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The Autecology of Major Tree Species in the North Central Region of Ontario

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Abstract

This report provides information on the autecology of twelve commercial tree species occurring in the North Central (NC) Region of Ontario. It is intended to provide forest and resource managers working in the NC Region with summarized ecological information for the following common forest trees: balsam fir (*Abies balsamea*), white spruce (*Picea glauca*), black spruce (*Picea mariana*), tamarack / eastern larch (*Larix laricina*), jack pine (*Pinus banksiana*), red pine (*Pinus resinosa*), white pine (*Pinus strobus*), eastern white cedar (*Thuja occidentalis*), balsam poplar (*Populus balsamifera*), trembling aspen (*Populus tremuloides*), white birch / paper birch (*Betula papyrifera*), and black ash (*Fraxinus nigra*). Based on the Northwestern Ontario Forest Ecosystem Classification's extensive databases, vegetation, soil and site conditions associated with each species are summarized for the NC Region. Common autecological properties that relate to each species' survival, establishment, reproduction and growth are briefly described.

Résumé

Ce rapport traite de l'autécologie de 12 essences commerciales d'arbres qui croissent dans la région centre-nord de l'Ontario. Conçu à l'intention des gestionnaires des forêts et des ressources qui travaillent dans la région centre-nord, il présente un abrégé de renseignements écologiques sur les essences suivantes : sapin baumier (*Abies balsamea*), épinette blanche (*Picea glauca*), épinette noire (*Picea mariana*), mélèze laricin (*Larix laricina*), pin gris (*Pinus banksiana*), pin rouge (*Pinus resinosa*), pin blanc (*Pinus strobus*), thuja occidental (*Thuja occidentalis*), peuplier baumier (*Populus balsamifera*), peuplier faux-tremble (*Populus tremuloides*), bouleau à papier (*Betula papyrifera*) et frêne noir (*Fraxinus nigra*). Ce rapport donne aussi un résumé des sites, des sols et de la végétation associée à chacune des espèces dans la région centre-nord; ces reseignements sont tirés des importantes banques de données de la classification des écosystèmes forestiers du secteur nord-ouest de l'Ontario. On y trouve en outre un condensé des propriétés autoécologiques communes à ces espèces et qui ont trait à la survie, à l'établissement, à la reproduction et à la croissance.

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We thank Ken Baldwin and Bill Towill for their important contributions of thoughts and ideas, and their careful review of draft manuscripts. Martin Siltanen helped with computer analysis of NWO FEC data. Botanical line illustrations were rendered by Annalee McColm; all other graphics materials were prepared by Richard Rawling. The map of the North Central Region was adapted from *Field Guide to the Forest Ecosystem Classification for Northwestern Ontario* (Sims et al. 1989).

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Orientation 1.

1.1. Background and Objectives

This report provides information on the general autecology of 12 common tree species occurring in the North Central (NC) Region of Ontario:

Common Name	Scientific Name	Abbreviated Name
Balsam Fir	*Abies balsamea*	**Bf**
White Spruce	*Picea glauca*	**Sw**
Black Spruce	*Picea mariana*	**Sb**
Tamarack / Larch	*Larix laricina*	**L**
Jack Pine	*Pinus banksiana*	**Pj**
Red Pine	*Pinus resinosa*	**Pr**
White Pine	*Pinus strobus*	**Pw**
Eastern White Cedar	*Thuja occidentalis*	**Ce**
Balsam Poplar	*Populus balsamifera*	**Pb**
Trembling Aspen	*Populus tremuloides*	**Pt**
White Birch/Paper Birch	*Betula papyrifera*	**Bw**
Black Ash	*Fraxinus nigra*	**Ab**

Intended mainly for forest and resource managers working in the NC Region, this report provides some life cycle and silvicultural information on these 12 tree species. Using summaries from the Northwestern Ontario Forest Ecosystem Classification (NWO FEC) database (Sims et al. 1989), an overview of these species' soil/site relations within the NC Region are provided. Vegetation, soil and site conditions associated with each species in the NC Region are outlined. Autecological properties related to reproduction, germination, survival, establishment and growth are reviewed and summarized.

