosses and 7 are liverworts. The most common mosses are Shreber's moss, stair-step moss, knight's plume, dusky fork mosses, and sickle moss or hook moss. The most common liverworts are Northern naugehyde and naugehyde liverworts, the leafy liverworts and ragged moss. Some common lichens are freckle pelt lichen, slender cup lichen and iceland moss (Ninestaedt and Zasada 1990).

2.2.3 GENETICS

White spruce is a species which shows a strong adaptive afinity to local environments and thus is highly variable over its range. The clinal variation pattern generally follows the latitudinal and altitudinal gradients. For example, southern provenances are the fastest growing and the latest flushing when tested near the edge of their range. In contrast, Alaskan trees are dwarfs and since they flush early, are susceptible to spring frosts. According to Nienstaedt and Teich (1972), both soil-related adaptive variation as well as variation in germination temperature requirements have been described. Furthermore, genetic variability is thought to be great enough that considerable gains may be possible through tree improvement programs (Steill 1976, Zasada 1969 In Gardner 1980).

2.2.3.1 Population Differences

Two major populations of white spruce have been found--one in the East, east of longitude 95° W., and another in the West (Nienstaedt and Teich 1972). Two high yielding provenances have been identified. In the East, a source in the Ottawa River Valley has been found (Little 1979) while in the West, the Birch Islands provenance has been identified.

Steill (1976) notes that provisional seed zones have been summarized for Canada, and Ontario and Quebec have gone as far as to develop general zones and identify superior and inferior seed sources (Nienstaedt 1982, Rudolf 1956). Seed transfer rules have also been tentatively suggested for British Columbia. With the analysis of enzyme patterns, new information on population structure is being provided. This information can be used in the improvement and refinement of seed management practices for reforestation (Alden and Loopstra 1987, Cheliak et al. 1985, Copes and Beckwith 1977).

There have been promising preliminary results regarding the testing of hybrids between provenances (Ying 1978a) leading to the possibility of increasing yields by selecting trees from seed orchards of mixed provenances.

2.2.3.2 Individual Tree Differences

A major consideration in silviculture today is the genetic variation that exists with a tree family or between individual trees. It has been found that large differences exist among families representing individual trees within a stand. For example, Dhir (1976) conducted a study of six families from each of seven stands in the Ottawa River Valley. The area covered by the study was over 3550 km^2, yet no differences could be demonstrated. One of Dhir's conclusions was that the best of all the families was 28 percent taller than the family mean height. This shows that through mass selection and low-cost tree improvement programs, a considerable improvement in the genetics of a species can be achieved.

Phenotypic selection in white spruce has been proven generally feasible (Jeffers 1969). Thus, it is advantageous in artificial seeding to choose seed trees that are superior in terms of rapid growth and other desirable characteristics. Nevertheless, this approach may lead to limited success in even-aged stands on uniform sites. For improvement, the slower growing poorer trees should consistently be thinned out.

It has been found that juvenile selections made in the nursery based on height growth maintain superior growth until the age of 22 years. This phenotypic growth superiority probably reflects genetic superiority according to Nienstaedt (1981). Extra large seedlings should thus be given preferential treatment. Propagules of such juvenile selections when used in intensively managed plantations may lead to immediate improvement (Nienstaedt and Jeffers 1976).

In contrast, selfing (or natural regeneration) results in serious losses in vigor as well as lowered survival. In a study of the performance of white spruce progenies after selfing, Ying (1978a) found that height growth reduction as great as 33 percent had been reported. Although knowledge regarding selfing in white spruce is weak, relatedness between individuals in a stand has been realized. White spruce manifests itself in terms of reduced set of seed and slower early growth (Coles and Fowler 1976).

2.2.3.3 Races, Varieties and Hybrids

No races of white spruce have been recognized, but four varieties have been named: *Picea glauca, Picea glauca* var. *albertiana, Picea glauca* var. *densata*, and *Picea glauca* var. *porsildii*. *Picea glauca* var. *albertina* is the form found in the Rocky Mountain region and Black Hills . It is characterized by somewhat shorter and broader cones (Preston 1976, Harlow and Harrar 1958) and a narrow pyramidal habit. It is speculated that it is actually a product of introgression with *P. engelmannii* (Garman 1957, Place 1955). The Black Hills spruce is also a slower growing form of this species and is somewhat superior as a specimen. It is more compact, with bright green to bluish-green foliage and is a favorite as an ornamental on small properties (Knowles 1975). Finally, *Picea glauca* var. *porsildii* is a variety that occurs throughout Alaska and the Yukon and is chiefly distinguished by a smooth bark with resin blisters (Hosie 1979) and a relatively broad crown.

In large areas in British Columbia, Montana, and Wyoming, white and Engelmann spruce are sympatric. While white spruce predominates at lower elevations (up to 1520 m) and Engelmann spruce predominates at higher elevations (over 1830 m), the areas of elevation between these ranges (1520 to 1830 m) support a swarm of hybrids between the two species. These hybrids are the type which gave rise to the so-called variety *albertiana* (Nienstaedt and Zasada 1990).

The hybrid *Picea x lutzii* Little is a natural hybrid between sitka and white spruce. The hybrid was tested on a large scale in Iceland in the 1950's. Presently, in northwestern British Columbia and in areas of Alaska the hybrid occurs where the two species (white spruce and sitka spruce) are sympatric. Another population is found in the Skeena Valley and has been studies in some detail since it represents a gradual transition from Sitka to white spruce, a hybrid swarm resulting from introgressive hybridization (Copes and Beckwith 1977, Roche 1969).

A hybrid between white spruce and black spruce occurring in Minnesota was first described in the 1950's (Little and Pauley 1958). Later, its hybrid origin was definitely established (Riemenschneider and Mohn 1975). Yet, natural hybrids between black spruce and white spruce are rare along the southern edge of the species' range. Nienstaedt and Zasada (1990) suggest this is due to the fact that the female receptivity of the two species is asynchronous. In the more northern areas, they are more common and north of the latitude 57° N. along the Alaskan highway in British Columbia, intermediate types occur (Roche 1969). Larsen (1965) has also noted that the hybrids have also been found along the treeline in the forest tundra.

Although many artificial hybrids have been produced (Jeffers 1971, Nienstaedt and Teich 1972), none have achieved commercial importance as yet. In addition, it has been noted that it seems unnecessary to distinguish varieties (Daubenmire 1974, Little 1979).

2.3 SPECIAL USES AND IMPORTANCE

The white spruce has many different uses and yields many different products (Nelson 1977, Sutton 1969b) but its most notable value is that of a commercial nature. White spruce is one of the most important commercial species in the boreal forest in Canada for pulpwood and its use in the manufacture of wood fiber and lumber products is very well known. Less well-known uses of white spruce wood are for logs, musical instruments (Figure 2-4) paddles and various boxes and containers (Peattie 1963).

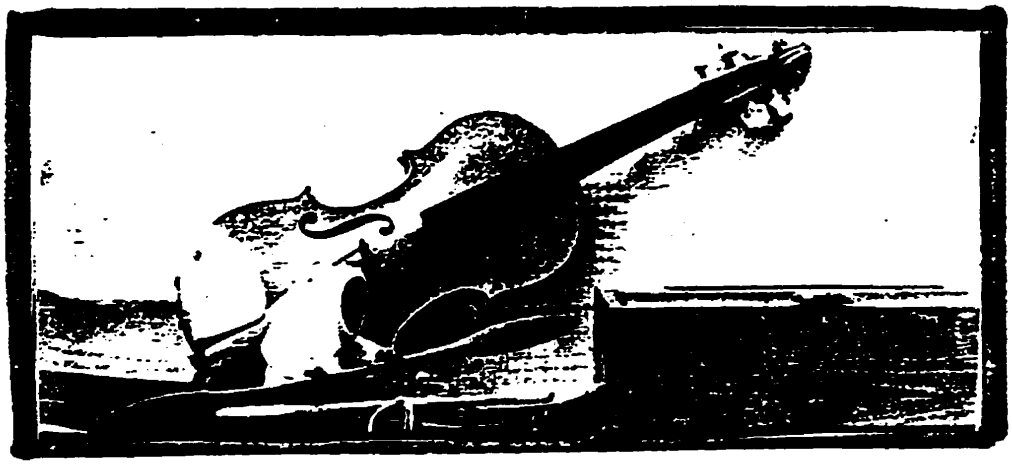

Figure 2-4: Violin made from white spruce wood (Zasada 1990).

It is also useful, from the landscape perspective, as a specimen, mass, hedge and/or windbreak. It can be planted as an ornamental and could possibly be relegated to garden status in the east due to its evergreen properties. One of the most popular varieties of spruces, white spruce are often grown in the garden as well as commercially to be used for Christmas trees (Hole 1997). It is widely used in flat areas (namely the prairies) as a shelterbelt because of its adaptability (Prairie Farm Rehabilitation Association, personal communication, Indian Head, Saskatchewan, 1997).

Historically, it is noted that white spruce was very important to both the Indians and white settlers of the northern forest. In interior Alaska, white spruce was the most important species of tree utilized by natives (Nelson 1977). Spruce branches have been used to make lean-to shelters, caribou hide tipi poles, windbreaks, tent-base wind barriers, carpets, caches, meat drying racks and dig shelters. Dried spruce wood is light and splits easily and straightly, ideal for making canoe frames, paddles, arrow shafts and snowshoes. Dead standing white spruce trees were used to make a moose hide stretcher and the

Woods Cree also collected the reddish, crumbly rotted wood of white spruce from old stumps and burned it in a slow fire to smoke-tan hides (Johnson et al 1995).

Other parts of the tree also had a purpose. The roots of this tree are so pliable that the natives often used them for lacing the birch bark on canoes as well as on baskets (Seton 1912). The Chipewyan melted hardened spruce pitch or boiled it in water and used it to caulk the outside seams of canoes. Soft pitch provided natural glue and waterproofing properties for sticking sheets of birch bark and twisted strands of willow bark twine together. The bark of white spruce was used for the cover of summer dwellings and the boughs for bedding.

The spruce pitch or resin and extracts from the boiling of needles were too strong in comparison to other spruces for making spruce tea but they were used for medicinal purposes (Viereck et al. 1983), the most notable of which may be in preventing scurvy among early European travelers. The crews traveling with Captain James Cook received a ration of spruce beer every other day.

The Chipewyan reportedly mixed spruce pitch with a 'rich' fat (such as otter, bear or beaver fat) which they first burned in a frying pan, to make a salve to apply to sores, infections, insect bites, boils, chapped hands, scratches and cuts and boiled the inner bark of white spruce to make a medicinal wash, applied directly to treat skin sores and infected or decayed teeth. Other tribes used the pitch or a boiled decoction mixed with fat, to make a salve to treat burns (including sunburn), rashes, boils (to draw out infection), scabs, and various skin diseases. The Woods Cree used a decoction as an ingredient for an arthritis remedy. At the first sign of a cough, they chewed the gum or sucked on young cones or lumps of dried pitch and swallowed the juices to soothe a sore throat or took boiled pitch as a cough syrup (Johnson et al 1995).

White spruce also serves as an important species with respect to wildlife. White spruce stands are an important source of forage and shelter for species of game such as moose and hare (see Appendix 3 for list of Latin names for mammals). Red squirrels and the spruce grouse not only live in the forests of white spruce but also consume parts of the tree. Furbearing prey species such as marten, wolverine, lynx, wolves and others also utilize these forests (Nienstaedt 1957).

White spruce forests have significant value in maintaining soil stability. They also provide a significant component to watersheds and to our fresh water supply. In addition, white spruce forests are part of ecologically significant areas and are often spiritual, hunting and gathering areas for aboriginal communities. White spruce forests provide recreational and aesthetic opportunities for all of western Canada.

2.4 CHAPTER SUMMARY

Evidently, there have been many uses of white spruce in the past, as there are today. Much of the land in the prairie provinces is forest, and though Manitoba is regarded as a prairie province, more than 60% (or 331,500 km^2) of its land base is classified as forested land. Most of the province's forest land is boreal forest, comprised mainly of white spruce, the provincial tree of Manitoba. Management of the boreal forest is an important consideration for such a highly valued tree such as the white spruce. In order to make the best use of the forests, an intensive and cost-effective silviculture program must be employed. Before this can happen, however, one must have a good knowledge of the ecology of this tree. The next chapter describes the ecology of the white spruce, focussing on some of its more important characteristics with respect to natural regeneration.

Chapter 3:
ECOLOGY OF THE WHITE SPRUCE

3.1 ORIGIN OF THE NAME *Picea*

There is some confusion regarding the scientific name of white spruce. *Picea glauca*, as adopted in many descriptions encountered, has, in the past, been approved by three leading American dendrologists--Sargent, Sudworth, and Rehder (Collingwood and Brush 1955). Some botanists prefer to use *canadensis*, published in 1678 by Philip Miller, an English botanist and Linnaeus' contemporary. Yet, Miller seems to have described white and black spruces and hemlock under this name. The word *glauca* applies to the pale blue, hoary, or even whitish tinge of the new needles, and provides one reason for the common name, white spruce (Collingwood and Brush 1955).

3.1.1. TAXONOMY OF WHITE SPRUCE WITHIN THE GENUS *Picea*

The following table helps to identify white spruce seedlings in relation to other species within the genus *Picea*, otherwise known as the spruces.

Table 2: Key to identifying white spruce seedlings (after Jeffers 1974).

1. Juvenile needles with entire margins 2
    2. Needles flat 3
        3. Needle apex obtuse or blunt, average needle length about 14 mm .... *P. breweriana*
        3. Needle apex sharp, needle length about 18 mm ..... *P. sitchensis*
    2. Needles four-sided or rarely three-sided 4
        4. Epicotyl curved, needles long, approx. 29 mm .... *P. mexicana*
        4. Epicotyl straight 5
            5. Cotyledons 4 to 5, needles short, approx. 15 cm ..*P. mariana*
            5. Cotyledons 6 to 7, needles intermediate in length, approximate average 21 mm .... *P. pungens*

5\. Juvenile needles with serrated margins 6
    6. Epicotyl curved, cotyledons 9 to 10 .... *P. chihuahuana*
    6. Epicotyl straight, cotyledons 5 to 6 .... *P. glauca, P. engelmanni*

3.2 MORPHOLOGY OF WHITE SPRUCE

3.2.1 LEAVES, BRANCHES AND BARK

The symmetrical conical crown and pronounced taper of its trunk are the most obvious characteristics of the white spruce.

Leaves of the white spruce are broad and needle-shaped and approximately 2 centimeters long (see Appendix 4 for imperial conversions for metric units). They are thick, stiff, sharp, four-sided in cross-section and straight (Figure 3-1). Their color is green to bluish-green but they often have a whitish bloom (Hosie 1979). The needles are spirally arranged on the stem and when crushed by the hand, the odor emitted by white spruce needles is sharp and spicy (Brayshaw 1960).

Branches typically extend to the ground in open stands but in dense stands the crown may occupy about half of the tree's height. The finer branchlets of white spruce are hairless with persistent woody leaf bases. Self-pruning of branches in white spruce is poor. The twigs of white spruce are usually without hairs and are a whitish-grey to yellowish color. They reveal a skunk-like odor when bruised. The outer-bud scales are pointed, but do not project beyond the tip of the bud (Figure 3-1).

The bark is usually thin and scaly (Figure 3-1). It is light greyish-brown in color, flaky or scaly and the inner bark is silvery-white to reddish (Scoggan 1978).

3.2.2 FLOWERS

The male flowers of the white spruce are pale red to yellow while the female flowers have red or yellow-green scales (Preston 1976). Male flowers are tiny, cone-like, deciduous, short-lived, and are situated at the end of the previous year's growth. Female flowers are erect, red cones with numerous spirally-arranged scales, also developing at the end of the previous year's growth (Fernald 1979).

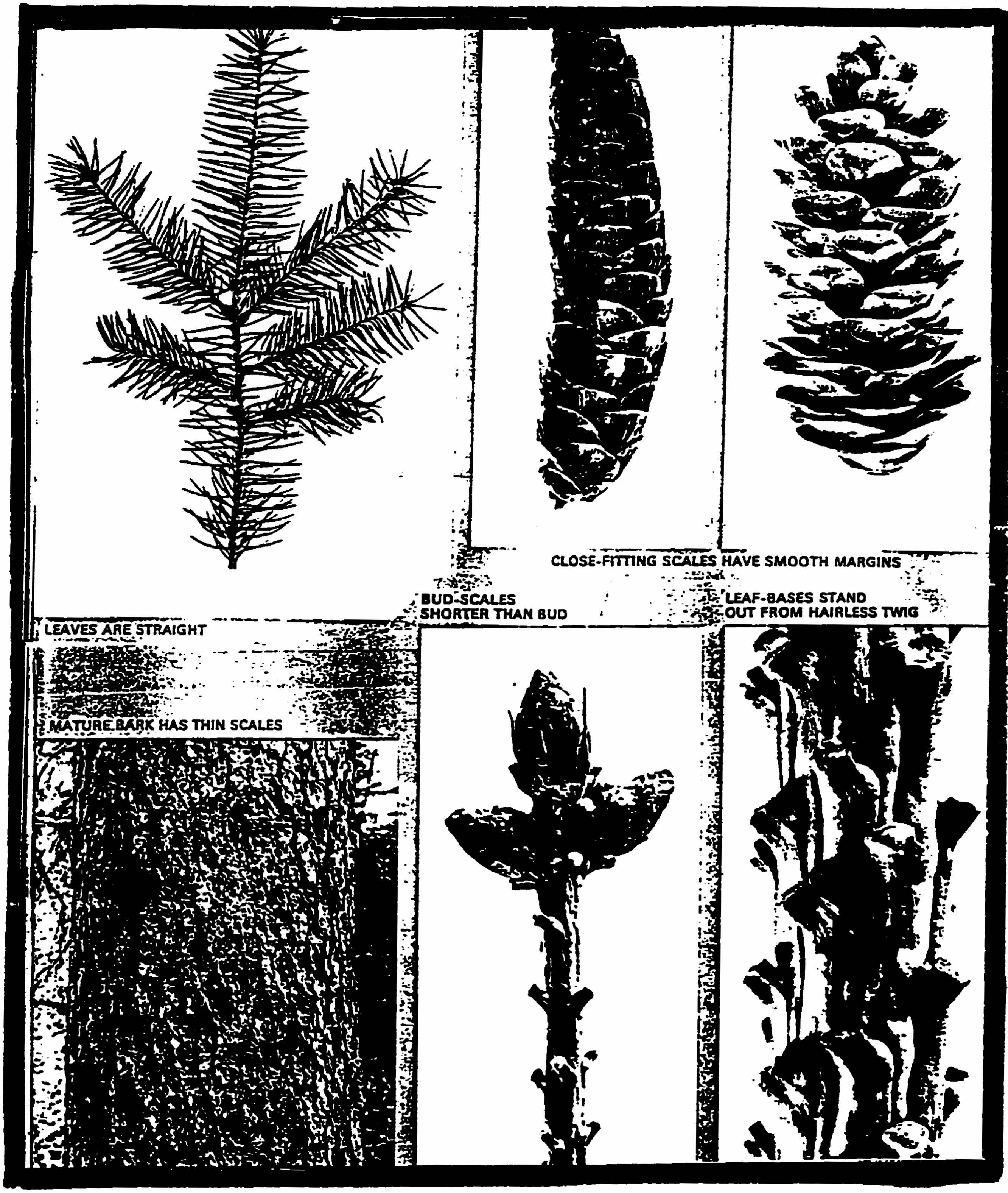

Figure 3-1: Diagram showing white spruce (1) straight leaves; (2) close-fitting scales have smooth margins; (3) mature bark has thin scales; (4) bud scales shorter than bud ; (5) leaf bases stand out from hairless twig (after Hosie 1979).

3.2.3 CONES AND SEEDLINGS

Cones are approximately 2.5 to 6.4 centimeters long, slender, cylindrical and light brown in color. They have stiff, smooth margined, often indented, and close-fitting light-brown scales. These scales are thin and flexible (not brittle to the touch as in black spruce and red spruce), usually truncate, rounded or slightly emarginate at the apex (Preston 1976, Harlow and Harrar 1958). They spread almost at right angles on open cones and are easily crushed. The cones open in the autumn and fall during the winter or the following spring (Hosie 1979). The fruit is a light green or reddish color before shedding seed and becomes a light brown and falls shortly after this color change.

The seeds are 0.3 cm long and pale brown with oblique wings 0.6 to 1.0 cm long (Harlow and Harrar 1958, Preston 1976). Seedlings consist of 5 to 7 thick seed-leaves. The juvenile leaves are toothed (Hosie 1979). See Figure 3-2, 3-3.

White spruce female cones are about 3.5 to 5.0 cm long, cylindrical, and have smooth-margined, woody cone scales which enclose the winged seeds (Schopmeyer 1974).

3.2.4 ROOTING HABIT AND WINDTHROW RESISTANCE

White spruce is moderately resistant to windthrow and overmature trees, especially those on shallow, organic and poorly drained silty or clay rich soil due to the restricted rooting depth. It is more windfirm on upland soils than either black spruce or balsam fir (Bowman 1944). Regardless, roots of white spruce require good soil aeration and rooting form and depth is highly variable in response to soil texture, drainage and moisture regime, soil fertility and the existence of impermeable soil layers (Sutton 1968, 1969a).

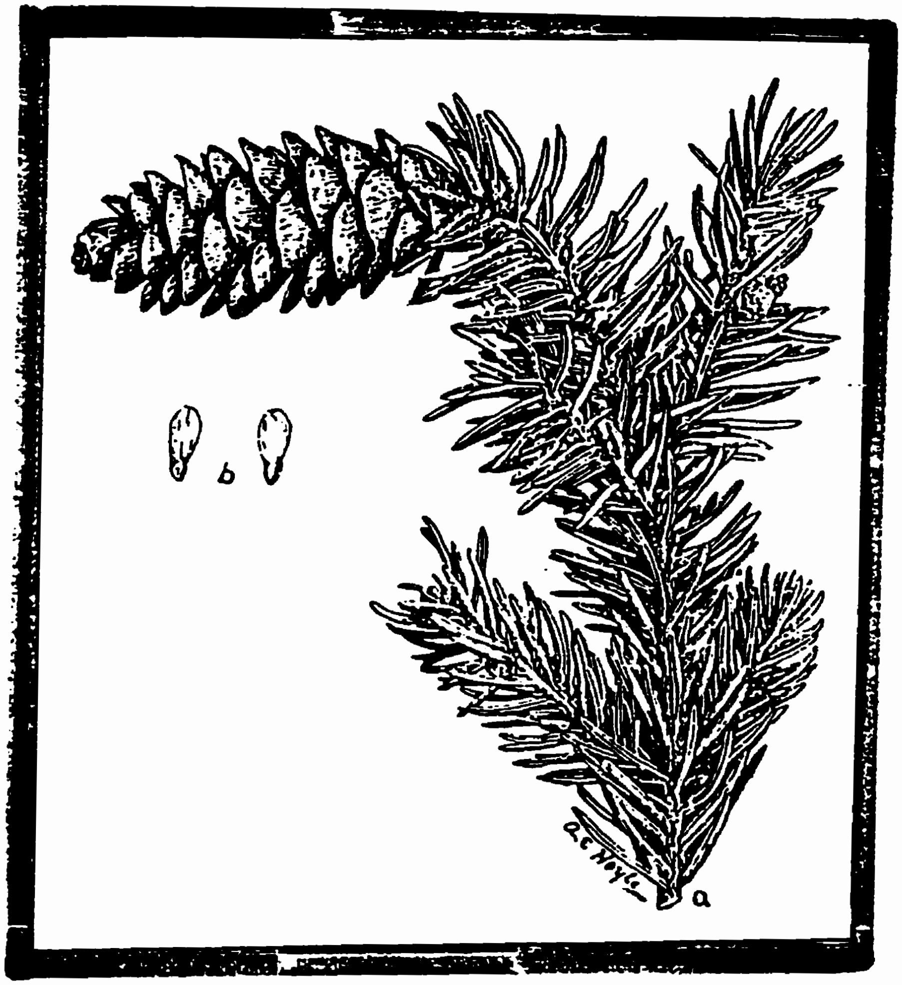

Figure 3-2: Diagram showing (a) branchlet with cone (x 1 magnification) and (b) seed (x 1 magnification)(after Preston 1978).

Figure 3-3: White spruce. 1. Closed cone and foliage (magnification x 3/4); 2. Open cone (magnification x 3/4); 3. Bark (Photograph courtesy Canadian Forestry Service IN Harlow and Harrar 1958).

Sometimes, white spruce have deep sinker roots and/or a shallow tap root but usually the root system is a shallow, platy and fibrous mat (Hosie 1969). White spruce has the ability to occupy sites where soil conditions limit rooting growth, thus the generalization of a shallow rooting system (Sutton 1969). Depending on the soil condition, competition and genetics, though, different forms of taproots and layered roots do develop (Strong and La Roi 1983, Wagg 1967). In fact, multi-layered root systems may develop in white spruce, particularly in areas of floodplains where trees from 2 to 132 years old grow new roots in response to silt deposits (Jeffrey 1959, Wagg 1964).

Depth of rooting in white spruce is generally between 90 and 120 cm, but taproots and sinker roots may descend to a depth of 3 m. In areas such as Ontario, white spruce has been found to concentrate much of its root mass on the top 30 cm yet farther north, large roots are heavily concentrated within 15 cm of the organic-mineral soil interface. Lateral spread of the root system was found to be as much as 18.5 m on sandy soils with lateral root extension estimated at 30 cm per year (Steill 1976, Strong and La Roi 1983, Sutton 1969).

Fine root production in a Maine plantation was 6990 kg/ha with 87 percent of this material concentrated in the top 15 cm of soil (Safford and Bell 1972). Fine roots in Ontario (0.25 cm in diameter and smaller) were found to comprise approximately 10 % (2670 kg/ha) of the total root biomass (Steill and Berry 1973). In a mixed spruce-fir stand in British Columbia, 67% of the fine root production was in the forest floor and A horizon, with the average depth of these horizons 8.3 cm (Kimmins and Hawkes 1978). An important component of the fine roots of most conifer species (Krasny et al. 1984) are mycorrhizae (Steill and Berry 1973) yet few of the fungi that form mycorrhizae have been found on white spruce.

3.2.5 SHADE TOLERANCE

White spruce's tolerance to shade is such that it can invade and eventually supplant hardwood stands, provided that surface conditions are favorable (Rowe 1956). Along with being very shade-tolerant, the species has the capacity to survive for 50 to 70 years suppressed in the understory because seedling and juvenile growth of white spruce is slower than its early successional associates (Arnup et al. 1988, Day 1972, Johnson 1986, Nanson and Beach 1977, Viereck 1970a, Walker and Chapin III 1986).

Although white spruce can survive in this suppression, growth is reduced (Steneker 1967). Seedlings grow well in 45% full sunlight until about the age of five but after age ten they require virtually full sunlight as well as minimum root competition in order to grow successfully (Steill 1976, Arnup et al. 1988). If they do not receive this degree of sunlight after age ten, stunting occurs. Optimum height growth of white spruce seedlings after nine years has been attained under 45% and 100% sunlight (Logan 1969) but white spruce of all ages show significant response to release resulting from natural causes or silviculture treatment (Berry 1982, Crossley 1976, Frank 1973, Steneker 1967, Zasada 1984).

Shade tolerance has also been suggested to be dependent on moisture according to a study in British Columbia by Krajina (1969). In this study, the shade tolerance of white spruce was found to be higher on drier sites and lower on mesic sites. Bakuzis and Hansen (1959) found that, based on a study of Minnesota forests, white spruce was given a ranking of 2.3 on a 5-unit scale (1=least to 5=greatest) for light requirements; 2.8 for moisture requirements; 2.2 for nutrient requirements and 1.5 for heat requirements.

Edaphic and climatic conditions are the main influences to seedlings' tolerance to shade. Seedlings are generally more tolerant than are the parent trees and will often grow in very shady areas. Propagation in these areas, however, usually results in spindly, weak trees due to the seeds being smothered by fallen and existing trees and shrubs. Seedlings which germinate in open areas are much sturdier and less susceptible to this vegetative competition.

3.2.6 REACTION TO COMPETITION

White spruce mixes with the true firs, maple, beech and other species forming multi-aged pure stands or a component of mixed-aged, late successional stands. Such stands range from 200 to 250 years of age in Alberta (Day 1972) to from 300 to 350 years of age in British Columbia and the Alaskan tree line (Nanson and Beach 1977, Densmore 1980). Depending on the age of the site, the soil conditions, stand history and other variables, natural stands occurring within relatively small areas can show markedly different age structures (Juday and Zasada 1984). Age distribution is not continuous but rather consists of several groups of ages separated by non-establishing periods.

3.2.7 FROST RESISTANCE

White spruce has a low to moderate resistance to frost. Since it flushes earlier than black spruce it is consequently more susceptible to spring frosts. In the spring, frost frequently causes damage to flowers and early shoot growth and seedlings are often damaged. This occurs especially in depressions and low-lying areas (Clements et al. 1972). Time of flushing varies as much as two weeks and so it is possible to breed late-flushing types in order to avoid spring frosts.

White spruce is more resistant to fall frosts. A study by Fraser and Farrar (1957) found that drought-exposed white spruce plants were more susceptible to fall frosts than were watered white spruce plants, indicating that moisture availability is of great importance with regard to frost resilience. Even so, white spruce is able to withstand severe winter temperatures and is more resistant to winter drying than its associates (Curry and Church 1952).

3.2.8 FLOOD TOLERANCE

White spruce has a moderate tolerance to flooding and grows relatively well on imperfectly drained alluvial floodplains (Gardner 1983). White spruce is less tolerant of prolonged flooding and although seedlings are tolerant of flooding, seedling vitality and survival are reduced after periods of prolonged flooding (Ahlgren and Hansen 1957, Zinkan et al. 1974). Cold-stored white spruce seedlings planted on cold, flooded soils in the spring will develop undesirable water relations patterns and reduced root growth with the possibility of increased mortality (Grossnicle 1987). Lees (1964b) has found, however, that with age, white spruce seedlings develop patterns of increased flood tolerance. Trees themselves, when subject to prolonged flooding inevitably experience mortality (Ahlgren and Hansen 1957).

3.2.9 FIRE TOLERANCE

Fire has played an important role in forest development and is currently used successfully as a management tool in western Canada (Zasada and Argyle 1983). Intervals between fires are estimated to be from 50 to more than 200 years. None of the species in spruce forests are resistant to fire; and in most cases, trees are killed by fires of light-to-moderate intensity. Pure spruce forests are more flammable than hardwoods because of the greater accumulation of cured fuels, and crown and foliage characteristics. Generally there are significant unburned areas within the perimeter of any burn due to varying species mixtures and site conditions. Site conditions, species composition, proximity to a seed source, fire intensity and postfire residual organic layer depths determine the rate of recovery following fire (Zasada and Argyle 1983).

3.3 CHAPTER SUMMARY

The relevant characteristics of white spruce ecology have been defined. The most important characteristic of white spruce, from a natural regeneration perspective, is its reproduction. This cycle is very complex and will be reviewed extensively in the next chapter to better understand the significance of the natural regeneration process.

Chapter 4:
REPRODUCTIVE CYCLE AND LIFE HISTORY

4.1 THE REPRODUCTIVE CYCLE

4.1.1. FLOWERING AND FRUITING

White spruce is entirely dependent on seed for its continued survival in the wild. It usually begins to produce seed between 40 and 60 years of age (Rowe 1956, Dobbs 1972), the variation being related to such factors as stand density and individual tree vigor. Moderate crops are borne at irregular intervals, usually every three or four years with light crops in the intervening years (Dobbs 1972). When large crops occur, a great amount of seed is produced. A single tree may easily bear 15,000 cones, each containing 50 or more seeds. As many as 11,900 cones and 271,000 viable seeds have been produced by a single white spruce tree (Dobbs 1972). Despite this reproductive potential, spruce does not easily invade established forest communities because the delicate seedlings produced from the small seed cannot compete with the large, vigorous perennial herbs and shrubs of the forest floor (Rowe 1956).

White spruce is monoecious with both male and female flowers occurring on the same tree, usually on different branches. Flower bud differentiation commences at the time shoot growth ceases (usually July), the year before flowering and seed dispersal (Alden 1985, Eis 1967a, Owens and Molder 1977). In British Columbia, the process occurs during the last two weeks of July over a variety of different sites. It lasts approximately one week according to Owens and Molder (1977) with development of reproductive buds continuing for 2 to 2.5 months and coinciding with shoot maturation. Male buds become dormant first followed by the vegetative and female buds about two weeks later.

Just before bud elongation in the spring, renewed cell division and growth begin. In British Columbia, this is six weeks before pollination at lower elevations and eight weeks before pollination at higher elevations (Owens and Molder 1979). During this period and about three weeks before maximum pollen shedding, meiosis takes place. Pollen shedding or flowering coincides with receptivity of the female flower (Nienstaedt

1958, Wright 1953) and occurs for three to five days (prior to the flushing of vegetative buds) in May, June or July. The date of flushing becomes later with increased age. Male strobili occur most abundantly in the middle portion of the crown and female strobili in the upper crown (Steill 1976).

The time of flowering varies with the geographical location and climate of the area. For example, over a four-year period flowering occurred between May 25 and May 30 near Ely, Minnesota and, from other observations from the same general area over a five-year period, pollen shedding varied between May 12 and June 1 (Ahlgren 1957). The average date of flowering was calculated to be May 25 at Dukes in Marquette County, Michigan and on the coast of James Bay north of 53° N latitude, pollination was as late as July 12 (Hustich 1950). In general, though, southern areas have earlier dispersal than northern areas but peak dispersals at latitude 48 to 50° and 65° N. can occur in the same calendar date (Nienstaedt 1958, Nienstaedt 1965b, Sutton 1969b, Zasada et al. 1978). In higher elevations, pollination is delayed up to five weeks (Owens and Molder 1977, Zasada et al. 1978). Latest pollination occurs near treeline elevations and latitudes.

Pollen shedding and coinciding female receptivity (Wright 1953) may vary as much as four weeks from year to year and are definitely temperature dependent (Forestry Sciences Laboratory n.d.). According to Zasada et al. (1977), pollen dispersal follows a marked diurnal pattern dependent on temperature, humidity and wind. This is most significant in the periods of peak pollination when seed production is at its most critical stage. At this time, seed production (and subsequent seed crops) may be adversely affected by a variety of detrimental weather conditions such as rain and frost (Maini 1966, Nienstaedt 1958, Zasada 1971a).

Male flowers, before pollen dispersal, are red and succulent. They are full of moisture and a substantial drop of water can even be squeezed from the conelet. Moisture content is 500 to 600 percent greater in male flowers before pollen dispersal than after. After pollen is dispersed, moisture content drops greatly as the male flower dries. Just before shedding, the color of the male flower changes from red to yellow and the conelet is almost dry. It is at this time when pollen collection is at its most optimum. After the pollen is dispersed, the fruit turns brown and then falls off the tree.

Female fruit is erect and about 20 to 25 mm long at maximum receptivity. Its color may vary from green to deep red. Color is found to be uniform within an individual tree but may vary among trees. Scales are widely separated when receptive. After pollination occurs, the scales close. Over a two to four week period, they turn downwards. It is during this time that the cone is growing most rapidly. Gradually, they dull in color.

Three to four weeks before pollination, fertilization occurs (Mergen et al. 1965, Owens and Molder 1979, Rauter and Farrar 1969). Maximum cone size and cone moisture content are attained in late June or early July. Zasada determined that in Alaska, final cone size is determined by the weather of the previous season and weather during cone expansion and heredity. This may vary considerably from year to year (Zasada et al. 1978).

After cones attain their maximum size, the primary period of embryo growth occurs. In middle to late July, cotyledons appear and embryo development is completed in early to late August in most of the range of white spruce (Mergen et al. 1965, Owens and Molder 1979, Rauter and Farrar 1969, Zasada 1988a). Although embryos have matured on the same date at both high and low elevations (Owens and Molder 1979), cotyledon initiation may differ from one to three weeks between sites of differing elevation and seed development may vary as much as three weeks from year to year (Edwards 1977). There can also be large differences in time of seed maturation between sites of different elevations (Zasada 1988b).

Edwards (1977), Winston and Haddon (1981), and Zasada (1973) have all concluded that the maturation process continues even after embryos attain physical and anatomical maturity. Cone dry weight usually increases during this period and production of high quality seed is dependent on adequate weather conditions. High latitude populations that are also at high elevation produce less than adequate seed during cold growing seasons. Immature seed with poorly developed embryos are inevitably the consequence (Zasada 1973, Zasada et al. 1978). Cones ripen in August or September, two to three months after pollen shedding (Cram and Worden 1957, Waldron 1965b, Winston and Haddon 1981, Zasada 1973). Cones open when cones obtain moisture contents from 45 to 70 percent and when specific gravities are between 0.6 and 0.8 (Cram and Worden 1957, Winston and Haddon 1981).

4.1.2 CONE CROPS AND SEED PRODUCTION

The heavier the crop, the further down the crown the cone-bearing zone extends. Reports on white spruce seed crop periodicity are extremely variable. Cone yields also vary widely. In 1950, what was described as a very heavy crop in southern Ontario averaged 8,000 cones/tree and in 1954 a 'fairly good crop' at Indian Head, Saskatchewan yielded just over 2000 cones/tree (Steill 1976).

Whereas spruce seed volume is largely determined by temperature conditions the year before flowering, the quality will be determined by temperatures during the summer and autumn when seeds ripen (Bergman 1981).

The best conditions for germination and survival are provided by a moist media free of aggressive competitors. Well-decayed wood (logs and stumps), wet muck soils such as drained beaver meadows, and mineral soil where severe fires have completely consumed the humus layer are the best mediums (Rowe 1956).

Several different variables can affect cone-crop potential. For example, hot, dry weather at the time of bud differentiation can indicate a potential crop, especially if the current and preceding cone crops have been poor. Cone-crops may be estimated by counting female reproductive buds in the fall or the winter, although differentiating male and female buds from vegetative buds may be difficult. Best ways to make the distinction are by observing the external morphology of the buds and their distribution within the crown (Eis 1967a). Male buds are generally located in the middle to lower crown (Eis and Inkster 1972) while female buds are concentrated in the top whorls. On 17-year-old grafts of female buds, the fourth whorl from the top was found to be most productive while the productive zone averaged 6.4 whorls (Nienstaedt 1981b). Highest cone concentration is closer to the top in light crop years as opposed to medium to heavy crop years.

Although cones and seeds have been produced by trees as young as four years of age (Sutton 1969b), production is usually lower in younger trees, depending on the site and the season. For most natural stands, seed production starts at approximately 30 years of age or older (Forestry Sciences Laboratory, n.d., Nienstaedt and Teich 1972). Optimum production occurs when trees are 60 years or older although excellent seed crops on 20-year-old white spruce plantations have been noted (Cook 1956). In Saskatchewan and Manitoba where mixed spruce and aspen stands are predominant, production begins when trees are between 45 and 60 years old (Rowe 1955). At more northern latitudes, seed production is more delayed and infrequent.

In general, white spruce is a prolific seed producer once it reaches 40 years of age with good crops occurring every two to six years and medium to absent crops during the intervening years. Most of the seed is released in the fall but some is retained in the until the following spring (Archibold 1980). The interval between good to excellent seed and cone crops and the amount of seed produced by white spruce varies with site and region of production. On good sites, good to excellent years can occur at 2- to 6- year intervals but may be as many as 10 to 12 years apart (Koski and Tallquist 1978, Waldron 1965a, Zasada 1980, Zasada and Viereck 1970). In certain regions, trees may produce large amounts of seed. For example, an open-grown 75 year old tree in northern Minnesota was known to produce 11,900 cones with a total of 271,000 viable seed in a heavy crop year (Lutz 1952). Meanwhile, a more intensive study in Canada (Tripp and Hedlin 1956) revealed the following statistics. Twenty-five trees had an average of 8000 cones per tree and in a good seed year, 25 percent of the potential seed production (or 23 seeds per cone) were filled and uninjured. Thus, the yield was approximately 184 000 good seed per tree in this study.

Hot, dry summers at the time of bud differentiation may be the cause of excellent seed years (Nienstaedt 1981a). Usually, these prosperous years are followed by poor ones, possibly the result of carbohydrate or nutrient deficiencies or the lack of sites in the crown able to produce reproductive buds (Nienstaedt and Teich 1972).

Female flowering may be substantially increased through different treatments. For example, a mixture of hormones, namely gibberellins (GA4/7), have been found to greatly increase flowering in white spruce (Cecich 1985, Pharis 1979). As well, it has been established by Cecich and Miksche (1970) that treatment of elongating shoots is effective. Application to dormant roots, however, is not. Fertilization with ammonium nitrate has also been successful in promoting flowering (Holst 1959).

Spacing of trees may also have some effect on seed production. In a study of a 30 year old plantation of white spruce planted at 1.2, 2.4 and 4.9 m spacings, cone length, full-seed yield per cone and full seed weight were all greatest in cones collected from the narrowest spacing (Caron et al. 1993) suggesting that white spruce produces best under more crowded conditions.

4.1.3 SEED COLLECTION

Cones must be observed closely in the last stages of maturity to ensure they are collected in the most optimum period. There are many indicators of cone maturity such as seed coat color, cone firmness, seed brittleness and various floatation tests (Steill 1976). Cone seed color may also be used as an indicator but is not the most reliable since no standardized cone color changes are associated with maturity and female cone color can be either red, pink or green (Teich 1970).

Seeds of white spruce may be collected from two to four weeks prior to their ripening. By storing the seeds under cool, ventilated conditions, seed quality may then be improved. The pre-chilling that is required for germination and early seedling growth are determined by the date of collection and the handling method used. There has been no consensus as to the best cone handling procedures to employ (Edwards 1977, Winston and Haddon 1981, Zasada 1973).

Although seed collection is expensive for white spruce seeds, cost may be reduced by robbing cone caches of red squirrels. The time elapsed between the time squirrels begin caching cones in quantity and the time squirrels cache their last cones does not affect the viability of the seed (Wagg 1964a). After one or two years in cache storage, however, viability drops nearly to zero.

Seed collecting costs may also be reduced by collecting seeds from downed tree tops (Slayton 1969). After topping, white spruce rapidly regenerates the crown and therefore restores seed-bearing capacity. Topping may even temporarily increase cone production (Nienstaedt 1982).

4.1.4 SEED SHEDDING AND DISSEMINATION

Initiation and pattern of seed dispersal is dependent on the weather. For example, cool, wet or snowy weather delays the onset of dispersal and causes cones to close after dispersal has begun. For cones to reopen, dry weather must follow. Mature cones hang pendantly then ripen in August or September and the majority of the seed is disseminated between 97 and 99 days after pollen shedding (Cram and Worden 1957). In the Northeastern United States, studies have shown (Roe 1946) that approximately eighty percent of the seed is shed within five weeks after cone ripening and 93.5 percent within nine weeks.

Although a small number of seeds are dispersed in August, most seeds fall in September (Dobbs 1976, Waldron 1965b, Zasada 1985, Zasada and Viereck 1970, Zasada et al. 1978). In the past, Waldron (1963) has also found that the period of maximum seedfall is generally mid-September. His records of research at the Riding Mountain Forest Experimental Area in Riding Mountain National Park, Manitoba have revealed that seedfall, in some years, commenced as early as the first of August and as late as October. Other research found that in northeastern Minnesota the first cones opened between September 5 and September 7 and in Marquette County, Michigan, the average date of cone-opening was September 17. Early seedfall is normally associated with below normal precipitation and above normal temperatures whereas late seedfall is associated with above normal precipitation and below normal temperatures. Seedlings that fall early and late also have a lower viability than the seeds that fall during the peak period (Waldron 1965a). On occasion, it has also been shown (Rowe 1955) that some seed is held in the cones into the following summer. Cones may also stay on the tree from 1 to 2 years after the majority of the seeds are dispersed. Cone opening and seed dispersal patterns may vary among trees within the same stand (Zasada 1985).

In one study, Dobbs (1976) observed seed traps on transects on a clear-felled site of 400 ha and on a 200-m-wide clear-felled strip from August 1970 to May 1971. The 1970 seed crop was medium to heavy, and the dissemination period of white spruce was protracted, with as much as one third of the seeds remaining in the cones at the end of October. The best-quality seed fell in September, the peak dissemination time, when the seeds originate from well developed central cone scales. Despite the commonly observed rapid decrease of seed-fall away from the stand edge, dispersed seed density was more than adequate for natural regeneration in the clear-felled strip, and within up to 300 m from the stand edge of the clear-felled site. Clear-felled sites of at least 36 ha could therefore be restocked from surrounding stands, given a sufficient seed crop and adequate seedbed preparation.

Average weight of white spruce seeds is between 1.1 to 3.2 mg (Hellum 1976, Zasada et al. 1978) and there are approximately 500,000 seeds per kilogram (U.S.

Department of Agriculture, Forest Service 1974). In good years, individual trees may produce between 8,000 and 12,000 cones or about 250,000 seeds (35 litres) (Hellum 1976). In Alaskan forests, yields are not as abundant (Zasada 1980). In mature stands, cone production occurs primarily in dominant and codominant trees with sporadic and low production in intermediate and suppressed trees (Waldron 1965b).

Total number of seeds per cone is variable and is dependent on specific tree and region. From 32 to 130 seeds per cone have been reported (King et al. 1970, Waldron 1965b, Zasada and Viereck 1970). Fogal and Aldemag (1989) did a survey of three Ontario plantations over two years and found that the number of sound seeds per cone varied from 0 to 162, with large differences from year to year and site to site in the amounts of viable seed produced. They provide a technique for constructing regression equations, using three variables (sound seeds per section, cone length and cone diameter as variable), for locations and crop years to aid in the determination of sound seeds per cone (Fogal and Alemdag 1989). The number of viable seeds per cone may be lower than expected, however, since seeds produced on apical and basal scales are not viable. For open pollinations, the number of viable seeds per cone is from 12 to 34 and for control pollinations, the number of viable seeds per cone is from 22 to 61 (King et al 1970).

Frank and Safford (1968) conducted a study on forest floor seedbanks in Maine for white, black and red spruce. This subject was of interest since trends in forestry at that time encouraged clear-cut harvesting in the northeastern spruce-fir forest. It was found that the viability of seeds of northern conifers does not apparently persist in the forest floor for more than one year, thus there is not a supply of viable conifer seeds on the forest floor for natural regeneration. A set of forest-floor samples collected two years after a heavy seed crop and one year after a seed crop failure did not produce any germinants, regardless of whether or not the surfaces of the samples were distributed. A second set of forest-floor samples collected the spring after a good conifer seed crop yielded many conifer germinants. The authors concluded that forest managers should not generally rely on seed in the forest floor for natural regeneration of conifers such as white spruce (Frank and Safford 1968).

By use of the seed trapping method, it has been established that seed dispersal not only varies by seed year but also varies from day to day. In Manitoba, the maximum annual total seedfall was $1400/m^2$ with 59 percent of the seeds filled. The seed rain exceeded $290/m^2$ in five of the ten years and 40 to 71 percent of the seeds were filled. For three years, it was less than $10/m^2$, and of these 2 to 36 percent were filled (Waldron 1965a). In Alaska, maximum total seed rain in one stand over a 13-year period was 4,000 seeds/m^2. In three years, seed rain exceeded 1,000 seeds/m^2 and was between 400 and 500 seeds/m^2 in two other years. In the remaining years, seed rain was less than $100/m^2$ (Zasada 1980).

Wind is the main transporter of seed and the time in flight and distance of flight for individual seeds is variable and depends on conditions at the time of dispersal (Zasada and Lovig 1983), although seed is usually not dispersed more than 100 to 200 m (Fowells 1965). Seed dispersal distances of 100 meters from a forest edge have been recorded for white spruce (Dobbs 1972). Generally, the farther the distance from the seeds source, the less chance there is that a seed may be dispersed there. At 50, 100, 200 and 300m distances from the seed source, seed rain may be as low as 7, 4, 0.1 and 0.1 percent of the number of seeds in the stand, respectively. The number of seeds reaching a particular distance may vary among sites within a local area and among geographical areas (Dobbs 1976, Zasada 1985) but with strong winds, dispersal of seed over more than 305 meters could be expected. This distance may be further increased through turbulence and convection currents. According to Rowe (1955), late fall seed may travel over the snow for more than a mile in most favorable conditions yet most seeds traveling in this manner are shed before snow arrives.

Phelps (1948) indicates that many seedlings become established but the majority fail to survive more than two or three years. In his study, of 500 sample plots established in Saskatchewan, only 40 % of the plots had any seedlings and of that 40 % of the average number of seedlings per hectare was about 940. In Manitoba, only 28 % of 1100 plots had spruce seedlings and stocked plots averaged 390 seedlings per hectare.

4.1.5 SEEDLING DEVELOPMENT

In the majority of its range, natural germination in white spruce usually takes place from mid-May through early August (Nienstaedt and Zasada 1990) the year following dispersal (as soon as adequate water and favorable temperatures are reached in the seedbed). However, other sources indicate that the germination period is mid-June to late July (Nienstaedt 1957). Germination is generally 75 to 100 percent complete by early July. On mountain podzols in Alberta, Crossley (1949) found that germination was completed by June 19. Manitoba and Saskatchewan, however, exhibit little germination until the warm weather in early July (Place 1955). Seeds are generally viable for one year, but in some cases white spruce seedlings are able to survive several wetting or drying cycles and still be viable (Hellum 1972a, Waldron 1966, Zasada and Gregory 1969). In spring-sown seeds, germination begins somewhat later than in fall-sown seeds but is complete in three to four weeks (Day 1963b, Eis 1965a). As well, adverse conditions may affect germination enough to delay it until the following year. For example, it has been noted that if seedbeds are dry, seed may remain in a state of dormancy until the second year upon which time germination is then favorable (Alden 1985, Anon. 1986a, Moore 1926). Such dry stored seed possess strong general dormancy and thus required stratification or overwintering in the forest soil in order to induce germination (Alden 1985, Anon. 1986a, Cram 1951).

Optimum germination temperatures are from 10° C to 24° C and maximum germination temperatures are between 29° C and 35° C. Minimum constant temperature is 5° C, but most germination ceases below 10° C. Densmore (1979) and Fraser (1971) have found that a diurnal fluctuation in temperature may be favorable.

White spruce seeds not only vary in response to temperature but also in response to light conditions. For example, seedlings developing after the middle of July and without sufficient sunshine have less chance of survival than those originating in early summer (Clautice et al. 1979, Ganns 1977, Hellum 1972b, Hocking 1971, Zasada et al. 1978).

Because white spruce shows conditional dormancy that varies in response to temperature and light conditions, it can be modified by stratification or prechilling. For the testing in seed lots and for improving germination capacity, energy and survival in nursery spring-sown seed, prechilling or stratification at 2° to 4° C is recommended although stratification is not necessarily a prerequisite for complete germination (Day 1963b, Fraser 1971, Wang 1974, Wang 1976, Zasada et al. 1978). Germination is epigeal (U.S. Department of Agriculture, Forest Service 1974).

Although the response is highly variable and density percent stocking is low, white spruce is capable of reproducing under mature stands of spruce and early succession tree species (Krasny et al 1984, Walker et al. 1986). One example is the white spruce in Saskatchewan versus those in Alaska. In Saskatchewan, in 88 percent of the stands studied, advanced regeneration was not present and one-half the remaining stands had fewer than 1,240 seedlings per hectare (Kabzems 1971). On upland interior sites in Alaska, however, advanced regeneration was observed. It ranged from 1 to 25 percent stocking and density from 120 to 640 stems per hectare (Institute of Northern Forestry n.d.).

White spruce is a mesic species, requiring well or moderately well-drained soils for germination and early growth (Fowells 1965, Nienstaedt 1982), although some genetic stock of white spruce may be poorly adapted to calcareous soil conditions (Teich and Holst 1974). Regeneration of white spruce under established stands occurs on a variety of different seedbed mediums but occurs most often on rotted logs (Day 1972, Wagg 1964b, Waldron 1966). This medium has several advantages over other natural seedbeds including more moisture, freedom from damping-off, less chance of smothering by fallen leaves, better temperature and light conditions, and perhaps better mycorrhizal development (Phelps 1948, Bedell 1948). Regeneration may be greatly restricted when soil humus layers L- and F- are greater than from 5 to 8 cm in depth due to the soil layers' inability to retain water. Although this seems to be the main detriment, Fisher (1979b) has suggested that allelopathy by forest floor components such as lichens may be the cause. Seedbeds such as humus, litter and moss are generally detrimental to spruce during the first season since they easily dry out to a depth 5 to 8 cm or more and moisture conditions of the seedbed is very important to germination and early survival of spruce seedlings (Long 1945a, Place 1952). When conditions favor a continued moisture supply, however, these mediums may support sufficient reproduction (Moore 1926).

Often on alluvial soils, white spruce seeds that fall among thick mats of grass may dessicate and die before their roots penetrate the soil. In autumn, these seeds may become suspended and as the dead blades of grass dry out in the spring, the germinants are left without a substrate (Eis 1981).

The small, winged seed is transported by wind and water and usually germinates in the early summer to produce a slender seedling whose top and root in the first season reaches lengths of only 2 to 5 cm. Consequently, mortality is high due to competition from vigorous perennials which not only deprive the seedlings of light and moisture but also crush them in the fall under a leaf mat , to which the weight of the snow is later added (Rowe 1970).

On exposed silty or fine loamy mineral soils, frost heaving is a serious problem for white spruce seedlings (Stiell 1976). This condition may be mitigated by maintaining the surface litter layer in cut over and seeded or planted areas. However, significant amounts of deciduous leaf litter on the forest floor may smother and crush young white spruce seedlings (Gregory 1966).

A sparse overstory may provide partial shade while serving to increase local humidity and soil moisture for seedling growth but in mature stands, where white spruce is in mixture with hardwoods, maintenance is very difficult due to the insufficiency of the hardwood litter seedbed (Place 1955) and the severe competition from surrounding herbaceous vegetation (Long 1945b). Areas of exposed mineral soil after windthrow and floods, though, have proven to be the best seedbeds for regeneration of white spruce seeds in mature stands (Copes and Beckwith 1977, Wagg 1964b), with stocking levels approaching 100 percent. In addition, spruce on mineral soil reaches breast height at 10 to 15 years of age compared to 20 to 30 years on decayed wood (Place 1955). Coarse mineral soils, however, may be too wet and cold under cover with the threat of frost heaving in the open and severe leaching in high rainfall areas (Place 1955). According to La Roi and Stringer (1976), feathermosses and associated organic layers are the most common seedbed surfaces.

In order to produce a seedling on recently exposed mineral soil, an average of 5 to 30 seeds are needed (Dobbs 1976, Eis 1967b, Gardner 1980, Horton and Wang 1969, Zasada et al. 1978). The number of seeds required increases each year following the exposure of the soil due to increasing plant competition and litter accumulation in the seedling's environment (Lees 1970a). Partly because of its small size in the first year, white spruce seedlings are not able to compete with the dense growth of perennials, shrubs and understory species (Bedell 1948, Place 1955, 1955b, Vincent 1955). Success of natural regeneration on organic seedbeds is generally believed to be low and seed per seedling ratios of 500 to 1,000 seeds are more are commonly reported in harvested areas (Eis 1967b). These surfaces vary considerably, however, most notably because of the other variables included. The amount of solar radiation at the surface, the type of organic substrate, the degree of disturbance to the other layers, amount of seed rain, weather conditions at the time of germination as well as other biotic and abiotic factors all affect germination and seedling establishment. When stands are undisturbed, seedlings are often found on organic matter, particularly rotting wood (Dyrness et al. 1988, Walker et al. 1986, Zasada 1986). This germination and subsequent seedling establishment on organic soil has been common after harvest in both the clearcut and shelterwood systems (Putman and Zasada 1986, Wurtz and Zasada 1987).

In greenhouses, optimum conditions for seedling growth have been determined. Alternating levels of temperature for the day and night is the most suitable environment for white spruce seedling development. At 400 lumens/m^2 light intensity, a 25° /20° C day/night regime is recommended (Carlson 1979, Pollard and Logan 1976, Tinus and McDonald 1979). Brix (1972) found that temperature and light intensity interact and that at about 40 lumens/m^2, a 28° /13° C day/night regime is favorable. Short photoperiods of 14 hours or less have proven to cause growth cessation, while photoperiods extended with low light intensities to 16 hours or more brings about continuous growth. Using more than 16 hours of low light intensity once seedlings are in free growth mode does not significantly affect the seedlings' growth although long photoperiods using high light intensities increases dry matter production. In fact, increasing the light period from 15 to 24 hours may as much as double the dry matter growth (Carlson 1979, Pollard and Logan 1976). In addition, growth of seedlings may be manipulated by controlling certain environmental factors. For example, short photoperiods induce dormancy and permit formation of needle primordia (Logan and Pollard 1976, Nienstaedt 1966, Pollard and Logan 1977).

Seedlings naturally regenerated, at the end of the first growing season, may be from 10 to 20 mm tall. Root length is generally from 20 to 100 mm but is dependent on seedbed type and site. Stems of these naturally regenerated trees are unbranched at this stage and the taproot usually develops lateral roots. These roots may be from 30 to 50 mm long (Eis 1965a, Hellum 1972a, Jablanczy and Baskerville 1969, Krasny et al. 1984, Zasada et al. 1978).

After 4 to 6 years, naturally regenerated seedlings usually do not exceed a height of 30 to 50 cm but do acquire a number of branches and their lateral root length may increase to as much as 100 cm. Rooting depth, however, does not increase significantly. Both shoot dry weight and root dry weight do increase between the ages of 2 and 6 (Eis 1970, Jablanczy and Baskerville 1969, Krasny et al. 1984, Wagg 1964b, Waldron 1966, Zasada and Grigal 1978). It generally takes approximately 10 to 20 years for the tree to reach breast height under open conditions but is dependent on site. Under stand conditions, the length of time to reach breast height may take 40 or more years (Hegyi et al. 1979).

Light intensity is an integral part of white spruce seedling growth. Young white spruce seedlings prefer full sunlight for optimum growth (Logan 1969, Brand and Janas 1988) yet are more tolerant of low light than black spruce (Sutton 1968, 1969). Fair growth occurs during the first five years in as little as 45 percent sunlight (Logan 1969). After the age of ten, full sunlight and minimal root competition is required in order for the tree to achieve optimum growth.

Under low light intensities, diameter and height growth, and root and shoot weights are all reduced. A reduction in light intensity by 50 percent in 10-year-old seedlings resulted in a reduction of height growth by 25 percent, a reduction of shoot weight by 50 percent and a reduction of rooting depth by 40 percent. In the same study, at 15 percent of full light intensity, no spruce seedlings survived (Eis 1970).

In juvenile stages, however, white spruce is capable of flushing and growing continuously if favorable environmental conditions are maintained (Steill 1976). Three years after planting, increases in growth of 38 and 92 percent have been recorded when surrounding herbaceous vegetation is controlled (Sutton 1975).

Early root growth is crucial to the seedlings' survival and transplanting often is detrimental to this growth. It has been determined that white spruce is sensitive to transplanting shock and that a period of post-planting depression known as 'check' is commonly suffered. This depression may last from 2 to 15 years (Steill 1976). Typical symptoms include short greenish yellow needles, poor retention of needles that are two or more years old, small buds, and very slow growth (Sutton 1975). The cause of check appears to be nutrient stress induced by the inability of the root of white spruce to exploit the rooting zone. This, however, is not fully understood but according to Steill (1976) and Sutton (1968), check is difficult to prevent and predict. Treatments which improve early root growth are beneficial (Blake 1983, Brand and Janas 1988).

In general, seed reproduction can be viewed on the basis of the factors mentioned. More specifically, Zasada (1990) has developed a conceptual model for assessing seed reproduction (Figure 4-1). The model includes several unique but interdependent steps (of varying degrees of importance) which ultimately determine an assessment of seed reproduction (Zasada 1990). When artificial regeneration is used (as opposed to natural regeneration), uncertainty of seed reproduction is diminished since adequate seedlings are assured.

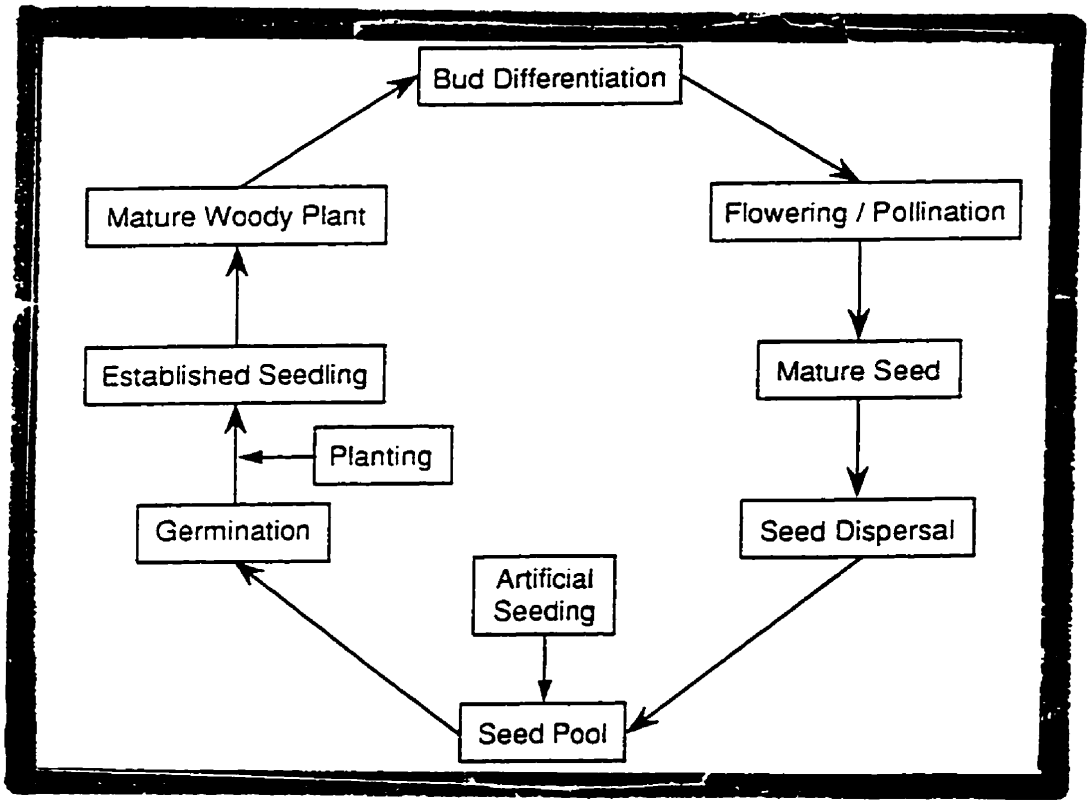

Figure 4-1: Conceptual model for assessing seed reproduction (Zasada 1990).

4.1.6 VEGETATIVE REPRODUCTION

Seed production is the primary reproductive mechanism for white spruce although in some areas, particularly in the north, layering is the primary reproductive strategy (Sutton 1968).

When reproduction of white spruce is inhibited by environmental conditions, layering often maintains the stand. Layering has been documented at treeline latitudes in both Canada and Alaska (Elliott 1979, Densmore 1980). It is most common in trees in open grown tree stands. Often soils are nutritionally poor, moss-dominated organic wet soils. Layers develop when the trees have lower branches which touch the ground. Eventually, the branch is covered by litter, moss, or soil and organic material and it subsequently roots from dormant buds near terminal bud scars of the branches. The ramets live connected to the ortet or parent for about 30 to 50 years. It has been found that they are actually no longer connected to their parent at this time but time required for the ramet to become independent is unknown (Densmore 1980). Trees in the far north that are vegetatively reproduced by layering may often reach a density of 1830/ha. This reproduction is inversely related to site quality.

Air-layering has also been shown to be successful on a 6-year-old spruce. The best time to prepare air layers is early May (Feucht et al. 1961). White spruce in the juvenile stage can also be propogated by root cuttings (Girouard 1974, 1975). By the time white spruce are 10 to 15 years old, rooting ability is substantially affected. Older trees, however, may be grafted. Grafting works best on forced rootstocks in the greenhouse in February or March (Nienstaedt 1966) and on dormant rootstocks in the fall (Nienstaedt 1959).

4.2 SAPLING STAGE TO MATURITY

4.2.1 GROWTH AND YIELD

In its early years, white spruce grows rapidly when under favorable environmental factors such as full sunlight. White spruce trees generally grow to 33.5 meters tall and 53 cm in diameter (Brown and Gevorkiantz 1934). Trees over 45 meters tall have been reported and on the alluvial flood plains along the Peace River, trees 56 meters in height have been measured. Near Hudson Bay, mature trees are from 12 to 15 metres tall and 13 to 18 cm in diameter (Ritchie 1960).

Strong apical dominance of the terminal shoot in white spruce leads to the excurrent growth form. As a result of variation in the growth of lateral branches due to tree or branch age, damage, or growing conditions, crown form may deviate substantially from the idealized conical shape. Near the treeline, the most serious deviations occur and marginal growing conditions may result in shrub-like trees. Free growth occurs when all growth factors are within the optimum range and trees are kept growing continuously. This often occurs in trees at the juvenile stage. Older trees experience determinate shoot growth. This is when the annual complement of needles is pre-formed in the overwintering bud (Nienstaedt and Zasada 1990).

The following year's buds are formed with the initiation of the first bud scales. In British Columbia, this occurs in late April or early May. After the period of shoot elongation, needles for the next growing season are started. This generally occurs in August or September. Signs of shoot growth may be observed in May or June on productive sites (Nienstaedt 1965b). Trees at higher elevations flush later; the higher the elevation, the later the flushing and a 500-m increase in elevation may result in a six week delay in flushing as compared to flushing time of trees at normal elevations (Owens et al. 1977). As well, the upper and leader branches grow for a longer period of time than do the lower branches (Fraser 1962).

Time of flushing is temperature dependent and thus varies with the weather. However, it has been determined that more than just air temperature controls the initiation of the annual shoot growth cycle since the number of degree days accumulated by the time of flushing varies from one year to another (Blum 1988). Nienstaedt (1981a) and Nienstaedt and King (1969) have found that among individual trees in a stand, there can be as much as a three-week difference. The period from flushing until the terminal leader completes 95 percent elongation varies among trees from different areas. For example, in Wisconsin and British Columbia, this period ranged from 26 to 41 days among individual trees whereas other reports have indicated this period is normally from 42 to 77 days (Nienstaedt 1965b, Sutton 1969b, Owens et al. 1977). Ultimately, the cessation of shoot growth is more dependent on photoperiod than on temperature (Owens et al 1977).

Both cambial and mitotic activity were studied in Alaska and Massachusetts (Gregory and Wilson 1968). It was found that in Alaska, the period of cambial activity is about half as long and the rate of cell division twice as great than in Massachusetts. Mitotic activity was observed to begin after 11 degree days (6° C threshold) in both areas. Thus, mitotic activity, or wood production, began in early May in Alaska and in late April in Massachusetts. In Alaska, eighty percent of the tracheids were produced in 45 days and in Massachusetts, eighty percent of the tracheids were produced in 95 days. Fraser (1962) reported that depending on site and year, variation of similar magnitude was observed within a small region in Ontario.

Rather than inhabiting good sites where trees normally attain maximum size, maximum individual tree age appears to occur on stress sites at latitudinal or elevational treeline. For example, a tree growing above lat. 67° N on the Mackenzie River Delta--the northernmost area of white spruce in North America--was found to have a 589-year tree ring sequence. As well, trees nearly 1,000 years of age occur above the Arctic Circle (Giddings 1962). Average sites usually produce trees which reach 100 years to 250 years of age while the oldest trees are often found on remote sites, such as those where they are isolated and protected from such damaging environmental agents such as fire. Islands and wetter, upland areas are the best sites for prolonged existence of trees (Zasada 1984, Juday and Zasada 1984).

Natural stands of white spruce generally respond well to cultural practices. It has been found that thin, fertilized stands begin growing earlier and have greater growth during the grand period than do stands which are not thinned and fertilized. In Maine, 71-year old trees that were released were found to have a higher mean annual increase in circumference than did control trees (Frank 1973). In 70-year old spruce in Alaska, basal area increment was increased by 330 percent when thinned and fertilized (220 percent by thinning; 160 percent by fertilization) (Van Cleve and Zasada 1976). Old white spruce may also respond to release but thinning does not affect termination of growth (Van Cleve and Zasada 1976).

The ability of trees to respond to release is dependent on the type of release practiced as well as on the amount of damage the stand sustains during the release (Herman 1981). In one study (Slayton 1969), spruce of all size classes in Manitoba doubled their diameter increment as a result of the removal of competing aspen in the stand. For those spruce with crowns at or below the height of aspen at any given time, height growth can be expected to double as a result of release of competing aspen in the area. Spruce volume can be increased as much as 60 percent with the combined effect of increased diameter increment and height growth as the result of release of competing species (Slayton 1969).

Site quality and initial spacing determine density-dependent mortality in plantations that have not been managed. Specifics for unmanaged white spruce plantations in Ontario have shown that mortality of trees at the age of 20 years will have occurred at a density of 6,730 trees per acre.

In the mixed-wood cover type in Saskatchewan, the average stand at maturity contains 377 trees per hectare, of which 147 are white spruce. The total cubic metre volume is 112 of which 61 or 55 percent is white spruce (Saskatchewan Department of Natural Resources 1955).

4.2.2 GERMINATION

Unless something is done to break the internal dormancy of white spruce seed, prompt and adequate germination is difficult to obtain (Crossley and Skov 1951). A common practice has been to store the seed in a moist medium such as sand or peat for 1 to 3 months at temperatures slightly above freezing. Tests of a shorter soaking period of 1 to 2 weeks indicated that the short cold-water treatment may be as effective as the longer cold stratification treatment. The main conclusions of Crossley and Skov's study were: (1) that a period of about 30 days is necessary to obtain complete germination, after a cold soaking; (2) that the cold soaking gave significantly greater germination than the unsoaked controls, with the 20-day treatment significantly better than either of the shorter periods; and (3) that changing the water at intervals during treatment gave significantly lower germination than when unchanged (Crossley and Skov 1951).

Phelps (1948) found that mortality was generally severe among seedlings during the first three years after germination. Seeds under the same conditions may vary as much as four weeks in the time taken for germination. Delayed germination promotes increased winter mortality through failure of seedlings to harden (Rowe 1953 in Newsome and Dix 1968).

Two successive summers with warm weather is a prerequisite for natural regeneration success - one summer when the flower buds are initiated and one when the seeds ripen. The chances of obtaining good results from natural regeneration from seeds depends on seed abundance, seed quality and regeneration receptivity of the soil. These factors are in turn influenced by habitat climate, habitat geology and habitat water (Bergman 1981). Thus, these environmental factors which affect white spruce natural regeneration must be explored.

4.3 CHAPTER SUMMARY

The characteristics of reproduction in white spruce are vast and exacting. White spruce requires adequate moisture, adequate light, a rotting wood or mineral soil substrate and little competing vegetation for successful reproduction. Unfortunately, success of this tree reproducing naturally is poor. In the next chapter, the method of natural regeneration will be thoroughly examined, including approaches to this method in past and present and the value of artificial regeneration as its complement.

Chapter 5:
NATURAL REGENERATION

5.1 ABOUT NATURAL REGENERATION

Natural regeneration is a common buzzword in silviculture but rarely is it thoroughly defined and examined. As with the general chapter on spruces (moving specifically to information on white spruce itself), this chapter introduces the reader to the meaning of natural regeneration and relates some history on this method of reproduction. This, in combination with general information on the white spruce should set the stage for further specific information and recommendations on the natural regeneration of white spruce in boreal mixedwoods.

5.1.1 DEFINING NATURAL REGENERATION

According to the Webster's II New Riverside dictionary, 'natural' is defined as "existing in or produced by nature" and 'regenerate' is defined (biologically) as "to replace by formation of new tissue". This would typically insinuate that natural regeneration is nature's replacement of lost tissues. This is in fact true however, as interpreted from a forester's point of view, 'regeneration' alone is defined as the renewal of a tree crop by natural or artificial means (Peterson and Peterson 1992). Zasada (1990) describes natural regeneration as referring to the production of seedlings from natural seedfall.

5.1.2 A PREFERRED OPTION

Natural regeneration, (and whatever other methods are necessary in order to successfully naturally regenerate a given site) should always be considered when selecting silvicultural alternatives (Zasada 1990). It is the preferred method of regrowing a harvested site for several reasons. By letting a site regenerate naturally or with minimal assistance, additional disturbance to a site is minimized. As well, since this method of reproduction is the most natural of the reproductive processes, it provides for the maintenance of the site's genetic and species diversity. Finally, natural regeneration is preferred since it is, in reality, the most cost-effective option.

5.1.3 REQUIRED ASSISTANCE

When assistance is required to aid in the natural regeneration process, the techniques chosen to assist in the process depend on the specific conditions of the site in question and the species to be regenerated. For example, jack pine sites would probably benefit from the scarification process which, in combination with clearcutting would mimic the effect of fire which is necessary for the regeneration of jack pine under natural conditions. For black spruce, seedbeds suitable for seeding (from remaining black spruce trees) may be created be disturbing the thick humus layer during the winter months with a ripper plow or shearblade. Required assistance for the successful natural regeneration of white spruce will be discussed in following chapters.

5.1.4 REGENERATION SURVEYS

Regeneration surveys are normally used as a measure to check for regrowth on harvested sites. This is necessary since cutovers must be regenerated to certain standards determined by a government regulatory agency. However, surveys are also carried out on burned areas and sites proposed for natural regeneration to establish baseline data. Such surveys are usually done three years after harvesting to determine whether natural regeneration will be successful. If it does not appear that sites favor natural regeneration, then measures are usually taken to treat the sites for planting.

Regeneration assessments are surveys taken at which point a forest manager must decide whether the regeneration or renewal phase of silviculture has been successful or needs remedial treatment. At the stand level, regeneration assessment is a complex decision-making process including a consideration of stocking, competition stress, growth performance, and opportunities for yield enhancement. To provide this basic ecological information, data should be collected on stocking, the free-growing status of each tree, growth rate (or ecological features allowing inference of forest productivity) and the spatial pattern or distribution of these factors to determine whether a given average stocking is uniform or irregular (Brand 1988).

5.1.5 SUCCESSFUL NATURAL REGENERATION

Many factors affect whether natural regeneration will be successful. Key elements in this determination include the type of ground cover or duff that presently exists on the site and the history of tree species that have previously grown on the site (Zasada 1990). For example, the sponge-like structure of the duff allows the soil surface to dry out rapidly while its insulating properties retain a low soil temperature. These two characteristics can be detrimental to tree seed germination and seedling establishment.

Sites with thin duff layers and trees that could potentially re-establish themselves can benefit from the aid of harvesting equipment (Zasada 1990). The harvesting equipment can sufficiently disturb the duff, expose the soil, and create favorable growing sites. When the heat of the sun opens the cones, the seed is able to fall on the newly exposed soil and germinate.

Areas with moderate duff layers are generally less successful in natural regeneration. However, natural regeneration can be stimulated with equipment which can distribute the cone-bearing branches in a manner to enhance the natural regeneration process. In addition to this, the equipment can disturb the duff and expose the soil, thus improving growing conditions. This process, known as scarification is most beneficial when it is executed during the spring, when temperatures and soil moisture favor seed germination (Zasada 1990). Scarification is especially effective for species such as jack pine that retain viable seed within its cones for several years.

In order to improve seedbed conditions and utilize seed supply more efficiently, site preparation is usually utilized. It is also important to recognize that the success of regeneration varies significantly among species. In a study of the natural regeneration of white spruce in Alaska, Zasada (1990) found that white spruce is generally more difficult than associated hardwoods to regenerate naturally.

Thus, in order to achieve successful natural regeneration, more consideration must be given to certain characteristics of given sites. These considerations include the size and configuration of cutting areas and retention of residual trees and stands for seed sources. As well, there must also be a good understanding of the characteristics of the individual tree species. This could, for example, help determine methods that could aid in predicting seed crops which would increase the probability of achieving successful natural regeneration, among other indications. Although the term natural regeneration implies that it can be timely and almost free, this is not the case. As with everything society wants, there is a cost. In this case, there is a huge resistance to changing logging approaches in order to achieve easier regeneration.

Destruction of natural regeneration mainly occurs in the skidding phase and to a lesser degree in the felling phase (Gingras and Ryans 1992). And, although new devices such as high-floatation tires and tracks permitting the reuse of skid trails have been developed, resistance is high because the cost of logging is so much greater than the cost of silviculture. Current logging practices also place more emphasis on harvesting efficiency than on the biological factors of seed availability, seed dispersal, seedbed and microsite conditions, all of which need to be considered for natural regeneration to succeed (Baskerville 1992, Arnott 1992, Weetman and Vyse 1990). In general, the approach has been to first cut it, then fix it later. This is illogical as lost growing time or lost soil cannot be replaced with money. So, natural regeneration, albeit a reasonable regeneration tool, is only as good as the crafters who use it (Baskerville 1992).

There are two main reasons why foresters are encouraged to reconsider the natural regeneration option. Firstly, public pressure is mounting to promote alternatives to the efficient but unsightly practice of clearcutting. Secondly, natural regeneration offers an opportunity to reduce forest renewal costs without sacrificing regeneration objectives (Weeman and Vyse 1990). Stand management is one aspect of silvicultural prescriptions in the effort to regenerate white spruce naturally.

Stand management may be defined as the method of attempting to reproduce the same forest, and more particularly, the species which was harvested (Rannard 1988). In some cases, the management strategy is to do nothing and let nature take its course. This case scenario produces a situation where successional changes take much longer, if they even occur, than would be the case for a stand following wildfire.

This type of stand management, that is a 'do-nothing ' approach, has also resulted in, for the most part, lower grade stands in which commercially important species are found in very few numbers, if at all. For example, Manitoba's forest landscape is covered with a number of forest areas where the 'do-nothing' approach has resulted in forests of lower quality and the costs of remedying this situation now are far greater than would have been if applied directly following harvest even though mechanically advantageous options are now available (Rannard 1988).

5.2.2 PAST APPROACHES TO NATURAL REGENERATION OF SPRUCE

Up to the 1950's natural regeneration was predominant in several countries, including Sweden. However, with the rationalization of forest practices and the introduction of new forestation methods, the percentage of naturally regenerated forests decreased (Jeansson et al. 1989).

The long-established way to regenerate a forest was to harvest the best tress and leave the rest to reproduce. The effects of this kind of management depended on the intensity of selection of parental trees (Savolainen and Karkkainen 1992).

In Manitoba, past harvesting practices, and in particular successful regeneration and forest renewal of some harvested areas, have resulted more from accident than by design or special harvesting techniques for the express purpose of ensuring regeneration. Professional regeneration attempts resulted in pure white spruce stands that were harvested to a minimum diameter limit, ensuring only larger trees were removed from the stand. Smaller-diameter spruce remained and continued to grow but the open stand often resulted in wind damage where pockets of tree were harvested on a clear-cut basis. Regneration of the species only ocurred if the soil was sufficiently disturbed (Rannard 1988).

Regeneration further west in the prairie provinces also proved difficult. In a study by Blyth (1955), on cut-over lands in subalpine Alberta, natural seeding was found to be a failure, averaging only 2% success. The author noted that natural regeneration was unsatisfactory on all ground treatments. Thus, the sparse information regarding past regeneration techniques seems to indicate that natural regeneration was not a favorable method of regeneration in Western Canada for white spruce. Furthermore, past regeneration surveys, such as those previous to 1981 only noted whether there were trees in quadrats (Todd 1982), a vague indicator of regeneration success.

Natural regeneration was practiced and studied extensively throughout British Columbia in the first half of this century but in nearly every region, it has been dropped in favor of planting. Planting has provided better control of stocking, early growth and subsequently, anticipated reductions in rotation lengths (Arnott 1992).

In a 1980 paper, Chrosciewicz stated that Canada's favorable position as one of the world's leading forest nations would be lost in the near future unless substantial improvements in regeneration of problem cutovers and other fail areas were soon made. Over the past two decades, alternative systems for regenerating white spruce have been explored and a broader array of treatment options developed. Application of this knowledge - the recognition of the problem, the understanding of the solution - is forcing a paradigm shift in how this mixedwood forest is being managed.

5.2.3 PRESENT APPROACHES TO NATURAL REGENERATION OF SPRUCE

Natural regeneration currently has an important role in forestry. Many artificially regenerated areas are spontaneously supplemented with advance growth to such an extent that the regeneration can be approved in spite of poor results of initial reforestation measures. Thus, an adequate use of advance growth can improve the regeneration result. In addition, during the seedling and thicket stage, the stocking of seedlings in natural regrowth increases with time (Jeansson et al 1989).

While there is an increased trend toward relying on natural regeneration throughout Canada, it is important to note that the shift is generally taking place in order to meet appropriate stocking guidelines. The Silviculture Contractor's Association (according to Brinkman 1993) recommended that an area is not considered regenerated until 'free growing'. That is, until the desired seedlings are the dominant plants on the site and are free growing. Free growing implies that the seedlings are at least 50% above the height of the surrounding vegetation (Brinkman 1993). The regeneration survey system has also been improved from the vague indications it gave in the past. The new survey system identifies the value of new treatment in a quadrat in relation to the number of free-growing healthy stems per acre that are desirable. This new system also confirms disease or an insect problem and can be used to make management decisions and prescribe future treatments (Todd 1982).

The increasing trend to natural regeneration has also been a result of shift in attitudes. Many concerned citizens view harvesting and silvicultural processes as unnatural and therefore destructive to the ecosystem as a whole (Moss 1993). As a result of increased awareness of the importance of multiple use and nature conservation, different attitudes about regeneration have been induced, implying new possibilities for natural regeneration methods. As Sweden has demonstrated, the establishment of larger, naturally regenerated areas is important for preserving natural forest tree gene resources throughout the country. Recently, interest in natural regeneration has increased in Canada for a number of reasons (Jeansson et al. 1989) which are listed below.

- There has been an increasing awareness of the importance of producing quality timber with natural regeneration as an attractive and cost-effective option to obtain regrowth.

- Naturally regenerated and well-tended forest stands have had a better ability to cope with impacts through environmental stress.

- There is a new consciousness of the value of multiple use aspects and the role of naturally regenerated stands in this context.

- There are conservation aspects and care for natural forest gene resources.

Although natural regeneration has been found to be a positive option to regenerating boreal mixedwoods, several problems with the approach have been recognized. The most notable of these problems is the lack of workable biological solutions for the establishment of regeneration to maximize growth which are absolutely necessary in order to make sound silvicultural prescriptions. Prejudice is the base of some of the reluctance for silviculturalists to try the natural regeneration approach, especially in the case of advance regeneration. Advance regeneration is usually regarded with suspicion as a clean planting site is ideal.

In some areas outside of western Canada, however (namely, the Prince George Forest Region of British Columbia), regeneration is looked upon favorably, but with allowances for implementation of harvesting and site preparation practices. These allowances are presumed to aid in achieving satisfactory levels of restocking and acceptable species within a maximum of 5 years on interior good and medium sites and 10 years for poor and low forest sites. Within these maxima, ecologically-based, site-specific time frames for natural regeneration can be determined by regional managers. Methods of classifying natural regeneration according to its potential have also been strongly suggested (Doucet 1992). In addition, policies have been developed for regeneration performance assessments.

In interior Alaska, natural regeneration has been the only means of forest renewal. Because forests cover much of the landscape, it is often believed that natural regeneration occurs automatically following natural or man-caused disturbance. A key question is whether or not foresters and other land managers can take advantage of or direct the regeneration capacity of these forests in order to establish forests of 'desirable' composition following harvesting.

Alaska results and observations confirm the general experience with white spruce in western Canada. Adequate natural regeneration of white spruce is difficult to obtain without management flexibility that includes assuring an adequate seed supply and seedbed conditions. Natural regeneration of white spruce is a complex process, perhaps more complex than for any other tree species in Alaska (Zasada 1980).

In addition, natural regeneration is not without its costs. Some problems include failing areas that require planting and uneven or excessive densities which require treatment. Overall, though, the cost should be lower than other alternatives and in these cases, seed tree and shelterwood methods of achieving natural regeneration are proving financially attractive (Vyse 1992).

Success rate of the natural regeneration technique must also be considered. Although the success rate for natural regeneration is much lower than for planting or for direct seeding, Kuhnke and Brace (1986) point out that these statistics can be considerably improved through site preparation. This has been the trend in Alberta, where forestry is currently moving toward the adoption of more-intensive, front-end regeneration treatments. Management objectives are being defined better, at least in terms of primary species of interest, and Alberta forestry is moving toward an optimizing rather than a minimizing outlook on regeneration expenditures. These changes bode well for the growth of new spruce plantations and for the contribution that white spruce will make to an increasingly dynamic forest industry in Alberta (Drew 1988).

5.2.4 NATURAL AND ARTIFICIAL REGENERATION AS COMPLEMENTARY PROCESSES

There are disadvantages and advantages to both natural and artificial processes, but their true value may be found in a combination of the two processes. In most cases, reforestation decisions involve both processes. Natural regeneration almost always adds additional seedlings and species to a planted site while planting is still often used to fill in areas that natural regeneration had failed to reforest in order to ensure a desirable mixture of species (Kimmins 1992). In the case of regenerating a natural white spruce stand, this is also applicable.

Although the white spruce planting program in the Prince George Forest Region, British Columbia was strongly supported in the 1980's (Coppersmith 1990), there may still be a place for regenerating some sites by seeding systems. Where local provenances of seedlings are not available or where summer access problems make planting difficult, direct seeding or natural regeneration may provide a useful alternative means of regeneration. The natural-and-artificial-seeding combination system is not new to white spruce silviculture and many references have indicated the near necessity for the allowance of mechanical assistance to aid in the natural regeneration process. Invariably, the two most important factors for the success of either system are the germination environment and the quantity of seed (Coppersmith 1990).