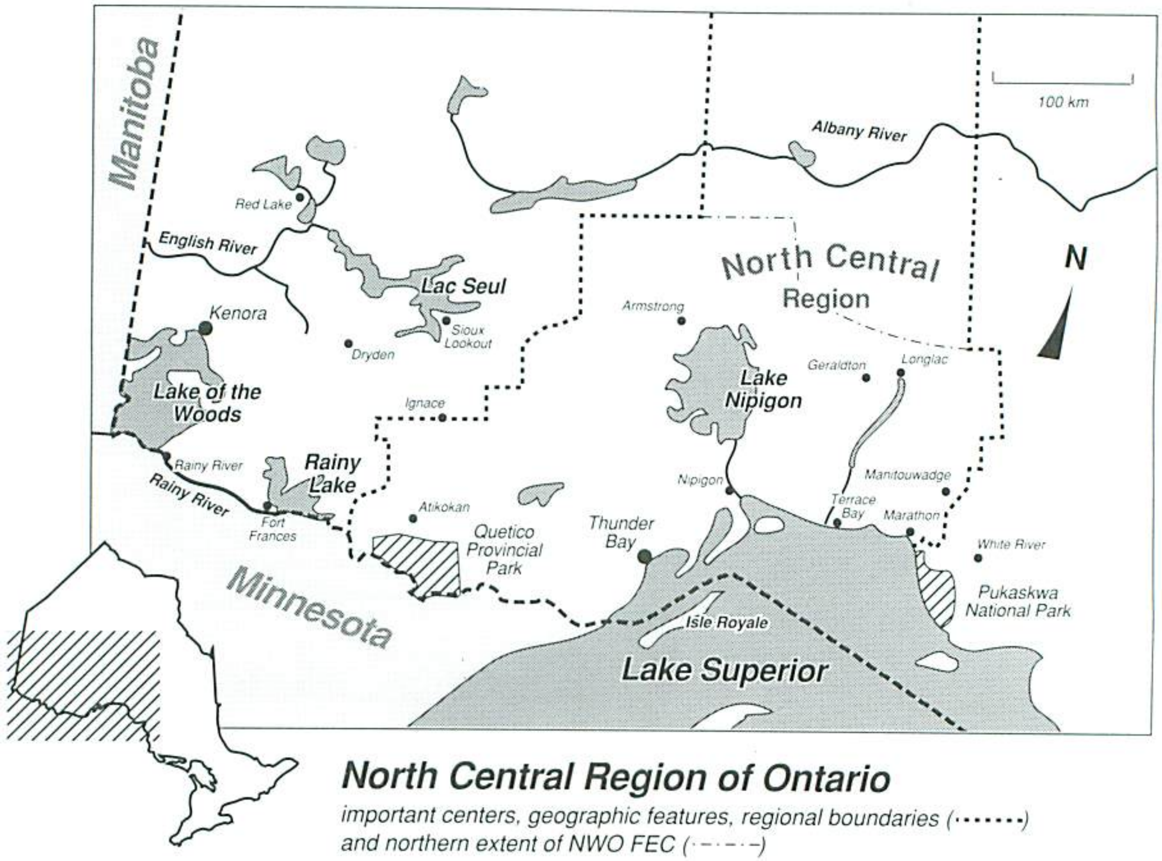
The material presented in this report should be considered as introductory; the literature cited section provides the reader with references to many more specific sources of information. This report complements recent and thorough monographs dealing with most of these species in Ontario (e.g., Robinson 1974, Heeney et al. 1975, Anon. 1986b, Arnup et al. 1988, Chapeskie et al. 1988, Davidson et al. 1988, Anderson et al. 1990) and elsewhere (e.g., Vincent 1965, Bakuzis and Hansen 1965, Maini 1968, Sutton 1969, Stiell 1976, Perala and Alm 1990a,b). In the northern United States, a series of useful forest management handbooks has been prepared (Marquis et al. 1969, Benzie 1977a,b, Johnston 1977a,b,c, Perala 1977, Tubbs 1977, Ohmann et al. 1978) to help apply autecological knowledge to operational forestry. Such publications may be consulted for more detail on individual topics.

Some suggestions are made here regarding common management options for various tree species, but these options may not be possible or appropriate in some instances.

1.2. Geographic Setting

This report deals with selected tree species and forest ecosystems found within the NC administrative region of the Ontario Ministry of Natural Resources (OMNR). The geographic area represented is actually only the southern, commercially forested zone of the NC Region; this substantial area extends generally north and northwest of Lake Superior, and ranges from the Quetico / Ignace area in the west to the Manitouwadge / White River area in the east. The area of interest extends southwest to the Ontario - Minnesota international border and northward to the limit of commercial forest in this part of the province. The total commercially forested landbase in the NC Region exceeds 184,000 sq km (Anon. 1988).

The commercially forested zone of the NC Region is mostly within the Boreal Forest Region (Rowe 1972) and is characterized by extensive black spruce, jack pine and balsam fir forests as well as mixed stands of conifers and northern deciduous species such as trembling aspen, white birch and balsam poplar. The southwestern corner of the NC Region lies within a portion of the Great Lakes - St. Lawrence Forest Region (Rowe 1972). This area has a greater diversity of coniferous and hardwood species than the Boreal Forest Region, and includes, in addition to the above mentioned species, scattered occurrences of white and red pine, black ash, red maple (*Acer rubrum*), yellow birch (*Betula alleghaniensis*), American elm (*Ulmus americana*) and some other species (Zoltai 1965a, Rowe 1972).