Most studies of white spruce natural regeneration suggest an incompatibility between the post-logging environmental conditions within clearcuts and the requirements of the species for germination, early growth and survival (Coppersmith 1990). The consensus of most research in both boreal and subboreal climates has been that white spruce natural regeneration is greatly enhanced by disturbance which exposes mineral soil. Seeds germinating on mineral seedbeds are less likely to suffer from severe drought or heat stress than those germinating on undisturbed organic layers. Seedlings germinating on humus are unable to produce a hypocotyl fast enough before summer periods of heat and drought. Successful regeneration of such sites without adequate mineral soil seedbeds is limited to exceptionally favorable years without a prolonged summer drought.

Direct seeding efforts resulted in less than desirable results, attributable to lack of receptive seedbeds. Of 34 documented direct seeding trials in Canada, half were failures (Coppersmith 1990). Another consideration regarding seeding systems is threat of vegetative competition during establishment. Seedbed conditions which promote good spruce seed germination may also promote intense vegetation competition. Brush competition is most severe on moist to wet sites.

It is clear that reliance on natural regeneration or direct seeding without adequate seedbed scarification will usually produce poor results (Coppersmith 1990). Seed supply in both natural and artificial seeding systems is critical to success. The timing of harvest relative to seedfall, as well as to cone crop periodicity, will also determine the volumes of seed dispersal to the clearcut. Enormous quantities of seed are required for successful natural regeneration. Reliance on direct seeding eliminates the concern for adequate seed dissemination from adjacent seed sources.

5.2.5 FUTURE ENCOURAGEMENT OF THE NATURAL REGENERATION APPROACH

In 1977, it was predicted that direct and natural seeding would continue to be the main method of reforestation with planting remaining as a support function, particularly for problem areas (Hellum 1977b). By the late 1980's, natural regeneration played a small role in regeneration programs in western Canada. With the popularity of increased silviculture, it was predicted that the role of natural regeneration would become minimal.

Vyse (1992) predicted, however, that the 1990's would be the main period of natural regeneration in British Columbia. Vyse predicted this based upon a) the success of natural regeneration on sites throughout the province; b) the high initial cost of artificial regeneration programs; and c) continuing strong social pressures to move away from clear-cutting as the dominant harvesting method.

Gingras and Ryans (1992) predicted that from 1992 to 2001, in eastern and central Canada (including the prairie provinces), environmental and economic incentives to favor natural regeneration would increase. This increase (from 53% of the area regenerated to 58%) was predicted in spite of the potential advantages of artificial regeneration with genetically-improved stock.

Presently, silviculturalists throughout British Columbia rely on natural regeneration to fill in gaps left by the failure of planted seedlings. In fact, regeneration surveys show that natural regeneration typically adds 1000 to 2000 stems per hectare to already-planted sites. Yet, the biggest drawback to acceptance of the natural regeneration process has traditionally been uncertainty. Since planting at one time was also uncertain (until research efforts made it successful), one could extrapolate this potential to natural regeneration (Vyse 1992). Zasada (1990) established, however, that natural regeneration programs are advantageous as there is generally less room for error than when using artificial regeneration systems.

Extensive studies have shown that natural regeneration is plentiful only if it is properly protected and in 1992, Doucet reported that one of the main proposals in the Quebec Ministry of Forests forest protection strategy included the use of careful logging, supporting encouragement and subsequent success of the natural regeneration process in the future. Indeed, literature suggests that several research incentives (with regard to natural regeneration) are underway on both provincial and federal levels, indicating the serious consideration of this regeneration technique (Arnott 1992).

In the immediate future, however, forest renewal in western Canada will continue to rely heavily on a tree planting program supplied by private, corporate and public sector forest nurseries that produce container-grown seedlings.

With the understanding of successful past regeneration efforts has come the pressure and momentum to change (Figure 5-1). Extensive regeneration systems will not provide us with conifer survival and growth sufficient to replicate the wild forest yields that are planned.

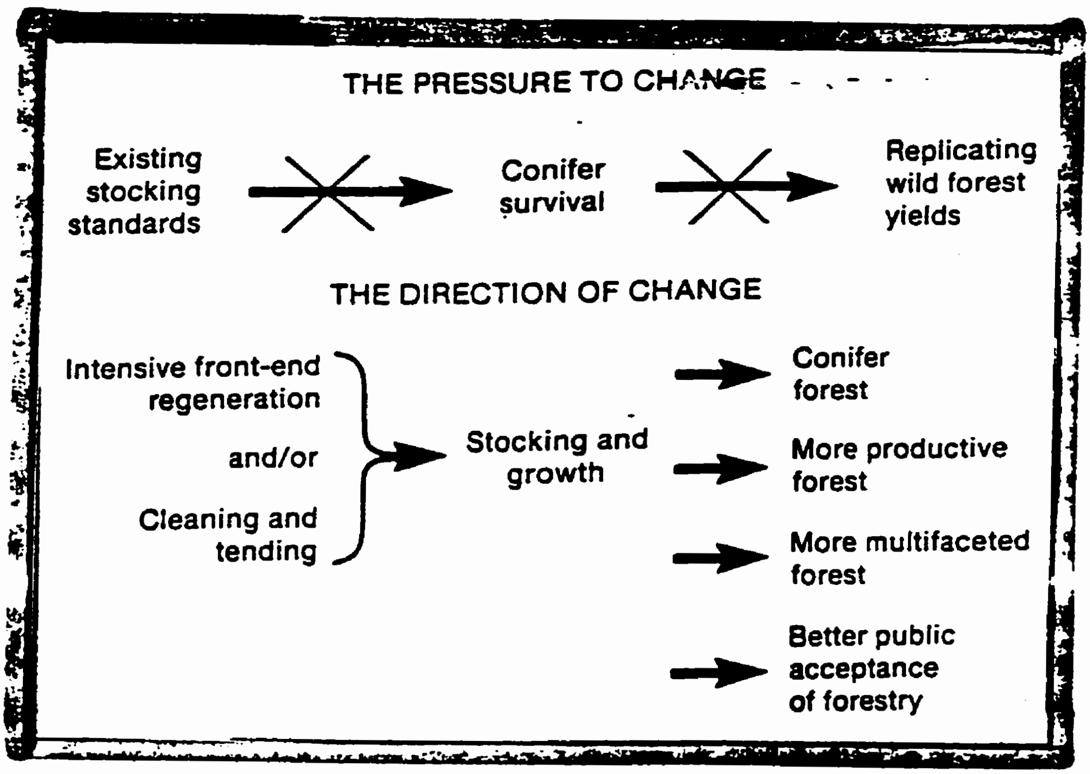

Figure 5-1: Understanding the paradigm shift: the pressure and direction of change (Drew 1988).

5.3 CHAPTER SUMMARY

Natural and artificial regeneration are most certainly complementary processes as adequate natural regeneration of white spruce is difficult to obtain without management flexibility that includes assuring an adequate seed supply and seedbed conditions (Zasada 1980). Natural regeneration of white spruce is a complex process that will not solve all problems, but it can go a long way towards implementing forest management activities that are environmentally desirable (Doucet 1992).

The most notable problem with the natural regeneration approach is the lack of workable biological solutions. This, according to Navratil et al. (1991) is relevant to the regeneration of any of the main boreal tree species. Most impediments to the natural regeneration of white spruce surround site influences and thus it is obvious that sound knowledge of the site and regeneration prescriptions surrounding site attributes are necessary before natural regeneration can be successful. A thorough examination of environmental factors affecting the success of white spruce natural regeneration will be the focus of the following chapter.

Chapter 6:
ENVIRONMENTAL FACTORS AFFECTING WHITE SPRUCE NATURAL REGENERATION

6.1 CLIMATIC INFLUENCES

6.1.1 TEMPERATURE AVERAGES AND EXTREMES

Climatic extremes for white spruce have proven variable according to the research. White spruce can survive in Alaska and parts of Canada in a climate where recorded extremes for one study area were -54° C in January and 34° C in July (Maini 1966, Van Cleve et al. 1986). A mean daily January temperature of -29° C for January has been recorded throughout most northern parts of its range. Mean daily July temperatures range form 21° C in the most southeastern area of range to 13° C throughout much of Alaska and Canada. In Manitoba, a maximum temperature of 43° C has been recorded.

6.1.2 LENGTH OF GROWING SEASON

The growing season of the white spruce varies from approximately 180 days in parts of Maine to as little as 20 or 25 days in parts of northern Canada. Generally speaking, however, white spruce grows best in regions where the growing season is about 60 days long (Canada Department of Transport 1954, Canada Department of Transport 1956, Nienstaedt 1965). A considerable part of the species' range falls within the permafrost zone of northern Canada.

6.1.3 AMOUNT AND EFFECTIVENESS OF PRECIPITATION

Precipitation ranges for white spruce are extreme as well. Mean annual precipitations vary from 1270 mm in Nova Scotia and Newfoundland to 250 mm throughout the Northwest Territories, the Yukon and parts of Alaska. It is found, though, that conditions are most severe along the southern edges of Manitoba, Saskatchewan and Alberta where a mean annual precipitation of 380 to 510 mm coincides with a mean July daily temperature maxima of 24° C or more.

6.1.4 FLOODING HAZARDS

White spruce has a moderate tolerance to flooding and grows relatively well on imperfectly drained alluvial floodplains (Gardner 1983). White spruce is less tolerant of prolonged flooding and although seedlings are tolerant of flooding, seedling vitality and survival are reduced after periods of prolonged flooding (Ahlgren and Hansen 1957, Zinkan et al. 1974). Cold-stored white spruce seedlings planted on cold, flooded soils in the spring will most likely have reduced root growth with the possibility of increased mortality (Grossnicle 1987). Lees (1964b) has found, however, that with age, white spruce seedlings develop patterns of increased flood tolerance. Trees themselves, when subject to prolonged flooding inevitably experience mortality (Ahlgren and Hansen 1957).

6.1.5 FROST HAZARDS AND SOIL HEAVING

White spruce has a low to moderate resistance to frost. Since it flushes earlier than black spruce it is consequently more susceptible to spring frosts. In the spring, frost frequently causes damage to flowers and early shoot growth and seedlings are often damaged. This occurs especially in depressions and low-lying areas (Clemens et al. 1972). Frost heaving is also a serious problem on these soils and similar coarse soils can dry our before establishment. A mulch of needles and or leaves on these soils is almost essential and greatly aids germination and growth.

Time of flushing varies as much as two weeks and so it is possible to breed late-flushing types in order to avoid spring frosts. White spruce is more resistant to fall frosts. A study by Fraser and Farrar (1957) found that drought-exposed white spruce plants were more susceptible to fall frosts than were watered white spruce plants, indicating that moisture availability is of great importance with regard to frost resilience. White spruce is able to withstand severe winter temperatures and is more resistant to winter drying than its associates (Curry and Church 1952). However, damage is possible by winter desiccation.

6.1.6 SUMMER DROUGHT AND WINTER CYCLING

The number of days of drought sufficient to cause mortality among seedlings varies from 7 to 24 (Phelps 1948) but death of whole trees or various degrees of die-back damage occur on conifers such as the white spruce as a result of winter dessication. This damage is also known as frost drought (Christersson et al. 1987, Sakai and Larcher 1987). The symptoms associated with the damage are discolored foliage and tree die back. The damage usually occurs when the aboveground or above-snowline parts of the tree are exposed to warm, dry air and sun while the ground is still frozen. This causes excessive transpiration and because no water is available from the roots, upper tree parts not protected by snow die back, often leaving the snow-cover height at time of damage visible on affected trees (Figure 6-1) (Hiratsuka and Zalasky 1993).

Figure 6-1: Winter dessication damage to white spruce showing snow-line delineation (Hiratsuka and Zalasky 1993).

6.1.7 LIGHT REQUIREMENTS

Photoperiod varies continuously over the range of the species from approximately 17 hours at summer solstice along the southern edge of the species' range to 24 hours north of the Arctic circle in Alaska and parts of northern Canada (Nienstaedt and Zasada 1990).

6.1.8 WIND DAMAGE

White spruce is moderately resistant to windthrow and overmature trees, especially those on shallow, organic and poorly drained silty or clay rich soil due to the restricted rooting depth. It is more windfirm on upland soils than either black spruce or balsam fir (Bowman 1944). Regardless, roots of white spruce require good soil aeration and rooting form and depth is highly variable in response to soil texture, drainage and moisture regime, soil fertility and the existence of impermeable soil layers (Sutton 1968, Sutton 1969).

Sometimes, white spruce have deep sinker roots and/or a shallow tap root but usually the root system is a shallow, platy and fibrous mat (Hosie 1969). White spruce has the ability to occupy sites where soil conditions limit rooting growth, thus the generalization of a shallow rooting system (Sutton 1969). Depending on the soil condition, competition and genetics, though, different forms of taproots and layered roots develop (Strong and La Roi 1983, Wagg 1967). In fact, multi-layered root systems may develop in white spruce, particularly in areas of floodplains where trees from 2 to 132 years old grow new roots in response to silt deposits (Jeffrey 1959, Wagg 1964b).

Depth of rooting in white spruce is generally between 90 and 120 cm, but taproots and sinker roots may descend to a depth of 3 m. In areas such as Ontario, white spruce has been found to concentrate much of its root mass on the top 30 cm yet farther north, large roots are heavily concentrated within 15 cm of the organic-mineral soil interface. Lateral spread of the root system was found to be as much as 18.5 m on sandy soils with lateral root extension estimated at 0.3 m per year (Steill 1976, Strong and La Roi 1983, Sutton 1969).

Fine root production in a Maine plantation was 6990 kg/ha with 87 percent of this material concentrated in the top 15 cm of soil (Safford and Bell 1972). Fine roots in Ontario (0.25 cm in diameter and smaller) were found to comprise approximately 10 % (2670 kg/ha) of the total root biomass (Steill and Berry 1973). In a mixed spruce-fir stand in British Columbia 67% of the fine root production was in the forest floor and A horizon, with the average depth of these horizons 8.3 cm (Kimmins and Hawkes 1978). An important component of the fine roots of most conifer species (Krasny et al. 1984) are mycorrhizae (Steill and Berry 1973) yet few of the fungi that form mycorrhizae have been found on white spruce.

Root grafting appears to be quite common in white spruce and in one study, about 27 percent of the trees had root grafts with other trees (Steill 1970, Sutton 1969b).

6.2 SUBSURFACE CONDITIONS OF THE SEEDBED

The most favorable seedbeds for white spruce are considered to be mineral soil, mixed soil and humus, and decayed wood (Steill 1976). Mineral soil is of prime importance for the germination of white spruce (Addison 1966).

On alluvial soils, the regeneration of succeeding spruce forests depends on seedling establishment on windthrow mounds. The occurrence of this phenomenon is generally sporadic and wind deposition of sediments appears insufficient to provide mineral soil seedbeds for spruce regeneration (Van Cleve et al. 1980).

6.2.1 SOIL ACIDITY

White spruce are able to tolerate a wide range of pH. They can grow on both acid and alkaline soils with pH values of 4.7 to 7.0. Higher pH values are probably an optimum (Steill 1976, Sutton 1969b, Wilde 1966, Arnup et al. 1988). For example, in the

Northwest Territories, white spruce grows in the alpine fir forest on strongly acidic soils with a surface pH of from 4.0 to 4.5, increasing to pH 5.5 at a depth of 15 cm. White spruce may also grow on the Adirondacks on sandy loam and loam soils derived from rocks rich in ferromagnesian minerals. The pH of this type of material is generally 4.5 to 5.0. In other areas, white spruce is supported by soils with a considerably higher pH value. For example, on the floodplains of the northern rivers, pH may vary from 5.0 to 8.2 (Zasada et al. 1977). In areas of lower elevation, mixed coniferous forest soils have a pH of 4.0 at the surface with a pH of 8.0 at a depth of 38 cm. A good example of this is in areas of Manitoba.

In one Manitoba study, two white spruce soil profiles were taken. One soil profile was found to have a pH of 7.6 at a depth of 10 to 43 cm below the ground surface. Below this, the pH was found to be 8.4. The other soil profile had a pH of 6.4 to 6.6 to a depth of 61 cm and was as high as 8.0 at greater depths (Stoeckeler 1938). Good growth on alkaline soils of the Manitoba Mixedwoods as well as in the other Prairie Provinces has been reported (Steill 1976). In other areas of North America, some calcium supply is required for the growth of white spruce.

It is also important to recognize the lime tolerance of the species. On heavily limed nursery soils with a pH of about 8.3, symptoms of chlorosis have occurred, indicating that factors associated with soil alkalinity must not be ignored. In all, of the wide range of soil types and site conditions upon which white spruce grows, soils in the orders Alfisols and Incepticols appear to be the most common.

6.2.2 SOIL FERTILITY

As was found with its exacting habitat, white spruce is also found to be more exacting with nutrient requirements than other associated spruces or pines. In a study of symptoms of potassium deficiency in spruce and pine plantations on sandy, worn-out agricultural soils in the Adirondacks (Heiberg et al 1951) and in studies of nutrient requirements (Paine 1960, Swan 1960), white spruce was more exacting than red pine, white pine, and Norway spruce. According to these studies, typical deficiency symptoms included stunted growth, yellowing and the early dropping of the needles. According to MacAurthur (1957), who studied the effects of manure on white and Norway spruce plantations at Grand Mere, Quebec, white spruce also responded well to fertilizer treatments.

There appears to be a lack of specific information available on the effects of fertilizer in natural stands of white spruce, but Steill (1976) has reported growth gains in white spruce after treatments given to overcome nutrient deficiencies. These positive responses to fertilization treatments may occur within a year of the treatment, even in established older stands (Brand and Janas 1988, Van Cleve and Zasada 1970). In addition, it has been suggested that application of 10- 10- 10 fertilizer may shorten the period of planting shock according to results of progeny test plots in northern Wisconsin.

Applications of micronutrients and major nutrient fertilizers have also resulted in a greatly increased volume of root systems and their absorbing capacity as well as top-root ratio in depleted nursery soils. Indiscriminate use of micronutrient fertilizers together with nitrogen fertilizers, however, may reduce seedling quality, making plants succulent, with high top-root ratio (Iyer 1977).

White spruce tolerates a wide range of fertility levels but is a more nutrient demanding species than black spruce and requires moderate fertility form optimum growth. In some soil types, such as alluvial soils commonly found along northern rivers, nitrogen may vary from 0.2 to 0.01 percent and phosphorus from 10 to 2 p/m. Adjacent upland soils derived from loess parent material may contain nitrogen from 0.1 to 0.4 percent and phosphorus from 10 to 3 p/m (Zasada et al. 1977). According to a study of Wisconsin native conifers, Wilde (1966) found that the minimum soil-fertility standards for white spruce are higher than for other conifers commonly planted in the Lake States. Further provisional data was gathered from sand-culture experiments (Swan 1971). Based on foliar analyses, fertility requirements for white spruce were found to be (in percent dry matter): nitrogen 1.50 to 2.50; phosphorus 0.18 to 0.32; potassium 0.45 to 0.80; and magnesium 0.10 to 0.20 (Iyer 1977). Plants will respond to fertilizer when they are at the lower end of the range. The results are in line with values published for 3-year old nursery seedlings.

6.2.3 ALLELOPATHY

Allelopathy, the direct or indirect deleterious effect of one plant upon another through the production of chemical inhibitors, is a potential cause of regeneration failures or delays in seedling growth. Although foresters generally think of interactions among plants in terms of competition for light, water, nutrients, or space, many species influence others through chemical inhibition or interference. One example is reindeer moss restricting the growth of white spruce by reducing root formation. Leachates from common forest plants such as the bog laurel and big-leaf aster inhibited germination and early growth of white spruce in the laboratory.

The yellow-green color and reduced growth of coniferous species on "poor" lichen covered sandy soils is a common sight in the boreal forest. The question often arises as to whether the poor site is due to the lichen ground cover or whether the lichen ground cover is due to the poor site. In greenhouse trials, lichen mulch significantly reduced growth as well as N and P concentrations of both seedlings and transplants of white spruce. This reduction in growth was due to the reduced availability of N and P in the meristemic tissues of the trees which seems to be due to the interference of the lichen in P and possibly N uptake. These results demonstrate that lichen ground covers can reduce the growth of both seedlings and transplants of white spruce. The trees are not killed but are merely stunted by the lichen. This stunting is accompanied by poor P and N nutrition that may be related to impairment of the trees mycorrhizae. The evidence indicates that the stunted condition of trees growing on "poor" sites with a lichen ground cover is due at least in part to interference by the lichen (Fisher 1978).

Foliage extracts of bearberry and sheep laurel were only slightly inhibitory to the germination and early growth of jack pine. The same extracts were progressively more inhibitory to red pine, white pine, white spruce and balsam fir. Since this is approximately the successional sequence for these species, it indicates one reason why jack and red pine are the most successful pioneers in the group. As in agriculture, it appears that foresters have learned to control many allelopathic interactions without knowing that they exist. Intensive site preparation, fertilization, weed control, and even planting of seedlings rather than seed, all reduce the allelopathic effects that new trees must endure. When and if forests must be established without these intensive silvicultural treatments, a more thorough knowledge of allelopathy will be necessary. Obviously, nature combats allelopathic effects, or there would be no forests; therefore, it seems likely that many ways to deal with allelopathic problems can be found (Fisher 1979a).

Transplants and seedlings of jack pine and white spruce were grown in sandy soil in the greenhouse and mulched with either of a few forms of reindeer moss. Mulch of both species of lichen significantly reduces growth as well as N and P concentrations of both seedlings and transplants of both species. The form of the root system of lichen-treated seedlings was altered. Reduction in growth was due to the reduced availability of N and P in the meristematic tissue of the trees, which seems to be due to the interference of the lichen in P and possibly N uptake. The trees are not killed, merely stunted by the lichen. Lichens have considerable ion exchange capacity and may filter out nutrients added to the site by rain or dust fall, a mechanism that did not operate in these experiments. The latter indicated that the stunted condition of trees growing on "poor" sites with a *Cladonia* ground cover is due in part to interference by the lichen (Fisher 1979).

Regeneration failures or delays in seedling growth sometimes have no clear-cut causes. Without knowledge of cause, foresters may attempt remedies that are unnecessarily costly or heavy handed, even when they succeed. If foresters know which trees are particularly susceptible, which plants are most likely to produce toxic effects, and which site conditions contribute to interactions, most allelopathic problems could be dealt with by site preparation and weed control. These and other practices often control allelopathy inadvertently. Allelopathy is not a problem for all plants nor at all locations where allelopathic plants occur. It should be considered as a potential cause of regeneration failure and analyzed as an explanation just as other possible causes are analyzed (Fisher 1980).

6.3 SURFACE CONDITIONS OF THE SEEDBED

Spruce regeneration in the undisturbed forest is generally found on decaying wood or on rare patches of exposed mineral soil which have more favorable moisture regimes (Dobbs 1972). Regeneration is successful where competitors have been destroyed or cannot themselves grow, such as severely-burned forest floors and exposed mineral soil free of broadleaf accumulation, and the decayed acid wood of old tree trunks and stumps (Rowe 1970). White spruce will tolerate a wide range of soil pH. Some trees have been observed growing in soil from pH 4 to 8 with optimum pH being from 5 to 6 (Dobbs1972).

A charred surface may get too hot in dry years for good germination and may delay germination until fall, with consequent overwinter mortality of unhardened seedlings. The soil needs to be moist near the surface during the germination period. Other germination requirements for spruce include optimum temperatures in the range of 18 to 24 ° C. Soil pH is unimportant in a wide range form very acid to alkaline and the value of had is debatable, although it may prevent excessive temperatures from developing. Survival and growth of germinants are also highly dependent on adequate soil moisture due to succulence and shallow root penetration of germinants (Steill 1976).

In a study of white spruce regeneration in northern Alberta and the Northwest Territories, it was found that the best seedling establishment was on patches of mineral soil while litter, raw humus and feather moss were ineffective leading to adventitious roots from the stems and branches as the materials became thicker and covered seedling stems and branches. Thus, survival and growth of juvenile spruce on all types of seedbeds is dependent on the development of adventitious roots (Wagg 1964b).

6.3.1 SURFACE SOIL MOISTURE

One of the singly most important factors affecting germination and early survival of spruce seedlings is moisture. Again, there is a narrow optimal range of moisture which favors white spruce seed germination. Adequate but not excessive moisture is required since white spruce seed is very small. Seedlings thus have small root systems which barely penetrate the ground in their first year. Therefore, seedbeds which have tendency to dry out to depths of five to seven centimetres can preclude spruce germination during the first season.

When natural regeneration or clear-cutting with site preparation and planting are the forest regeneration systems of choice, water is of particular importance for tree seedlings which must survive and grow with little buffering from the extremes in weather that occur near the soil surface. Often, the site preparation methods ameliorate expected shortages or excesses of water (Spittlehouse and Childs 1990).

Although the species will tolerate a wide range of moisture conditions, it performs poorly on dry or poorly drained soils. Favorable growth requires a dependable supply of well-aerated water but white spruce will grow on dry but fertile sites. Stagnant water inhibits the growth of white spruce as this condition reduces the rooting volume.

Many factors have been shown to influence thermal and moisture regimes of the soil and seedling. These regimes can be modified by forest management practices. For example, clear-cutting or brush control affect the sun's energy received at the soil surface, road building influences local drainage, and slash burning and scarifying the surface change soil reflective and thermal properties. The author stressed that improving one aspect of the seedling's environment may be detrimental to another aspect. Thus, physical modification to the site should not be done without considering all possible effects on the chemical and biological processes present at the site (Spittlehouse 1985).

6.3.2 SURFACE SOIL TEMPERATURE

White spruce optimally germinate in temperatures between 20 and 30 °C. Germination may be prevented by temperatures over 33 degrees Celsius. This narrow range of temperatures optimum for germination may preclude germination on cool, moist seedbeds that exist under forest canopies and on burned surfaces of dry sites where temperatures may be extremely high.

6.3.3 NATURE OF MINERAL SOIL SURFACE AND MICROTOPOGRAPHY

A number of different soils occur throughout the range of the species. Soils range from heavy clays in the Upper Peninsula of Michigan to the alluvial plains along the Peace River in Wood Buffalo National Park, Alberta, where white spruce reaches peak development (Place 1955). Generally, though, white spruce inhabits brunisolic, luvisolic, gleysolic, regosolic and podzolic soils. According to Nygaard, McMiller and Hole (1952), white spruce is considered very important on the gray wooded soils and the brown forest soils but on the sandy podzols, white spruce is usually a minor species. It is known to reach its best development on the podzolized gamma gley loams and on the strongly podzolized clays, which are most prevalent over the range of the species. It is also common on sandy flats and other coarse-textured soils. In Saskatchewan, it grows on shallow mesic organic soils and in the central Yukon on organic soils along with black spruce (Van Cleve et al. 1986, Sutton 1969b).

Although white spruce is able to grow on a variety of very different sites, to achieve its best success, it is generally more demanding than its associated conifers. White spruce is found to be exacting with respect to its habitat conditions (particularly in the boreal forest in Canada) as opposed to its associated conifers--balsam fir, black spruce, jack pine, and tamarack (Nienstaedt 1959). As one moves northward in the species' range, climate becomes more severe and the range of sites supporting the species becomes more limited (Figure 6-2)(Sutton 1969b).

White spruce are known to be a major component of the stands on the calcareous podzol loams and clays in the Algoma district of Ontario and is found to develop exceptionally well on melanized loams and clays (Wilde et al. 1954). Typical soils are calcareous tills (Figure 6-3) and are featured on fresh sites (Waldron 1966). In Saskatchewan, white spruce does best on the moderately well-drained clay loams (Kabzems 1971). White spruce of the Alberta Mixedwoods develops best on well-drained lacustrine soils (Heger 1971). In northern Canada and Alaska, exceptionally productive stands are found on moist alluvial soils along rivers (Jeffrey 1961, 1964, Lacate et al. 1965, Viereck 1973) and on south-facing upland sites (Farr 1967, Van Cleve et al. 1986). Alpha gley soils produce poor white spruce stands yet productivity increases with an increasing depth into the gley horizon (Wilde 1940).

Seedbeds of mineral soil are generally the best for germination of white spruce whereas litter, humus and moss are generally poor. Humus, litter and moss may easily dry out to a depth of 5 to 7.5 cm or more and this is detrimental to white spruce seedling establishment and first year growth. However, humus and moss, if ensured a continued supply of moisture, can provide an adequate seedbed for white spruce reproduction (Long 1945a, Place 1955). Poor or late germination often occurs on heavy mineral soils. These soils often possess excess moisture and insufficient heat in order for successful germination to take place.

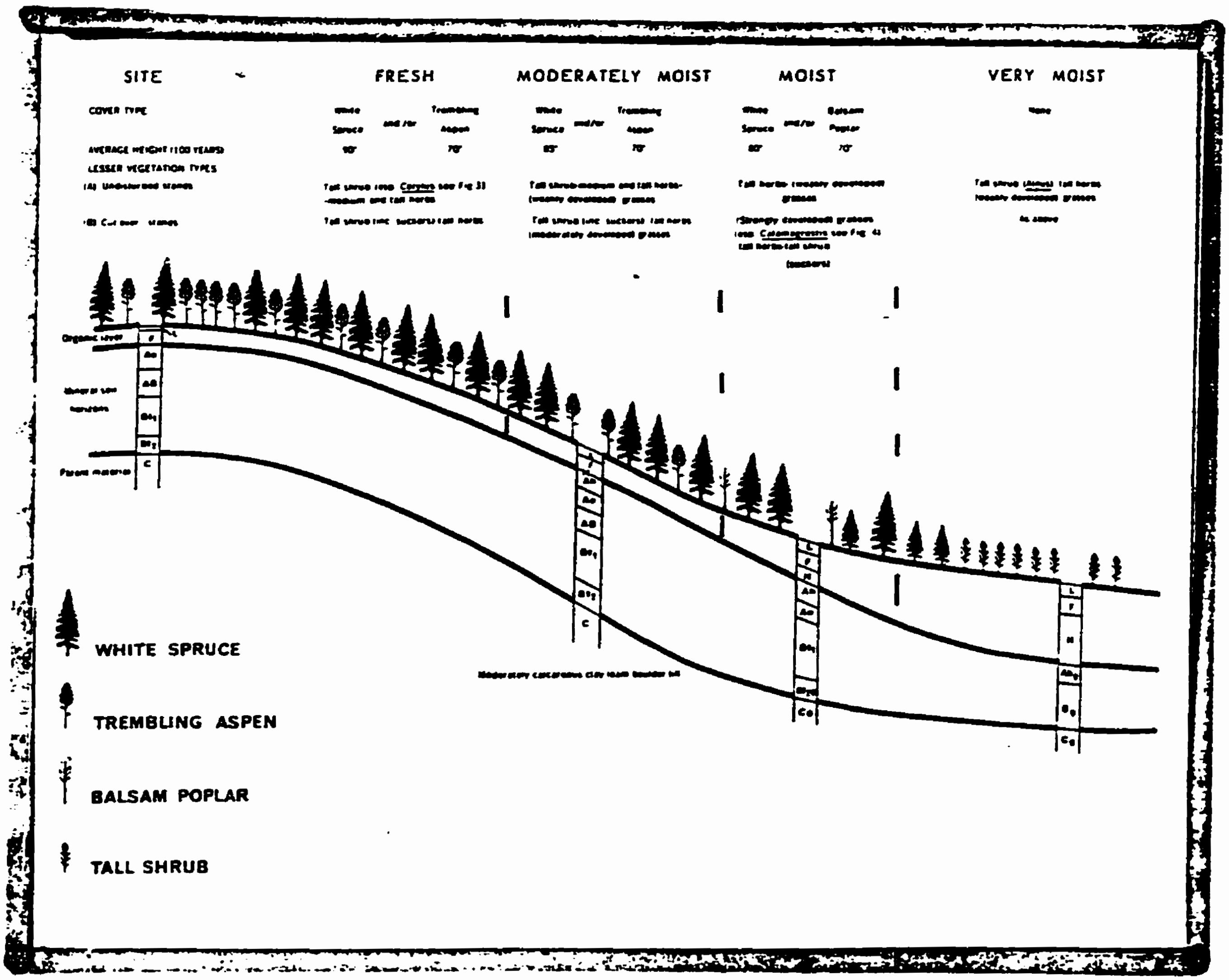

Figure 6-2: Typical forest type, associated vegetation and soil profile development of white spruce in western Canada (after Waldron 1966).

Figure 6-3: Typical soil profile (calcareous till) for white spruce (after Waldron 1966).

The best seedbeds for germination and survival of white spruce seedlings in the prairie provinces observed by Jarvis (1963) were mineral soil and mineral soil mixed with organic material for both disturbed and undisturbed sites. Early studies in the Mixedwood Forest Section showed that the removal of all organic matter by fire to expose mineral soil under stands of white spruce and aspen on upland sites provides favorable seedbeds for the establishment of white spruce. In a study of Riding Mountain Park and Pine Falls, Manitoba in 1963, it was found that in comparing germination and survival on different seedbeds created by fire, stocking of white spruce after two growing seasons was about the same on each of the sites (Jarvis 1966). Seedbed type had no effect on germination but did influence stocking after two growing seasons. In general, stocking was highest on mineral soil, intermediate on humus, and lowest on partially decomposed duff. This study indicated that for successful regeneration fore has to be severe enough to expose mineral soil (Jarvis 1966).

In 1960 a microenvironmental study was made of spruce and fir regeneration on logged-over land in a subalpine forest in Alberta. The study showed that seedling growth is very slow, and abundant regeneration becomes established infrequently. Since most seedlings were found in cool, moist, and shaded microenvironments and were growing in moisture retentive beds, it is suggested that regeneration methods which provide shelter and conserve soil moisture be tested. It was noted that during a 20-year logging period only a single peak of regeneration occurred. This followed a heavy seed crop in 1954 and favorable weather in 1955. Most of the spruce and fir seedlings had become established in moist and shaded microenvironments. Shaded decayed wood, mineral soil with incorporated humus, and F and H humus were the best seedbeds. Most of the spruce seedlings growing on sloping ground were on cool microslope aspects. The results suggest that regeneration cuttings which provide shelter for spruce regeneration should be tested (Day 1964).

In a regeneration survey in the Duck Mountain Forest Reserve, Bedell (1948) found that spruce regeneration did not readily establish on a heavy layer of litter and humus but did so on exposed mineral soil, as has been noted in many cases (Figure 6-4).

Where the depth of litter and humus was reduced by fire in poplar stands, spruce regeneration was often observed, indicating that nearby spruce stands were the seed source. Within stands, seedlings were mostly established on rotten logs or stumps which were covered in moss. This indicates that moisture is a crucial factor in spruce regeneration and development. Good spruce reproduction has also been observed on old timber berths where brush was not burned at the time of cutting, the regeneration possibly a result of the moisture-conserving properties of the brush.

Figure 6-4: Vigorous 7-year-old white spruce seedlings at the base of a fallen tree on mineral soil (Reserve, Saskatchewan, 1949 IN Rowe 1955).

6.3.4 DECAYED WOOD

Decayed wood is a common medium in undisturbed forests and provides one of the most advantageous habitats for seed propagation for several reasons. The medium of decayed wood possesses better moisture conditions and provides less opportunity for leaves to collect and smother seedlings (Newsome and Dix 1968). It also offers better temperature and light conditions, freedom from damping-off and perhaps even better mycorrhizal development.

Regeneration in the uncut, mature forest was found to be much better than on the cutover areas, because of the existence of rotten logs and old stumps which favor spruce regeneration (Figure 6-5) at the expense of balsam fir (Hosie 1947). Phelps (1948) concedes and found that most spruce seedlings had germinated on rotted logs or stumps in seedling success plots in both Manitoba and Saskatchewan.

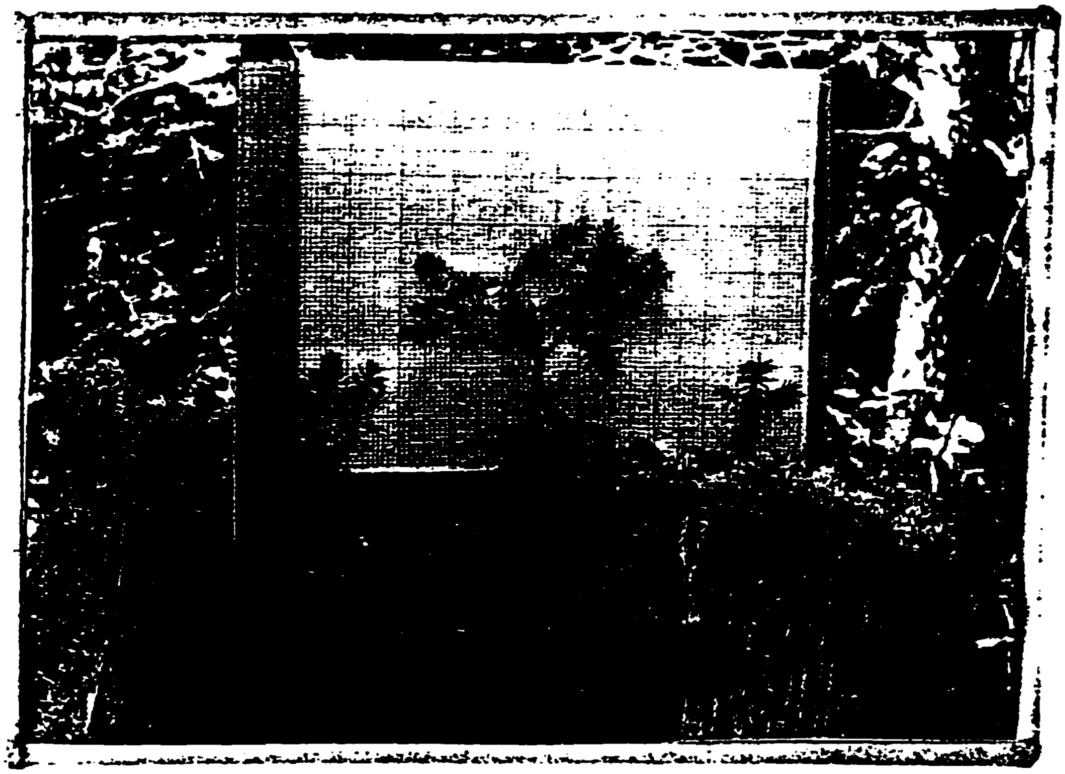

Figure 6-5: White spruce seedlings (about 7 and 12 years old) growing on a rotted stump (Reserve, Saskatchewan 1949 IN Rowe 1955).

6.3.5 LITTER

Phelps (1948) reported that in his study of seedling success in plots in Manitoba and Saskatchewan, in undisturbed stands the number of seedlings decreased as the depth of the litter increased while in logged and burned areas, there was a less pronounced relation between litter depth and number of seedlings. He also concluded that undisturbed litter is unfavorable to both establishment of seedlings and their subsequent survival, even with experimental seeding and watering. When litter is raked to expose mineral soil, or if it is burned, a favorable seedbed is provided.

6.4 VEGETATIVE INTERACTIONS

Competition from vegetation is one of the most universal problems in securing white spruce regeneration (Dobbs 1972). Cut-over mixed woods often support poplar and dense undergrowth. Spruce reproduction is poor on these sites (Figure 6-6).

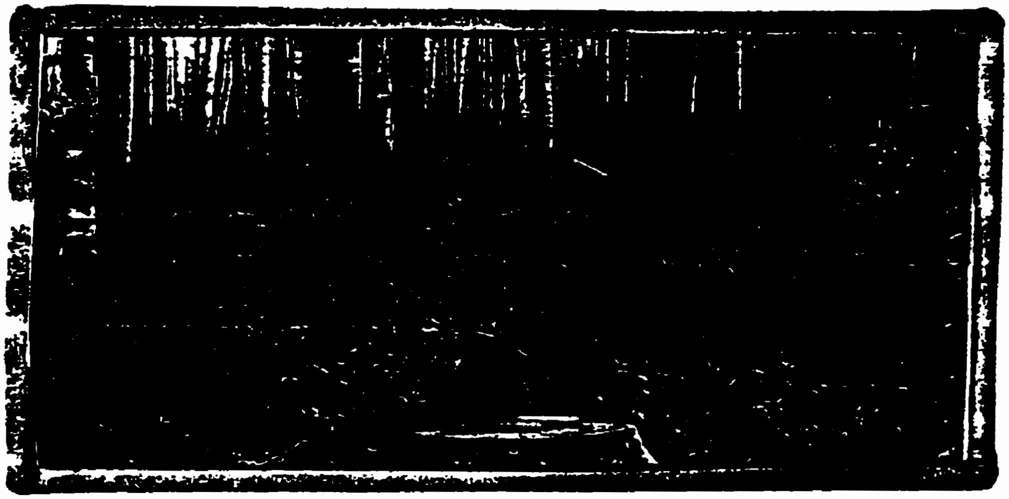

Figure 6-6: Cutover mixed woods showing residual poplar and dense shrub-herb undergrowth (Reserve, Saskatchewan, 1949 IN Rowe 1955).

6.4.1 MOSSES AND GRASSES

Foresters in British Columbia have claimed that grass has been a main competitor of tree seedlings for moisture in interior British Columbia. McLean and Clark (1980) record that the presence of domestic grass had little effect on the germination or survival of conifers on clear-cut areas, except where stands of grass became overly dense. In cases where inhibiting effects were apparent, the competition from native vegetation was of as much consequence as competition from domestic grasses (Figure 6-7).

White spruce in Alberta has been managed under a model of extensive management systems with the objective of replicating wild forest yields and species. This model is being rendered inadequate by the competition of several elements, including grasses, which are often lethal to young regenerated seedlings.

Figure 6-7: Grass development following clear-cutting of white spruce on moist site (Waldron 1966).

6.4.2 SHRUBS AND HERBS

Shrub competition is one of the main factors affecting the survival and growth in white spruce reproduction (Rowe). Shrubs such as hazel can invade quickly and greatly affect the amount of light and moisture avalable to white spruce seedlings (Figure 6-8, Figure 6-9). The influence of various amounts of shrub and herb cover on microclimate and on survival and growth of Engelmann spruce and lodgepole pine was examined in plots established in the Engelmann Spruce - Subalpine Fir zone of south central British Columbia. The site was harvested in winter 1977-78 and a shrub community subsequently developed. Certain ericaceous shrubs - rhododendron, black huckleberyy and Menziesia species and the valerian (a perennial herb) were dominant. After three growing seasons, survival of both conifer species was >95%, except at the highest levels of vegetation cover, where survival was 76-80%. Results suggest that soil temperature, air temperature, and light level are the primary factors controlling conifer seedling performance in an undisturbed vegetation community (Coates et al. 1991).

Figure 6-8: Hazel development in and undistubed harwood stand. Hazel in foreground is one year old (Waldron 1966).

Figure 6-9: A 20-year-old white spruce seedling under dense cover of hazel. The pole intervals equal one foot (Waldron 1959b).

6.4.3 ASPEN AND BIRCH

White spruce seedlings that originate under natural conditions in the aspen and white spruce-aspen stands in Manitoba and Saskatchewan have little chance of surviving. Among the more common factors that cause early seedling mortality are insufficient light and inadequate moisture, principally resulting from intensive vegetative competition. It has been suggested that favorable microsites may exist immediately at the base of aspen trunks, as it is common to see 'twinned' spruce and aspen in mixedwood stands. Usually, spruce becomes established on the north side of aspen. As a result of a study in Riding Mountain National Park, Manitoba, scalps prepared at the base of aspen were the most favorable seedbed for seedling survival as compared to in the humus layer or in moss (Waldron 1961).

Birch is a prolific seeder and can maintain itself by coppicing. The chief problem with birch in white spruce stands is that some of the habitats suitable for establishment of spruce such as decayed logs and peaty humus, are also suitable for birch. birch is often left as the sole hardwood species in very old conifer forests after poplar dies out. It may also be the chief invader if such forests are burned (Rowe 1955).

Among the more common factors that cause early seedling mortality are insufficient light and inadequate moisture and the autumnal layer of dead leaves and other vegetation which, when compressed by snow, crushes the seedlings below (Waldron 1961).

Removal of litter and sod (combined with cultivation of the area proved to be the best treatment for regeneration of white spruce according to Blyth (1955).

6.5 OTHER BIOTIC INFLUENCES ON CONES, SEEDS AND SEEDLINGS

6.5.1 DISEASES

6.5.1.1 Cone and Needle Rusts

The spruce cone rust is the most significant in attacking the white spruce. In 1962, this cone rust occurred quite extensively in the Riding Mountain area to the point that nearly every tree was infected to some degree. White spruce is also attacked by a number of needle rusts (Nordin 1956), the most common of which is the spruce needle rust (Cerezke and Gates 1992) but it is rare, however, that these infestations are serious. Finally, the large-spored spruce-labrador tea rust has been observed to damage spruce in Alberta and Saskatchewan (Brandt 1994).

6.5.1.2 Other Fungal Diseases

Surprisingly, white spruce is mainly free of serious fungal diseases. The most damaging diseases that white spruce are exposed to include the snow blight , which causes damage to small seedlings. Snow mold has been found common on spruce at high elevation in Waterton Lakes National Park, Alberta (Brandt 1994).

The leucostoma canker of spruce is a branch and stem canker that has been found on shelter-belt grown spruce in southern Manitoba (Cerezke and Gates 1992). The cytospora canker has damaged white spruce on shelterbelts in Manitoba (Brandt 1994) and, elsewhere, cankers resulting from infection caused by *Valsa kunzei* have been found on trees weakened by drought (Jorgensen and Cafley 1961). Yellow witches'-broom is caused by a particular fungi, *Periderium coloradense*. This disease, however, was relatively unimportant to white spruce in the past and was only occasionally observed on white spruce. It can cause deformation, loss of growth, and sometimes even death (Bourchier 1953) and 1991, it was found common on mature spruce throughout the province of Alberta (Cerezke and Gates 1992). Eastern dwarf mistletoe and lodgepole pine mistletoe both affect white spruce but not significantly.

The red ring rot is the only member of the heart-rot fungi that is very important in white spruce. Many different species of this ring rot affect white spruce, but not significantly. Only one of these has been particularly reported in Denmark (Ferdinandsen and Jørgensen 1938). Armillaria root rot and fusarium root rot have been noted to cause damage to white spruce in the prairie provinces of Canada (Cerezke and Gates 1992, Hord and Hildebrand 1956). A brown cubical rot and the red brown rot may cause some damage on the species and other rots have also been observed (Weiss and O'Brien 1953). In the maritime provinces, butt rot fungi were common (Davidson 1952) while in the prairie provinces, butt and top root fungi are more significant (Denyer and Riley 1954).

6.5.2 INSECTS

A number of insects consume white spruce (Trip and Hedlin 1956). Some of the most serious pests of the white spruce are the spruce gall aphid, the ragged sprucegall adelgid, the spruce spider mite and the white pine weevil, as well as the spruce seedworm, the spruce cone maggot, and the cone borers. The cone borers are especially serious in years of heavy cone crops and the borers appear to be found particularly when cones develop in clusters (Peterson and Worden 1960). Several Cecidomyids and Chalcids (Morley 1948) also attack seed and cones. All the above insects are especially detrimental in light seed years.

The eastern spruce gall aphid has been known to seriously affect the crowns of some trees and, when heavily infested in trees can kill up to 85 percent of the crown. Individual trees, however, vary greatly in their susceptibility to attack.

In 1993 (according to Brandt 1994), the spruce cone axis midge, spruce seed chalcid, spruce seed moth and spruce cone maggot were all found feeding in spruce cones collected for seed in Alberta.

In addition to feeding on cones, insects also attack white spruce foliage and the most important of these include the spruce budworm, the European saw-fly and the eastern spruce beetle. Leaf-feeders of some importance in the attack on white spruce are the yellow-headed spruce sawfly as well as other varieties of leaf feeders.

The budworm is known to cause extensive mortality in heavy outbreak areas, especially where white spruce is associated with balsam fir. Budworm attacks have been found to severely reduce diameter growth in the second to fourth year after heavy defoliation with extensive mortality resulting (Blais 1958). White spruce, however is much more resilient to budworm attacks than is balsam fir (Anon et al 1954). Conditions generally found to precede outbreaks include sunny summers for 4 to 5 consecutive years. These summers favor male flower production and subsequent rapid larvae development as well as female fecundity of the budworm (Greenbank 1956). Mortality caused by the saw-fly is generally limited to the east and the spruce beetle generally attacks older stands in northwestern Canada and Alaska.

Other defoliators such as budminers (McLeod and Blair n.d.), *Argyrethsia* species (Lindquist and Sippell 1961) and the spruce midge, (Clark 1950) are of considerably less importance.

Several different beetles are also enemies of white spruce. The eastern spruce beetle is known to kill mature and overmature timber and other beetles attack trees weakened by the budworm (Thomas 1958). The Alaska spruce beetle has caused extensive mortality in mature timber in northwestern Canada and in Alaska, it is considered potentially the most destructive forest insect.

A number of borers also attack white spruce, but they are of little or no economic importance.

White spruce is highly resistant to the white pine weevil but not so resistant to the spruce root collar weevil. The spruce root collar weevil is known to attack the roots of older trees. Although this does not necessarily directly kill a tree, it does provide ports of entry for root rots (Whitney 1952). Damage is more common on wet sites than on dry ones and roots less than 2.5 cm in diameter and the distal parts of roots less than 5 cm in diameter on larger trees are seldom damaged (Warren 1956).

6.5.3 BIRDS AND MAMMALS

White spruce is sought after by several birds including the chickadee, the pine grosbeak, the rose-breasted grosbeak and the crossbills. Little information has been documented, however, as to the nature of this attack.

The seed of the white spruce has been documented to be important food for a variety of mammals including red and gray squirrels, chipmunks, and voles and mice. Red squirrels are also known to cut off the leaders and the ends of upper branches and damage is extensive especially in years of light seed crops (Rowe 1952). In these cases, leaders are often replaced by laterals and damage is minimal unless the laterals form an integral part of a fork. Protection of seed from rodents was essential according to Blyth (1955). Animal browse (hare, ungulates) is still a problem in Manitoba where light browse damage has been detected in several plantations (Cerezke and Gates 1991).

Snowshoe hare are known to cause considerable damage to white spruce, especially during population peaks. The snowshoe hare often severely browses on seedlings which are set out close to the brush in attempt for some type of cover (Figure 6-10). Repeated browsing of some trees up to one meter tall have resulted in their death in some areas. Drew (1988) confirms that these hares provide competition to Alberta's natural regeneration option, ultimately limiting the practicality of mixedwood management systems that plan for spruce development in an understory position. Recently, severe tree mortality in white spruce regeneration in Saskatchewan was noted to be caused by snowshoe hare (Brandt 1994).

Except for toxicants, which are not used in Alberta, no effective hare control technique has yet been found (Radvanyi 1987) though two avenues are being explored.

Evaluation of a range of control options from repellents to trapping and fencing is ongoing but there is recognition that if all else fails, our focus must change to one of coexistence. In terms of this latter strategy, a combination of intensive regeneration, cleaning and tending to promote fast, early growth and an understanding of the dynamics of the hare population and the use of repellents and other control measures at the appropriate time should enable us to see spruce through the hare "booms", given the hare cycles and spruce seedling growth rates projected for Alberta (Figure 6-11).

Deer, moose, and elk do considerable damage to white spruce while rubbing their antlers against the stem and by browsing during food shortages. Porcupines cause damage by eating the bark and black bears have been reported to remove strips of bark from the lower part of the tree's trunk (Lutz 1951). However, the magnitude of the effects of this damage by black bears on white spruce is not known.

During 1962-1967, the fate of 7, 800 white spruce seedlings was studied in western Alberta. In this study, Radvanyi (1970) found that approximately 50 per cent of spring-placed seeds were destroyed by small mammals within four months whereas only 19 per cent or less of wintering-placed seeds were lost within a year. Calculated ground-eating small mammal populations were, on average, 4.5 animals per acre in the spring and 8.1 animals per acre in the fall. From this, he concluded that the percentages of seed destroyed were more directly related to the time of seeding as opposed to the number of animals present.

There are frequently large numbers of fallen shoots about 5 cm long on the ground beneath fir and spruce trees. It is very common in the Maritime Provinces to find such shoots practically covering the ground. This is most noticeable on the snow during late winter, but freshly dropped shoots may be found from late summer to spring. Many shoots have borne male flower buds at the bases of the needles and in most cases these have been removed. The shoot buds are generally intact. Another common type of injury consists of cutting of leaders and sometimes laterals from the tops of small fir and spruce.

Some of the large buds are often also removed. Many crooks and double leaders result, but spruce and fir generally correct these rapidly so that the form of the mature tree is not noticeably affected (Balch 1942).

Figure 6-10: White spruce seedling showing hare damage (after Kolabinski 1994).

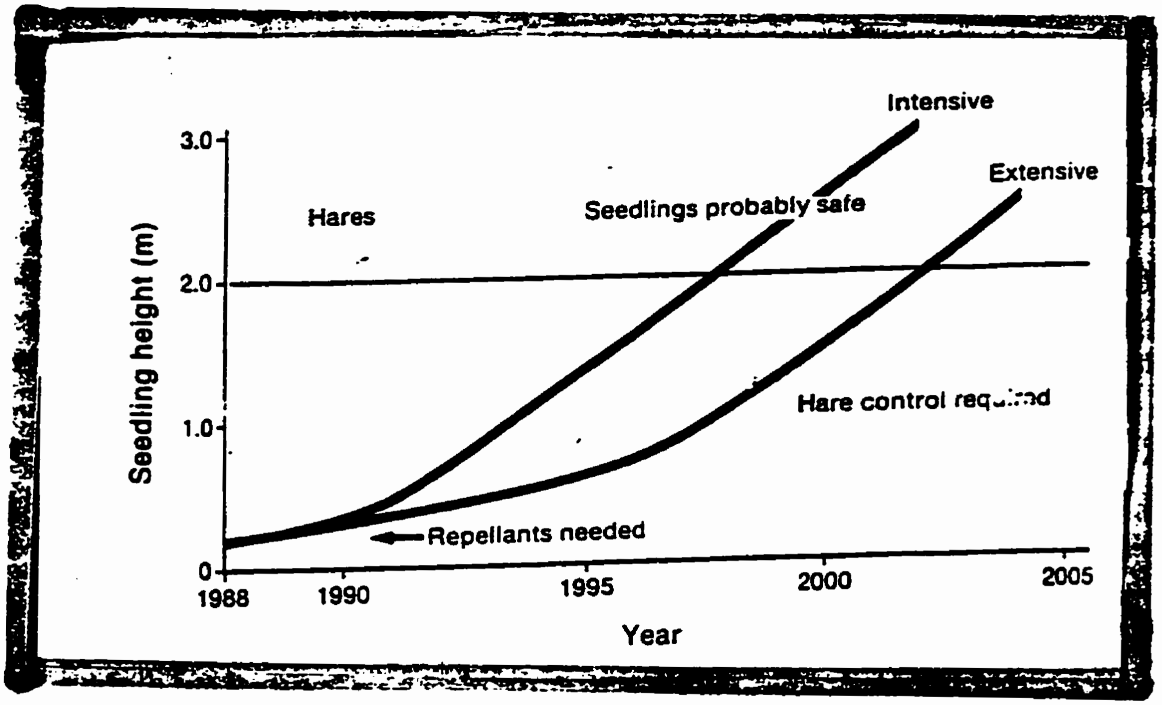

Figure 6-11: Growing spruce to coexist with the hare cycles in Alberta: the need for intensive regeneration treatments (after Radvanyi 1987).

6.5.4 HUMAN INFLUENCES

A number of human influences affect the establishment of white spruce seedlings, both to the advantage and the disadvantage of the species.

Flowering may be affected in that it may be stimulated more than 15 fold in ten-year-old trees by an application of 200 grams of ammonium nitrate per tree before the flushing of foliage. The trees used in this study had previously flowered and attempts to induce flowering on four to six -year-old trees were unsuccessful (Holst 1959).

Other influences include harmful harvesting practices, pollution, harvesting without replacement and purposeful destruction. Cerezke and Gates (1992) identify that chemicals affected all species of trees, including the white spruce in the prairie provinces in 1991. Misuse of soil sterilants and herbicides in urban and rural areas contributed to the mortality of ornamental trees in shrubs. Deicing salt applied to roadways also killed roadside native-grown conifers.

6.6 CHAPTER SUMMARY

Several different environmental factors affect the success of white spruce natural regeneration--from climate to soils to diseases and wildlife. In order to compensate for the detrimental effects of some of these factors, alternative regeneration systems have been created. These regeneration systems include the seed tree approach, harvesting options and tree selection and will be the focus of the next chapter.

Chapter 7:
ALTERNATIVE REGENERATION SYSTEMS FOR WHITE SPRUCE

Now that the influences on natural regeneration of white spruce have been identified and examined, regeneration systems must be analyzed. Regeneration systems are different approaches to white spruce silviculture with natural regeneration in mind. Alternative regeneration systems are those which, aside from allowing a site to regenerate in the natural sense, allow for natural regeneration while practicing silvicultural approaches that may enhance the natural regeneration to take place.

Silvicultural systems are complex management strategies which outline how a forest stand will be harvested, regenerated, and tended in order to meet defined objectives. No one system is considered superior to all others, and none satisfies all resource needs. It is important to recognize the difference between regeneration method and silvicultural systems. A regeneration method is the manner in which a stand is cut to ensure regeneration. Silvicultural systems, on the other hand, are an order of magnitude greater than the regeneration method. They are defined as "a process by which crops constituting a forest are tended, removed, and replaced by new crops, resulting in the production of woods of distinct form" (Camenzind 1989). Silvicultural systems encompass the life of the stand, are unique to every stand, and are therefore countless in their variations. Silvicultural options are often viewed by the public as universal in their acceptability. That is, that all options are available regarless of site conditions and stand composition (Zasada 1990). This, in reality, is not true--options must be well-understood and applied on a site-specific and species-specific basis, considering all factors (Figure 7-1).

Methods must be well understood and tailored to the site in order to allow for the stand to follow a natural process and successfully allow for the Acceptable Regeneration Delay Period (ARPD)--the maximum time allowed for the establishment of the minimum number of well-spaced, acceptable trees, the growth of which is not impeded by competition from plants, shrubs or other trees (Camenzind 1989).

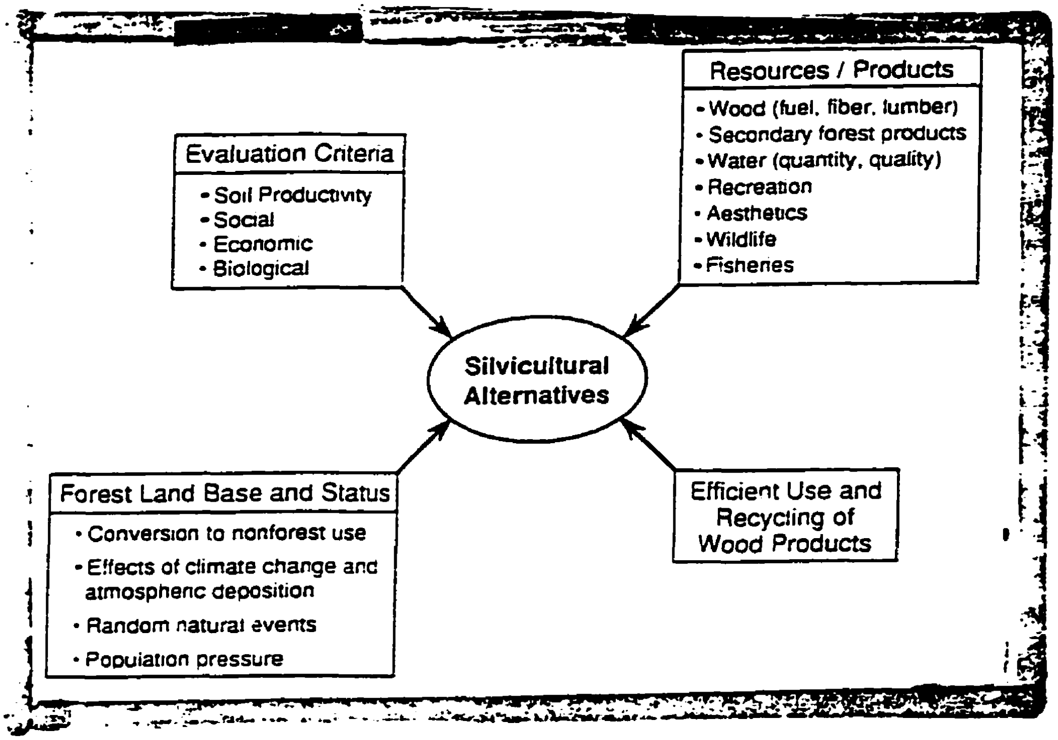

Figure 7-1: Factors affecting choices of silvicultural alternatives (Zasada 1990).

There are, in general, four basic regeneration alternatives: natural regeneration; modified logging that leaves residuals; direct seeding; and planting (Brinkman 1993). From these, several types of systems have been developed, studied and reported sound results--clearcutting, the seed-tree approach, group selection and individual tree selection and seeding and the spreading of cones. Zasada (1990) used several of these in a model (Figure 7-2). Included in this chapter are many of those such alternatives.

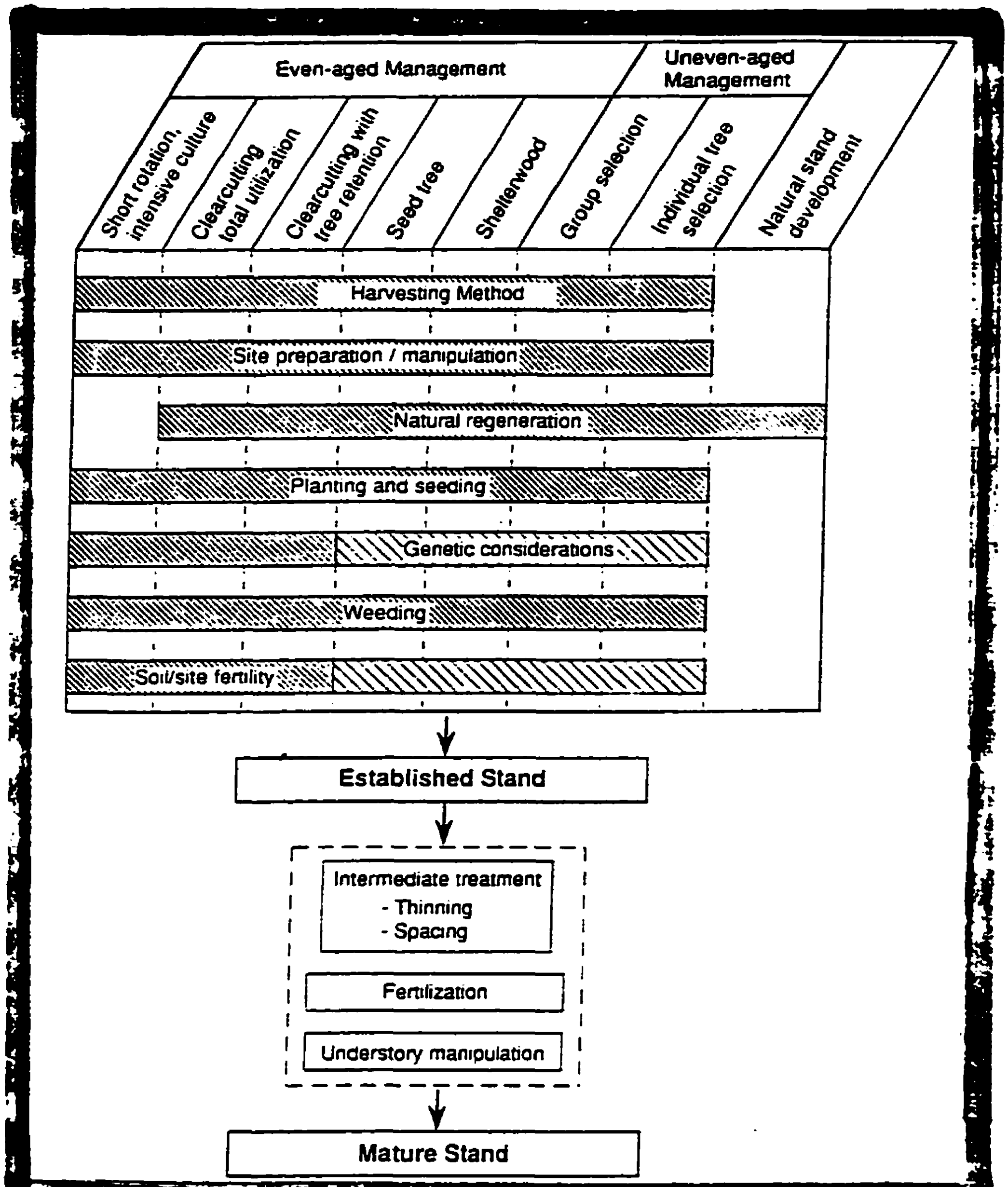

Figure 7-2: Silvicultural alternatives available for developing silvicultural systems for regenerating and managing white spruce in Alaska (Zasada 1990).

7.1 HARVESTING OPTIONS FOR MIXED STANDS

Poor natural regeneration of softwoods following forest harvesting is a major problem in many areas of the boreal forest region. This is perhaps mostly due to increased mechanization (Webber et al 1968, Weetman 1983) and the impact of heavy machinery on advanced regeneration. However, the biophysical characteristics of the site also influences the severity of harvest impact and the quantity of regeneration present in the early years following cutting (Harvey 1989).

Up to 1960, two basic cutting practices classified as regeneration cuts were used in Alberta and British Columbia. These were strip, block and patch clear-cutting and clear cuts with seed blocks reserved (Clark 1960).

When experimental cutting in a mixed wood stand in Saskatchewan was applied in 1924, the result was that the white spruce component of the new stands which were created by various cutting methods equaled or surpassed that of the original stands. Although this was partially attributed to an exceptionally heavy white spruce seed year, there did appear to be some relationship between the amount of white spruce replaced in the stands by 1956 and the residual base area of all species (Waldron 1959a).

In 1950 and 1951, Lees applied eight harvest cutting methods ranging from clear-cut to individual tree selection (plus an uncut control) to an experimental block of spruce-aspen stands in the Mixedwood Section of Alberta. Limited trials of hand scarification were carried out in each cutting area.

7.1.1 LOGGING

There are different opinions as to the effect of white spruce regeneration on mixed stands in which logging has been a harvesting option. Prochnau (1958) found that white spruce survives equally well in logged and logged-and-burned areas while seedling survival is low for natural stand areas. However, Hosie (1947) states that there is no evidence to suggest that logging is helping to increase the spruce content of the forest. The only practical way of doing that is to plant spruce on the logging roads immediately after logging, at a rate of about 900/ha which would ensure at least 1/3 of the cutover area being fully stocked with spruce.

Johnstone (1978) found that spruce logging residuals showed significant growth release after logging. The greatest release was in diameter growth and white spruce demonstrates the largest response in the species examined (alpine fir and black spruce) in west-central Alberta.

Cullen (1993) points out that without considerable intervention, areas logged for white spruce will most likely regenerate vigorous stands of hardwoods along with grasses and shrubs, which may or may not eventually come back to spruce through the understory. In fact, there are large areas logged in the earlier part of this century that are almost pure aspen.

In an experimental forest areas in British Columbia, Pogue (1949) found that logged areas were mostly in bad shape and where there was adequate restocking of cutover area, it was a result of a well-distributed stand. Openings and clumps of large spruce trees can result in fail spots which lower restocking. Thus, trees to be cut must be marked to avoid these problems. Marking should consider not significantly increasing opening size, chosing trees which have large crowns capable of healthy growth, leaving a fair amount of shade of the ground and improving the quality of the residual stand. Spruce not forming part of the first cut must be protected (Pogue 1949).

Light logging disturbance in northwestern Quebec resulted in low advance reproduction of white spruce which appear to have been favored by creation of seedbeds during harvesting. The study also found that fertile lacustrine clays are the most problematic of sites as they are susceptible to compaction and other harvesting impacts, resulting in high mortality levels and intense competition (Harvey and Bergeron 1989).

Froning (1980) found that careful logging of hardwoods can preserve a high proportion of white spruce understory. Guidelines for this logging should be based on the percentage softwood stocking for trees less than 10 m in height and reduction of stocking should be used as a measure of logging performance. More suitable equipment could be used for felling to preserve white spruce understory. Hardwood logging in problem stands at very low temperatures should be avoided as this has proven to cause increased damage and destruction of spruce. This activity must be monitored and guidelines enforced.

7.1.2 OTHER TREATMENTS

Treatments other than blade scarification, which retain fertility of the surface organic matter available to the seedlings can double or triple early productivity of standard stock (McMinn 1986).

7.2 CLEARCUTTING

Clearcutting involves the harvest, usually in one pass, of all of the merchantable trees on a given tract of land. The size of a piece of land so harvested can vary significantly and still be known as a clearcut. With the usual intent to promptly renew the forest, natural regeneration is often the chosen method. In this case, the clearcut may be interspersed with seed trees or patches or by leaving cut and uncut strips of about equal width (Prebble 1990).

Throughout Canada, clearcutting has been a common method of harvesting softwood timber, although cutting in a strip-like fashion is slowly gaining popularity under some conditions. Selection cuts are often practiced in mixed stands in order to remove the more valuable individuals while the others are left standing (Crosciewicz 1980).

Clearcutting appears to provide conditions necessary to achieve prompt natural regeneration (Zasada and Grigal 1978). The effect of clear-cutting is likened to the result of that of slash fires (Hosie 1947) and white spruce has been found to regenerate best after a catastrophe, following evidence gathered at a fluvial site along the Peace River in Wood Buffalo national park, Alberta (Jeffrey 1961). This indicates that systems of partial cutting are not advisable in the white spruce forest although this may be necessary due to its low resistance to windthrow. Since most stands are regular in structure, clear-cutting is likely to result in troublesome standing residual material. Thus, the recommended treatment is clear-cutting by strips or patches, accompanied where necessary, by scarification or controlled burning for the providing of mineral soil. Doucet (1992) supports this, indicating that these methods are favored to ensure natural regeneration and avoid degradation of sites.

In a study of clearcutting alternate strips and scarifying in pure white spruce stands in Manitoba and Saskatchewan, Kolabinski and Jarvis (1970a, 1970b) concluded that white spruce can be reproduced after logging provided that scarification creates seedbeds on planting sites and sites are restricted to fresh, moderately moist, and moist sites. Seeds are not removed from the site by clear-cutting (Moore and Wein 1977) but adequate seed crops are still necessary to provide regeneration but not necessarily in the same year as scarification since seedbeds remain receptive for a number of years.

Glew (1963) found that alternate strip cutting improved spruce regeneration, especially on areas that had been scarified. The problem, Glew identified, was then in the remaining strips. They could be harvested once the cut strips are satisfactorily restocked --then an artificial regeneration program is needed. If the strips are retained until the new stand is capable of producing seed, they could sustain serious losses from blowdown, disease and insects. Prescarification of the natural stand may induce windfall.

When land is clear-cut to those trees 2-3 cm in diameter such as is done in northeast Unites States, there may be limited means for regeneration unless advance reproduction is present or a seed source is available. The limitation of this method is that a harsh micro-environment may develop making regeneration difficult. Slash can smother seedlings or inhibit establishment. By clearcutting in alternate or progressive strips or in patches whose width does not exceed half the height of the trees harvested, maximum shelter can be obtained and more moderate surface temperatures and higher soil moisture can be obtained, improving the chances of seedling survival (Frank and Bjorkbom 1973).

Size of strips have also influenced regeneration success. When logged strips in Alberta were sampled to determine the relationship between distance from the nearest stand edge and amount of regeneration, results indicated that a short, wide strip within the 16-24 ha restriction would probably do as well as a long, narrow strip. The density of trees in the latter would be higher but this could be a disadvantage later when juvenile stand treatment may be required to reduce stocking (Johnson and Gorman 1977).

In 1990, Fielder conducted a study in Montana. The objective of this study was to estimate stocking of natural regeneration following clear-cutting for nine habitat type/site preparation combinations in western Montana's spruce-fir zone. Probability of stocking was significantly related to habitat type and site preparation method, and increased with lower grass/sedge, forb, and shrub cover, cooler aspects, gentler slopes, and time since treatment. Fielder concluded that the National Forest Management Act criteria for adequate regeneration may be unrealistic, since stocking probability increases significantly over time. Instead, flexible stocking standards with only moderate levels of site preparation seem preferable from both a biological and cost standpoint (Fielder 1990).

Clearcutting on Willow Island in Alaska, followed by broadcast slash burning resulted in the most marked changes in vegetation and soil temperature. Many of the pre-disturbance species dropped out and post-treatment vegetation was dominated by invading species and deep rooted species. Clearcutting without burning diminished the impact on the site (Dyrness et al 1988).

In Alaskan floodplains clearcutting has resulted in a total radiation increase at the soil surface, decreased levels of organic matter, total N, available NH_4 and P, and extractable Mg and K as well as an increase in pH. Decomposition of spruce foliage on the forest floor surface was also observed to be slower in clearcut. Nitrogen immobilization occurred during the first 2 years of decomposition (Yarie 1993).

Regeneration proved inadequate on soils in northern Alberta 8 years after clear cutting (Wagg 1964). As well, in Montana, probability of stocking was poor and dependent on habitat type, site preparation method and increased with lower competition, cooler aspects, gentler slopes and time since treatment (Fiedler 1990).

The applicability of the clearcutting method to spruce is limited for several reasons. First, spruce seed does not lie dormant for very long and second, seedlings demand some shelter from drying. Overmature, even-aged stands of spruce may be removed since regeneration of these stands is dependent on seed stored in the ground or windthrow from existing timber. Clearcutting for natural reproduction is best limited to clear-cutting in strips or groups of overmature spruce swamps (Robertson 1927).

7.3 SEED TREE APPROACH

In Canada, the seed-tree system is restricted to a few isolated instances (Crosciewicz 1980) and generally, very little work is being done using this method, although controlled burning under seed trees is usually highly successful in terms of forest regeneration (Chrosciewicz 1980). Thus, this method is applicable primarily to the tree species such as jack pine, lodgepole pine, and to some degree black spruce that develop and store large quantities of seed in tightly closed cones. When fire burns underneath, the heat triggers cone opening and thus aids in seed dispersal. White spruce do not possess this capacity but develop and freely disperse their seed at irregular intervals. The differentiation in both production and storage of seed must be considered when the use of seed-tree systems is contemplated for white spruce natural regeneration.

Large full-crowned trees are generally selected as seed trees. As dominants, they are windfirm, heavy seed producers due to their fully developed crowns, and because of their height advantage, they are able to disperse seed over a wide area.

Evidence of past cone production in the form of cone scales in the litter and at the base of the tree or remnant cones on the tree are useful aids in selecting consistent producers. Intermediate and small trees are poor choices since seed production is restricted by the overstory prior to harvest and by the limited crown size following harvest. Theoretically adequate practice would be to choose one large dominant per 2.5 ha but practice indicates between 5 and 12 trees per ha are chosen. Future salvaging of seed trees is not recommended because of the damage that will accrue to the established regeneration and because of the continuing value of having seed trees in any cutover in the event of fire or regeneration failure from other uncontrollable causes (Lyon and Robinson 1977).

The effectiveness of the seed tree system is dependent on the forest manager's ability to detect a future seed crop as early as possible so that the other phases of the overall treatment can be planned. The recommended method is simply to monitor the development of white spruce buds as they break dormancy each spring. This can be done with binoculars to avoid destructive sampling. During the summer of the seed year, seedbed preparation should be undertaken. Although the first and second years following mechanical seedbed preparation are best for highest germination and survival, predicting the coincidence of a seed year with the peak effectiveness of a seedbed prepared a few years earlier is extremely difficult and thus, scarification is best done the summer of the seed year. Regardless, the receptive mineral seedbed created will usually last about three years before invasion by competing species makes it less than desirable (Lyon and Robinson 1977).

Experience in Ontario, however, indicates that the seed-tree system is not wholly site specific and can be considered over the wide range of soil and stand conditions under which mature white spruce reaches its best or acceptable development (Lyon and Robinson 1977). It can be applied on a variety of different soil types -- deep, well-drained loams of glacial till origin, sands of lacustrine or alluvial origin, on silts and clays of lacustrine origin. Seed trees must be selected before harvest and be well-marked at breast height as well as at stump level to ensure their visibility during both the harvest and site preparation treatments. Marking is of prime importance as safeguarding these trees is the key to the success of this system (Lyon and Robinson 1977). Seed trees can be reserved any time in advance of the harvest but the most convenient time for seed tree selection is in a seed year when cones can be observed.

Elsewhere in Ontario, experiments were conducted on productive mixedwood sites to promote natural regeneration of white spruce using the seed-tree method. The site was

- provision of a mineral soil seedbed which is receptive to seed for 5 years;
- prevention of competition from intolerant or light-demanding trees and from lesser vegetation; and
- accelerated growth on crop trees.

Not all shelterwood trials are satisfactory, however. In a two-cut shelterwood system with seedbed scarification between cutting in Alberta's mixedwood forest, regeneration status on all sites was unsatisfactory, although moist sites had higher seeding stocking than dry sites. After three growing seasons, the site did possess areas which had been scarified that would be receptive to seedling growth. Lees (1970b) found that the reinvasion by ground cover, especially grasses, was outstanding.

In another study, white spruce 15 years after the first felling in a two-stage shelterwood operation revealed that very few potential crop-tree seedlings in the sample had arisen as advance growth in the original stand. Seedlings, later developing into potential crop trees had apparently established as a direct result of the two shelterwood removals as opposed to the advance regeneration present under the old stand.

Bedell (1948), in a summer regeneration survey in the Duck Mountain Forest Reserve found that when considering white spruce alone, shelterwood cutting resulted in an improvement to stand composition on half of the stands examined. He also found that where white spruce seed trees were left, stand composition deteriorated in all cases.

The shelterwood approach is found favorable by Vyse (1992) and Doucet (1992). As with the seed-tree approach, Doucet (1992) favors this approach as it ensures natural regeneration and avoids degradation of sensitive sites.

Shelterwood cuttings have also been applied outside of western Canada. In Willow Island, Alaska, a group of treatments were applied to a white spruce stand. The shelterwood cutting resulted in significant increases in soil temperatures that were roughly comparable to those measured in clearcut areas (Dyrness et al 1988).

As with the seed-tree method shelterwood methods also have their drawbacks. In the shelterwood approach, relatively few large trees are left to reproduce. The effect of this is that the stand may not maintain sufficient genetic variability and the selection of big trees may result in directional changes in genetic composition. In fact, selection for size has not influenced allozyme frequencies systematically and population sizes are not small enough for drift to have a measurable influence in one generation. Thus, from allozyme evidence, shelterwoods or seed tree stands seem to be a very natural way to regenerate forests.

Zasada and Wurtz (1990) attempted to maximize the probability of good spruce regeneration through the use of conservation regeneration cuts (small clearcuts and shelterwoods) and site preparation. They found that there were no significant differences in stocking and density between clearcuts and shelterwoods. After thirteen years, seedling height and diameter were not significantly affected by site treatments but seedlings were significantly smaller in shelterwoods than in the clearcuts. In some areas (Alberta's subalpine forest --Day 1970), although seedfall and environments appear satisfactory for abundant reproduction under this approach, seedling growth is often poor because of severe root competition and diffuse light. In order for the Shelterwood felling system to be successful, it is dependent on the provision of abundant seed and adequate environments for germination and growth that are not subject to excessive heating and drying of the seedbed.

7.5 GROUP AND INDIVIDUAL TREE SELECTION

Single tree selection is a more favored method than strip or clear cutting and is used in even-aged, all-aged, mixed immature or hardy, mature stands. The cutting objectives involve removal of volume to result in an even-spaced, even-level canopy of thrifty residuals which can respond to release and/or provide a well-distributed seed source for regenerating the openings created by the first cut (Clark 1960). This selection method offers the best protection for soil and seedlings and provides for repeated cuts of large timber with a minimum of danger from windfall.

The tendency of this method is towards over-cutting and demands greater skill in marking than in any of the other systems. The selection method is best applied to even-aged stands, mature or nearly mature, or mixedwood stands when all species are being cut (Robertson 1927).

The selective logging method was the first method used in attempt to secure adequate restocking of white spruce in British Columbia (Addison 1966). In this system, all trees were removed down to a fixed diameter limit in the first cut, while the second cu' would be made up of the residual stand and from the trees resulting from the advanced regeneration left after the first cut. After World War II, there was a notable change from the old horse-logging methods where logs were skidded out in tree lengths, causing great damage to the residual stand. The change was evident in a system in which trees that were to be cut were marked with remaining trees being the ones that would provide the best residual stand. Theoretically, this system would provide adequate shade for reproduction while at the same time, control the underbrush. This method had relatively poor results.

The selection cutting method, in effect a two-cut shelterwood system, resulted in highest stand growth rate, low mortality and best regeneration status. It was found that:

(a) a bare mineral seedbed prepared by scarification provided a receptive medium for spruce seedling establishment under all harvest cuttings

(b) seedling survival did not vary between treatments;

(c) overall regeneration establishment including unscarified conditions was unsatisfactory

(d) mortality and windfall in the residual stands was slight, occurring mainly in stems damaged by logging

(e) individual tree growth rates improved following cutting with the best in the lightest residual stands

(f) selection cutting which was in fact a two-cut shelterwood system provided highest stand growth rates, low mortality and best regeneration
(g) the spruce responded to release under all partial cutting treatments
(h) more intensive marking carried out under the 'selection' treatment resulted in improved quality growing stock which will provide high yield at the final felling (Lees 1964a).

Draper (1982) notes that in harvesting spruce in western Canada, single-tree selection was tried in 1949 then replaced by alternate strip cutting in 1954. These methods were again replaced by alternate-strip cutting plus scarification in 1956.

Alternate strip cutting was introduced as a supplement to single tree selection with the silvicultural aim of natural regeneration. Scarification for adequate seedbed preparation was included. Although there was adequate supply of seed, the seedling establishment and growth was problematic. Minor vegetation rapidly invades a scarified area and unless a good seed year occurs at the time of scarification, abundant natural regeneration is unlikely (Addison 1966).

In sensitive ecosystems, low-impact harvesting has become an option. In Footner Lake, Alberta, there has been an attempt to achieve a stand where mature, juvenile and seedling trees exist. To achieve this, one third of trees in a mature forest are harvested, and replanting takes place, with seedlings eventually naturally cast (Soulodre and Benedictson 1993).

In a white spruce stand in Alaska, Dyrness et al (1988) found that logging was one of the most effective treatment for regeneration. With the logging treatments, soil temperature increases were less that half those measured on clearcut and burned sites due to the remaining insulation provided by the forest floor and vegetation cover. Thinning treatment appeared to have the least impact on vegetation and soil temperatures increased only slightly.

Zasada et al (1987) found that winter logging on the Tanana River Floodplain in interior Alaska variably damaged residual white spruce stands. In fact, the study showed that winter roads of ice and snow were easily developed over a variety of surface conditions and appeared to have little lasting impact. The logging activity created two distinct snow layers - an upper layer mixed with logging debris and a lower, compacted layer that showed little evidence of being physically disturbed. The compacted layer could provide good physical protection to seedlings and protect the forest floor from disturbance. Any damage that did occur could be prevented by better harvesting methods.

In an article by Day (1970) where the expense of the shelterwood approach in subalpine Alberta is reviewed, he suggests that progressive strip cutting could provide an economically feasible alternative to the present patch-cutting system.

Glew (1963) noted that in spruce-fir forests of interior British Columbia, single tree selection failed to produce any appreciable silvicultural benefits.

7.6 SEEDING AND SPREADING OF CONES

Regeneration by seeding produced superior results in a study by Blythe (1955). Seed stratification resulted in earlier germination but had no significant effect on survival.

In studying the red squirrel response to systems in interior Alaska, squirrels moved out of clearcuts and reduced their numbers in shelterwoods and the long-term suitability of the shelterwood was determined by both the response of the squirrels to the more open stand conditions, especially the spacing of cone-bearing trees and by cone production (Wolff and Zasada 1975).

7.7 CHAPTER SUMMARY

Several different alternative regeneration systems for spruce have been presented--clearcutting, seed-tree, shelterwood, and selection approaches. Each approach allows a different method of harvesting a stand and must be applied to specific sites as specific silvicultural objectives. As the focus of this monograph is specifically the natural regeneration of white spruce, the next step is to more thoroughly examine the silvicultural prescriptions applied when regeneration is the desired result.

Chapter 8:
SPECIFIC REGENERATION-RELATED SILVICULTURAL OBJECTIVES

This chapter includes a review and discussion of specific silvicultural objectives as they relate to regeneration of white spruce. Silvicultural objectives are special silvicultural practices, such as selection and maintenance of seed trees, site preparation to reduce vegetative competition and other methods of preparation for spruce regeneration. Knowledge of regeneration under various silvicultural prescriptions can be very useful. Age, growth characteristics and origin of regeneration in both time and space must be known in order to judge the success of a particular silvicultural prescription and to predict the performance of individual trees (Blum 1973). Eleven different objectives will be reviewed and discussed, drawing particular attention to their effectiveness in promoting natural regeneration of white spruce.

8.1 PROTECTING THE WHITE SPRUCE UNDERSTORY

Mixedwoods are highly productive and are an important source of fiber to the Alberta forest industry. The conifer overstory and understory can grow in dense pure stands, clumps, or as scattered stems mixed with other species. To date, the experience of Alberta foresters indicates that mixedwood stands with a coniferous understory often revert to hardwoods after harvesting. This is due mainly to two factors. First, conventional harvesting equipment damages the white spruce understory during harvesting (Figure 8-1), and second, aspen naturally regenerates vigorously by suckering, reducing the survival and growth of conifer regeneration (Sauder 1992). An alternative to regenerating conifers through plantations is to utilize immature understory stems as the basis for future coniferous stocking. Provided that significant numbers of understory stems exist and remain undamaged after harvesting, and that these residuals are windfirm, the cost of regenerating the conifer to a free-to-grow status may be reduced. The severity of damage to understory spruce during extraction is related to the method of felling and extraction, and to the size of the equipment.

Figure 8-1: Spruce understory is frequently damaged in hardwood logging operations (Froning 1980).