North Central Region of Ontario

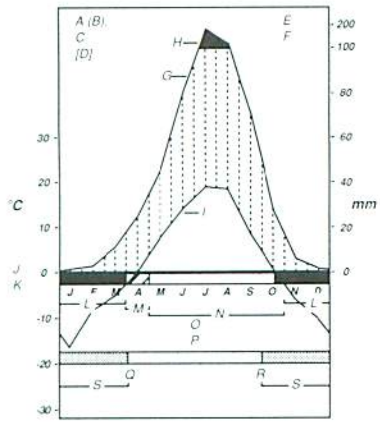
important centers, geographic features, regional boundaries (·······) and northern extent of NWO FEC (·-·-·-)

The forests of the NC Region comprise a diverse mosaic of vegetational and soil/site conditions. For example, pure, even-aged jack pine stands occur widely on well-drained, coarse-textured soils. Black spruce-dominated stands, often with poorly developed understory vegetation, occur across a range of soil and site conditions from shallow, mineral soils overlying bedrock to poorly drained, organic wetlands. Balsam fir, white spruce, trembling aspen, black spruce and white birch often occur in stands of mixed composition on a variety of dry to moist, coarse to fine textured soils. Tamarack and eastern white cedar are typically found in small pockets in peatland areas, although the latter species occasionally grows on more mesic sites. Extensive and repetitive forest fires, cyclical insect infestations, disease, logging and other factors have an ongoing and pervasive effect on the forests of the NC Region (Bedell and McLean 1952, Gross 1985, Arnup et al. 1988, Davidson et al. 1988, Anon. 1988).

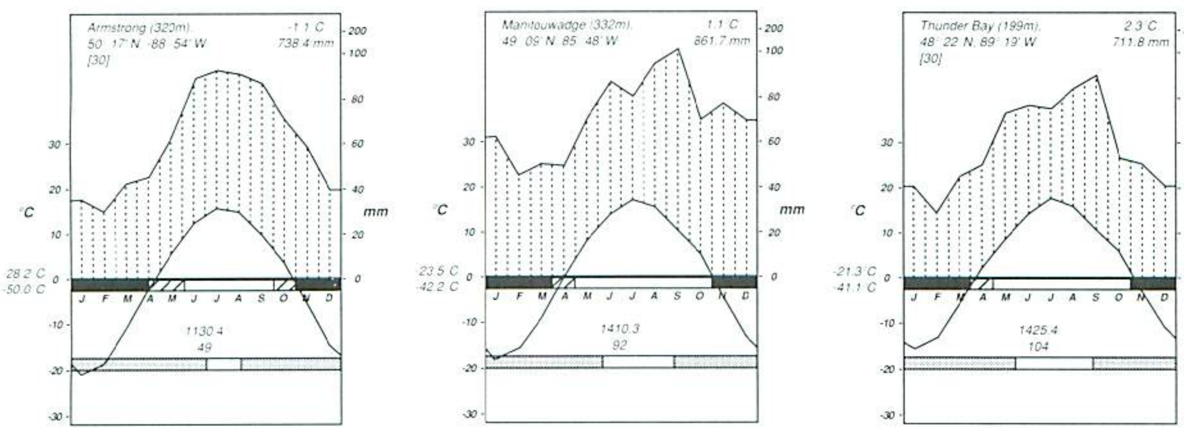
With the exception of a zone of strongly broken topography along the Lake Superior coast, the NC Region is characterized by an undulating, bedrock-dominated terrain (Zoltai 1965b). Surficial features generally reflect the effects of four major glaciations, the last ending approximately 10,000 years ago (Zoltai 1965b, 1967). Common surficial landforms include shallow glacial drift, undulating ablation and basal tills, morainal and drumlin features and large expanses of predominantly thin glacial sediments over rolling to rugged bedrock (Zoltai 1967, Sado and Carswell 1987). Glaciofluvial and glaciolacustrine deposits are very common but tend to be more localized. Other common surficial features in the NC Region include spillways, aeolian deposits and organic peat accumulations.

The climate of the NC Region is microthermal [C'21 to C'22] and humid [B'1 to B'3 - B'4] (Sanderson 1948). Two climatic gradients — temperature and humidity — generally stratify the area. Seasonal temperatures tend to increase with decreasing latitude and are moderated in proximity to Lake Superior (Chapman and Thomas 1968, Anon. 1982, 1987a); mean annual temperatures, for example, range from 0°C in the northern part of the Region to +2°C near the U.S. border in the southwestern corner of the Region (Anon. 1987a). Humidity (and precipitation) trends range from drier conditions in the west to moist in the east (Hills 1952, 1961, Hills and Pierpoint 1960, Chapman and Thomas 1968); mean annual precipitation ranges from less than 550 mm west of Kenora to over 800 mm in the Marathon / Manitouwadge general vicinity (Anon. 1987a).