Results of post-harvesting surveys indicate conventional feller-bunchers and grapple skidders protected more advanced regeneration than cut-to-length equipment. FERIC (Forest Engineering Institute of Canada) suggested that the following protective harvesting methods which could limit understory damage in mixedwood stands.

- There should be careful planning before an area is harvested. Sites with soil of a high moisture content should be cut in winter instead of summer.
- Selecting the most appropriate equipment will assist in reducing damage to spruce understory stems, and ensure that the feller equipment cuts a trail wide enough for the skidders or forwarders to minimize the number of residuals damaged on side trails.
- On-site supervision can reduce understory damage and costs and will ensure the crew clearly understands how the harvest plan will be implemented and what their participation will be (Sauder 1993).
- Modified operating techniques are required during the harvesting phase to minimize damage to understory stems.
- Crew motivation: An incentive program that emphasizes protecting understory should be considered; the program could complement the operator's existing base rate payment system.

- Training of supervisors and operators in the effectiveness of modifying harvesting operations for reducing damage to understory stems will reduce the time associated with learning new skills on the job, will provide guidance to supervisors so they understand what proportion of advance regeneration can be protected during harvesting.

- Cooperation from Other Agencies: Provincial authorities must cooperate with equipment operators, contractors and license holders when enforcing operational ground rules for utilization and ground disturbance (Sauder 1992).

Sauder and Sinclair (1991) discuss the preliminary results of a mixedwood harvesting study in central Alberta. The objectives of their study were to determine the costs, productivity, and effectiveness of using different types of harvesting equipment and systems to protect the white-spruce understory while the mature aspen and conifer overstory is harvested. Observations from studies completed to date indicate understory damage can be reduced through careful planning, supervision, equipment selection, and operational practices. Careful planning involves: matching equipment to stand conditions; incorporating work practices that are most effective in relation to the amount of supervision available; and balancing harvest costs with the benefits achieved. Individuals responsible for layout need to consider understory protection as early in the planning process as possible. Supervisors must explain to the crew what the objective of the plan is and how the plan will be carried out. A supervisor must be on site to ensure the crew understands and is achieving the desired result, and to modify the plan as required. Protection of the white spruce understory can only occur with cooperation and active involvement of all individuals: crew, supervisors, and regulatory agencies (Sauder and Sinclair 1991).

Brace and Bella (1988) identify another aspect crucial to white spruce management in regard to understory protection. The long-term supply of commercial white spruce from mixedwoods can only be maintained by successful establishment, growth and protection of regeneration. White spruce saplings occur in substantial amounts in understories in inventoried stands but current inventories do not document their amount, size or distribution. As these stands are being scheduled for harvest, information about the understory component becomes crucial to spruce management planning.

The need for protection of spruce as a component of boreal mixedwoods goes beyond concern for the future commercial softwood timber supply. Concerns also include fisheries and wildlife habitat, aesthetics and recreation, a general dissatisfaction with clear-cutting in mixedwoods and a strong interest in mixedwood perpetuation. There is clearly a need to develop new approaches to mixedwood harvesting. Further, stands with white spruce understories are an important component of the mixedwood mosaic. Current harvesting practices do not provide adequate understory protection. Recent dramatic increases in aspen utilization are resulting in the allocation of large volumes of aspen.

Brace (1991) suggests that major improvements in the protection of understory white spruce during aspen harvesting are possible using conventional logging equipment like feller-bunchers and grapple skidders in stands up to 1200 understory spruce/ha and using equipment similar to that used in Sweden shortwood systems in understory densities of 2000/ha or more. Brace (1991) identifies the key to success as *protection effort*, regardless of equipment. This protection effort includes management objectives set for all relevant resource interests at the stand level, supported by an adequate stand inventory. The stand inventory consists of the following identification and action.

- the amount and distribution of spruce understory;
- selecting equipment and harvesting patterns to match stand and site conditions;
- pre-planning and pre-locating skid trails, landings, and protective features like rub stumps in relation to understory density and distribution;
- adequate crew training and supervision; and

•acceptable spruce residuals which must be defined in management objectives, and equipment, planning, training, and supervision adapted accordingly.

There is still no consensus among forestry professionals regarding the feasibility of retaining viable spruce residuals when harvesting overstory hardwood but there is plenty of evidence in this and other trials that a favorable ruling is possible if both government and industry are *committed* to such work (Brace 1991).

Extensive studies of softwood and mixed wood forest have shown that advance regeneration is often plentiful thus a large proportion of mature stands that are presently logged could be adequately regenerated if advance growth were protected. Advance growth was found to be abundant in mature stands of coniferous and mixed stands in every cover type, except jackpine, in all ecological zones (Doucet 1988). Protection of this advance growth should not be difficult according to studies of stands clearcut in the early seventies in which there was extensive precommercial thinning (Doucet 1992).

Froning (1980) conceded with other researchers in that careful logging of hardwoods can preserve a high proportion of white spruce understory. Froning developed guidelines for this logging, which, he suggested, should be based on the percentage softwood stocking for trees less than 10 m in height and reduction of stocking should be used as a measure of logging performance. More suitable equipment could be used for felling to preserve white spruce understory. Hardwood logging in problem stands at very low temperatures should be avoided as this has proven to cause increased damage and destruction of spruce. This activity must be monitored and guidelines enforced, but common-sense practices can certainly save spruce (Figure 8-2, Figure 8-3).

Figure 8-2: High stumping along skid trails protects spruce (Froning 1980).

Figure 8-3: Tight bunching saves spruce from damage or destruction (Froning 1980).

8.2 SLASH MANAGEMENT

In the early 1970's, mechanical tree harvesting was just starting to be used as a harvesting method in northeastern spruce-fir forests. Use of these machines raised several questions about the natural ability of the cleared strips to produce a new crop of trees of the desired species. It is known that reproduction is usually present in spruce-fir stands. What was in question was, first, how much damage is done to the stocking of seedlings in the understory during the harvesting operation; and second, what happens to the surviving seedlings in their drastically changed environment. Frank and Putnam (1972) concluded that heavy slash accumulations create the least favorable site conditions for seedling survival (Figure 8-4). Until any benefits can be demonstrated from dense piles of slash, the authors recommended that heavy concentrations be avoided. They also recommended that strip widths not exceed 60 m.

Figure 8-4 : Compaction of slash in this cleared strip still evident one year after harvesting (after Frank and Putnam 1972).

Others have suggested that narrow strips, not exceeding one-half of stand height, be cleared if spruce and fir is to be favored over hardwoods. Length of strips would not be a factor in stocking of skidroads if total length does did exceed 400 m.

Another option for management of this slash accumulation is burning. Although prescribed burning may be an efficient slash disposal method, low seedling establishment rates suggest that this method is not an optimum technique for regeneration (McCaughey et al 1991).

Despite the fact that slash and pre-existing windfall are an obstacle to scarification, it should also be remembered that they provide the necessary degree of shade for successful spruce regeneration and by no means present an insurmountable obstacle to hand scarifying, which, incidentally, has the distinct advantage on some sites of preserving the existing desirable regeneration better than does tractor scarifying.

Further, to obtain reasonable breakdown of slash and pre-existing windfall, bucking will only continue to be conducted to obtain maximum contact with the ground. Lopping will also be employed for quicker breakdown of light fuel, access to logged areas and amenity purposes. Slash burning practices will probably continue only where considered essential as a fire prevention measure (Moss 1960).

8.3 PREPARING SITES FOR SPRUCE REGENERATION

The idea that some form of seedbed preparation is necessary for successful re-seeding operations has been well documented (Arnott 1973, Griffin and Carr 1973, Richardson 1973, Steill 1976, Zasada 1969, Zasada 1972). Site preparation treatments are almost essential in contributing to the success of natural regeneration, as can be observed in Figure 8-4, from a study by Quaite (1956) on the survival of white spruce seedlings resulting from scarification in a mixedwood stand.

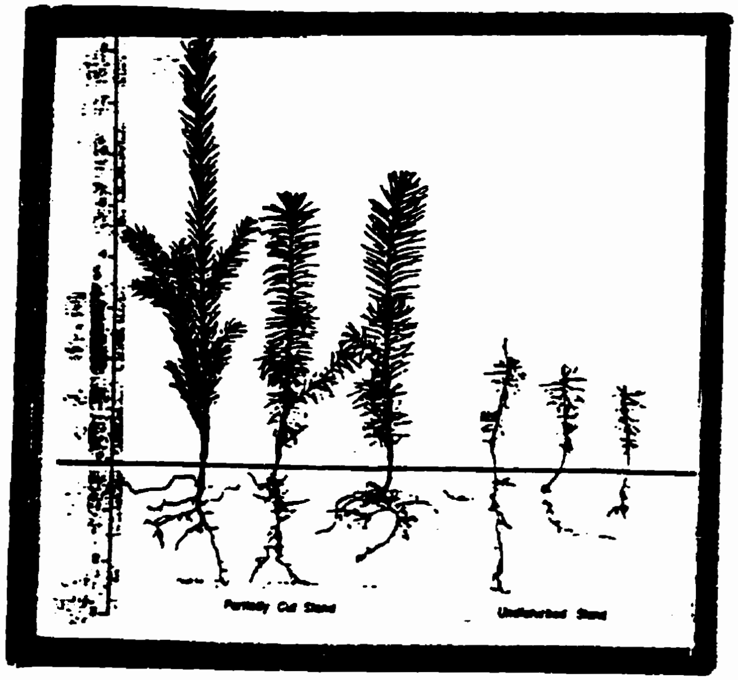

Figure 8-5: Three year old white spruce seedlings from mixedwood plots (Quaite 1956).

Regeneration of harvested areas, as of 1982, was accomplished by one or more of the following techniques (Ferdinand 1982):

- No treatment. This generally applies to areas where regeneration already exists in the form of advance growth or the site has good potential for regenerating without assistance. The latter is difficult to identify and is not significant in relation to the total program.
- Scarification and natural seeding. The seed source for this technique was seed-producing stands adjacent to cutovers for spruce.
- Scarification and artificial seeding;
- Scarification and planting;
- Planting with and without scalping

8.3.1 SITE PREPARATION TREATMENTS AND OBJECTIVES

Site preparation treatments are used in post-harvest natural regeneration or artificial regeneration systems. Objectives of the treatment vary but can include forest floor disturbance to improve survival of germinants, increasing soil temperature, improving aeration and drainage, increasing nutrient mineralization rates and physically disturbing competing vegetation. Putkisko (1980) lists the following as objectives of site preparation.

OBJECTIVES OF SITE PREPARATION (Putkisko 1980)

1. Improving the capability of seedlings to compete with other vegetation.

2. Improving the growth conditions of seedlings by adjusting the heat economy of the ground.

3. Improving the water economy of the ground in order to advance the development of young growth.

4. Changing the physical structure of the ground so that the development possibilities of the roots of seedlings improve.

5. Improving the nutritional state of the soil so that the humus layer rich in nutrients is mixed with the mineral soil.

6. Improving the light supply to seedlings.

7. Decreasing frost damages.

8. Increasing the oxygen content of growth sites.

9. Decreasing danger of insect damage.

Site preparation methods include mounding; scalping; disc trenching; mixing; and ripping/plowing, among others. When applied incorrectly or on the wrong site or ecosystem, site preparation can create unfavorable growing conditions but with proper ecosystem-based prescriptions site preparation can accomplish any or all of the following beneficial effects according to Von der Gonna (1992): the temperature in the root zone can be increased; available oxygen in the soil can be increased; the risk of frost damage can be decreased (in some cases); moisture problems, such as drying out or waterlogging, can be overcome; competing vegetation can be reduced; nutrient availability can be increased; risk of insect attack can be reduced; and planting can be made easier. Although site preparation is suitable for most sites, it should be avoided under the following three circumstances:

- dry, nutrient-poor sites - these often have coarse-textured soils and a shallow duff layer;
- naturally regenerated sites - where a new stand is established through natural regeneration from the old stand;
- small wet pockets - some sites contain small sections of wet ground that require different scarification equipment, are often quite productive, and where a decision must be made based on the total area to use a different machine or to leave untreated (Von der Gonna 1992).

Before site preparation techniques are applied, though, some preparatory action usually has to be taken in the area. For example, the regeneration site should be cleared by gathering and burning slash, lifting and removing stumps and smashing slash (Putkisto 1980). Then, a number of treatments can be applied. These include different types of scarification, ditching and burning.

8.3.2 SCARIFICATION

Clearly, the main effects of scarification or the absence of it have exerted the greatest influence to date. Unscarified ground provides few if any of the requirements of spruce seed necessary for regeneration --good moisture capacity, an absence of competition and a ready source of soluble nutrients. In a study in Yukon territory, all trials resulted in favor of scarified treatments (Gardner 1980). Stocking of white spruce is indeed improved by prompt scarification after logging (Johnstone 1976, Zasada and Grigal 1978) despite evidence in the mid-70's which contradict this evidence. In particular, small-scale scarification can enhance spruce stocking and lead to larger seedlings in later growing seasons (Zasada and Grigal 1978).

Scarifying is an old method of site preparation. In this method, patches for regeneration are removed of their humus layer via scalping the ground at predetermined spacing. Scarifying is best applied to water-soluble soils as this method applied to clayey soils can form water holes, in which seedlings cannot develop (Figure 8-6).

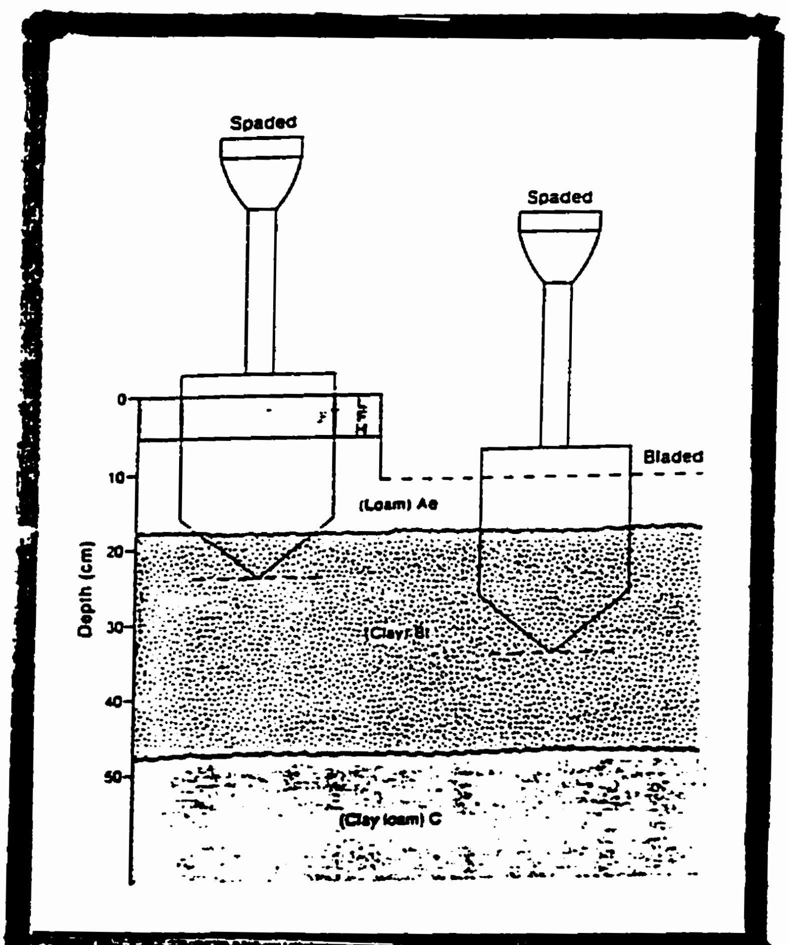

Figure 8-6: Site preparation treatments (after Ball 1990).

Scarification has been in use as early as the times of horsedrawn equipment and under certain circumstances, acquired good results. Alberta reported that 50-60% of scarified areas left to regenerate naturally white spruce did so, compared to 20-25% of non-scarified areas (Kuhnke & Brace 1986) and so scarification continues to be used as a site preparation treatment (Figure 8-7).

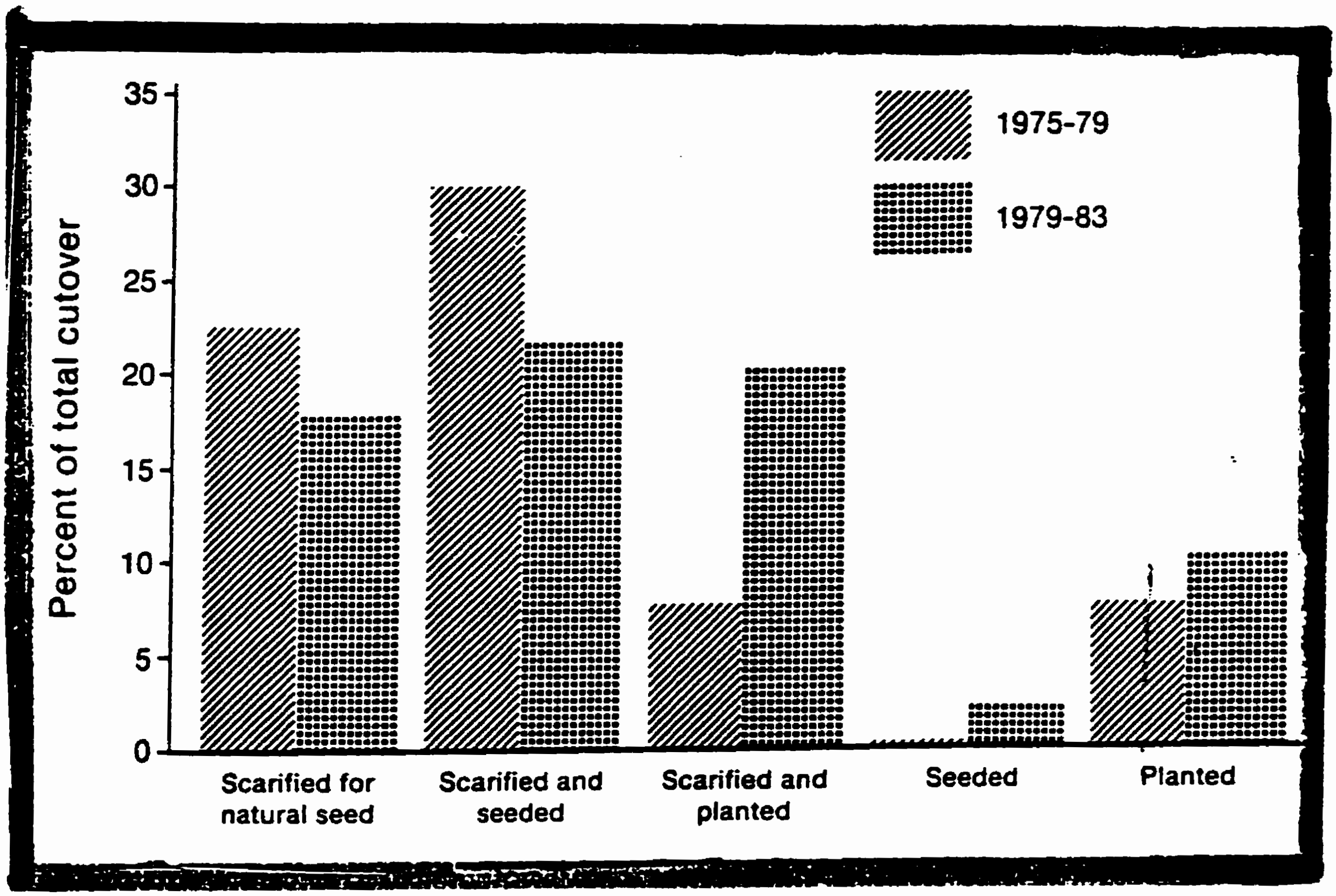

Figure 8-7: Regeneration treatments adopted in Alberta in the late 1970s and early 1980s (Drew 1988).

Presently, scarifiers are drawn by forest tractors and they automatically make two rows of patches simultaneously. Scarifiers are usually equipped with two or four 4-toothed ripping wheels, the rotation of which is stopped automatically at fixed distances with the help of hydraulic brakes. At this stage, the teeth scalp the patch to the ground and turn the humus layer into the direction of the pulling tractor. Distance between patches is adjustable.

In practice, scarification includes all degrees of mineral soil exposure, from very minimal to extreme. It is designated to improve the conditions for either planting or seeding. The exposure may be at random with considerable intermixing of organic materials, in parallel furrows, or in uniformly spaced scalps. Among the equipment currently used are: 1) diverse bulldozer blades, multiple discs, drums and anchor chains for more or less random scarification; 2) plows, rippers, and disc trenchers for scarification in furrows; and 3) various spot cultivators for scarification in scalps (Cayford et al. 1967; Cayford and Bickerstaff 1968; Hellum 1973; Richardson 1973; Rudolf 1973; Waldron 1973; Norman 1978, Cros 1980)

In 1952 a study was begun in 110-year-old spruce-aspen stands in the Mixedwood Section of Alberta to investigate scarification for white spruce regeneration before and after partial cutting to four residual stand densities: control, heavy, medium, and light. It was found that only the scarified seedbed permitted satisfactory establishment of spruce regeneration and it remained receptive for five years (Lees 1963). Regeneration establishment was not affected significantly by residual stand density or time of scarification. This agreed with earlier work by Smithers (1959) which found that up to 1956 there was no significant difference in either number of spruce germinants or percent stocking to spruce between blocks, times of scarification, or between cutting treatments. Spruce seedlings were most vigorous where the canopy was open. Good spruce seed crops are infrequent, occurring about once every seven years. As the period during which scarified ground remains receptive to seed (about 5 years) may be shorter than the intervals between adequate seed crops, scarification in partial cut stands should be synchronized with good seed years, otherwise some artificial seeding or planting may be necessary to obtain adequate regeneration. The author considered the advantages of scarification sufficient to warrant its inclusion as a standard procedure in regeneration silviculture in spruce-aspen stands (Lees 1963).

Indeed, Soos and Mueller (1970) found that low intensity scarification in Rocky Mountain House area of Alberta caused poor stocking of spruce under partially logged mixedwood stands. To achieve spruce regeneration by direct seeding, aided by scarification, the authors recommended: about 60% of the total area should be scarified to achieve 40% stocking of spruce; under partially cut stands, large patches should be scarified to delay the invasion of grasses and shrubs; where dense competing vegetation is present, deep scarification should be practiced; wet areas should not be scarified because they are not suitable for spruce seeding due to flooding mortality; where inferior young aspen stands are converted to softwoods, the whole strip should be scarified to compensate for the residual strip; and seeding should be carried out in the late fall, winter, or early spring with only high spots seeded if microtopographic conditions are not uniform.

The occurrence of natural regeneration depends on the scale and type of disturbance that initiates the regeneration cycle and on the reproductive potential of trees within or on the edge of disturbance. There are two main types of disturbance: *severe* disturbance and *releasing* disturbance. With severe disturbance, the forest stand and vegetation are destroyed. Severe disturbances favor species that store seed in the soil or dessimate their seed by wind (Weetman and Vyse 1990). Releasing disturbance refers to disturbance which kills or removes some or all of the trees in the forest canopy but does not disturb the understory vegetation.

Crossley (1955b) applied 11 different methods of scarification on the Kananaskis Forest Experimental Station, Alberta and found that all methods of soil treatment under the study proved more effective than the untouched control. The author found the following.

1. Scarification of the forest floor on a non-reproducing cutover area effectively increases its receptivity to spruce regeneration;

2. The more completely the mineral soil is bared and compacted, the better the results appear to be;

3. Soil-heaving on scarified soil is a major factor in seedling mortality during the first three years after germination, but is negligible after that time;

4. A heavy seed crop is necessary if the demands of birds, rodents and insects are to be satisfied before germination takes place, or stated another way, the most receptive seedbed had not resulted in a stand that met minimum stocking requirements (40 %) five years after germination, when its seed originated from a light seed crop;

5. The effect of treatment still remains evident in degree of seedbed receptivity five years after completion.

In summary, all methods of soil treatment under study proved more effective than the untouched control. Several of the methods satisfy even the most demanding stocking requirements, and certain degrees of improved receptivity are still evident five years after treatment. In addition it is apparent that loss of seed prior to germination is a factor of major importance, and seed crop evaluation is intimately connected with choice of seedbed treatment.

8.3.2.1 Mechanical Scarification

Kolabinski and Jarvis (1970b) found that mechanical seedbed preparation in partially cut mixedwood stands on mesic sites in the Mixedwood Forest Section will provide favorable habitats for white spruce regeneration. The catch of seedlings in any given year, however, is dependent upon the seed source available and the amount of seed produced from the previous year. The amount of regeneration obtained depends directly upon the thoroughness of the scarification and the amount of the area actually treated. Growth of regenerated white spruce is slow but is better on scarified areas than on unscarified areas.

Site preparation for regeneration on steep terrain is carried out entirely by mechanical means in Alberta. The purpose of site preparation is to improve the environment for the germinating seed or planted seedling and to reduce the slash fire hazard. Crawler tractors, in the D6-D8 size range, have been found the most suitable. Anchor chain drag scarifiers of various sizes are the first choice for most pine sites while brush rakes are generally used on spruce sites with heavy duff and logging residue. Following a properly planned and executed site preparation, satisfactory regeneration can be expected on 80-90% of the pine sites and 70-80% of the spruce sites. At the time of this article the policy for regeneration of harvested forest lands in Alberta was as follows:

- All cutovers must be regenerated to at least 790 evenly distributed, established seedlings trees per hectare of specified age and species by the end of the 10th year following harvest;
- Reforestation treatment, such as site preparation, seeding, or planting is to be completed within two years of harvest on all areas judged to require assistance in regeneration;
- Formal regeneration surveys are to be completed by the end of the 7th year after harvest for the purpose of determining the level of restocking on each individual cut block;
- Insufficiently restocked areas are to be given remedial treatment by the 8th year;
- The re-treated areas are to be regeneration surveyed again by the end of the 10th year after harvest to determine the new stocking level.

In 1949, on a sandy-textured podsol on the Kananaskis Forest Experiment Station, Alberta, an experiment was carried out by Crossley to determine the effect of mechanical disturbance of the forest floor under a mixedwood stand of poplar, spruce, and fir with a view to conversion to a coniferous stand. Surface soil scarification with a bulldozer gave pronounced increases in germination of spruce seed compared to untreated areas. Rate of survival, and size and vigor of germinants were more pronounced on scarified soil than on the control. The high rate of survival and the vigorous seedlings on the mechanically disturbed forest floor suggest it is unwise to ignore the potential ultimate stagnation of stands of such origin.

Investigations of the effects of fire and mechanical preparation of seedbeds receptive to white spruce reproduction on inadequately stocked cutovers on the Kananaskis Forest Experiment Station, Alberta, began in 1948 (Crossley 1955), with this report providing three years of data following an earlier report. Scarification of the forest floor on a non-reproducing cutover area effectively increases its receptivity to spruce regeneration. The more completely the mineral soil is bared and compacted, the better the results appear to be. Soil-heaving on scarified soil is a major factor in seedling mortality during the three years after germination, but is subsequently negligible. A heavy seed crop is necessary if demands of birds, rodents, and insects are satisfied before germination takes place. The most receptive seedbed had not resulted in a stand that met minimum stocking requirements of 40%. Crossley suggested that the poorer the seed year, the more intensive must be the soil treatment. The effect of treatment remains evident in degree of seedbed receptivity five years after completion. Losses to animals must be accounted for in regeneration assessments (Crossley 1955a).

Fire has also been used in combination with mechanical distribution. On a loamy podzol on highly calcareous parent material at the Kananaskis Forest Experiment Station, Alberta, a study was undertaken to investigate the use of fire (and of various mechanical methods in the scarification of the forest floor) in an effort to induce regeneration of white spruce on inadequately restocked cutover areas. Equipment used to scarify the forest floor included: Athens type disc-plow; Punch packer; bulldozer blade; growser plates on a crawler-type tractor; and heavy green tree trunks with long branch stubs. Initial germination was in all cases adequate and in some cases remarkably abundant. Two years later mechanical intervention wiped out the regeneration on the untouched control and reduced the numbers of seedlings on treated areas considerably. It is apparent that scarification of the forest floor on a non-reproducing cutover area effectively increases its receptivity to spruce regeneration. The more completely the mineral soil is bared, the better the results (Crossley 1952a, Crossley 1952b).

In Alberta, much of the acreage requiring treatment is scarified using D6, D7 or equivalent crawler tractors equipped with conventional or specialized blades. V-blades have become popular because they provide better mineral soil exposure and continuous non-stop scarification with minimum back-up time. On some sites, scarification is attained with D8, D9 or equivalent crawler tractors utilizing drags constructed from old crawler tractor pads (Smyth and Karaim 1972).

Alberta's usual scarification techniques are separated into five basic categories. These are strip scarification, zig-zag scarification, windrow scarification, drag scarification, and dip'n'dive scarification. With the exception of drag scarification, all methods require the use of front-mounted blades to remove surface debris, duff, and top soil. The choice of winter scarification over summer scarification to overcome the problems of poor footing and difficult access often leads to other serious problems such as deep snow and either too much or too little ground frost. In 1974, North Canadian Forest Industries Limited of Grande Prairie, Alberta, developed a sixth scarification technique involving ripper scarification. The key principles of this method are: (1) the site preparation mechanism is rear-mounted, which provides the crawler tractor continuous undisturbed logging slash for excellent footing; (2) the rear-mounted ripper gives increased machine traction and stability; (3) ripper site preparation creates less site disturbance yet produces an excellent mixed soil seedbed; (4) initial investment in this specialized equipment is very low; and (5) it is very effective and productive under winter conditions on all types of sites (Norman 1978).

8.3.2.2 Disking, Plowing, Scalping and Blading

Early trials in 1952 in Riding Mountain National Park, Manitoba showed that early survival and growth of white spruce could be improved by blading to mineral soil and disking with an Athens plow (Figure 8-8) (Waldron 1964). Further study in 1962 in the same general area showed that the physical nature of the B horizon of the heavy clay loam tills impeded root development and the cultivation would increase height growth of white spruce transplants.

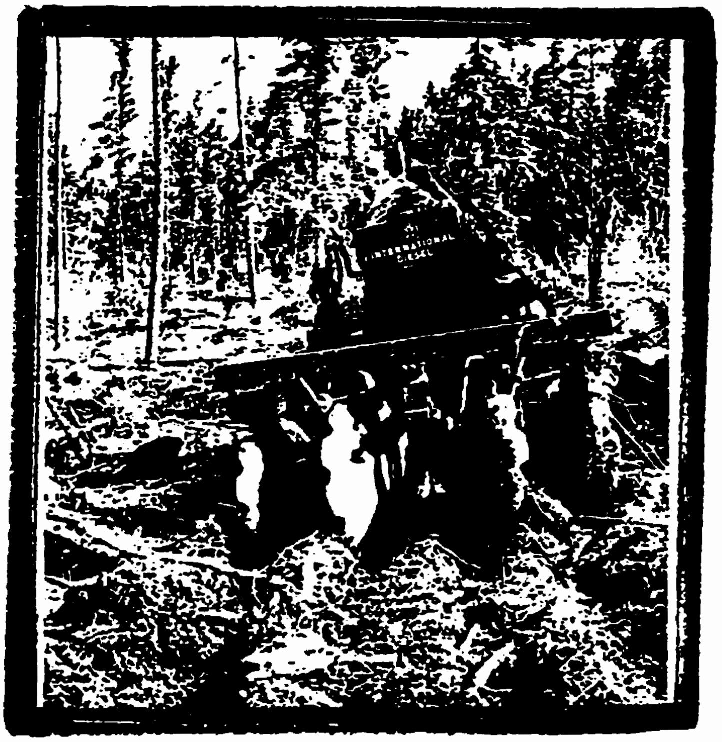

Figure 8-8: Athens disc plow drawn by tractor (Waldron 1966).

Blade scarification which scalps the organic material from the soil subsurface is a practical method of providing receptive seedbeds for the procurement of white spruce. However, heavy scalping and excessive removal of organic material reduces fertility. With treated moist and very moist sites which are prone to flooding, this treatment can create water ponding which may take these areas out of production (Kolabinski 1994).

In 1949, Phelps reported that considerable mortality of white spruce may be expected after scarification in the Riding Mountain areas, Manitoba and that competing vegetation did not appear to be a serious factor at the end of the first growing season. He also found that establishment and survival of white spruce seedlings could be improved by scarifying the litter and humus with an athens disc plow to expose mineral soil (Phelps 1947).

In the Alberta mixedwood forest, double disking has proved to be an effective site-preparation tool, controlling hardwood ingress while providing soil tillage. Tillage on the heavier-textured clay soils is very beneficial to seedling growth. Plowing, such as with the Finnish Marttinni plow, has also provided good regeneration results.

The practice of blading or scalping substantial portions of cutover areas for landings in standard tree-length logging operations may be detrimental in that blading exposes soil horizons with high bulk density, which results in decreased seedling growth (Corns 1988). Such blading in low areas can cause minor depressions prone to later flooding.

In a study by McMinn (1982), findings were that blading assists survival through long-term vegetation control; however substantial difference in growth two decades later suggests that alternative site treatments such as winter blading may be desirable. This treatment, which leaves the duff and fertile upper soil horizons would improve seedling growth (McMinn 1982). Survival could be improved by reducing competition with careful application of herbicides such as glycophosate before or after planting (Ball 1990).

Plowing is another method that is generally reserved to wet sites with a thick peat layer. The objectives of plowing are loosening of the soil, diminishing the moisture of the surface layer and raising the temperature of the soil, so it is applicable to fresh and solid or fine-textured mineral soils. The most efficient equipment for forest soil preparation is a reforestation plow. It makes a furrow 20 to 60 cm deep with an upper width of about 80 cm. The result is a bed of about 60 cm in width in which mineral soil is uncovered.

Before herbicides became registered for vegetation control in forest plantations, summer "straight blading" was often the prescribed treatment in the Mixedwood Section of the Boreal Forest Region (Rowe 1972). The scalping treatment was fairly severe, intending to get sufficiently deep to take out roots of aspen and other perennating vegetation (Ball 1990). Care in seedbed scalping to avoid excessive organic top soil removal is emphasized (Kolabinski 1994).

The density of preparation traces is dependent on the desired number of seedlings per unit area. The form of driving for soil preparation varies according to the shape of the area to be prepared. For example, roundish areas required drive around circling.

Haig (1964), in a study of silvicultural operation in white spruce-aspen stands on the Riding Mountain Forest Experimental Area in the early 60's, found that areas scalped with a bulldozer blade had a much greater average of white spruce seedlings per hectare than those undisturbed quadrats and concluded that scalping prior to partial cutting may be an effective, low-cost method of obtaining white spruce regeneration in mature mixedwood stands. Although, in years when the natural seed crop is inadequate, at least some of the newly scalped seedbed area may need to be artificially seeded.

Zasada and Wurtz (1990) attempted to maximize good spruce regeneration in Alaska by the use of conservative regeneration cuts and site preparation. They found that stocking and density of white spruce seedlings were significantly greater on scalped areas compared to unscalped seedbeds and that, unexpectedly, relatively good spruce regeneration also observed on unscalped surfaces.

Arlidge (1967) suggests that for best results, scarified areas should be seeded naturally or artificially the same year and not later than one growing season after scarification. Improved scarification to increase exposure of mineral soil is recommended.

8.3.2.3 Harrowing

Harrowing has become a more popular method of soil preparation since it prepares the soil adequately regardless of soil type. In this method, rather continuos furrows are formed and the mineral soil is thus uncovered in the bottom of them. Humus and possible slash are thrown to the side of the furrow. The most commonly found harrows are called disc trenchers. They have two or four toothed discs which are hydraulically controlled by the operator in his cabin of the pulling tractor. There are different harrows for different types of condition, including ones which create hummocks which have, in some, cases, proved the best for receptivity of seedlings Harrowing is generally applied to almost or quite dry mineral soils and on moderately stony upland vegetation.

8.3.3 DITCHING

Ditching is mainly applied to draining peatland for forest growing. The technique of draining is problematic, though. Ditches are usually created with a forest ditch plow or with an excavator equipped with a shaped bucket. Rotary ditchers may also be used.

8.3.4 BURNING

Burning is one of nature's own means to improve the regeneration conditions of forests. Fire not only improves the site for seed germination but also contributes to the return of a healthy balance of forest in the area.

8.3.4.1 Broadcast Burning

In the 1950's broadcast burning was very commonly used in preparation of regeneration areas. Soon after, the treatment was almost completely abandoned since insurance companies began refusing to offer insurance to areas to be burnt. Within recent years, fire techniques have developed greatly and controlled or prescribed burning is again a favored method of site preparation treatment (Petkisko 1980).

8.3.4.2 Prescribed Burning

Controlled burning generally covers both clearing and preparing a regeneration area and is applicable to areas with a thick raw humus layer and to stony soils, especially if there is plenty of slash or the area is damaged by certain fungi (Petkisto 1980).

Research results do not consistently support prescribed burning as a means of preparing spruce cutovers for regeneration. Germination and survival seem reduced on exposed burn areas, while growth may be somewhat enhanced. Germination delays, with consequent increased winter mortality, may also occur on burned sites (Dobbs 1972).

In interior Alaska, prescribed burning is advocated for fuel reduction and site preparation prior to the planting of white spruce (Zasada and Norum 1986). It was found that subsequent mechanical site preparation was required to provide the mineral soil exposure necessary for adequate, well-distributed regeneration from seed.

8.3.5 LIMITATIONS OF SITE PREPARATION TREATMENTS

Site preparation treatments can have negative consequences associated with them. Soil erosion, loss of nutrients through leaching or displacement, soil drying, frost heaving, and improved germination of wind-dispersed seed from competitive species are some of the limitations of these treatments. These conflicting effects lead to differences in response among different site types (Brand 1991).

Other problems are those associated by the limitations of nature. Ferdinand (1982) studied site preparation for regeneration on steep terrain in Alberta. This site preparation is carried out entirely by mechanical means, particularly crawler tractors in the D6-D8 size range. Brush rakes are generally used on spruce sites with heavy duff and logging residue. Following a properly planned and executed site preparation, satisfactory regeneration can be expected on 70-80% of the spruce sites. Drawing of site preparation equipment is possible on a side slope of 10% at the most while the uphill limit is 20%. Steeper slopes require driving downhill.

Although site preparation dramatically increases stocking and seedling density in many studies (Zasada and Grigal 1978), it created two problems for future management:

1. The density created is excessive and requires drastic precommercial thinning and/or weeding

2. The pattern is one of overly dense scarified areas alternating with less-well-stocked untreated areas. A remedy would be smaller scalped or scarified patches at closer intervals. Soil movement can also be minimized by the small size and discontinuity on the scarified surfaces.

8.4 SPRUCE RELEASE THROUGH PREPARATORY CUTS

White spruce normally grows in association with trembling aspen in the Mixedwood Forest Section (Rowe 1959) of Manitoba and Saskatchewan. Aspen usually forms the upper canopy in young and intermediate-age stands, thereby suppressing spruce and exposing it to mechanical injury (Kittredge and Gevorkiantz 1929). The growth rate of spruce is thus often impaired and its potential volume lost (Kagis 1952, Kabzems 1952, Cayford 1957, Steneker 1963, Steneker and Jarvis 1963, Lees 1966).

Almost all studies show that white spruce responds to release treatment (except Steneker 1974) in most ages and sizes. The amount of response depends on the intensity of the release cutting, with 30 to 60 year old trees having the greatest ability to increase growth for a given degree of release (Jarvis et al. 1966, Steneker 1967).

Releasing spruce from aspen overstory may provide an excellent alternative to planting spruce. A large proportion of the understory can be preserved by careful logging of hardwoods (Froning 1980). With the increased demand for aspen over the last few years, a greater incentive to manage the mixedwood forests in this manner has been created along with making release cutting more economically feasible. It is generally commonly accepted that release cutting improves the growth success and yield of spruce but response in growth and volume yield to release cuttings applied at different ages and stand conditions need to be quantified before the management implications of release cutting can be fully assessed (Yang 1989) found that release cuttings are not justified in stands having less than 250 stems/ha and stands with over 2500 stems /ha require thinning to improve spruce merchantable volume. Spruce release generally reduced mortality but mortality was dependent on tree size. Release reduced mortality for trees under 3 cm in diameter because small trees were vulnerable to suppression and browsing. Mortality of large spruce was higher in release stands due to windthrows.

Release stimulates spruce diameter at breast height and height growth more in young than in intermediate-age stands but very young trees risk being overtopped by new aspen suckers. Release is therefore recommended for stands at least 3.5 m in height or 25-30 years of age to prevent aspen sprouts and other underbrush competition (Yang 1989).

Experimental improvement cuttings to favor the white spruce component of mixedwood stands in Manitoba were first conducted by the Department of Forestry and Rural Development in 1936 (Steneker 1963). Later, between 1951 and 1954, a series of release cuttings were made in Manitoba and Saskatchewan to determine the effects of partial and complete removal of aspen upon the development of the white spruce understory. Ten-year growth results indicated that diameter and height increment of spruce can be doubled by removing the aspen canopy. This in turn, can increase merchantable volume production by spruce about 60 percent (Steneker 1967).

In Alberta, two-storied stands are typical of the spruce-aspen forest. The aspen, a vigorous pioneer species, forms the overstory for most of the natural rotation of the stands. Previous to this study, it was not known how early competition for the commercially important spruce begins, or how late the spruce will respond to release from aspen. This study indicated that release of individual spruce stems from aspen competition will be successful on all sites which were sampled and that the treatment will be widely applicable in the study region. At the time of the 10-year assessment the small (up to 1 m tall) spruce stems that were released were suffering from heavy and repeated browsing and from ground vegetation competition. It was concluded that release was effective over a wide range of ages and diameters on all sites sampled. These represent the most extensive and commonly occurring fresh to moist sites with predominantly clay loam and clay soil textures. The results agree with those of parallel release studies in Manitoba and Saskatchewan within the same forest section. It was recommended that release of spruce be carried out before spruce and aspen crowns are co-dominant (Lees 1964a, Lees 1966).

Vincent (1956) found that adequate reproduction of white spruce on cutover mixedwood sites in northeastern New Brunswick required treatment of shrubs to reduce the establishment period for the new stand by releasing the advanced reproduction which is suppressed.

Immature mixedwood stands containing white spruce occupy large areas in the mixedwood forest sections of Manitoba, Saskatchewan and Alberta. Unfortunately, the overtopped spruce often suffers severe suppression from the hardwood overstory, mainly aspen. Kagis (1952) mentioned that as a result of competition and suppression from aspen, white spruce losses are enormous. Kabzems (1952) claimed that height growth of white spruce in mixedwoods stands is always lower than that in free white spruce stands, attributing this in part to mechanical damage to spruce leaders from overtopping hardwoods. Cayford (1957) analyzed the effect of an aspen overstory on the growth of white spruce and found that in mixed stands up to 100 years of age, volume production of white spruce may be as much as 50% lower than that of nearby freegrowing white spruce of the same age. Kittredge and Gevorkiantz (1929) mentioned that white spruce may be freed from overhead suppression when the hardwood stand component starts to deteriorate, but at this time white spruce has often already been severely damaged and suppressed.

Releasing disturbance kills or removes some or all of the trees in the forest canopy but does not disturb the understory vegetation. Releasing disturbances generally favor species that germinate under shady conditions (Weetman and Vyse 1990).