Legend



A	Name of climatic station
B	Elevation of climatic station (meters above sea level)
C	Latitude and longitude of climatic station
D	Number of years of observations
E	Mean annual temperature (°C)
F	Mean annual precipitation (mm)
G	Curve of mean monthly total precipitation
H	Mean monthly total precipitation (scale reduced 1/10 for rainfall greater than 100 mm) [shown in black]
I	Curve of mean monthly temperature
J	Mean daily minimum temperature of the coldest month (°C)
K	Lowest recorded temperature (°C)
L	Months with mean daily temperature below 0°C (shown in black)
M	Months with mean daily temperatures above 0°C, but mean daily minimum temperatures below 0°C (diagonal hatching)
N	Months with mean daily temperatures above 0°C
O	Mean annual number of degree days (above 5°C)
P	Frost free period (days)
Q	Last frost
R	First frost
S	Frost period (screened area)



Climatic summaries for selected locations in the NC Region, Ontario *(Anon. 1982)*

1.3. Autecology Report - Layout and Methods

The description for each tree species is headed by the common and scientific name of the species followed by the taxonomic family name. Short summaries are provided on growth habit, shade tolerance, climatic range, frost resistance, flood tolerance, fire tolerance, successional status, and reproduction strategies, including crop cycle, crop abundance, seed viability, and seed dispersal. Factors required for germination, seedling survival and growth are identified. Height growth, root development, stand development and soil fertility requirements are briefly discussed. Examples of some common insect and disease problems are listed. Notes are provided on general management, but this section is not complete; only introductory and general comments are provided on the management of each species.

Much of the information provided here was obtained from searches of the scientific literature. Where information was directly available for either the NC Region, or geographically and climatically similar areas, it was used. Sometimes it was only possible to provide general or incomplete comments; unfortunately, many gaps still remain in our scientific and technical understanding of the autecology of these species.

In a number of places, this report makes reference to the Northwestern Ontario Forest Ecosystem Classification (NWO FEC). Some general background on the NWO FEC is provided in Section 1.4.; however, the reader is referred to the *Field Guide to the Forest Ecosystem Classification for Northwestern Ontario* (Sims et al. 1989) for further explanation.

During the NWO FEC program, considerable information was collected on soil and site factors associated with each of the 12 tree species. Data were collected in more than NWO FEC plots located throughout the NC Region (Sims 1989a,b, 1990, Sims et al. 1986). Microcomputer and VAX, minicomputer facilities at Forestry Canada, Ontario Region were used to summarize a variety of parameters (Appendix I), often according to class attributes for soil and site factors.

The dominant tree species associated with each NWO FEC plot in the NC Region was determined by comparing species' percentage-cover estimates from the overstory (i.e., *tree layer*, which includes individuals with diameters at breast height of 10 cm or greater and/or heights of 10 m or more). Plots were assigned to the species with the highest cover over 40%.

Overstory tree, shrub, herb, lichen and moss associated with each dominant tree species were compiled using species lists and percentage-cover information from NWO FEC field plot descriptions (Sims et al. 1986, 1989). Common vegetation associations were considered to be those which occurred with at least 40% frequency in plots in which a tree species was dominant. NWO FEC Vegetation Types associated with each of the 12 tree species were also identified.

The distribution of stands dominated by each tree species is shown in the NWO FEC Vegetation Type ordination diagram (page 8). Ordination of the NWO FEC Vegetation Types is described in section 2.1. and a few examples of environmental overlays are provided. For comparison, Section 2.1. also provides *habitat diagrams* for all of northwestern Ontario for the 12 tree species described in the report.

Soil/site parameters were field sampled and defined using standard soil and site description conventions (Canada Soil Survey Committee, Subcommittee on Soil Classification 1978, Working Group on Soil Survey Data 1978, Jones et al. 1983, Ontario Institute of Pedology 1985, Sims et al. 1989). NWO FEC Soil Types associated with stands dominated by each species are identified. Using soil pit information obtained during the NWO FEC field surveys, soil factors including deposition, texture, drainage, moisture regime, stoniness, structure, site position, and litter depth are described for each species, mostly based upon frequency occurence of stands associated with each soil/site condition.

Some soil/site attributes were subsequently grouped for analyses. Mode of landform deposition was summarized into 5 classes (Sims et al. 1989): morainal, glaciofluvial, fluvial, lacustrine and organic deposits. Soil texture classes were summarized according to family particle size classes for the *surface layer* (top 25 cm, typically portions of the A and B horizons), and *parent material* (C horizon) textures (Ontario Institute of Pedology 1985, Sims et al. 1989).

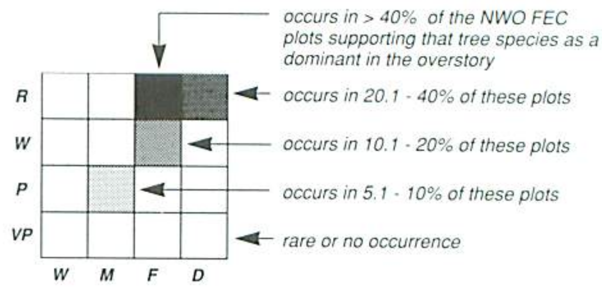
Soil moisture regime and soil drainage (Ontario Institute of Pedology 1985) were each summarized into 4 classes; a simple cross-tabulation of grouped moisture regime and drainage classes is provided for each tree species. The class groupings are:

Moisture Regime (x-axis):

W (wet)	moderately wet, wet, very wet	MR 7,8,9
M (moist)	moderately moist, moist, very moist	MR 4,5,6
F (fresh)	moderately fresh, fresh, very fresh	MR 1,2,3
D (dry)	dry, moderately dry	MR Ø,0