In 1936, Steneker carried out an experimental cutting to release spruce in a 50-year old spruce-aspen stand. Results to 1957 revealed that the total volume of white spruce on the treated plots was almost double that on the control. Light and heavy release cutting resulted in board foot volumes of white spruce that were double and triple respectively that of the control plot (Steneker 1963).

The report of Crossley (1976) indicates that stems that are below merchantable size in climax spruce/fir stands in Alberta are generally of advanced age and are the result of long periods of suppression, based on a study (in the tenth year after felling) of the response to release of residual black and white spruce and alpine fir trees in a climax stand in west central Alberta. Data on the immediate and sustained response to release suggest that these residual trees may be regarded as established regeneration, and can eventually be harvested at the same time as the new incoming regeneration (Figure 8-8) (Crossley 1976).

McAughey and Schmidt (1982) describe release of advance regeneration of spruce and fir in even-aged (clear-cuts) and uneven-aged (partial cuts) management systems in Utah, Idaho, and Wyoming. Both spruce and fir responded by substantially increasing their height growth after adjusting to the residual overwood; growth response was greatest in clearcuts, intermediate in partial cuts, and zero in the uncut areas. Trees on clearcuts grew an average of nearly four times faster during the 6- to 10-year period, whereas before release spruce and fir height growth was about the same on all areas. Fir responded sooner than spruce on both partial cuts and clearcuts.

Figure 8-9: Originally suppressed residuals 10 years after harvest (Crossley 1976).

8.4.1 ADVANTAGES AND DISADVANTAGES

Advantages and disadvantages of using advance regeneration (McAughey and Schmidt 1982) for at least part of a new stand after harvest cutting can be summarized as follows.

ADVANTAGES

1. Serves as immediate growing stock; provides shade for supplemental natural and artificial regeneration;

2. May provide continuity of forest for wildlife and aesthetics objectives; some forest cover provides soil protection;

3. Time needed for merchantable trees is reduced; reduces amount of site preparation needed; and

4. Species diversity may be enhanced.

DISADVANTAGES

1. Logging damage to advance regeneration predisposes it to disease problems;

2. The predominant advance regeneration (fir) has more disease and insect problems and less management potential than spruce;

3. Advance regeneration is already physically older and thus prone to insect and diseases associated with age;

4. Encourages dysgenic practices;

5. May be inappropriately relied upon on sites needing more intensive management;

6. Harvesting costs are increased by a need to protect advance regeneration; and

7. Site preparation for subsequent regeneration is more difficult.

Logan (1953) described a mixedwood stand in which an improvement cut was carried out in a 45-year old stand in 1926. During a 1952 re-measurement cut, compared to an untreated control area, there was better stocking of well-established spruce.

In 1949 balsam fir and white spruce in northwestern New Brunswick were released by cutting the shrubs in or overhanging a circle of 1 m radius about each stem. An adjacent 0.4 ha plot was used as the control. The two plots were located in a former softwood stand which had been clearcut in 1941 for pulpwood. This study showed that fir and spruce respond remarkably well to release from shrub competition. The technique used to release the trees is too costly for practical application, but it should be noted that the increased rate of height growth continued even after the shrubs had closed in again (Baskerville 1961). It seems unnecessary to totally destroy the shrubs but only to remove competition by killing the tops back for about four years. This permits the softwoods to increase their height growth and soon rise above the competition (Baskerville 1959).

8.5 SELECTION AND MAINTENANCE OF SEED TREES

This is the technique normally used for natural regeneration--to leave a few seed trees after final felling. These trees are normally storm-resistant trees with full crowns providing an adequate supply of cones. Because spruce roots generally provide poor anchorage, this method is usually only practiced around stand edges and in gaps but may also be successful under a fairly dense shelter of trees which retain basic stand characteristics (Bergman 1981).

The chances of obtaining success from natural regeneration from seeds depends on seed abundance, seed quality and the general regeneration receptivity of the soil. These factors are in turn influenced by habitat climate, habitat geology and habitat water (Bergman 1981).

Areas with high summer temperature and a long growing season will produce more high-quality cones and seeds. Two successive summers with warm weather is a prerequisite for natural-regeneration success -one summer when the flower buds are initiated and one when the seeds ripen. When new spruce are established, the seed trees must be removed. If this is not done, the parent trees will eventually give heavy competition for water and nutrients leading to uneven stocking of the natural regeneration. If the regeneration area is carefully inventoried and the seed trees cut down as soon as stocking is adequate, this can be avoided. In areas where both climate and soils are suitable, natural regeneration can create perfectly adequate regeneration and viable new stands (Bergman 1981).

8.6 PROMOTION OF SEED PRODUCTION

Spruce seed volume is largely determined by temperature conditions the year before flowering. The quality of seed is determined by temperatures during the summer and autumn when seeds ripen (Bergman 1981).

Three to five ramets were selected from each of five white spruce clones for this study. Seed cones (megastrobili) were pollinated once and some were sampled at the different stages of development to study the pollination mechanism, seed-cone receptivity, and seed production potential. The proximal end of a seed cone emerged from the bud scales and was the area to be receptive first. As the seed cones continued to develop, the margins of the cone scales became reflexed to increase the surface area and to funnel pollen along the margins of two adjacent scales onto the micropylar arms. Pollen was transferred to a deep depression in the nucleus and it germinated in the depression a week after pollination. Another week later the micropyle was sealed by the ingrowth and divisions of the cells in the micropylar canal. Receptivity of the seed cone lasted for about 10 days and the end of receptivity was signaled by the closure of cone scales. The optimal receptivity appeared to occur when seed cones approached the end of receptivity and this coincided with the peak of pollen shedding. It was evident that seed cones pollinated at this stage produced the most filled seeds, an average of 41.6 from a seed production potential of 88 seeds per cone. Total cone scales averaged 67.7 per cone, of which 43.6 scales were fertile, mainly in the mid-portion of a cone (Ho 1984).

Repeated pollinations with brush had very little effect on the production of filled seed, and pollen from the first pollination was the most likely to accomplish fertilization in white spruce. Therefore, one good pollination may be sufficient for a seed cone at its peak of receptivity and contamination as a result of the opening of bags for pollination may not be a major problem because of the first-come, first-served effect (Ho 1985).

8.7 SEED COLLECTION, HANDLING AND PROTECTION

Seed maturity depends to a great extent upon the environment under which the seeds develop. Little attention has been paid to this well-known relationship. A quantitative measure of the progress of the ripening season can be obtained from a computation of average daily temperatures and degree-day summations. Studies with white spruce in Alaska have shown that degree-day summations are potentially more reliable indicators of seed maturity than calendar date. Until recently, almost all investigations have tended to concentrate on the fruits/seeds themselves, paying little or no attention to the climate in which seed development occurs. Few efforts have been made to directly relate summer weather and seed ripeness in a quantitative manner, although it has long been understood in a general way that ripening progressed more fully if the climate were warmer and drier than if it were cooler and more moist. Although still relatively crude, summation of degree-days over and above a given minimum temperature threshold have been shown to be a means of assessing maturation. Refinements based on other weather variables, such as radiation and precipitation, have yet to be made. Estimations based on such environmental parameters may be more universally applicable than fruit and seed parameters, which implies that they could produce more consistent and reproducible results. There appears to be a critical stage in the development of a fruit: if the fruit is removed from the parent plant before this stage has been reached, the seeds contained within the fruit fail to mature, regardless of how the fruit is subsequently handled (Edwards 1980).

White, black, and Engelmann spruce were included in this review of methods to predict the size of cone crops and seed yields. Predictions can be made at three main stages in the reproductive cycle: (1) the crop year before flowering; (2) the early spring of the crop year, and (3) after flowering, when conelets are visible. Predictions in the crop year before flowering are the most complex, since they are based on factors influencing the initiation of reproductive structures and their development. The period between good seed crops varies within and among species. The phenomenon of fluctuating cone production is due to the developing crop having a negative effect on the subsequent year's crop. The authors indicate that white and black spruce are among those tree species in which seed production increases following a warm, dry summer. For predictions in early spring of the crop year, after bud burst, potential seed crops can be estimated from the abundance of developing strobili. However, cold weather may cause pollen cone drop in white spruce and rain may damage the quantity and viability of white spruce pollen. Predictions of the seed crop when the developing cones are visible on the trees are the easiest to use and most accurate. When rating a crop, attention has to be confined to that portion of the crown expected to bear cones. For white and Engelmann spruce this means the upper two-thirds of the crown. Two common errors made in rating cone crops are counting old cones that have shed their seeds and evaluating roadside trees which, because of their increased exposure to sunlight, often bear a heavier crop than trees further in the stand. Decisions on whether to collect a crop should be based on the amount of sound seeds forming in the cones. In many species, cones will develop without pollination but no seeds will be produced so an inspection of the developing seeds is essential. Abundant pollen is required for a good seed set regardless of female strobilus production. Heavy male and female flowering usually occur in the same year and this is reflected in a higher yield of sound seeds. Good seeds may be found in relatively small areas even in poor years, but these crops should be carefully inspected before collections are undertaken (Edwards 1985).

In the spring of 1963 an experiment was initiated to find ways of predicting seed crops of white and black spruce in the interior of British Columbia. Morphology and anatomy of the buds were studied. Initiation of reproductive buds of both species started in late July. By late August, reproductive buds of white spruce and male buds of black spruce could be distinguished macroscopically by their size and shape. Without dissection it was difficult to distinguish between white spruce male and female buds and between black spruce female and vegetative buds in the fall. Using information gained from investigation of bud morphology, a failure or a poor cone crop may be forecast accurately. High frequency of reproductive buds indicates only a potential seed crop as adverse conditions during the following year may unfavorably affect the developing cones or seeds. However, once the buds have formed in fall, though the number of cones may be reduced considerably, a complete seed failure is improbable, because of environmental and phenological variation amongst trees and stands (Eis 1967a).

Interior spruces are sporadic cone producers; good crops occur about once in six years, with usually one or two light crops in between. Cone production starts around 40 years of age. Pollination lasts about 8 to 10 days between the end of May and the end of June. At pollination time, the seed cone stands erect. After pollination, the female cones become pendant and turn green. Fertilization takes place about 4 weeks after pollination. Cones reach their full size by the beginning of August. Most seed dispersal takes place in September but in some years seed is still available for dispersal on the snow in winter. There are 8-20 seeds per cone, and white spruce has 300,000 to 900,000 seeds/kg while Engelmann spruce yields 250,000 to 700,00 seeds/kg (Eis and Craigdallie 1981).

In September preceding the seed year, reproductive buds of white spruce can be recognized with the naked eye. The numbers of ovulate buds are a good indication of the prospective cone crop. A method of sequential sampling on a small number of trees, which enables a prediction of cone crop potential on a stand or regional basis, is presented. This advance information facilitates planning of seedbed preparation for natural regeneration, seed collection and artificial reforestation (Eis and Inkster 1972).

The increased demand for seed for use in reforestation in Newfoundland has focused attention on increasing the productivity of programs of seed collection. One method is to begin harvesting cones early to reduce losses to predators. Various dates of collection were examined for black spruce, white spruce, and tamarack. White spruce seed matured the earliest of the three. For Newfoundland, recommended cone collection dates are 20 August for white spruce and tamarack and 30 August for black spruce. Early collections will reduce cone losses to squirrels and prevent seed losses from natural seed dissemination (Curran et al. 1987).

Of the 40 or more species of spruce, eight are native to North America and four grow in British Columbia. White and Engelmann spruce are similar species, especially in cone production characteristics, and are known to hybridize over a considerable portion of their range. For this reason, they are often referred to collectively as "interior spruce". Problems in achieving prompt natural regeneration of interior spruce have been encountered. In view of this difficulty, and the broad distribution of the species, seedling production has increased and interior spruce now represents a major component of the reforestation program. For these hybrids, pollination occurs in mid-May to early June; cones are ripe from mid-August to early September of the same year. Cones are ready for collection when seed coats and wings have become golden-brown, the endosperm tissue is firm, and the yellow-green embryos have elongated to 75% of their potential length. In black spruce, pollination occurs in mid-June and cones mature in early September of the same year. Cones are persistent and semi-serotinous; viable seeds are shed slowly over a period of about 4 years. Although this semi-serotinous habit ensures an almost constant seed supply, it is best to collect shortly after the cones mature (Dobbs et al. 1976).

With regard to cone collection and specific methods for collecting and handling cones of British Columbia conifers, there is also a generalized account of cone and seed crop development, not specific to particular coniferous species. For white and Engelmann spruce, considered jointly as interior spruce, seed production is summarized as follows.

Table 3: Summarization of seed production for white and Engelmann spruce (after Eremko 1989).

Reproductive cycle	2 years
Cone length (cm)	3-6
Cone bearing age (collectible quantities)	40 years
Cones/hectolitre	10,000
Periodicity of good crops	6 years
Viable seeds/hectolitre of cones	347,163
Position of cones in crown	Top 1/3
Ease of cone detachment	Moderate
Plantable trees/hectolitre of cones:	
Bareroot	84,000
Container	73,000

Recommended collection standards are:

Filled seeds/half-cone	7
Cone color	Lustrous light brown
Storage tissue	Opaque, firm and resembling coconut meat
Seedcoat	Glossy, pale to dark brown
Seedwing	Light brown, with a dark stripe along one edge
Embryo	Should occupy 90% of the cavity; yellowish; firm
Cleanliness	Less than 5% debris and unacceptable cones

Insects and diseases affecting spruce cone and seed production are:

- Insects
  - Coneworm
  - Seed chalcid
  - Spruce cone axis midge
  - Spiral spruce cone borer
  - Spruce seed midge
  - Spruce seedworm
- Diseases
  - Inland spruce cone rust
  - Seed fungus or cold fungus

8.8 SITE PREPARATION TO PROVIDE SEEDBEDS AND TO COUNTERACT ADVERSE MICROSITE CONDITIONS

Seedling loss appears to depend on the nature of the seedbed. On scarified areas the greatest mortality is due to soil heaving from spring frosts. It is suggested that heaving loss can be expected for a period of 3 to 4 years after scarification treatment. With regeneration so prolific, perhaps such thinning is beneficial. However, mortality on mounded and untreated or control areas cannot be attributed to soil heaving and may be a result of competition from surrounding vegetation (Crossley 1952b).

Because site preparation can alleviate low soil temperature, a major climatic constraint on successful forest renewal in boreal and subboreal spruce zones, connections between climate and white spruce seedling performance should form a basis in site preparation practice (McMinn and Herring 1986). In particular, Dobbs and McMinn (1977) have mentioned the potentially beneficial effects of site preparation on soil temperature regimes with results indicating that increased soil temperatures within the rooting zone occur after mechanical site preparation and persist at least through the subsequent summer.

Corns (1988) examined soils developed on four parent materials (glaciolacustrine clay, clay loam till, coarse fluvial, and loamy eolian) in west-central Alberta to determine residual effects of logging and use of site-preparation equipment upon soil bulk density. Lodgepole pine and white spruce seedlings were grown on the four soils compacted in the laboratory to three bulk densities approximating the following field conditions: (1) those observed or expected immediately following logging and site preparation; (2) those observed 5-10 years after logging and site preparation; and (3) undisturbed control. In most cases, significant reduction in nine expressions of seedling growth (maximum root depth, maximum root depth in soil core, total weight, shoot weight, root weight, stem diameter, shoot height, seedling survival, and shoot weight:root weight ratio) was observed with increased bulk density.

The beneficial effects of mineral soil exposure are well-defined by Baker (1950): " The infiltration capacity and aeration is good yet the soil packs well around the seed, which thus secures close contact with films of moisture. The soil has good heat conducting capacity and will warm up faster than the loose organic horizons. There is no great resistance to the process of germination".

Although white spruce is generally considered a difficult species to regenerate and successful regeneration of this species is considered to require a mineral soil seedbed usually provided by scarification, some evidence suggests that scarification may not be necessary for sufficient stocking under certain conditions. Wurtz and Zasada (1987) found that if a large seed crop is imminent and if the dimensions of the harvested area are small, scarification may actually result in such dense stands that it is detrimental to seedling growth. As well, such formidable seedbeds are unfortunately ideal for the seedling success of spruce's main woody competitors. Evidently, however, the unexpected result that spruce also did well on unscarified surfaces was most likely due to the small dimensions of harvested units and the large seed crop.

8.9 SITE PREPARATION TO REDUCE VEGETATIVE COMPETITION

Lees (1964a) observed that scarified seedbed receptivity to natural white spruce seedfall was reserved to two growing seasons by vegetative competition in low lying grassy areas of high moisture regime status. He identified that in scarification operations in the Boreal Mixedwood, such areas should be avoided unless larger scarified plots can be created.

Litter depth is also an issue. Phelps (1948) reported that in his study of seedling success in plots in Manitoba and Saskatchewan, in undisturbed stands the number of seedlings decreased as the depth of the litter increased.

In Alberta, however, proper establishment of seedlings required a seedbed layer which will stay free of competition for up to four years. In Alberta, moist spruce site types are found on fine-textured soils with a duff layer typically 10-15 cm deep. This type is associated with alder, grass, high-bush cranberry and various feather mosses. Soils are usually moderately well drained. Proper establishment of seedlings requires a seedbed which will stay free of competition for up to 4 years. Bottomland areas require more severe scarification than uplands and should be prepared with planting rather than seeding in mind. Results will be good with proper seeding and good scarification coverage. Failure may be due to poor coverage, poor quality seed, inadequate seeding, or flooding. Wet spruce sites are found on fine textured and/or organic soils with a heavy duff layer (greater than 20 cm). These sites are associated with alder, black spruce, willow, and birch. These areas can only be scarified in the winter because of poor drainage the rest of the year. After logging there is usually heavy growth of reed grass or blue joint grass. To prepare for planting, remove as much duff as possible by scarifying. Scarify in the direction of ground water flow to allow for surface drainage of excess water. Success should result when careful planting, proper seedling size, and a well prepared site are combined. Failure could be caused by flooding and competition. The moist spruce-aspen type is most often found with medium duff (10-15 cm) on fine-textured soils and is associated with alder, birch, poplar, and low- and high-bush cranberry. Grass and herbs offer heavy competition after cutting. Residual aspen provides shade for spruce seedlings and if the residual is knocked down, profuse suckering will result causing serious competition to the seedlings as well as impeding mobility increasing treatment costs. Good coverage and adequate seed will provide success. Failure may result from poor scarification, poor or insufficient seed, climate, leaf smother, and flooding in very low areas (Alberta Forest Service 1977).

Furthermore, spruce regeneration was surveyed 11 growing seasons after scarification west of Sundre, Alberta. Mechanical scarification was not an effective means of augmenting reproduction on a logged-over alluvial flat which had thin sandy loam soil overlying gravel. Declining stock percentages showed that spruce seedlings had died during the last seven years, and preceding the survey not enough new regeneration had become established to offset the mortality. Heavy reinvasion of vegetation in the years immediately following scarification may have caused poor initial growth of spruce regeneration on mineral soil, but the lack of soil moisture and the exposure of nutrient-poor layers of the soil were thought to be more serious causes of scarce regeneration and poor seedling growth (Day 1963a).

8.10 VEGETATION MANAGEMENT AND THE ROLE OF HERBICIDES

Selective use of herbicides has shown to be effective in controlling hardwood ingress, stimulating rapid early growth on planted spruce (Drew 1988).

Planting in the rough without some form of site preparation has been correlated with poor seedling performance in operational plantations in the prairie provinces; the consequences of which are usually dense vegetative competition with associated high mortality (Froning 1972).

Forest managers are under increasing pressure to decrease herbicide use throughout North America. Forest managers must attain a greater knowledge of how to minimize vegetation management problems in young stands if herbicide use is to be reduced. Silvicultural activities--their type, intensity, timing, and frequency--interact with the autecological characteristics of forest weeds to affect their survival and subsequent invasion. When these characteristics are not considered, release treatments are then required to remove or suppress forest weeds. If silvicultural activities are modified based on an analysis of site conditions and an understanding of plant ecology, vegetation management can be more of a preventative measure, thus reducing dependence on herbicides for stand tending (Wagner and Zasada 1991). Although not specifically related to white spruce, this review provides an important ecological perspective for the forest manager. As vegetation management is most often directed at reducing competition by removing or suppressing forest weeds, it also is important to consider the potential role of non-crop vegetation in the forest ecosystem. The beneficial aspects of non-crop vegetation that should be considered in vegetation management prescriptions for conifer production include:

- Preventing soil erosion on disturbed or unstable sites.
- Uptake, storage, and recycling of nutrients that might otherwise be lost from the ecosystem.
- Improvement of soil physical and chemical properties through the addition of organic matter and nutrients.
- Improvement of excessively hot, dry, or cold microclimatic conditions through shade or mulching effects.
- Protection of tree seedlings from browsing animals.
- Reduction or elimination of diseases in desired tree species.

Not all forest sites develop weed problems to the same degree. Also, weed development on some sites occurs sooner, following harvest, than on others. Near Prince George, British Columbia, mesic ecosystem associations rarely presented problems before the seventh growing season, whereas on moist, rich sites, prompt shrub development resulted in serious weed competition problems by the third growing season. Weed control predictions should be made prior to site disturbance. If one ignores prediction and waits to see if weed problems develop, before the necessary corrective action can be taken it may be too late to do any good. Weeds are known to affect tree seedlings in at least five ways. They compete for site moisture and nutrition, reduce light reception, change the temperature regime around the seedling, as well as cause physical stress by crushing. Unfortunately very little research information is available on the effects of weeds on seedlings in the field environment. The effect of weed shading on spruce growth is a good example; light interception by weeds may have more impact on spruce seedling performance than commonly thought. Identification of seedling stress symptoms is based on needle color, height growth, and stem form as well as a silviculturist's inherent ability to tell whether a seedling is healthy or unhealthy. One can usually tell when a seedling is under serious stress. However, there is considerably more difficulty in detecting subtle competition symptoms. The greatest need for research in silvicultural weed control lies in the investigation of basic seedling growth processes under weed competition stress (Herring 1985).

In British Columbia's Boreal White and Black Spruce Biogeoclimatic Zone, the author noted that white spruce displayed an immediate growth response to brushing and weeding during the second growing season. Brushing and weeding resulted in a 30% improvement in seedling diameter growth whereas height growth was unaffected. The growth improvements associated with soil cultivation are most likely attributable to treatment effects on vegetation competition levels and soil temperatures (Herring 1989).

Moss (1993) stresses that many concerned citizens view harvesting and silvicultural practices as unnatural and therefore destructive of valuable parts of the system. To support their case, they use the example of the effects of herbicides on willow, and the subsequent effects of sickly or dead willow on moose. Some citizens also criticize the broad scale reduction of aspen, a naturally occurring species which they believe has much to offer wildlife. It is thus necessary to come to a consensus as to whether foresters are being asked to provide a defense of herbicides or whether or not sustainable forestry is being practiced (Moss 1993).

White spruce may be managed by weed killers during the early part of the growing season, but in a study in Lower Michigan, herbicides were used to control brush without damage to the spruce (Arend 1955).

The Quebec Ministry of Forests proposed a forest protection strategy minimizing the use of chemicals (mainly pesticides). The strategy places emphasis on natural regeneration in relation to the major forest types in Quebec. The main objective of the strategy is to protect the forest and its environment with better management methods, while achieving sustained yield (Doucet 1992).

Herbicides have also been used to control hazel in Riding Mountain Experimental Area, MB and subsequently release white spruce. Treatment of aqueous solutions of 2,4-D, 2,4,5-T, ammate or 50-50 mixture of 2,4-D and 2,4,5-T produced a fairly complete kill of hazel and resulted in an increased growth rate of natural white spruce reproduction and it is believed that most of the white spruce which were released will not again be overtopped by hazel (Waldron 1959b).

8.11 BIODIVERSITY AND WILDLIFE HABITAT ASPECTS OF SPRUCE REGENERATION

A heavy seed crop is necessary if demands of birds, rodents, and insects are satisfied before germination takes place. The most receptive seedbed had not resulted in a stand that met minimum stocking requirements of 40%. The author suggested that the poorer the seed year, the more intensive must be the soil treatment. The effect of treatment remains evident in degree of seedbed receptivity five years after completion. Losses to animals must be accounted for in regeneration assessments (Crossley 1955a).

8.12 CHAPTER SUMMARY

There are many different silvicultural prescriptions aimed specifically at regeneration of spruce. Some of these objectives are highly successful in promoting regeneration while others are not. Factors behind this include various features of stand development in boreal mixedwoods which affect the natural regeneration of white spruce.

Chapter 9:
FEATURES OF BOREAL MIXEDWOOD STAND DEVELOPMENT THAT INFLUENCE NATURAL REGENERATION OF WHITE SPRUCE

Along with the ecology of the white spruce and associated environmental factors which influence its natural regeneration capabilities are several features of its main habitat, the mixedwood forest, which affect natural regeneration of white spruce. Fire, successional influences, natural stand characteristics and origins, and wildlife population fluctuation influences are examined in detail to determine their effect on natural regeneration of white spruce.

9.1 NATURAL STAND ORIGINS

There are few influences regarding natural stand origins which significantly effect the natural regeneration of white spruce. However, it should be noted that prolific species such as paper birch and gray birch can produce large quantities of seed. This could hinder the development of a subsequent stand of softwood species (Frank and Safford 1968).

9.2 FIRE AND OTHER DISTURBANCES

9.2.1 NATURAL FIRE

Since fire is the method through which nature has long maintained the boreal forest, ample reforestation generally follows. Fire tends to favor species such as pine and aspen with spruce developing an understory which eventually takes over the canopy (Nyland 1977). Van Wagner (1983) reiterates that none of the common Canadian boreal tree species (conifer or hardwood) will germinate or survive well except on burned or bared surfaces. There are several immediate physical effects of fire listed below.

- Fire kills all or some of the overhead canopy.
- There is removal of all or some of the soil's organic layer.
- There is some control over minor vegetation.

White spruce regeneration requires one or more of these physical effects, and thus fire is advantageous. One of the most important physical effects of fire for regeneration in the northern upland forest is its influence on the seedbed. Van Wagner (1983) suggests that the northern limit of tree distribution (tree line) may simply be the latitude at which fires fail to produce appreciable mineral seedbed. The first factor coming into play with distance north may be the failure of the organic layer to dry enough to burn. This expands on the widely accepted idea that there is a direct climatic limitation on growth or winter survival. Regardless, it seems that most fires are followed by a forest not unlike the original one (Van Wagner 1983).

In a study of regeneration after forest fires east of Prince George, B.C., reproduction was found to be unsatisfactory due to the delayed regeneration on the poor seedbeds which resulted from hot fires (Garman 1929). The density and species of the reproduction were often found to be governed by soil-moisture conditions after fire and by the abundance of the seed produced during seasons adjacent the year when a burn occurred. There was no correlation between the degree of stocking and the age of a burn. Reproduction was not established on exposed mineral soil on severe burns subject to excessive evaporation, or under dense herbaceous and shrubby vegetation sometimes found on good soils (Garman 1929).

In northern Alberta, northern British Columbia and Alaska, fire is an integral feature as shown by the ubiquitous presence of charcoal in the upper soil horizons and the widely distributed boreal broadleaf trees and conifers well-adapted to fire. White spruce becomes increasingly prominent on forest stands from the moist east to the drier northwest boreal region. White spruce is a 'weedy' species like other boreal conifers and is dependent on small, prolifically-produced seed for migration and on a minimum of competition for early survival. Although seed is scattered in autumn, a small proportion is held in cones and shed during the winter, spring and summer. This may explain the sometimes unexpected regeneration of the species following summer fires (Rowe 1970).

Severity of fire has an important bearing on the success or failure of spruce regeneration. Light surface burns, such as occur in early spring when the subsurface humus is wet, do not provide suitable conditions for spruce seedling survival. Severe fires which consume the humus layer totally are much more effective in eliminating competition as most forest plants have their perennating parts on the organic horizon. The exposed or thinly covered mineral soil then provides a suitable seedbed for spruce germination and seedling survival. The prerequisite for severe fire, a deep accumulation of fine, dry fuel, is found more often under spruce than under broadleaf trees. Therefore, in mixed stands, there is a tendency for severe burning under spruce and light burning under aspen, so that spruce seedlings tend to reappear in the former and aspen suckers in the latter locations. In northwestern Canada, there is evidence that many succeeding spruce stands originated after fire and, more specifically, fire followed by alluvial deposits.

Seedling survival is also found to be better on burned areas. Phelps (1948) states that on lands that had been burned 6 to 21 years before seeding success was surveyed, survival of seedlings was somewhat better than on cutover areas. On burned areas, mixedwood types (conifer content 26 to 75%) had the greatest number of plots with white spruce reproduction, compared to hardwood and softwood stands. There was no definite relationship between numbers of seedlings and numbers of years since disturbance.

Forest fires have similar effects as shelterwood and seed tree methods in the manner of selecting trees for regeneration. After fires, the biggest trees are most likely to remain alive and contribute progeny to the next generation.

Rowe (1970) hypothesized that fire removes the stand and prepares the area but spruce regeneration is not accomplished until a flood provides the mineral soil substrate.

9.2.2 PRESCRIBED BURNING

The use of burning for silvicultural purposes is proving to be of considerable value. Controlled burning was introduced to Saskatchewan in 1970 as an optional treatment testing its postcut uses in reduction of slash fire hazard and preparation of sites for either planting or seeding a number of conifers. A controlled burn usually burns the slash, the aerial parts of vegetation, surface moss and litter and, depending on site and weather, varying quantities of the underlying mor or peat. Organic materials remaining after the fire normally include charred stumps and other large pieces of wood, partially burned peat and unburned plant roots in such peat. These conditions are usually adequate for planting softwoods, and if the fire burns deep enough into the peat, they can be favorable also for the reproduction of softwood by seeding. Thus, this may suggest that natural regeneration or natural regeneration success may occur on these types of sites following fire.

Jarvis (1966) found that for successful regeneration, fire must be severe enough to expose mineral soil, suitable seedbed type for the germination and survival of white spruce seedlings. However, *complete* burning of the forest floor materials is neither required nor desirable. The best fire-produced seedbeds on moderately dry to moderately moist upland sites are in those situations where exposed mineral soil and thin residual peat alternate, and both have uniform distribution. Deeper mors and lowland peats, which normally occur on moist to very moist sites, become favorable seedbeds as soon as the fire burns off the loose, surface moss and litter. Means of selecting the proper conditions for burning the desired amounts of mor or peat are already available (Chrosciewicz 1959, 1967, 1968, 1974, 1976, 1978a, 1978b, 1978c). It is likely that operational burning with subsequent planting or seeding will find their primary applications on those non-reproducing areas that are for some reason totally devoid of natural sources of conifer seeds. Unstocked or poorly stocked older cutovers and burns and areas requiring radical sanitation, as in cases of mistletoe infestation would also qualify (Chrosciewicz 1988).

In general, light surface fires produce unsatisfactory conditions for spruce reproduction because they stimulate renewed growth of competing herbs, shrubs and hardwood trees. It was once thought that all seed was shed in fall and winter soon after cones ripened, but a small amount is regularly retained on the trees in a small number of cones until the following season. This persistent seed source may have considerable significance for regeneration following spring and summer fires. Several ground fires which burn away the humus layer favor establishment of spruce by simultaneously destroying competing plants and baring a mineral soil seedbed. In mixed stands, it has been observed that ground fires often burn away all humus under spruce while only lightly burning the surface under adjacent aspen, and thus spruce regeneration is favored where spruce grew before, just as aspen is favored where it formerly existed (Rowe 1956).

Hosie (1947) found that severe fires favor spruce reproduction whereas light fires favor coppice and sucker growth of hardwoods. Severe fires reduce the humus to a fine texture and kill the roots of hardwoods, producing adequate environmental conditions for spruce regeneration. Fires occurring in logging slash, however, when the humus is wet are frequent and disastrous. All coniferous growth is killed and though seed may be left on the tops of spruce the seedbed is already destroyed, negating any chance of growth.

Van Cleve et al. (1980) established that in order to expose soil for spruce regeneration, site preparation after logging such as mechanical treatment or burning is necessary. Burning could have the added advantage of resulting in release of at least a portion of the nutrients previously tied up in the forest floor.

Archibold (1980) studied seed input into a postfire site in northern Saskatchewan. He postulated that the concentration of seeds in the moderately and heavily burned plots could reflect the activity of seed predators which were restricted to the less disturbed but better protected sites. Restocking potential for white spruce was considerably reduced after the first year. Other research suggests that most postfire regeneration in white spruce typically develops from seed blown in from adjacent stands but because of the short dispersal range of seed (normally less than 100 meters), recruitment is slow (Archibold 1980).

Clautice (1974) observed white spruce, black spruce, and paper birch sown on post-fire seedbeds on north and south aspects the first spring following a fire. Germination of seeds, survival of seedlings, and natural revegetation were observed during the succeeding summer. Intense burning provided the best seedbeds for tree seed and southern aspects supported the best seedling growth. Germination occurred almost wholly on mineral soil but a minor amount occurred on ash. Charred organic matter did not support germination. White spruce and black spruce germination patterns were very similar. Black spruce showed the highest survival on both aspects, white spruce was intermediate, and paper birch had the lowest survival. Most naturally occurring revegetation originated from seed on the south slope and from vegetative means on the north slope.

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9.2.3 HOW FIRE MAY HINDER NATURAL REGENERATION OF WHITE SPRUCE

Newsome and Dix (1968) indicate that white spruce reproduction is hindered by fire. Rowe (1953) also states that burned seedbeds delay germination of white spruce seedlings nearly 2 months and that delayed germination promotes increased winter mortality through failure of seedlings to harden.

Holman and Parker (1940) found that it is spring and early summer fire that restrict spruce to muskegs and river bottoms and causes its gradual disappearance. Where fire or logging has not occurred and not removed the moss, duff or debris to a compact moisture-retaining seedbed, no reproduction occurred, even when sufficient seed trees had been left. Where fire or logging occurred resulting in the removal of moss and debris, reproduction has always occurred if an adequate seed supply were available. They concluded that a main deterrent to spruce regeneration was man-made fires which burn at the wrong time of the year, or too lightly, or both, leaving unsuitable conditions for spruce regeneration (Holman and Parker 1940).

Germination has also proved poor on sites influenced by high temperatures such as those in fires. Coyea (1988) studied two environmental factors common after slash burning because of their potential impact on white spruce seed germination: seedbed temperatures, and the physical and chemical effects of burned residues from boreal mixedwood forest litter. Data were gathered from an upland burned site in north-central Alberta. A factorial experiment under controlled laboratory conditions tested the germination response of two white spruce seed sources to four seedbed conditions (distilled water, fresh ash, leached ash, and leachate from ash) subjected to five temperature regimes. Percent germination decreased as temperature increased. Germination was consistently lowest on fresh ash, with distilled water yielding highest germination percentages at all temperature treatments. The number of days required for

50% germination increased as temperature increased. Poor germination on ash substrates was not due only to salinity, although high pH may have been partially responsible. The markedly low germination on the leached ash suggested some other chemical inhibitors, possibly organic compounds, may have been present.

9.2.4 LOGGING

Although second growth forests arising after commercial logging are less productive and less stable than renewal after natural fire disturbance for white spruce (Weetman 1980), it has been found that natural regeneration after logging on well-drained sites is generally adequate. However, it is a slow process that may take up to 20 years before full stocking is obtained. Generally, summer-logged areas and small patch cuts tend to have the best regeneration. Natural regeneration after logging on riverflats and poorly drained sites is generally inadequate, especially those sites where periodic flooding occurs (Nyland 1977).

Candy (1951) reported that in Manitoba, on areas disturbed by logging, reproduction ranged from understocked to moderately stocked, and was unsatisfactory. There was also considerable type conversion to intolerant hardwoods following logging. In Saskatchewan, on areas disturbed by logging, coniferous reproduction was understocked. On areas disturbed by logging and fire, coniferous reproduction ranged between understocked and failure. Type conversion to intolerant hardwoods was problematic. On areas disturbed by fire, reproduction of conifers was a failure in the eastern part of the province, but was moderately stocked in the western section. The white-spruce intolerant hardwood sub-type was the most serious reproduction problem in the province. In Alberta, reproduction of conifers was moderate on areas disturbed by logging and well-stocked on areas disturbed by logging and fire. In the foothills district of Alberta on areas disturbed by logging, coniferous reproduction was understocked or a failure with moderate stocking on areas disturbed by fire or logging and fire. This is a reversal of the results obtained east of central Saskatchewan.

9.3 SUCCESSIONAL INFLUENCES ON REGENERATION

There are a variety of ecological disturbance which exist in the environment of white spruce. These disturbances interact with species to initiate different successional pathways (Figure 9-1)(Wagner and Zasada 1991).

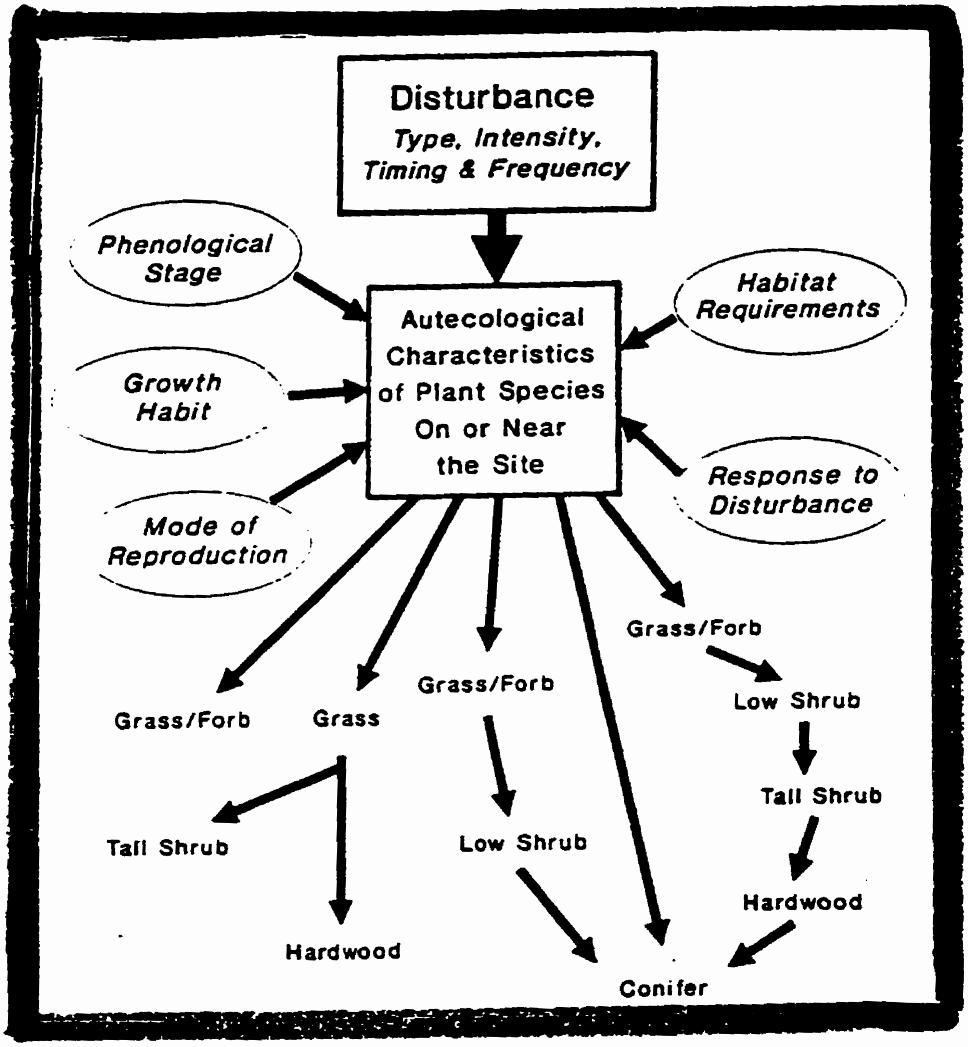

Figure 9-1: Successional pathways (Wagner and Zasada 1991).

Forest harvesting is typically focused on mature or overmature forest age-classes. However, silvicultural practice in British Columbia and elsewhere is focused primarily upon activities in the 20-30 year period following disturbance. Some analysts have noted that it is an 'occupational disease' of the forester to deal more with regenerating forest stages than final ones. The majority of silvicultural expenditures is in the first 20 years following disturbance. This equates with early successional vegetation complexes. A major consequence of regeneration delay in the Prince George Forest Region is the development of competitive vegetation. A more comprehensive knowledge of successional pathways arising from treatments on a given site is a prerequisite to setting priorities for vegetation management. While the scale of vegetative competition problems exceeds our operational capacity to address them, this need for site- and treatment-specific priority assessment will remain high. The classification of forest ecosystems is a fundamental step in improving the understanding and management of forest lands. The extension of existing climax-oriented classifications to include predictive models of forest succession is a logical and important development from this classification base (Draper and Hamilton 1984).

In a study of seedling success in plots in Manitoba and Saskatchewan, white spruce seedlings were the most abundant in the oldest stands, probably due to stand break-up with dying trees creating openings as well as litter disturbance and the exposure of mineral soil during uprooting of old or dead trees (Phelps 1948).

9.4 STAND DENSITY INFLUENCES ON REGENERATION

Spruce reproduction was most abundant in stands of moderate density. Dry conditions in a stand with an open canopy would likely be unfavorable to the establishment and survival of seedlings and may also cause abnormal mortality of seedlings already established. In stands of high density, much competitive vegetation would be excluded and moisture would be conserved, but there is a possibility that light intensity would be so low that normal vigorous growth would be impeded and many seedlings would consequently die (Phelps 1948).

The prime objective of spacing control is to enhance merchantable volume production. Spacing is usually an issue in planting to attain reforestation standards, but the results could indicate the most suitable spacing for white spruce natural regeneration in theory (Bella 1986). Initial spacing of trees has a major effect on subsequent growth, yield and quality of wood produced as well as the cost of planting and subsequent management practices. Bella and Franceschi studied the early results of spacing studies of three indigenous conifers in Manitoba in 1974. They found that there was no significant spacing effect on height growth but that spacing significantly affected crown development. Crown width increased directly with spacing. Initial growth of white spruce was less than half of the initial growth of the other two pines studied in the Sandilands Forest Reserve.

9.5 OTHER STAND CHARACTERISTICS RELEVANT TO SILVICULTURAL ENCOURAGEMENT OF NATURAL REGENERATION

9.5.1 INFLUENCE OF THE ASPEN OVERSTORY

In the mixedwood forest of Saskatchewan, aspen usually forms an overstory in young and intermediate-aged stands but in older stands the spruce exceed the height of aspen. Observations suggested that white spruce under an aspen canopy are both retarded and damaged. A study was carried out in five mixed stands of aspen and white spruce to determine the effect of the aspen overstory on the spruce understory. Height, diameter and volume growth of free and suppressed spruce were examined. It was found that aspen overstory may, by suppression, considerably reduce the height and diameter growth of young and intermediate-aged spruce. White spruce suppressed by aspen may be expected to take longer to reach breast height than free growing spruce and aspen overstory will lower the quality of spruce by causing forked top, crook and sweep. Release treatments are therefore suggested (Cayford 1957).

9.6 CHAPTER SUMMARY

As established throughout this chapter, there are several influences of stand development of boreal mixedwoods which directly effect white spruce natural regeneration. Natural stand origins, fire and other related disturbances, succession and stand density are some of the more important influences. These influences alter the environment and ultimately either favor or deter spruce regeneration. It is obvious that to find the most suitable prescription for the natural regeneration of white spruce and to meet stocking standards, human intervention is necessary. Over the past few decades, several alternative regeneration systems for white spruce have been postulated and tested. Keeping the influences on natural regeneration in mind, natural regeneration will now be reviewed with regard to decision-making in boreal mixedwoods.

Chapter 10:
NATURAL REGENERATION OF WHITE SPRUCE IN THE CONTEXT OF DECISION-MAKING FOR BOREAL MIXEDWOOD MANAGEMENT

Management practices are the last task in the recipe for successful white spruce regeneration. This chapter will examine different forestry practices and how they contribute to white spruce management. It will also cover specific management options for white spruce given a variety of scenarios.

10.1 FORESTRY PRACTICES AND THEIR CONTRIBUTION TO MANAGEMENT

The creation and maintenance of productive forests is a main goal of foresters throughout the high latitude areas of the world. The top portion of Figure 10-1 suggests one way of visualizing the process. In the figure, one must recognize that the compartments or steps are all interrelated and that any particular compartment is affected by those which precede it and the activities which occur during that phase of management affect subsequent management strategies. As well, within any compartment, there is an array of potential practices. Each management practice can be conducted at a variety of intensities.

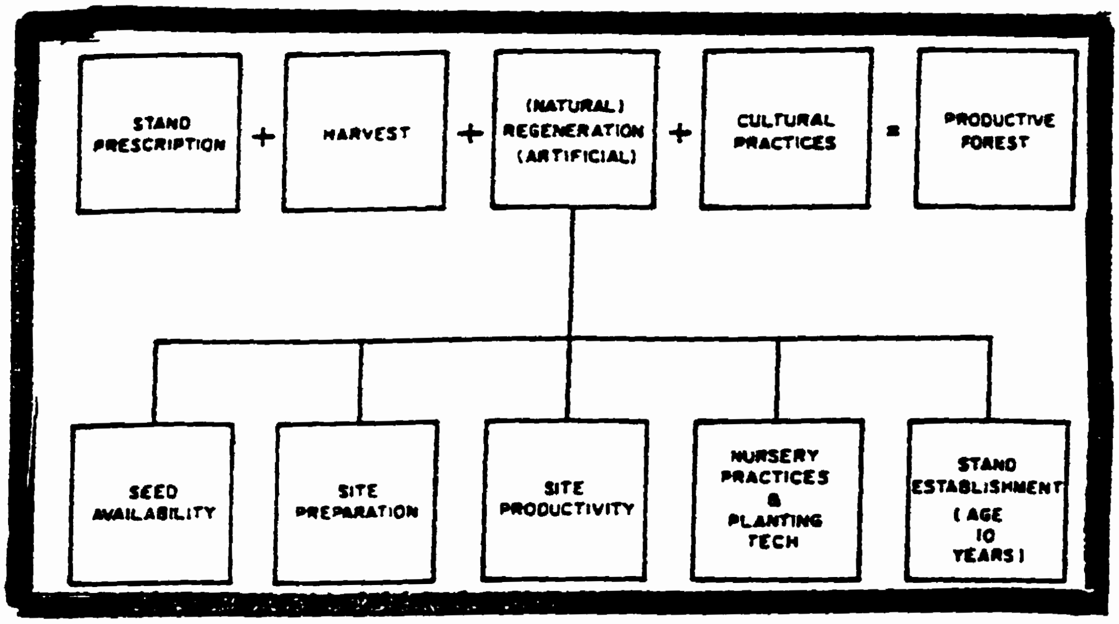

Figure 10-1: Elements of productive forest management (Zasada 1980).

In terms of regenerating spruce, there is little option but to intensify silvicultural practice. As clearly, the spruce forest is an essential contributor to the basic principles of sustained yield and multiple use values. The decision to grow either conifer or hardwood under more intensive culture will not remove the traditional mixedwood scene of aspen and spruce from the forest mosaic as each is fairly ubiquitous under our present harvesting patterns.

The prevailing laissez faire attitude to mixedwood management-regenerate extensively and live with what you get - will effectively over time, cause the harvested conifer forest to be replaced with by stands of hardwood and brush fields of reed grass. If this scenario were to continue, the nature of the forest would change, making it less ideal for meeting either sustained yield or multiple use objectives (Drew 1988).

10.1.1 EXPERT SYSTEMS

Brand (1991) stresses that although unassisted natural regeneration is sufficient, it can be enhanced by forest management practices such as partial canopy removal, site preparation and weed control. The challenge, however, is to effectively choose among complex enhancement options that result in vastly different outcomes depending on the site. This favors the use of decision support tools such as expert systems which can encode knowledge and professional tools and link with secondary programs or geographical information systems. These tools can assist silviculturalist in defining the criteria for choosing among regeneration systems and help to determine the best choice in any particular instance. Thus, due to the complexity of forest regeneration decision-making process, the development of expert systems is recommended.

10.1.2 HARVESTING GUIDELINES

These guidelines were considered by Zasada (1972) to be a first approximation of prescribing harvesting methods, silvicultural systems, and site preparation for white spruce natural regeneration in interior Alaska. The recommendations that are presented may be interpreted for white spruce in western Canada, considering the site specific differences. Key factors to be considered during preharvest stand and site inventory include the following:

- depth of moss and other organic layers,
- depth to permafrost,
- aspect,
- slope and slope position,
- soil texture and depth,
- insects,
- diseases, and
- squirrel activity.

Under the heading of overstory treatment and seed source regulation, there are separate recommendations related to clear-cut systems, shelterwood system, seed- tree system, and selection system.

Separate recommendations are given for site preparation under the headings of harvesting, mechanical site preparation and prescribed burning.

The basic assumptions behind these guidelines were as follows: white spruce can be naturally regenerated following harvesting of mature stands; natural regeneration is to be relied upon in reforesting harvested or otherwise disturbed areas; the first cuts in mature white spruce stands are to be regeneration cuts; even-aged management is to be practiced in areas designated for wood production; the management objective if to form stands in which white spruce comprise 90% or more of the stems; only those portions of harvesting and site treatment which specifically pertain to securing regeneration are considered; and these guidelines provide a basis for regeneration practices during the 10 years following their publication. The author recommended that after 10 years the guidelines should be updated and changes made where practice and research indicate the need for change (Zasada 1972).

10.1.3 PRESCRIBED BURNING IN BOREAL MIXEDWOODS

The first experimental prescribed burns in spruce-aspen stands in Riding Mountain National Park, Manitoba, were done in 1966. The trials indicate that prescribed fire can be used successfully to clean up cutovers and reduce slash hazard. However, little reduction in the organic mantle or damage to plant roots is likely to occur. If white spruce regeneration is desired, supplementary mechanical scarification will probably be needed but treatment should be less expensive because of the reduction of slash. On the other hand, if aspen regeneration is desired, further treatment of the burned areas may be unnecessary. During the early September burns, slash accumulations burned fiercely and the fire consumed all the material except the large stems. The fires, however, did not spread much beyond the slash-covered areas and only about 35% of each plot burned. Because of the high moisture content of the *F* and *H* horizons, reduction in the depth of the organic horizon was almost nil, even under the large slash piles (Tucker and Jarvis 1967).

Also, in 1966, three experimental burns were carried out at Riding Mountain, Manitoba with the objective was to determine if prescribed fire were a feasible tool for use on upland white spruce-aspen cutovers to eliminate slash fire hazards, stimulate aspen suckering, and create favorable habitats for conifer reproduction. During burning operations, it was observed that the fire consumed practically all the organic mantle wherever it had been accidentally disarranged and churned-up. On the basis of these observations, two other small experimental areas were established to determine if prescribed burning following scarification with finned barrels might appreciably reduce the organic mantle and improve habitat for conifer reproduction. The authors doubted that many suitable habitats for conifer reproduction were created. In most places the organic mantle was still 2 cm or more deep and would provide harsh and drought environments for newly-germinated conifer seedlings. In addition, many of the roots of competing vegetation were not destroyed. In spite of the fact that habitats deemed suitable for spruce reproduction have not yet been created, burning and reburning after scarification reduced the depth of the organic mantle considerably (Jarvis and Tucker 1968).

Forest regrowth after a fire depends on: (1) the reproductive capacity of the tree, shrub, and herbaceous species in and adjacent to the burned area; (2) the ability of the species to occupy the burn; and (3) the capacity of the species to utilize the site conditions created by the fire. The Alaska work summarized in this article had the following objectives: to determine the amount off seed available on productive upland sites that had supported commercial white spruce stands before the fire; to determine seed germination and survival patterns of first-year seedlings resulting from naturally dispersed seeds, artificially sown seeds, and seedbed requirements that promote regeneration. The quantity of white spruce seedfall at 50 m along the transect into the fire was less than 20% of the within-stand seedfall into the source area. It was less than 10% at 100 m. Most seedlings occurred on seedbeds with an ash and/or organic layer depth of 2.5 cm or less. However, on sites where a good seed source was nearby, spruce and birch seedlings were found on organic seedbeds more than 5 cm deep. Distribution of white spruce and birch seedlings in the Rosie Creek burn did not necessarily follow the pattern that would be expected had seed been the only factor limiting regeneration. These results point out the importance of seedbed conditions and other biological variables that interact with seedfall in determining success of regeneration (Zasada 1985).

White spruce and black spruce are two boreal forest species that benefit from prescribed fire during the regeneration step. Research has shown that post-treatment tending requirements and associated costs were lower on burns. It is generally agreed that secondary mechanical site preparation may be necessary to expose the mineral soil if prescribed fire did not reduce the organic layers sufficiently. Prescribed burning is a powerful tool, but not a panacea for all forest land management applications and problems. In many instances, prescribed fire has to be used together with additional forestry practices such as compressing debris or insect-killed overstory prior to burning, herbicide use before or after burning, mechanical site preparation after burning, planting, replanting or interplanting, and brushing and weeding (Weber and Taylor 1992).

Where forest stands are being harvested in large clear-cut blocks in Manitoba and Saskatchewan, there is a need for low-cost methods of regenerating a forest resource. Prescribed burning, as a silvicultural tool is becoming more widely used. An advantage is that it can remove thick, organic layers to expose mineral soil seedbeds at low cost compared to machine methods. As of 1970, prescribed burning had not yet been proven reliable for preparing seedbeds in hardwood or mixedwood stands (Sando and Dobbs 1970).

Regeneration of overmature spruce-fir stands after clear-cutting is a problem in the Hinton area, Alberta, partly because soils there have a thick layer of unincorporated organic material and a continuous moss cover. These layers are very poor substrates for spruce seed germination and seedling growth. Fire can be beneficial in such cases if it consumes only part of the organic horizons and leaves the mineral soil intact. In a test area, involving a moderately well-drained Orthic Gray Wooded soil on a mixed glacial till, prescribed fire had the following effects: increase of pH of surface organic layer; decrease of organic matter and total N; increase of total and available P; increase in water-soluble Ca and K; increase in number of days with soil temperatures between 6 and 8 degrees C; and increased soil temperatures. It is known that water and mineral uptake and tree growth increase with higher temperatures. Therefore, if fire lengthens the time of favorable soil temperatures, accelerated physiological processes should increase the rate of seedling growth. As a result of faster growth, spruce seedlings could reach the mineral soil sooner and become less susceptible to drought (Lesko 1971).

The spruce-fir forests of the Alberta foothills are often characterized by deep organic matter accumulations on the soil surface and cold soil temperatures, both of which make reforestation difficult. Prescribed burning was tested as a means of seedbed preparation and site amelioration on representative spruce-fir cutover problem areas. It was concluded that prescribed burning did not produce a significant reduction in the organic layers or a large increase in soil temperature on the sites tested. Increases in seedling establishment, survival, and growth on the burned sites were probably the result of slight decreases in organic layer depth and increases in soil temperature (Endean and Johnstone 1974).

Prescribed fire can have beneficial effects on seedling microclimate, but the effective use of fire as a silviculture tool depends not only on increasing our knowledge about microclimate changes and responses by seedlings and competing vegetation but also on delivering information in the form of guidelines appropriate for prescribed fire decision-making. The authors suggest there is not enough quantitative knowledge about the response of seedlings to changes in microclimate, and field experiments must use a holistic approach incorporating studies on fire impacts, microclimate, nutrients, and seedling response. The authors believe there are opportunities for applying prescribed fire more effectively in rehabilitating NSR sites in the subboreal spruce zone in British Columbia. Useful guidelines can be developed for using fire and will require the incorporation of site-specific information gathered from integrated studies which examine fire impacts, microclimate, nutrients, and seedling response into fire effects models (Silversides et al. 1986).

In the Sub-Boreal Spruce (SBS) Zone of British Columbia prescribed burning is used on over half of the area harvested to prepare sites for planting and reduce fire hazard. The steep, rough terrain and unstable soils typical of many sites in the SBS restrict the use of other site preparation treatment. Burning is often more cost effective than other site preparation treatment and is therefore used most often. Vegetation development patterns in different ecosystems are determined by burning severity, which influences the degree of resprouting and establishment success of off-site seeds. In subhygric sites, shrubs and herbs will generally overtop spruce within a few years after burning and often continue to shade the seedlings for five years or more. The authors noted that burning promotes the sprouting of fireweed from rhizomes, as well as its establishment from seeds. Fireweed will dominate most sites for the first 10 years until overtopped by conifers or other taller vegetation. Burning also stimulates the germination of seed-banking species including elderberry and red raspberry (Hamilton and Yearslay 1988).

The increased interest in the ecological role of fire in the boreal forest will lead to more sophisticated fire management and a greater desire and need for better prediction of fire behavior (Van Wagner 1983).

10.1.4 THINNING OF BOREAL MIXEDWOODS

Steill (1970) considered the benefits of thinning in his study of thinning 35-year old white spruce plantations from below. The study was designed for examining the relation of stand growth to density of residual growing stock and the emphasis is on evaluation of biological response to thinnings rather than the degree of profitability. 10-year results indicated that although full utilization of the site was not possible, the larger spacings would probably result in slightly less wood production yet cheaper planting costs, larger trees, easier access and comparable response to thinning.

Payandeh (1977) developed a simulation model to aid forest managers in making rational economic decisions with respect to the various regeneration systems. The cost effectiveness of four regeneration systems was compared: seeding jack pine; planting jack pine; planting white spruce; and planting black spruce. On the basis of the approximate present cost structure and the probability of stocking success as derived from existing literature and according to the opinion of experts, planting white spruce will be the most cost-effective of the four regeneration systems compared. Using the results of such an analysis, the forest manager may choose the most economical regeneration system for a desired probability level or may select the regeneration system which has the highest probability of meeting the desired objectives. This work is background to the present interest in modeling of all alternatives for forest regeneration in Ontario.

Other techniques for regeneration may be possible through adept use of alternative harvesting systems such as patch or strip cutting or through shelterwood cuttings. These systems require an increased level of forest management (Gardner 1980).

10.2 OTHER ASPECTS OF WHITE SPRUCE MANAGEMENT

There has been a dramatic improvement in the mechanized equipment available for harvesting. The equipment is smaller, faster and more efficient, providing managers with more opportunities to become more flexible when choosing cutting methods. Methods such as the modified clear cut and selective cutting will become more viable and forest management will grow more intensive in Canada in the next 10 to 20 years. Thus more attention and effort will be placed on smaller areas creating a more specific land harvesting. Regeneration is thus also expected to become more site-intensive (Prebble 1990).

Regardless of available site preparation equipment, it must be recognized that there are limitations under which fully stocked stands cannot always be attained. Foresters must recognize this and identify that it is not feasible or desirable to treat all of the usable soil resource. Doing so may actually cause harm, taking areas out of production completely (Kolabinski 1994). Marek (1992), in a study of spruce regeneration in northwestern Ontario, found that drainages and some disturbed organic sites in his study produced low levels of regeneration and should have been left untreated.

Guidelines for spruce management in Ontario largely ignore white spruce and the variety of techniques available. Assessment of conditions is subjective and interpretation of prescriptions is also subjective. The knowledge, skill and intuition of the field forester is still of paramount importance in both assessment and interpretation (Marek 1992).

10.2.1 WHITE SPRUCE MANAGEMENT IN THE ABSENCE OF CONIFERS

The change in soil properties is another management consideration which must be taken into account in designing forest management plans. Although balsam poplar may be the most appropriate hardwood to plant on early successional sites, it probably would not be the best suited species to plant after harvesting mature white spruce. Capillarity in high terraced locations no longer maintains high levels of soil moisture, causing the sites to be drier during the growing season, requiring a more drought-tolerant tree species.

Land managers should also be aware of the importance of alder in early succession in supplying soil nitrogen. Any practice that precludes the development of alder on sound sediments would seriously jeopardize future soil nutrient supplies and the productive capacity of the site (Van Cleve et al 1980).

In fact, the regenerated conifer forest under more intensive culture, may be six times as productive as the forest it replaced (Boyd 1985 in Drew 1988) and the thermal cover it would ultimately provide to browsing animals is necessary.

10.2.2 EFFECT OF WHITE SPRUCE MANAGEMENT ON OTHER SPECIES

In a study by Wurtz and Zasada (1987), they found that scarification could also be detrimental to the survival of spruce seedlings in the event of natural regeneration. This study revealed that scarification improved conditions for birch establishment even more than it did for spruce. Scarification increased spruce frequency by 50 % while it lead birch frequency to increase by 300 % in clearcuts and 500% in shelterwoods. The end result was that scarified areas were severely crowded with the combined spruce and birch density of 60 seedlings per square meter. Low level management would allow the crowded seedlings to self-thin with the dominantly seedlings gradually establishing themselves as dominants. A more intensive management plan would seek to ensure that each dominant spruce seedling was free to grow.

10.2.3 WHITE SPRUCE MANAGEMENT ON FLOODPLAIN SITES

The floodplains of Alaska's rivers are some of the most productive forest sites in the state, particularly for white spruce. Although these studies specifically target Alaska sites, similar sites exist in Northern Alberta where white spruce also thrives.

Management experience and research information that can be applied to management of floodplain sites is limited. In contrast to the lack of management experience is the availability of a relatively large body of basic ecological information for floodplain sites which provide valuable information on site development and forest succession. However, they do not deal with secondary forest succession following such disturbances as fire and harvesting. This paper considers factors that affect white spruce regeneration on floodplains. Two broad categories of management practice must be considered for regenerating such sites. First, practices needed to regenerate white spruce following harvest on sites currently supporting white spruce would be those normally associated with white spruce regeneration such as clearcutting, followed by site preparation, and natural or artificial regeneration, or a shelterwood system followed by site preparation and natural regeneration. Second, practices are needed to promote or encourage optimum regeneration and early development of white spruce during the initial stages of forest development. The rational behind these practices is that natural regeneration of white spruce is not always adequate in certain vegetation types. The objective would be to bring white spruce stocking to a level that would ensure well-stocked stands as white spruce became dominant during the normal course of succession. Some cultural practices may be generally appropriate to both these situations, although site conditions may differ considerably. For example, site preparation may be necessary in both situations but the nature of the forest floor may require different methods to obtain the necessary microsite conditions. Whichever management practices are considered, the question of site stability and longevity must be addressed. Will a given site still be present when the forest crop is ready for harvest? Even though higher terrace elevations make white spruce sites seem relatively more stable than younger sites, they do erode. There is no method of predicting site stability over the length of a white spruce rotation at present. Examination of old aerial photographs, observations of current rates of bank erosion, distance from the main channel, and other variables can help predict stability, but nothing can provide an absolute answer. Some level of vegetation or site classification must have both soil and vegetation components to be useful in silviculture planning. For example, it is known that the stands with the slowest height growth are those growing on the deepest organic layers and coldest soils. In such cases, removal of the overstory and disturbance of the organic layers will increase soil temperatures and decomposition rates, thereby enhancing forest growth and development. It is also known that different treatments and/or equipment may be needed for some stand types. For example, site preparation with a patch scarifier and rubber-tired skidder was easier and appeared to be more effective on the better drained sites. This observation suggests that nonmechanical site preparation (e.g. prescribed burning) may be more effective on the wet sites, or that mechanical scarification should be delayed until frost levels are deeper and the surface soil is better drained (Zasada 1984).

10.2.4 WHITE SPRUCE MANAGEMENT AND SUCCESSION

In general, foresters have been noted to concentrate on forests in the stages of regeneration as opposed to those in the final stages. Indeed, forest harvesting is typically focused on mature or overmature forest age-classes. However, silvicultural practice in British Columbia is primarily focused on activities in the 20-30 year period following disturbance. This equates with early successional vegetation complex. Often surface conditions, including competing vegetation is the cause of regeneration delay and a more comprehensive knowledge of successional pathways arising from the treatments on a given site is a prerequisite to setting priorities for vegetation management. Managers need to be aware of the variables controlling competing vegetation to maximize efficiency of natural regeneration following disturbance. Recognition of these variables during project planning could reduce costs and greatly improve management efficiency. It will also provide the land manager of early indications of the feasibility of achieving adequate natural regeneration and allow for a selection of options, such as artificial regeneration or site preparation to assist the natural regeneration process in meeting stocking standards (Zasada 1986).

From the study of white spruce on interior Alaskan floodplains, we may infer that management practices must conform with the dynamic nature of the ecosystem in question. In other words, forest land managers should design their treatments to conform to the successional sequences rather than trying to work at cross-purposes to succession.

10.3 WHITE SPRUCE MANAGEMENT FOR WILDLIFE AND RECREATION

Spruce, by way of its contribution to timber, wildlife and aesthetics, is deemed to be a necessary ingredient to our forest cover. It will take some effort to maintain its presence, but in doing so, better forest management and a more dynamic forest industry will be the result.

10.3.1 MANAGEMENT FOR RECREATION

Nonconsumptive wildlife-related recreation is a significant leisure activity among Albertans and contributed to about half a billion dollars in direct expenditures to the provincial economy in 1990. There are several opportunities for forest management to enhance Albertans' enjoyment of wildlife. There is the potential for urban forestry programs to increase opportunities for people to enjoy wildlife near their homes because most nonconsumptive wildlife-related recreation occurs in residential settings.

About one-third of people who take long trips to view wildlife visit nondesignated lands (McFarlane and Boxall 1993). Forest companies can play a key role in enhancing regional tourism by incorporating viewing opportunities in their management plans.

Interpretive material can vastly increase the understanding of how their forest management includes considerations for wildlife and this may enhance public support. By considering the needs of the nonconsumptive wildlife recreationist, forest companies can enhance and expand the distribution of public benefits from forested lands (McFarlane and Boxall 1993).

10.3.2 MANAGEMENT FOR WILDLIFE ENHANCEMENT

Most forest companies today have implemented some sort of wildlife management system to address the biodiversity issue as well as citizens' concerns. In Manitoba, several partners have joined to create The Manitoba Forestry/Wildlife Management Project with the goal of sustaining the richness and diversity of our forest resource. Through population monitoring of indicator species and computer modelling (which helps predict the impact of forest management practices on the supply and quality of habitats for resident wildlife), the program allows forest, wildlife and outdoor recreation managers to share skills and knowledge in the effort to shape actions which could potentially affect the viability of our forest communities in the years to come.

10.4 EFFECTIVE MANAGEMENT OPTIONS FOR WHITE SPRUCE

10.4.1 MANAGEMENT OPTIONS FOR SOFTWOOD STANDS

Management in this area has generally involved merely reintroducing the softwood component into previous softwood stands. Several options have been described more thoroghly in other chapters. Management options have been traditionally limited to past practices and ideas. Policy has been that if a stand is merchantable on a coniferous basis, it should be reforested to conifer with the logic that aspen will inadvertently return. This obviously indicates a bias toward softwood and a more proactive management position must be taken (Denney 1988).

Increasing efforts have been made in Manitoba for both artificial and natural reforestation; these on natural forest openings on prairie land or on harvested sites that had sat idle until stumps and roots had rotted to allow site preparation equipment to do a satisfactory job. White spruce, requiring site preparation, was extremely difficult to establish on freshly harvested sites.

10.4.2 MANAGEMENT OPTIONS FOR HARDWOOD STANDS

There has been an effort to introduce a softwood component to an already existing hardwood or trembling aspen stand via two different techniques. In one, a bulldozer cleared seven-to-eight- foot wide strips through a residual trembling aspen stand originating from fire. The strips were then planted with white spruce seedlings in about three rows, alternately spaced. The alternative was to carry out broadcast seeding on these cleared strips. Older residual stands sometimes required girdling the older trembling aspen to reduce the shading effect of the older trees resulting in a fairly significant blowdown of girdled timber.

Other follow-up treatment included applications of various repellent products to discourage hungry deer and rabbit from disrupting the seedlings. This was not entirely successful. Since then, follow-up treatments involving release through mechanical and/or chemical means have been developed.

A more recent management technique was an attempt at complete conversion in residual hardwood stands that were originally mixedwood until their conifer component was removed through harvesting. Follow-up treatments included herbiciding with poor results in most cases (Randall 1988).

10.4.3 MANAGING MIXEDWOOD STANDS

There is great variation in the utilization and subsequent management of mixedwood stands. Either the softwood component was harvested, leaving the residual stand to regenerate naturally or there is a conscious effort to ensure that the softwood component is regenerated. A number of techniques have been attempted (Randall 1988).

Mitchell (1992) concluded that stand tending must be viewed as an integrated part of establishment practices that include stock quality, site preparation, and vegetation management. Site selection and stand-management decision making require that both biotic and abiotic factors be considered. Knowledge of the physiological differences and differences in nutrient- and water-use efficiency among forest tree species will be needed if silvicultural recommendations are to be broadly applied. Ecological, climatic and treatment-induced problems not only present individual constraints to growth but they also may limit silvicultural options through their interactions. For example, on favorable sites it is unlikely that nutrition or water will be a problem once the trees are established, but regeneration may be so dense and so diverse that growth of individual crop trees will be limited by competition from other softwood and hardwood species. In this situation, thinning or spacing could be used to reduce the demand on site water and nutrient resources, but the understory vegetation may respond to the increased light that results from the treatment by using a significant amount of the newly available water and nutrients. This would mean that the expected growth of crop trees in response to thinning may not be realized.

Cullen (1993) stressed that there are difficulties regenerating spruce, complicated by such factors as poor planting stock and constraints to the use of herbicides, explaining perhaps the apparent continuing shift in forest structure from conifer to deciduous. Despite or because of this, there is a present focus on white spruce regeneration and little interest in true mixedwood regimes.

Denney (1988) does not believe that we are at a level of expertise where we can effectively regenerate and manage a mixedwood stand. There needs to be separate land bases for hardwoods and softwoods. The best method, in the short term, would be to reforest the area in proportion to the volumes of hardwoods and softwoods removed

For success, though, the current regulation on reforestation responsibility would have to be modified to give both hardwood and softwood operators responsibilities for both.

Realistic comparative values for hardwoods and softwoods--both in current and projected future values-- must be obtained before rational mixedwood management decisions can be made. Biological factors on tree growth and production costs and market values also have to be taken into consideration. This will be difficult but worthwhile.

As time goes on, we should be looking to amalgamate the land base and harvesting rights under one dual tenure disposition. In order to achieve full advantage of the opportunities mixedwood has to offer, management has to be under the direction and operation of one decision-maker. Government policy, regulation and development proposals should be encouraging this as much as possible (Denney 1988).

One trick in managing the boreal mixedwood forest is to prevent it from becoming completely hardwood, given the aggressive, fast-growing and strong poplars. There is a need for the continued presence of spruce for several reasons: there is still a demand for it from the sawmill industries and from a wildlife perspective, it is extremely important.

Although diversity is important, it is difficult to maintain and improve spruce. Keeping spruce in the mix is important since under proper management and free of competition, it can outgrow aspen on many sites in the boreal mixedwood forest. This is not often evident, since spruce is slow to get established and has trouble outcompeting other species without the use of herbicides.

Herbicide use is a contentious issue in mixedwood management due to the major public misconceptions and their concern about monoculture. The only way to obtain the public's consent is to through communication and education to establish that it is not going to result in monoculture management and that wildlife concerns are factored in (McDougall 1988).

A shelterwood treatment involving the scarification on the lee side of white spruce and regeneration by natural seeding was applied in mixedwood stand where the majority of shelterwood had been removed through harvest with a conscious effort made to retain seed trees. Following the establishment of conifer regeneration, residuals were removed in a clean-up harvesting operation (Randall 1988).

10.4.4 ENHANCEMENT OPTIONS

The paradigm under which white spruce has been managed in the mixedwood forest zone of Alberta - a reliance on extensive management systems with the objective of replicating wild forest yields and species - is being rendered inadequate by the competitive pressures of grass and brush and hares. Over the past two decades, alternative systems for regenerating white spruce have been explored and a broader array of treatment options developed. In Alberta, the trend is toward the adoption of more intensive, front-end regeneration treatments. The mixedwood forest is unlikely to regenerate itself successfully with an extensive "we'll take what comes back" statement of objectives. The wood-growing potential of Alberta's mixedwood forest zone is high. Soils and climates are favorable, and the sites are generally nutrient-rich with adequate moisture. This potential is currently not being realized because of general reliance on extensive regeneration systems that result in few areas growing free of the nemeses of the new forest: grass, brush, hardwood, and hares (Drew 1988).

Thus, if we are willing to regenerate spruce with a high probability of success, we must recognize that to do so will force a paradigm shift in the way we manage boreal mixedwoods in Alberta. Application of more intensive regeneration systems in those areas designated for conifer production will necessitate the expenditure of more front-end dollars in establishment. These expenditures will both secure the success of regeneration and will produce better, faster-growing stands than would be obtained naturally. The practice of regenerating spruce is no longer a minimizing exercise to be accomplished as cheaply as possible, but rather an investment decision--toward getting the most from the dollars expended in regeneration (Drew 1988).

Regardless of which method is ultimately employed to regenerate white spruce, it is important to recognize that there is a need to do it. There lies a responsibility with foresters to maintain a viable renewable resource wherever it may be.

Regeneration surveys on 9 logged areas in the vicinity of Fairbanks, Alaska, indicated low white spruce regeneration. In view of the limited field data, Monte Carlo simulation methods were used to estimate the probabilities of obtaining various amounts of white spruce stocking by the 1st and 10th years after logging. The simple model combined the irregular seed production of white spruce with a declining seedbed availability to estimate quadrat stocking ($4m^2$ plots). Results of simulation experiments indicated that the probability of achieving greater than 40% stocking by the 10th post-harvest year was 0.63. This result was sensitive to initial post-harvest seedbed conditions and the frequency of good to excellent seed years and to non-spruce revegetation rates. Both the field data and simulation results indicated that the prospects of obtaining adequate white spruce restocking after timber harvest by unassisted natural regeneration were poor. However, simulation results also indicated that seedbed management may increase the probabilities of regeneration success significantly (Fox et al. 1984).

Administrative, economic and ecological factors important to the selection of cutover regeneration prescriptions are outlined, and discussed in the context of present day Canadian forestry conditions and practices. Virgin boreal forests are often only marginally economic to harvest (particularly montane black spruce forests, and white spruce forests, mixed or pure in western Canada) because of the expense of a road system, and the large proportions of overmature wood, stems too small to cut or non-commercial species which may be present. The author outlines the difficulties of developing feasible prescriptions when growth rates for natural regeneration and rotation ages have been much longer than previously predicted (Weetman 1989).

The first essential in spruce silvicultural management is that one is not dealing with spruce alone but with spruce forest associations. One cannot think solely of spruce, although it is a natural tendency to do so, particularly when aiming for the ideal maximum production of the most commercially valuable species. The production of spruce monocultures may be an invitation to failure in management. Fortunately, the inclusion of natural associates in future spruce stands is not a difficult objective to achieve. The author points out that while slash and pre-existing windfall are an obstacle to scarification they provide the necessary shade for successful spruce regeneration and do not present an insurmountable obstacle to hand scarifying. Hand scarifying has the advantage on some sites of preserving existing natural regeneration better than does tractor scarifying. The author believed that scarification to obtain spruce regeneration would develop into general practice for good spruce seed years (Moss 1960).

10.5 INTEGRATED RESOURCE MANAGEMENT

Although timber harvesting has been conducted extensively for more than 50 years, there has been little active management for the protection of 'other forest values'.

Integrated resource management is a planning process that directs forest harvesting in a manner consistent with the production of other wood products and the conservation goal for maintenance of biodiversity (Thompson and Welsh 1993).

Thompson and Welsh (1993) have identified goals of integrated management for areas of pulpwood logging operations in the Canadian Boreal Forests. These are:

- sustainable production of commercial forest products and
- conservation of biodiversity

For achievement of both these goals, a suitable approach is through maintenance of ecosystem types at the landscape level. This, however, is more easily said than done as conservation of wildlife (defined as all organisms) is a relatively new discipline in Canada and ecosystem management causes certain problems for agencies attempting to pursue these goals resulting from:

- poor autecological knowledge
- conflict of habitat requirements with timber harvesting goals
- legacy of past forest management
- lack of management regimes
- few techniques applicable at the ecosystem level

Steps toward a more integrated approach to forest resource management include:

- recognition of institutional shortcomings
- development of predictive models using a common language for foresters and wildlife managers
- re-tooling with G.I.S. technology and decision support systems
- development of habitat models to be used within landscape-scale management plans

Species selection is also open to question and perhaps mixed species management should also be the goal rather than the re-establishment of pure stands of white spruce. Such stands would be more similar to those occurring on upland sites and should have a favorable effect on soil nutrient levels (Van Cleve et al. 1980).

One successful model of innovative forest management success is Manitoba's Model Forest. The forest, which is the principal wood supply for the area, is one of 10 across Canada and is managed by a partnership of over 30 organizations. The Model Forest promotes innovative forest management. It contains protected areas, essential wildlife habitats and species and promotes a multitude of forest values and uses--such as hunting, fishing, recreation, wild rice production and traditional aboriginal pursuits.

10.6 PROBLEMS OF MIXEDWOOD MANAGEMENT

Opportunities of mixedwood management include the achievement of higher merchantable volumes at the time of harvest--up to double the yield per acre when both the hardwoods and softwoods are taken.

Mixedwood stands provide stability for the industry since hardwoods and softwoods are going to different markets. Yet there are two challenges:

1) operational challenges to utilize the crop we have i.e. cutting rights for the hardwoods in a mixedwood stand are held by one party and the softwood rights are held by another party--these must be coordinated in order to harvest the forest in one pass

2) tie the current operational situation into the longer-term timber supply (Denney 1988)

Brinkman (1993) indicates that a sound forestry policy should use all four basic regeneration alternatives ; natural regeneration, modified logging that leaves residuals, direct seeding and planting.

Under '*Forest Care*', an initiative developed by member companies of the Alberta Forest Products Association to ensure their industry will contribute strongly to the province's prosperity today and tomorrow, while protecting the forest, the environment and the community, a number of suggestions are stressed: the importance of member companies to do the following:

- select a harvest system that will encourage quick and effective reforestation
- identify the reforestation strategy to be used
- identify and protect any unique, localized values
- maintain site productivity
- protect juvenile understory where it is healthy and will grow in response to the mature canopy
- sustain wildlife habitat
- protect watershed quality and aquatic habitat
- respect scenic values

The Alberta Forest Products Association (1993) also stresses the importance of ensuring that a diversity of tree species and other vegetation are maintained in areas being reforested.

10.7 REGENERATION PLANS

Regeneration plans, according to Crosiewiez (1980) should be formulated well in advance of timber harvesting and should include the following:

1. Plan must be based on thorough evaluation of forest ecosystem under consideration, with particular attention given to its productive capacity, soil, topographic position and microclimate, successional tendency in terms of vegetation changes after disturbance.

2. Include specifications pertaining to the type and season of harvest cutting plus the types and sequence of silvicultural treatments needed - all in view of the pre-selected tree species that best fit the anticipated environmental conditions.

10.7.1 REGENERATION MONITORING PROGRAMS

Pearce (1990) has developed several simple elements which regeneration monitoring programs must have in order to achieve their purpose of improving reforestation results:

1. Incentives. There must be an incentive to improve regeneration results if a monitoring process is to be taken seriously.
2. Linkages. Regeneration programs are carried out within complex physical and biological systems. Climate, site factors, and seedling condition can singly, or through interactions, influence the success of reforestation.
3. Stratification. Differences in site and stand conditions and in treatment characteristics should be distinguished to explain the effects of a treatment on a forest site.
4. Objectives. In a regeneration program, both short-term objectives for specific treatments and long-term objectives for free-growing stands should be defined.
5. Feedback. The results of the monitoring program should be quickly passed on to the people responsible for setting objectives and implementing the treatments.
6. Flexible design. Monitoring activities should be updated frequently as knowledge improves and objectives and treatments change.
7. Practical procedures. Simple procedures are more likely to produce the desired results than are highly detailed, complicated procedures.

The free-growing stage of stand development is defined as the time from the start of harvesting until a minimum number of acceptable, well-spaced, free-growing stems are established on a site. The free-growing period is defined for each site according to the site conditions, the characteristics of the crop tree species that are to be established, and the time period during which non-crop vegetation may threaten crop tree success. In British Columbia the free-growing stage ranges from 6 to 15 years for most sites.

10.8 CHAPTER SUMMARY

Although the complexity of vegetation management problems is beyond our ability to address them, the need for site and treatment specific priority assessment will be very important in boreal mixedwood management. In addition, the classification of forest ecosystems is a fundamental step in improving the understanding of management of forest lands. The extension of existing climax-oriented classifications to include predictive models of forest succession is a logical and important development which will be invaluable in use in the future (Draper and Hamilton 1984).

Chapter 11: SUMMARY AND CONCLUSIONS

11.1 SUMMARY IN GENERAL

Undoubtedly, conifers and hardwoods will be of interest in the forest industry for some time and indications have been that a new philosophy for the management of mixedwood stands must be developed. Thus, it is imperative that continuing consideration be given to management and renewal of softwood species, and a greater attention will have to be given to sound and economical techniques to ensure the softwood component is maintained.

11.1.1 THE EVER-CHANGING FOREST

Change in our environment is always ocurring and change in the forest ecosystem is no exception. Forest ecosystems are dynamic and change is constant--whether natural or man-induced. As well, forest stands go through successions of maturity. Each stage has its own unique characteristics--nutrient cycling, amount of biomass, aesthetic ability and favoring of wildlife species. Thus, there is no single silvicultural prescription, no particular recipe for successful white spruce regeneration.

From a more philosophical point of view, perhaps we should view our management decisions in light of this fact--that change is always occurring (Figure 11-1). Often, and especially in forestry, things tend to be planned around what occurrences will happen and what effect they will have because they generally have a high probability of occurring. However, chaos is evident when an event of low probability takes place in relation to the planning already incurred. Perhaps we should spend more time thinking of the consequences of low probability events in the forestry industry. C.S. Holling has based his views on the idea that life in the world has generated surprises (meaning that change could not have been anticipated) (Holling and Bocking 1991).

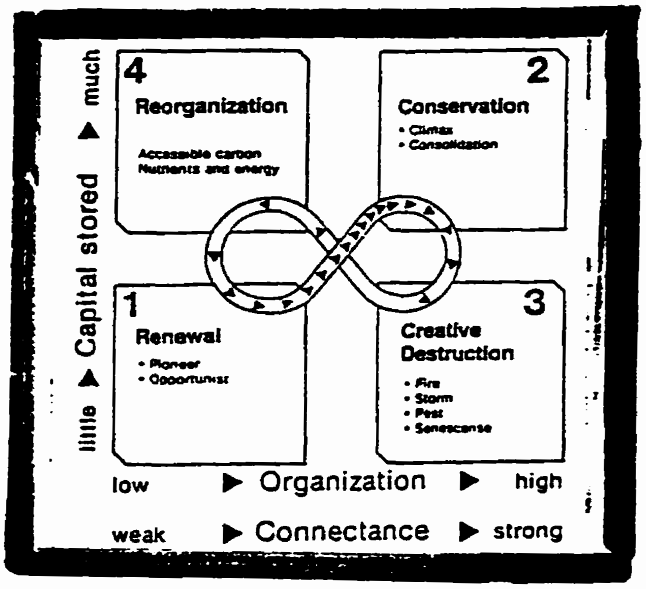

Figure 11-1: The cycle between four ecosystem functions (after Holling and Bocking 1991).

With this in mind, unforeseen and often unfortunate circumstances (creative destruction) as related to forestry models may be avoided, or at least reorganized by assessing their organization and connectance to forest renewal and forest conservation.

11.2 SUMMARY OF FAVORABLE AND UNFAVORABLE ASPECTS OF WHITE SPRUCE NATURAL REGENERATION

There are a number of advantages and disadvantages to white spruce natural regeneration as identified in the literature. These will first be identified followed by a summary of conditions favorable and unfavorable to white spruce natural regeneration.

11.2.1 ADVANTAGES OF NATURAL REGENERATION

• Natural regeneration (in the context of forest regeneration only) is in its most primitive form is 'without cost', although there are many other costs/benefits to the ecosystem. In addition, harvesting costs may be increased by the use of harvesting methods or silvicultural systems that are needed to promote natural regeneration (Brinkman 1993) or lower regeneration establishment costs (Arnup et al 1988).

• In many cases, naturally regenerated seedlings have either had better survival and/or earlier growth rates than planted seedlings, because of mistakes in the way seedlings were grown, stored, handled and planted.

• Natural regeneration usually requires use of smaller clearcuts that can successfully be regenerated by planting because of the need for microclimate modification and for the input of seed from adjacent mature forest. This can subsequently be advantageous for the long-term future of the forest stand.

• Natural regeneration preserves the genetic adaptation to the local ecosystem (Brinkman 1993) and contributes to the retention of local gene pool (Arnup et al. 1988).

•Natural regeneration adds additional seedlings and species to a planted site (Kimmins 1992).

• Natural young stands tend to be non-uniform in vertical and horizontal spacing (Clarke 1992). This inevitably promotes a more pleasing and natural stand pattern.

• Methods associated with natural regeneration often cause less soil disturbance resulting in less severe competition from brush species than with assisted regeneration (Doucet 1988).

• Naturally regenerated stands are more likely to be well mixed than plantations (Weetman and Vyse 1990).

• Profuse natural regeneration can be an advantage where fast early growth of crop trees is not wanted (Arnup et al 1988).

11.2.2 DISADVANTAGES OF NATURAL REGENERATION

•The natural regeneration method is limited with regard to white spruce due to long intervals between seed years and the mixed nature of the stand in which spruce grows (Arnup et al 1988).

•In many forest systems it is unreliable, especially where clearcutting is the harvesting method.

•The natural regeneration method can often fail to reforest vast areas (Kimmins 1992). Although planting can fill in these areas and can ensure a desirable mixture of species, natural regeneration alone is often not desirable in these situations.

•Advance regeneration usually develops into a thicket and density control is necessary to maximize early tree growth (Arnott 1992).

•Natural regeneration is not necessarily cheaper than planting, particularly if stocking of acceptable species cannot be easily attained or if significant amounts of respacing are required to reduce stocking of dense, naturally-regenerated stands to desired target levels (Arnott 1992).