Soil Drainage (y-axis):

VP (v. poor)	very poor	Drainage Class 7
P (poor)	imperfect, poor	Drainage Classes 5,6
W (well)	well, moderately well	Drainage Classes 3,4
R (rapid)	very rapid, rapid	Drainage Classes 1,2



Depth of litter (LFH or O) was summarized into 4 classes: thin (1-5 cm of LFH), moderately thick (6-15 cm LFH), thick litter (>16 cm LFH) and organic (O >20 cm). Slope positions were combined into 4 classes (Ontario Institute of Pedology 1985): crest, upper/mid-slope, toe and depressions (lower/toe-slope, depressions) and level (no slope). Soil structure was summarized into 4 categories (Ontario Institute of Pedology 1985): blocky, single grain, amorphous and platy.

Sets of generalized height growth - age curves are provided for most tree species. Several of these sets of curves, which describe the growth potential of trees (cf. Plonski 1974), are derived from databases obtained from stands within the NC Region. However, where these did not exist, curves which may be generally applicable within the NC Region were selected from other geographic areas. These latter curves should be used with caution as their accuracy within the NC Region has not been properly assessed. The height - age curves all provide site index estimates for age 50 years (based on the height of dominant trees), unless noted otherwise in the figure caption.

1.4. The Northwestern Ontario Forest Ecosystem Classification (NWO FEC)

The NWO FEC system is an ecologically based system of site classification for NW Ontario (Sims et al. 1989). It forms a framework for effective organization, communication and application of forest management expertise (Sims and Towill 1988, Towill et al. 1988, LeBlanc and Towill 1989a, Racey et al. 1989a, Stocks et al. 1990) and is a valuable tool in the development of land management strategies. Moreover, the NWO FEC system should help forest managers and others to better appreciate and understand some of the ecological relationships embodied within our important forest resources.

The NWO FEC computerized database, which includes detailed soil, site and vegetation information from approximately 2100 mature forest stands (about 1320 in the NC Region) throughout NW Ontario, is contributing to the development of a better understanding of the nature, distribution and relationships of forest vegetation and soils throughout NW Ontario (Towill and Sims 1989, Baldwin and Sims 1989, Racey et al. 1989b, Scarratt 1989, Baldwin et al. 1990, Bell 1990, Wickware et al. 1990, Towill and Buse 1990).

The NWO FEC system involves a two-stage allocation process. Once allocated using the field keys, modal descriptions of NWO FEC Vegetation and Soil Types are compared in sets of *factsheets* in the field guide (Sims et al. 1989).

Step 1. A stand is allocated to one of 38 Vegetation Types (V-Types). The user applies a simple field key which incorporates overstory trees and diagnostic understory plants. There are three main groupings: **Mainly Hardwood** (11 V-Types), **Conifer Mixedwood** (9 V-Types) and **Conifer** (18 V-Types).

NWO FEC Vegetation Type Names

Mainly Hardwood	**V1**	Balsam Poplar Hardwood and Mixedwood
	V2	Black Ash Hardwood and Mixedwood
	V3	Other Hardwoods and Mixedwoods
	V4	White Birch Hardwood and Mixedwood
	V5	Aspen Hardwood
	V6	Trembling Aspen (White Birch) - Balsam Fir / Mountain Maple
	V7	Trembling Aspen - Balsam Fir / Balsam Fir Shrub
	V8	Trembling Aspen (White Birch) / Mountain Maple
	V9	Trembling Aspen Mixedwood
	V10	Trembling Aspen - Black Spruce - Jack Pine / Low Shrub
	V11	Trembling Aspen - Conifer / Blueberry / Feathermoss
Conifer Mixedwood	**V12**	White Pine Mixedwood
	V13	Red Pine Mixedwood
	V14	Balsam Fir Mixedwood
	V15	White Spruce Mixedwood
	V16	Balsam Fir - White Spruce Mixedwood / Feathermoss
	V17	Jack Pine Mixedwood / Shrub Rich
	V18	Jack Pine Mixedwood / Feathermoss
	V19	Black Spruce Mixedwood / Herb Rich
	V20	Black Spruce Mixedwood / Feathermoss
Conifer	**V21**	Cedar (incl. Mixedwood) / Mountain Maple
	V22	Cedar (incl. Mixedwood) / Speckled Alder / Sphagnum
	V23	Tamarack (Black Spruce) / Speckled Alder / Labrador Tea
	V24	White Spruce - Balsam Fir / Shrub Rich
	V25	White Spruce - Balsam Fir / Feathermoss
	V26	White Pine Conifer
	V27	Red Pine Conifer
	V28	Jack Pine / Low Shrub
	V29	Jack Pine / Ericaceous Shrub / Feathermoss
	V30	Jack Pine - Black Spruce / Blueberry / Lichen
	V31	Black Spruce - Jack Pine / Tall Shrub / Feathermoss
	V32	Jack Pine - Black Spruce / Ericaceous Shrub /Feathermoss
	V33	Black Spruce / Feathermoss
	V34	Black Spruce / Labrador Tea / Feathermoss (Sphagnum)
	V35	Black Spruce / Speckled Alder / Sphagnum
	V36	Black Spruce / Bunchberry / Sphagnum (Feathermoss)
	V37	Black Spruce / Ericaceous Shrub / Sphagnum
	V38	Black Spruce / Leatherleaf / Sphagnum