•Controlling canopy opening to achieve the best environmental conditions for a desirable species, or regulating logging operations to protect advance regeneration is likely to cost more than standard operations (Weetman and Vyse 1990).

•Even under most favorable conditions, natural regeneration is slow (Arnott 1992, Weetman and Vyse 1990).

•Advance or post-harvest natural regeneration methods give little control over the density and distribution of crop trees. This results in slow growth due to intraspecific competition and is frequently countered by juvenile spacing or precommercial thinning (Brand 1991).

•Natural regeneration is a complex process and the chance of failure at any one of four stages (seed production, seed dissemination, germination, seedling survival and development) is high (Zasada 1991).

•Natural regeneration is difficult due to poor planting stock and constraints to use of herbicides (Cullen 1993).

•Natural regeneration is less certain than planting (Weetmen and Vyse 1990).

11.2.3 NATURAL REGENERATION AS BOTH AN ADVANTAGE AND A DISADVANTAGE

The irregular thinning and spacing of natural regeneration can be both an advantage and disadvantage as naturally regenerated stands almost always require density reduction or spacing between treatments to maximize early crop tree growth.

11.3 MAJOR CAUSES OF REGENERATION FAILURE

According to Crosciewicz (1980), there are several major causes which contribute to the failure of the natural regeneration process.

- Loose, surface forest floor materials, when undisturbed, do not make for a good environment for white spruce natural regeneration.

- Surface materials are subject to rapid losses of moisture when exposed to increased solar radiation or ventilation making them poor media for seed germination and seedling survival.

- Overshading created by logging slash and often severe competition from deciduous vegetation can further hinder the re-establishment of softwoods such as white spruce after cutting.

- Wildfires destroy young softwood stands or burn through softwood clearcut areas in the absence of marginal seed sources.

- There is a need for adequate protection from insects, disease and mammals. These influences can lead to total devastation of naturally regenerated white spruce seedlings.

- Hardwood species can hinder the softwoods in a mixed stand.

The most applicable prescription, according to Crosciewicz (1980), is mechanical scarification or controlled burning, with provision for subsequent planting or seeding.

11.4 NATURAL REGENERATION OR PLANTING?

There is a long list of advantages and disadvantages to both natural regeneration and planting but generally, the following recommendations have been developed. The choice of method should be species specific, site specific (climate and soils), dependent upon biological factors determining the success of naturally regenerated and planted seedlings and management considerations including economics. Usually a combination of both is desirable (Kimmins 1992, Weetman et al. 1990). Natural regeneration systems are highly site specific and a sound knowledge of the site characteristics is required for their success (Arnup et al 1988).

McMinn (1986) found that planting results in much higher early productivity than either seeding or natural regeneration. However, in a study comparing natural seedling growth rates with artificial seedling growth rates in Alberta, Hellum (1978) describes seven plantations of white spruce seedlings in central Alberta which were studied to evaluate their growth in relation to natural seedlings originating on site from seed. The study found that, in general, white spruce seedlings growth in a container and grown as bare root nursery stock did not out-perform the natural seedling in the field. The only advantage the nursery-grown stock seemed to exhibit was its growth, having been grown in a nursery environment. However, the container-grown seedlings often have an alarmingly large shoot-root ratio which, if continued, could contribute to lack of windthrow resistance in later years. Hellum concluded that neither container-grown stock nor bare-root stock of white spruce could favorably compare with local natural regenerated stock of the same species.

If natural regeneration is to be used, and used successfully, the best point of departure is consideration of the natural disturbances that bring it into being in nature. If natural regeneration can meet the prescribed stocking goals for a particular site within the acceptable regeneration delay period, costs associated with planting can be avoided. Yet natural regeneration itself is not without cost (Weetman and Vyse 1990).

In the circumstances in which natural regeneration is applied, a range of regeneration techniques from high-cost to low-cost is needed to suit the particular situation There is an equal need to match regeneration strategies to the range of forest types in each management unit (Jeglum 1992). Aside from economics, successful regeneration also depends on the characteristics of a particular site to be regenerated, but is in general quite variable.

For example, according to Lorimer (1990) natural regeneration is more dependable in humid climates (such as the climate of western Canada) than in semiarid climates. However, success in favoring a particular species is likely to be variable in almost any region due to the following reasons:

- Adequate seed production in some species may occur almost every year and in some species only at long or irregular intervals.

- Seedling germination and survival in some species is greatly influenced by the weather and as a result regeneration may be inadequate even in years of good seed production.

- The microclimate of the stand must be favorable if regeneration is to be satisfactory.

- The condition of the ground surface or seedbed is of prime importance.

- In advance regeneration, if the shrub layer and sprout layer are dense, they may preclude the establishment of other, perhaps more desirable species.

- Seed or seedling predators are sometimes partly or largely responsible for regeneration failures.

If natural regeneration is acceptable and if it can be protected, it can provide an assured renewal if the necessary conditions are present (Doucet 1988). More specifically, natural regeneration is a viable alternative on those sites where the land manager has the flexibility to time site preparation with the occurrence of seed years (Zasada 1980).

11.5 MODEL FOR WHITE SPRUCE NATURAL REGENERATION

11.5.1 ABILITY TO PRODUCE REPRODUCTIVE STRUCTURES

The production of white spruce seed cones varies annually and is dependent on such factors as tree age, the previous year's weather conditions, previous seed and cone crops and other factors.

11.5.2 QUANTITY OF REPRODUCTIVE MATERIAL ON SITE

The quantity of seed available for dispersal will be determined by the amount of filled seed on the tree in late August, seed dispersal, and fate once seed reaches the seedbed. Seedlings are the most susceptible during the first year following germination. A range of factors affect their survival and many of these factors will never be as crucial again during the life of the tree.

11.6 CONCLUSION

Natural regeneration is a favorable method for white spruce regeneration, given that scarification takes place and proper treatment for vegetation management and other species is provided. Silvicultural prescriptions must be made on a site-specific basis, taking all environmental factors into consideration. Thus, all aspects of white spruce --the ecology, formidable regeneration systems, alternative regeneration systems and the management of boreal mixedwoods must be well-versed before any decision-making takes place.

Chapter 12: RECOMMENDATIONS: INFORMATION GAPS AND RESEARCH NEEDS

A more comprehensive knowledge of successional pathways arising from treatments on a given site is a prerequisite to setting priorities for vegetation management. While the scale of vegetative competition problems exceeds our operational capacity to address them, this need for site- and treatment-specific priority assessment will remain high. The classification of forest ecosystems is a fundamental step in improving the understanding and management of forest lands (Draper and Hamilton 1984).

Careful observation of natural regeneration and successional trends can help foresters build much local knowledge about regenerating stands. Once foresters have gained a good basic knowledge about local natural regeneration, they can begin to determine what factors contribute to its success and failure. Foresters must always keep regeneration principles in mind and not allow the European precedent of formalized 'systems' of natural regeneration to straitjacket their thinking about ways to obtain natural regeneration. Systems and methods developed for other species and climates are not readily portable. Blind testing of a reproduction method to find a solution to poor natural regeneration or failing plantations without considering the silvics of the species and careful observation to local conditions is likely to be unsuccessful (Weetman and Vyse 1990).

12.1 KNOWLEDGE GAPS

There is a considerable body of knowledge in the field of forest regeneration, but it must be better utilized for the site-specific needs that may arise. Intensive forest management will soon take precedence and we must be prepared through research to take a meaningful part in its implementation (Chrosciewicz 1980).

The paucity of information on prescribed burning effects on spruce sites as well as inconsistent research results, argue for further research on the subject (Dobbs 1972).

Natural regeneration became a new project that Ontario recently introduced under the Sustainable Forestry Initiative in the early 1990's. Their aim was to understand the key plant factors influencing the establishment of seedlings in natural stands over a range of site, harvesting and competition conditions. By using this knowledge obtained on the structure and function of naturally regenerated seedlings, quality of nursery-produced stock may be improved. However, there are still a number of research needs which must be addressed. Mohammed (1991) identified several of these:

•determine the effects on ecosystem diversity and stability using monoculture planting stock versus natural regeneration

•understand the effects of environmental disturbance (e.g. global warming, pollutants) on natural regeneration of commercial species

•develop harvesting techniques that will favor natural regeneration of conifers

•identify attributes of naturally regenerating seedlings that favor successful stand establishment

•compare growth and yield of natural and planted stands.

12.2 HIGH PRIORITY RESEARCH NEEDS FOR WHITE SPRUCE

Since there is a lack of workable biological solutions for the establishment of regeneration to maximize growth and since the main reasons for inadequate spruce regeneration in the boreal mixedwoods have surrounded the influence of site conditions, it is obvious that there is a need for sound knowledge of the site and the use of regeneration prescriptions reflecting site attributes (Navratil et al. 1991). Further, sufficient information does not exist on the establishment and growing requirements of the white spruce to take into account site variations and appropriate site-specific treatments, key to the successful natural regeneration process.

Regeneration research in the Prince George Forest Region has evolved with a primarily biological or ecological orientation. Future research must retain this biological focus but must also be designed to permit economic assessment of management alternatives. Although research is needed in artificial regeneration, natural regeneration must not be neglected. It is difficult to imagine broad new profitable avenues of natural regeneration research. Instead, emphasis must be placed upon preparation of local management guidelines and regeneration models such as those presented by Zasada (1972, 1980) for Alaska. A detailed understanding of regeneration components and local interpretation offers a practical opportunity to improve natural-regeneration success (Draper 1982).

As a result of research by Doucet (1992), it was determined that mature stands that are presently logged could be regenerated if advance growth were protected. Although this may not be difficult, the author suggests that methods for classifying advance regeneration according to its potential for survival and growth must be developed so that long-term productivity of the resulting stands could be estimated.

Much research has been focused on determining the value of advance regeneration, particularly its potential to grow rapidly after harvesting and the disease risks associated with stem damage incurred during logging (Arnott 1992).

Zasada and Wurtz (1990) suggest that the knowledge of the relationship between organic surfaces and white spruce is incomplete. In a study they did on maximizing white spruce regeneration in Alaska, they found, unexpectedly, that relatively good spruce regeneration was observed on unscalped surfaces.

When examining records of treatment costs and results in terms of regeneration, none of the data truly shows how much can really be accomplished due to the shortage of reliable data on the conditions of the resulting stands some 10 or more years after treatments. Thus, results of much shorter duration will have to be used in selecting treatment combinations (Crosciewicz 1980). We should anticipate that longer studies must be conducted in order to make informed decisions regarding forest management in the future.

Chrosciewicz states that more information is required on how to further reduce the costs of planting and seeding to make the combined treatments more effective (1988).

Within the context of current issues such as biological diversity, climate change, and long-term site productivity, there is a need for better understanding of the reproductive process of each boreal tree species (Zasada et al 1992).

Blum (1973) suggests further investigating the idea of advance regeneration, and more particularly 'well-established' regeneration that can be relied upon to reproduce the next stand. In a study of a shelterwood operation 15 years after treatment, there appeared to be no remaining seedling trees, only those produced as a result of the shelterwood method. Thus, it is not clear whether adequate advance regeneration can be obtained in stands that have not been subjected to immediate harvests or modification of the crown canopy from natural causes.

12.3 OTHER RECENT RESEARCH SUGGESTIONS FROM WHITE SPRUCE RESEARCHERS

Integrated resource management includes forest management and is frequently related to public benefits. Few attempts are made, however, explicitly to assess the impacts of forest management on the magnitude and distribution of benefits--mainly due to lack of knowledge on the human dimensions (the people-aspects of natural resources management) promoting the integration of social sciences with biology and ecology to maximize human benefits from the management of renewable natural resources (Gigliotti and Decker 1992) of various forest uses. For example, managers have often not identified the users of forested lands.

12.4 INFORMATION NEEDED TO ENHANCE NATURAL REGENERATION

In general, three levels of future forestry with respect to natural regeneration can be mentioned with different consequences for applied research.

If there is little concern, when harvesting, for further development or yield, little research or knowledge is needed. This is a low intensity approach which is rather rare in these days of consciousness for the future of today's forests.

Harvesting merchantable trees while securing natural regeneration is of medium intensity level and depends greatly on climate, soil and species, thus vast knowledge on these specific factors is important.

Artificial regeneration or intense natural regeneration is of the high intensity level and generally involves a multitude of questions requiring research.

Regardless, a regeneration program for research and applied management of any intensity level is based on the existing conditions for instance terrain, site, species, and climate (Braathe 1980).

12.5 SUMMARY OF INFORMATION GAPS

Undoubtedly, conifers and hardwoods will be of interest in the forest industry for some time and indications have been that a new philosophy for the management of mixedwood stands must be developed. Thus, it is imperative that continuing consideration must be given to management and renewal of softwood species, and a greater attention will have to be given to sound and economical techniques to ensure the softwood component is maintained.

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Appendix 1:
GLOSSARY

The majority of the information gathered in the Glossary was consolidated from the glossaries of the following three sources:

Peterson and Peterson 1992;
Little 1980; and
Johnson el al. 1995.

abiotic: 1) having no life; lifeless; 2) independent of the vital processes of a living organism.

alkaline: containing unusually high levels of soluble mineral salts (usually chlorides, sulfates, carbonates, and bicarbonates of sodium, potassium, magnesium and calcium).

alluvium (alluvial): material such as clay, silt, sand and gravel deposited by modern rivers and streams.

allelopathy (allelopathic): a form of antibiosis in which chemicals produced by one plant species inhibit the germination, growth, or occurrence of other species.

allozyme: sex chromosome.

annual: living for only one year.

annual allowable cut: the amount of timber that is permitted to be cut annually from a specified area in accordance with the objects of management.

apical: at the apex or tip.

aquatic: living or growing in water.

Autecology: the study of the physiological functions of individual organisms in field environments or communities; life history studies of species or ecotypes.

bark: the outer covering of the trunk and branches of a tree, usually corky, papery or leathery.

basal area: the area of a cross section of a tree at breast height usually expressed at the summation of the basal area of trees in a stand per unit area of land.

biological diversity (biodiversity): the variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems, and the ecological complexes of which they are part. This includes diversity within species, between species and of ecosystems.

biomass: the living matter of a given habitat, expressed as fresh or dry weight of living matter per unit area of habitat.

bisexual: with male and female organs in the same flower.

blight: sudden and severe damage to leaves, flowers and stems.

bole: the unbranched stem or trunk of a tree.

bloom: a waxy powder covering the surface.

bract: a reduced or specialized leaf associated with , but not part of, a flower or flower cluster; in conifers, an appendage of the central stalk of a cone; a modified and often scali-like leaf, usually located at the base of a flower, a fruit, or a cluster of flowers or fruits.

branchlet: a small branch.

browse (browsing): grazing of shrubby or woody material.

bryophyta (bryophytes): division of plants kingdom comprising liverworts, mosses and hornworts; a small group of plants with wide distribution and various habitats; some are epiphytes, others aquatic; small plants, flat, prostrate, or with a central stem up to 30 centimeters in length bearing leaves; lacking vascular tissue; attached to substratum by rhizoids; reproduce sexually by fusion of male and female gametes produced in multicellular sex organs.

bud: a young undeveloped leaf, flower or shoot, usually covered tightly with scales.

calcareous: calcium-rich; soil rich in lime.

cambium (cambial): a single layer of cells between the woody parts of the tree and bark; division of these cells results in diameter growth of the tree through formation of wood cells (xylem) and inner bark (phloem).

canopy: the more or less continuous cover of branches and foliage formed collectively by the crowns of adjacent trees and other woody growth; layers of canopy may be distinguished by the terms overstory and understory.

chlorosis (chloritic): an abnormal condition in plants in which the green parts are blanched or yellow due to inadequate formation of chlorophyll, usually resulting from lack of iron or magnesium in the soil, or from a lack of light.

claypan: 1) a layer of clay in the soil 2) a slight depression or shallow hole in the surface of the ground, having a bottom of clay or silt.

clear-cutting: the harvesting of all trees from an area of forest land in a single cut; a forest management method that involves the complete felling and removal of a stand of trees. Clearcutting may be done in blocks, strips or patches.

climax species: species of trees or other vegetation often found in a forest ecosystem at the final stage of its development.

cone: a conical fruit consisting of seed-bearing, overlapping scales around a central axis.

conifer: cone-bearing tree that has needles or scale-like leaves, usually evergreen; the wood of conifers is known commercially as softwood.

controlled burning (prescribed burning): the knowledgeable application of fire to a specific land area to accomplish predetermined forest management or other land management objectives.

coppice system: a system in which trees or shrubs are cut or trimmed to promote further regeneration.

crown: the upper part of a tree carrying the main branch system and foliage.

cull: any item of production (trees, logs, lumber) that is rejected because it does not meet certain specifications. The unusable, decayed portions of stems are referred to as cull.

cultivar: a contraction of 'cultivated variety'; a named group of plants within a cultivated species.

cultivated: planted and maintained by man.

damping-off: death of seeds or seedlings, usually by soil-borne fungi.

decay: disintegration of wood tissue.

deciduous: shedding leaves seasonally, and leafless for part of the year.

density, stand: a quantitative measure of tree stocking, expressed as a number of stems per unit area.

dieback: any plant part that dies; death of extremeties of the branches or leaves; usually used to describe winter injury.

dissemination: the act or process of scattering of state of being scattered widely ; a spreading abroad; diffusion.

dorsal: on the upper (outer) side, the side away from the stem; opposite to ventral.

duff: decaying vegetable matter such as fallen leaves, covering the ground in a forest.

dysgenic: having to do with or causing generation in the type of offspring produced.

ecosystem: a community of organisms functioning and interacting together within their physical environment; also the integration of all living and non-living components of the environment in a defined space and time.

edaphic: referring to the soil; the influence of soil upon plant growth is referred to as an edaphic factor.

efficacy: the effectiveness of a given technique for controlling a given target species or species group.

epigeal: living close to the ground, as some insects.

epiphytes: a plant growing on or attached to another plant, or often on some non-living support, but not parasitic upon the plant or support to which it is attached.

ericaceous: belonging to the heath family.

escaped: spread from cultivation and now growing and reproducing without aid from man.

fen: a mineral-rich wetland with slow-moving often alkalaine water with sedge and brown moss (not *Sphagnum*) peat.

ferromagnesian: containing iron and magnesium silicates.

fleshy: plump, firm and pulpy; succulent.

floodplain: a plain bordering a river and built up with stream deposits from repeated flooding.

foliar: of or having to do with a leaf or leaves.

follicle: a dry, 1-celled fruit, splitting at maturity along a single grooved line.

forb: any herb, excluding grasses and plants resembling grasses; a broad-leaved, non-woody plant that dies back to the ground after each growing season.

forest life cycle: the natural development of the forest from seedling to maturity, decline and back to seedling.

forest management practices: techniques and applications used to manage a forest to maximize economic, environmental or social goals.

forest use: consumptive and non-consumptive uses, whether for commercial or non-commercial purposes. e.g.: recreation and park development, trapping, timber harvesting, etc.

forest resources: the supply of goods and services from the forest. e.g.: trees, wildlife, recreational opportunities, etc.

free-growing: a height class that refers to young trees that are as high or higher than competing brush vegetation. An example of a precise definition of "free-growing" specifies that there should be a 1-m radius of free space surrounding the growing tip of a young tree. When this condition prevails, the tree is classified as 'free-to-grow'.

fruit: a ripened ovary, together with any other structures that ripen with it as a unit.

genus: a group of closely related species. Plural, genera.

gibberellins: any one of a group of hormones that are synthesized in the protoplasm of plants and that increase the rate and the amount of growth.

girdle (girdling): to kill a tree by severing or damaging the cambium layer and interrupting the flow of food between the leaves and the rest of the tree.

gley (gleysolic): a sticky, clayey soil developed under the influence of excessive moistening.

goegraphical information system (G.I.S.): a computerized information system which uses a special database to provide answers to queries of a geographical nature through a variety of manipulations such as sorting, selective retrieval, calculation, spatial analysis and modelling.

graft: a shoot or bud of one plant inserted into the stem or trunk of another.

habit: the characteristic growth form or general shape of a plant.

hardwood(s): trees belonging to the botanical group Angiospermae having broad leaves that are usually shed annually. Also refers to stands of such trees and the wood produced by them.

heartwood: the central part of a tree that does not conduct water.

heath: 1) open wasteland with heather or low bushed growing on it ; moor. A heath has few or no trees. 2) any one of various plants and low bushes growing on such land. Heather is one kind of heath. 3) Any one of a group of low evergreen shrubs with needlelike leaves.

herb: plant with no persistent parts above ground, as distinct from shrubs and trees.

herbicides: any chemical agent used to kill plants, especially weeds or weed seeds.

humus: the fraction of the soil organic matter that remains after most of the added plant and animal residues have decomposed. It is usually dark in color; may also refer to all the dead organic material on and in the soil that undergoes continuous breakdown, change and synthesis.

hybrid: 1) genetic: an organism resulting from a cross between parents with different genotypes; 2) taxonomic: a cross between parents of different species.

hydric: a hydric habitat is characterized to be very poorly drained soils in which the water is removed so slowly that the water table is at or above the soil surface all year. These soils are usually gleyed mineral or organic.

hypocotyl: the part of a plant embryo below the cotyledons, between the stem and the roots.

integrated forest resource management: a holistic approach to forest management involving preservation, protection, extraction and development that includes managing two or more resources in the same general area, such as water, soil, timber, grazing land, fish, wildlife and recreation.

intensive forest management: the practice of forest renewal, improvement of plantations and natural stands and tree improvement.

intergradation: the gradual merging of 2 or more distinct forms or kinds, through a series of intermediate forms.

introduced: intentionally or accidentally established in an area by man, and not native; exotic or foreign.

introgression: the introduction, often by chance backcrossing, of the genes of one species into another species.

kame: a hill or ridge of glacial detritus; esker.

lacustrine: 1) of lakes; 2) living or growing in lakes; 3) of or having to do with strata that originated by deposition, at the bottom of a lake.

layering: a form of vegetative reproduction in which branches droop to the ground and root.

leaching (leachates): the removal by percolating water of soluble constituents (leachates) from humus, soil, or other parent materials.

leaflet: one of the leaflike subdivisions of a compound leaf.

linear: long, narrow, and parallel-sided.

litter: the uppermost slightly decayed layer or organic matter on the forest floor.

liverworts: Hepaticae; class of Bryophyta; living in wet conditions, on soil or as epiphytes, or in water; consisting of a thin, prostrate plant body or a creeping central axis up to approximately 5 cm in length, provided with leaf-like expansions; attached to soil by rhizoids growing from under surface; sexual organs antheridia and archagonia, variously grouped, male gametes motile by flagella; fertilization is followed by development of a capsule containing spores which, being shed, germinate in most forms to form a short, thalloid protenema from which new liverwort plants arise.

luvisolic: an order of soils that have eluvial (Ae) horizons and illuvial (Bt) horizons in which silicate clay is the main accumulation product. The soils developed under forest or forest-grassland transition in a moderate to cool climate.

male cone: the conical, pollen-bearing male element of a conifer.

megastrobilli: seed cones.

melanized: darkened.

merchantable : commercial, marketable, salable.

meristemic: the undifferentiated, growing cellular tissue of the younger parts of plants; actively dividing cell tissue.

mesic: a habitat that is medium in moisture supply; the water is removed somewhat slowly in relation to supply; soil may remain moist for a significant, but sometimes short period of the year; characterized by medium moisture supplies; neither very wet nor very dry.

micropyle (micropylar): the minute opening in the outer layer or layers of an ovule, through which pollen enters.

microsites: small or very small, microscopic areas delimited by fairly uniform climatic and soil conditions.

mixedwood: a forest composed of trees of two or more species; usually at least 20% of the trees are other than the leading species.

monocultures: cultivation of a single crop or product on a piece of land to the exclusion of other products or crops; raising crops of a single species, generally even-aged.

monoecious: having the stamens and pistils in separate flowers on the same plant.

mor: a peaty kind of humus, poor in lime and nitrogen and unsuitable for plant growth.

morphology: the study of the form, structure, and development of organisms.

mosses: Musci; very small, soft green or brown plants that grow close together like a carpet on the ground, on rocks or on trees. There are various kinds, making up a class of plants called Bryophyta; mosses have small stems and numerous , generally narrow leaves: world-wide distribution, occurring in damp habitats e.g. moist woodland, in water, and under drier conditions, e.g. on heaths, walls; a moss plant consists of a prostrate or erect stem, bearing closely arranged leaves and anchored to the substratum by rhizoids.

mycorrhizae (mycorrhizal): the symbiotic relationship between certain fungi and the roots of certain plants, in which the fungus grows on the outside of the root of in the outer root tissues, taking on the function of root hairs; an association between hyphae of certain fungi and roots of higher plants.

natural regeneration: renewal of a tree crop by the natural occurrences of seeding, sprouting, suckering or layering.

naturalized: a foreign species that has adapted to the environment of the region.

needle: the very long and narrow leaf of pines and related species.

needle cast: lost or casting needles of coniferous trees.

old-growth forests: a stand of mature or overmature trees relatively uninfluenced by human activity; forest stands essentially free from catastrophic occurrences (such as fire) containing large, old trees of long-lived species; stand can contain multiple layers of tree canopies and various ages and species of vegetation.

overstory: those trees that form the upper canopy in a multi-layered forest, with smaller trees and shrub layers referred to as the understory.

parasite: an organism living in or on another living organism and obtaining its nutrients from the host; compare saprophyte.

Pathology: the study of diseases. Pathogens are agents such as viruses, bacteria, or fungi which transmit or cause diseases.

peat: a kind of heavy turf of partly rotted moss and other plants, especially sphagnum moss. It is used as a fertilizer and fuel in some countries.

perennial: growing for three or more years, usually flowering and producing fruit each year.

permafrost: permanently frozen ground.

pesticides: any chemical agent or biological substance used to destroy or suppress animal (e.g. insect) or plant pests.

phloem: a layer of tree tissue just inside the bark that conducts food from the leaves to the stem and roots.

pioneer: a plant capable of invading newly exposed soil surfaces and persisting there until supplanted by successor species. A species that can serve as a nurse crop because it will tolerate planting on a bare site where it can prepare the site for successor species.

pioneer species: tree species that establish themselves before other species in a forest area that has recently been cleared by nature or by mechanical means.

pith: the soft, spongy innermost tissue in a stem.

podzol (podzolic): white or grey soil that is highly leached, found in certain cool, moist climates.

powdery mildew: a fungus belonging to the order Erysiphales of the class Ascomycetes.

primordia: 1) the very beginning or earliest stage 2) the first cells in the earliest stages of the development of an organ or structure.

prescribed fire: controlled application of fire to fuels in either their natural or modified state under such conditions of weather, fuel moisture, soil moisture, etc. as allow the fire to be confined to a predetermined area and at the same time to produce the intensity of heat and rate of spread required to further certain planned objectives of silviculture, wildlife management, grazing, fire-hazard reduction, etc.

production (productivity): production refers to the total quantity of organic material produced within a given period by organisms, or the energy that this represents such as gram-calories per square centimeter per year. Productivity is a more general term referring to the innate capacity of an environment to produce plant and animal biomass or the capacity of the soil to produce a certain crop under a defined set of management conditions.

propogation: the increase of the number of plants, either through seed production or vegetatively by cuttings of stems, roots, or other asexual organs.

propagules: a bud or other offshoot able to develop into a new plant.

progeny: something that is produced by or originates from something.

prolific: conducive to abundant growth or production.

provenance: the geographic place of origin of seeds or other plant materials used for propogation.

ramet: in horticulture, one of the plants in a clone.

reforestation: the natural or artificial restocking (planting, seeding) of an area with forest trees; also called forest regeneration.

release: term used to indicate the 'freeing-up' of space for a designated tree species through the removal of part of its surrounding tree vegetation in order to increase growth potential

regeneration: the renewal of a tree crop by natural or artificial means.

reproduction method: the combination of cutting methods and other treatments by which a stand is established or renewed.

resinosis: excessive outflow of resin from coniferous plants, ususally resulting from injury or disease.

rhizome: an underground, often lengthened stem; distinguished from root by the presence of nodes and buds or scale-like leaves.

roots, adventitious: a root that has developed at a location other than the usual or expected, such as roots growing from leaves or from aboveground stems.

root, lateral: a root that extends more or less horizontally from the central vertical axis of a root system.

root, sinker: a root that extends vertically from lateral roots or from the central part of a root system.

root, primary: the first root of a germinating seed usually grows directly downward and is known as the primary root.

rot: disintegration and decomposition of plant tissue accompanied by discoloration.

rotation: the planned number of years between the regeneration of a stand of trees and its final cutting at a specified stage of maturity.

rotation age: the age at which a stand is considered to be ready for harvesting.

scarification: a method of seedbed preparation that consists of exposing patches of mineral soil through mechanical treatment with heavy equipment.

selective harvesting: a silvicultural system in which trees are removed periodically in small groups, resulting in openings of 1 ha or less in area. This leads to the formation of an even-aged stand in the form of a mosaic of age-class groups in the same forest.

selective logging: a partial-harvest method that removes only the most valuable species of trees, or only trees of prescribed size and quality.

serotinous: appearing, blooming or producing leaves late in the season; often applied to the cones of evergreens that remain on the tree unopened until high temperatures melt their resins, opening up the scales.

shade tolerant (intolerant): the capacity (incapacity) of a tree or plant to develop and grow in the shade of other trees or plants.

sheath: a tubular, surrounding structure; in some conifers, the papery tube enclosing the base of a bundle of needles.

shelterwood: harvest removals from a stand by a series of partial cuttings, resembling thinnings, that remove the entire stand within a period of years which is a small fraction of the rotation age; the goal of this silvicultural system is to encourage natural reproduction under the protection of the residual older stand, with gradual release of the regeneration from this shade and protection when it is able to endure the exposure.

shoot: a young, actively growing twig or stem.

short-wood harvesting systems: a harvesting method by which a tree is cut down, delimbed and cut into 1.3-, 2.6-, 3.2-, or 4.8- metre (4-, 8-, 12-, or 16-foot) lengths before being transported to a mill.

shrub: a woody plant, smaller than a tree, with several stems or trunks arising from a single base; a bush.

silviculture: theory and practice of controlling the establishment, composition, growth and quality of forest stands to achieve certain management objectives.

silvicultural system: a process whereby forests are tended, harvested, and replaced, resulting in a forest of distinctive form; silvicultural systems are classified according to various methods of carrying out the fellings that remove the harvestable crop with a view to regeneration and according to the type of forest thereby produced/the planned program of silvicultural treatments during the life of a stand.

site: an area delimited by fairly uniform climatic and soil conditions, essentially equivalent to habitat.

site index: a numerical evaluation of the productivity of forest land, commonly expressed as the average height of several dominant trees in a stand, on a species by species basis, at some index age of 50, 70, or 100 years.

slash: the residue left on the ground after harvest removal, including unused logs, uprooted stumps, broken tops, and branches.

slashburning: burning the residue on the forest floor that is left after stand tending or harvesting , or after accumulating from natural causes.

softwood(s): cone-bearing trees with needle or scale-like leaves belonging to the group Gymnospermae; also refers to stands of such trees and the wood produced by them.

soil horizon: a layer of the soil, approximately parallel to the soil surface, with distinctive characteristics produced by soil-building processes.

species: a kind or group of plants or animals , composed of populations of individuals that interbreed and produce similar offspring.

stand: a community of trees sufficiently uniform in species, age, arrangement, or condition to be distinguishable as a group from other groups of trees in a forest.

stand management: management of natural and planted forest stands, generally for fibre production.

stocking: a measure of stand density, usually expressed as number of stems per hectare, although it is sometimes estimated by crown closure on aerial photographs; when a site is not occupied by as many trees as it could support for maximum productivity, it is called understocked; if there are too many trees per unit area to allow their development to harvestable size, the stand is classified as overstocked.

strobile: any seed producing cone, such as a pine cone, or a compact mass of scalelike leaves that produce spores, such as the cone of the club moss.

sub-: almost.

subalpine: of or having to do with, or characteristic of mountain regions next in elevation below those called alpine, usually between 1200 and 1650 metres in most parts of the North or South temperate zones.

substrate: the surface on which something grows.

succession (successional): the gradual replacement of one plant community by another in a naturally occurring, progressive development toward climax vegetation.

sucker (suckering): a shoot arising from a root system or from the underground part of the stem or base part of a tree or shrub.

sustainable development: sustainable development of the forests and their multiple environmental values involves fostering, without unacceptable impairment, the productivity, renewal capacity and species diversity of forest ecosystems.

sustained yield: a method of forest management that calls for an approximate balance between net growth and the amount harvested over the rotation age on a management area.

sympatry (sympatric): the existence of plant or animal species in the same area without hybridization through interbreeding.

synecology: the study of habitat factors and the physiological response of species and species groups to these factors; study of community functioning and the niche functions of plant populations in an ecosystem context

taproot: a primary, descending root.

tenure: a holding or designation of land for a given period or the rights and responsibilities associated with managing that land or its resources. Tenure holdings on provincial Crown lands include provincial forests, provincial parks, ecological reserves, forest management licenses, etc.

thinning: removal of selected trees from a stand for the purpose of improving the growth and value of the remaining crop trees.

tracheid: an elongated, more or less lignified cell with thick, perforated walls, that serves to carry water and dissolved minerals through a plant, and provides support.

tree line: the upper limit of tree growth at high latitudes or on mountains, timberline.

understory: those trees or other vegetation in a forest stand below the main canopy level, which is referred to as the overstory.

vegetative reproduction: producing new plants from asexual parts (e.g. rhizomes, leaves, bulbils); offspring are genetically identical to the parent plant.

volume, merchantable: the amount of sound wood in a single tree or stand that is suitable for processing into specified products; the gross (total) volume of a tree stem is commonly reduced by the amount of cull in the stem to arrive at an estimate of merchantable (net) volume of usable wood in the stem.

wildfire: an uncontrolled forest fire.

windfirm: virtually unaffected by wind.

windthrow: trees uprooted by wind.

witches' broom: a proliferation of branches caused by a disease or other causes.

wood: the hard, fibrous inner tissue of the trunk and branches of a tree or shrub.

xylem: complex tissues in the stems of plants that provide strength to the stem and also serve as the main water-conducting tissue from the roots through the stem to the photosynthetic system in the foliar canopy.

Appendix 2:
LIST OF SCIENTIFIC AND COMMON NAMES FOR PLANT AND PATHOLOGICAL/ENTOMOLOGICAL SPECIES

Scientific Name	**Common Name**
FOREST TREE SPECIES:	
Abies balsamea	Balsam fir
Acer pensylvanicum	Striped maple
Acer rubrum	Red or soft maple
Acer spicatum	Mountain maple
Alnus crispa	American green alder
Alnus spp.	Alder species
Betula glandulosa	Ground or dwarf birch
Betula lenta	Cherry or sweet birch
Cornus stolonifera	Red-osier dogwood
Fraxinus americana	White ash
Larix laricina	Tamarack
Ostrya virginiana	Ironwood
Picea abies	Norway spruce
Picea engelmannii	Engelmann spruce
Picea glauca	White spruce
Picea mariana	Black spruce
Picea rubens	Red spruce
Picea sitchensis	Sitka spruce
Pinus contorta var. *latifolia*	Lodgepole pine (mountain form)
Pinus contorta	Lodgepole pine (shore form)
Pinus ponderosa	Ponderosa pine
Pinus resinosa	Red or Norway pine

Scientific Name	Common Name
Pinus strobus	EasternWhite pine
Populus tremuloides	Trembling aspen
Prunus serotina	Black Cherry
Quercus rubra	Red oak
Salix arbusculoides	Littletree willow
Salix bebbiana	Bebb willow
Salix glauca	Greyleaf willow
Salix spp.	Willows
Sorbus americana	American mountain-ash
Sorbus decora	Showy mountain-ash
Tilia americana	American basswood
Ulmus americana	White elm
Ulmus thomassi	Rock elm

UNDERSTORY SPECIES (Shrubs, Herbs, Mosses):

Amelanchier alnifolia	Saskatoon or western serviceberry
Arctostaphylos uva-ursi	Bearberry
Aster macrophyllus	Big-leaf aster
Blepharostoms trichophyllum	Ragged moss
Calamagrostis canadensis	Blue-joint grass
Calamagrostis spp.	Reed grasses
Cetraria islandica	Iceland moss
Cladonia alpestris	Reindeer moss

Scientific Name (Authority)	**Common Name**
Cladonia gracilis ssp. *turbinata*	Slender cup lichen
Cladinia rangiferina	Reindeer lichen
Cladonia spp.	Club or cup lichens
Cornus canadensis	Bunchberry
Corylus cornuta	Beaked hazel
Dicranum fuscescens	Curly heron's-bill moss
Dicranum spp.	Broom mosses
Drepanocladus uncinatus	Sickle moss or hook moss
Empetrum nigrum	Black crowberry
Epilobium angustifolium	Fireweed
Equisetum arvense	Field horsetail
Equisetum sylvaticum	Woodland horsetail
Gaylussacia baccata	Black huckleberry
Gaylussacia spp.	Huckleberry species
Goodyera repens	Dwarf rattlesnake-plantain
Hylocomium splendens	Stair-step moss
Hylocomium spp.	Step mosses
Kalmia angustifolia	Sheep laurel
Kalmia polifloia	Bog laurel
Kalmia spp.	Laurel species
Lathyrus venosus	Purple paevine
Lathyrus ochroleucus	Creamy paevine
Lathyrus spp.	Paevine species

Scientific Name	**Common Name**
Ledum groenlandicum	Labrador tea
Linnaea borealis	Twinflower
Lonicera canadensis	American fly honeysuckle
Lophozia venticosa	leafy liverworts
Lycopodium annotinum	Stiff club-moss
Menziesia spp.	Menziesia species
Mitella nuda	Naked bishop's cap
Moneses uniflora	One-flowered wintergreen
Peltigara apthosa	Freckle pelt
Peltigera canina	Dog pelt
Pleurozium scheberi	Shreber's moss
Prunus virginiana	Chokecherry
Ptilium crista-castrensis	Knight's plume
Ptilidium ciliare	Northern naugehyde liverwort
Ptilidium pulcherrimum	Naugehyde liverwort
Pyrola secunda	One-sided wintergreen
Rhamnus alnifolia	Alder buckthorn
Rhododendron spp.	Rhododendron species
Ribes triste	Red currant
Ribes spp.	Gooseberries and currants
Rosa acicularis	Prickly wild rose
Rubus idaeus	Wild red raspberry
Rubus spp.	Raspberry species

Scientific Name	Common Name
Shepherdia canadensis	Buffaloberry or soapberry
Solidago canadensis	Goldenrod
Solidago spp.	Goldenrod species
Sphagnum fuscum	n.a.
Sphagnum spp.	Sphagnum species
Symphoricarpos albus	Snowberry
Vaccinium membranaceum	Black huckleberry
Vaccinium uliginosum	Alpine blueberry
Vaccinium vitis-idaea	Mountain cranberry
Valeriana spp.	Valerian species
Viburnum edule	Squashberry
Viburnum trilobum	High bush cranberry

PATHOLOGICAL/ENTOMOLOGICAL SPECIES:

Adelges strobilobius	Spruce gall aphids/ adelgids
Arceuthobium americanum	Dwarf misteltoe
Arceuthobium pusillum	Dwarf mistletoe
Argyrethsia spp.	Budminer species
Armillaria ostoyae	Armillaria root rot
Cacoecia fumiferana	Spruce budworm
Chermes abietes	Spruce fall aphid

Scientific Name	Common Name
Chionaspis pinifolia	Pine needle scale
Chrysomyxa arctostaphyli	Broom rust, yellow witches' broom
Chrysomyxa ledi	Needle rust
Chrysomyxa ledicola	Large-spored spruce-Labrador tea rust
Chrysomyxa pirolata	Spruce cone rust
Cydia strobilella	Spruce seed moth
Dendroctonus borealis	Alaskan spruce beetle
Dendroctonus piceaperda	Eastern spruce beetle
Diorictria spp.	Cone borers
Diprion polytomum	European saw-fly
Fomes pini	Red ring rot
Fusarium spp.	Fusarium root rot
Herpotrichia spp.	Snow mold
Hypomolyx piceus	Spruce root collar weevil
Kaltenbachiola rachiphaga	Spruce cone axis midge
Laspeyresia yougana	Spruce seedworm
Leucostoma kunzei	Leucostoma canker of spruce
Leucostoma kunzei var. *piceae*	Cytospora canker
Megastigmus atedius	Spruce seed chalcid

Scientific Name	**Common Name**
Oligonychus ununguis	Spruce spider mite
Pegohylemia anthracina	Spruce cone maggot
Phacidium infestans	Snow blight
Pikonema alaskensis	Yellow-headed spruce sawfly
Pissodes strobi	White pine weevil
Polyporus schweinitzii	Red brown rot
Polyporus sulfueus	Brown cubical rot
Pucciniastrum americanum	Needle rust
Rhabdophaga swainei	Spruce bud midge
Strobilomyia neanthracina	Spruce cone maggot
Zeiraphera ratzebugiana	Defoliator

Appendix 3:
LIST OF SCIENTIFIC AND COMMON NAMES FOR MAMMALIAN AND AVIAN SPECIES

Scientific Name	Common Name
Alces alces	Moose
Canis lupus	Wolf
Cervus canadensis	Elk
Clethrionomys spp.	Red-backed vole
Erethizon dorsatum	Porcupines
Ursus americanus	Black bear
Gulo gulo	Wolverine
Leporidae	Hares and Rabbits
Lepus americanus	Snowshoe hare
Lynx lynx	Lynx
Microtus spp.	Meadow voles
Martes americana	Marten
Odocoileus virginianus	White-tailed Deer
Sciurus carolinensis	Gray squirrels
Tamias stiatus	Eastern Chipmunk
Tamiasciurus hudsonius	Red squirrel

Scientific Name	**Common Name**
BIRDS	
Tetraonidae	Grouse and Ptarmigan
Loxia spp.	Crossbills
Parus spp.	Chickadees
Pheucticus ludovicianus	Rose-breasted grosbeak
Pinicola enucleator	Pine grosbeak

Appendix 4:
IMPERIAL CONVERSIONS FOR METRIC UNITS FOUND IN DOCUMENT

Metric (SI) Unit		Imperial Equivalent
LENGTH:		
1 cm	=	.393700 inches
1 metre	=	3.280840 feet
1 metre	=	1.093613 yards
1 kilometre	=	.621371 miles
AREA:		
1 square metre	=	10.76391 square feet
1 square metre	=	1.19599 square yards
1 hectare	=	2.47105 acres
1 square kilometre	=	.38610 square miles
VOLUME:		
1 cubic centimetre	=	.061024 cubic inches
1 cubic metre	=	35.31467 cubic feet
1 cubic metre	=	1.30795 cubic yards
MASS:		
1 gram	=	.035274 ounces
1 kilogram	=	2.204622 pounds
RATIOS:		
1 square metre/hectare	=	4.34782 square feet/acre
1 cubic metre per hectare	=	14.28571 cubic feet/acre
1 cubic metre per hectare	=	.111607 cords per acre
TEMPERATURE:		
1 degree celcius	=	(degrees Farenheit-32)/1.8

IMAGE EVALUATION TEST TARGET (QA-3)

150mm

6"

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