Step 2. The soil is directly characterized in terms of a few critical parameters (e.g. soil depth, parent material texture, soil moisture regime) sampled from a soil pit or auger hole. A two-part field key is used to allocate soils to either an S-Type (deeper soils) or an SS-Type (shallower soils). There are three main groupings of deep soils: **Dry to Fresh Mineral** (6 S-Types), **Moist Mineral** (5 S-Types) and **Wet Organic** (2 S-Types). There are four main groupings of shallower soils: **Very Shallow** (4 SS-Types); **Dry to Fresh, Shallow to Moderately Deep** (3 SS-Types); **Moist, Shallow to Moderately Deep** (1 SS-Type) and **Wet Organic / Rock** (1 SS-Type).

NWO FEC Soil Type Names

Deep Mineral	**S1**	Dry / Coarse Sandy
	S2	Fresh / Fine Sandy
	S3	Fresh / Coarse Loamy
	S4	Fresh / Silty - Silt Loamy
	S5	Fresh / Fine Loamy
	S6	Fresh / Clayey
	S7	Moist / Sandy
	S8	Moist / Coarse Loamy
	S9	Moist / Silty - Silt Loamy
	S10	Moist / Fine Loamy - Clayey
	S11	Moist / Peaty Phase
Deep Organic	**S12F**	Wet / Organic [Feathermoss]
	S12S	Wet / Organic [Sphagnum]
Very Shallow	**SS1**	Discontinuous Organic Mat on Bedrock
	SS2	Extremely Shallow Soil on Bedrock
	SS3	Very Shallow Soil on Bedrock
	SS4	Very Shallow Soil on Boulder Pavement
Shallow to Mod. Deep	**SS5**	Shallow - Moderately Deep / Sandy
	SS6	Shallow - Moderately Deep / Coarse Loamy
	SS7	Shallow - Moderately Deep / Silty - Fine Loamy-Clayey
	SS8	Shallow - Moderately Deep / Mottles - Gley
	SS9	Shallow - Moderately Deep / Organic - Peaty Phase

Site classification researchers have recently been successful in integrating a wide variety of forest management interpretations into site classification systems (e.g. Comeau et al. 1982, Klinka et al. 1982, Corns and Annas 1986, Pojar et al. 1987, Stanek and Orloci 1987, Kotar et al. 1988, Green 1989, Merchant et al. 1989, Steele and Geier-Hayes 1989, Zelazny et al. 1989, Munson and Timmer 1989a,b, Burger and Pierpoint 1990, Meades and Moore 1990). Once a forest site in NW Ontario has been classified using the NWO FEC system, forest management interpretations may be considered and applied (Racey et al. 1989a).

The NWO FEC system is applicable at a variety of levels or intensities, and consequently is valuable for different users in applications involving various forest management objectives; for example, Vegetation and Soil Types may be aggregated into Treatment Units for many forest management applications (Racey et al. 1989, Sims et al. 1989). The NWO FEC system can be incorporated into an operational cruise or pre-cut assessment survey (Towill et al. 1988). NWO FEC mapping and photo-interpretation applications are currently being tested (Towill and Sims 1989, Sims 1990).

Species Comparisons

2.

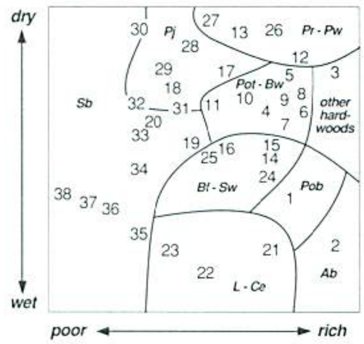
2.1. NWO FEC Vegetation Type Overlays

The diagrams shown here and in Section 3 of this report are based on a computer-assisted *ordination analysis* of vegetation data collected during the NWO FEC program. Ordination (Hill 1979, Gauch 1982) is a mathematical procedure that synthesizes and graphically summarizes large, complex datasets into a simple, readable form. The technique has received widespread use for the study of ecological relationships of boreal and northern mixedwood forest communities (Jeglum 1974, Carleton and Maycock 1978, Bouchard 1979, Jones et al. 1983, Pregitzer and Barnes 1984, Spies and Barnes 1985, Stanek and Orloci 1987, Zelazny et al. 1989). The ordinations presented here are based upon *all* of the cover-abundance information for *all* species of vegetation recorded in more than 2100 NWO FEC field plots.

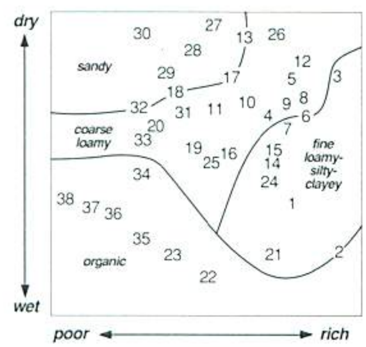
Each of the 38 plotted points (**V1**-**V38**) in the ordination diagram represents an average vegetational composition for a V-Type. Types that are close together on the ordination (e.g., **V20** and **V33**) tend to be more alike in terms of their general vegetation conditions than those which are far apart (e.g., **V27** and **V2**). The distance between any two points (V-Types) graphically illustrates the relative degree of similarity or difference between those Types.

Although neither axis is calibrated to an absolute scale, two main gradients can be inferred along the V-Type ordination axes. Along axis 1, from left to right, a nutrient-richness gradient ranges from poor to rich. Along axis 2, from bottom to top, there is a wet to dry soil moisture gradient. Thus, the ordination effectively provides a pictorial representation within which V-Types may be related to moisture/nutrient conditions as well as to patterns of average vegetational composition.

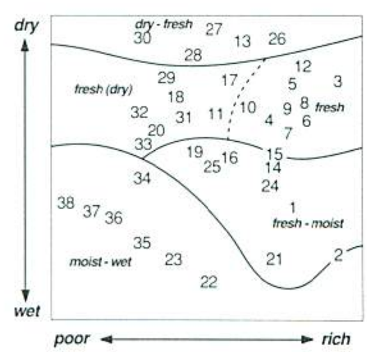
Information about other soil/site or vegetation parameters may be overlain on the V-Type ordination to elucidate relationships. In the diagrams presented on this page, mean values are overlain for occurrence of major tree species groupings, dominant soil texture classes and general soil moisture regimes.



Major Tree Species Groupings



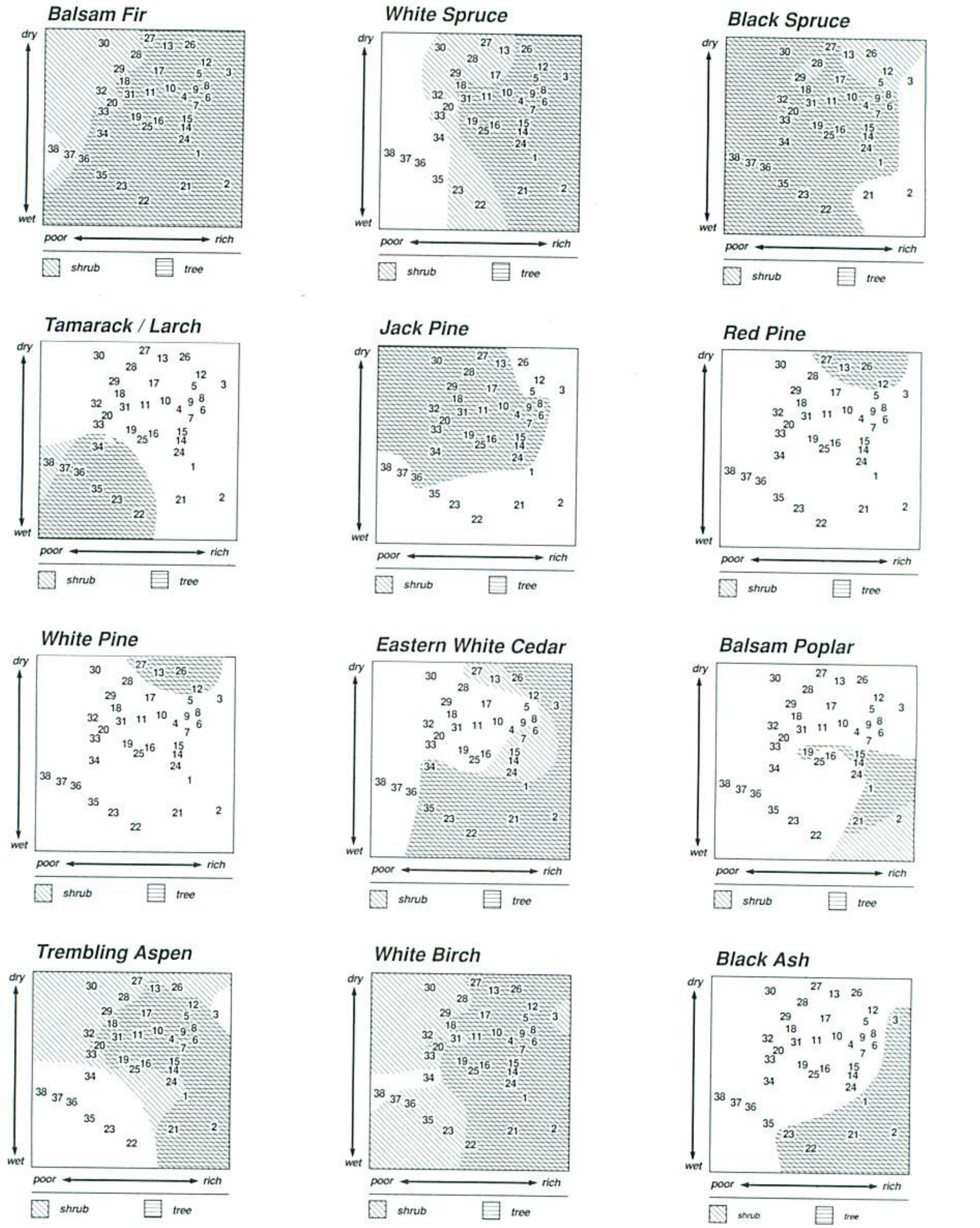
Soil Texture (C Horizon) Classes



Soil Moisture Regime Classes

NWO FEC Vegetation Type Ordination

overlain with dominant overstory tree species, parent material (C horizon) soil texture and soil moisture regime groupings (from Sims et al. 1989).



Habitat diagrams showing distribution across the NWO FEC Vegetation Types of the 12 main tree species in NW Ontario *(from Baldwin and Sims 1989).*
Hatched zones on the ordinations highlight V-Types where the species commonly (minimum 10% occurrence within more than 2100 NWO FEC plots) occurs in just the shrub layer (diagonal hatching) or both the tree and shrub layers (cross-hatching).

The habitat diagrams presented on page 8 are another form of V-Type ordination overlay. Distribution information for each species, according to V-Type, was compiled from the NWO FEC dataset. In the habitat diagrams, distributions of the 12 tree species across the V-Types are shown based on a minimum 10% occurrence either as an overstory or an understory species in the *overall* NWO FEC dataset (i.e. from both the NW and NC Regions).

As already discussed, major gradients can be interpreted along the ordination axes. Thus, from the habitat diagrams one can usually estimate for a species the general range of moisture and nutrient regimes across which it tends to occur in the natural forest. Used in conjunction with soil/site overlays, the habitat diagrams permit a better appreciation of the autecology of each tree species. However, the habitat diagrams should only be considered as guides; because of the natural variability that characterizes forests throughout the NC Region, species may sometimes be found in V-Types not indicated in the habitat diagrams.

Delineated distributions on the ordinations in Section 3 are different. These show those V-Types for which the tree species occurred as the dominant overstory species (based on percentage ground cover) in NWO FEC plots sampled within the NC Region.

2.2 Soil Texture

The diagrams on page 10 show frequency distributions of B and C horizon soil textures associated with dominant tree species within NWO FEC plots in the NC Region. Sample sizes for each species are provided in Section 3; texture class groupings follow those defined for the NWO FEC (Sims et al. 1989). Tree species are grouped as follows: a) jack pine, red pine, white pine; b) balsam fir, white spruce, black spruce; c) balsam poplar, trembling aspen, white birch; and d) tamarack, white cedar, black ash.

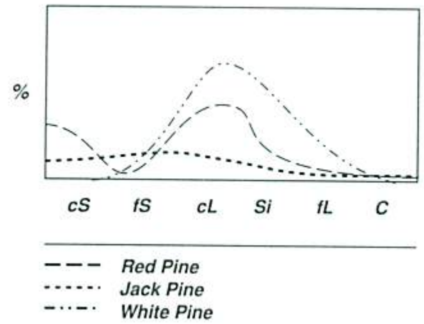
2.3. Soil Moisture Regime and Soil Drainage

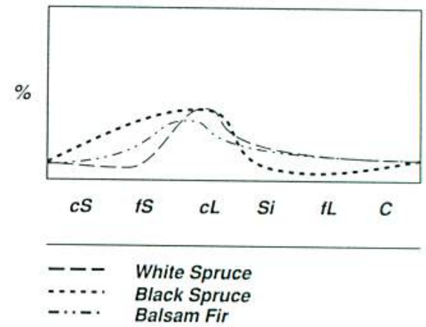
The diagrams on page 11 show frequency distributions of soil moisture regime classes and soil drainage classes for soils associated with dominant tree species in NWO FEC plots within the NC Region. Sample sizes for each species are provided in Section 3; moisture regime and drainage classes follow those defined by the Ontario Institute of Pedology (1985). Tree species are grouped as follows: a) jack pine, red pine, white pine; b) balsam fir, white spruce, black spruce; c) balsam poplar, trembling aspen, white birch; and, d) tamarack, white cedar, black ash.

2.4. Tree Volumes by NWO FEC Vegetation Types

The diagrams on page 12 show mean total volumes for the 12 tree species according to NWO FEC Vegetation Types. These volumes are based on mature stands in NWO FEC plots within the NC Region; sample sizes for each species are provided in Section 3. Additional mensurational data are provided in Appendix II.

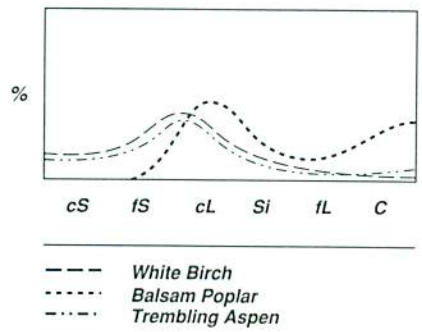
Texture of B Horizon

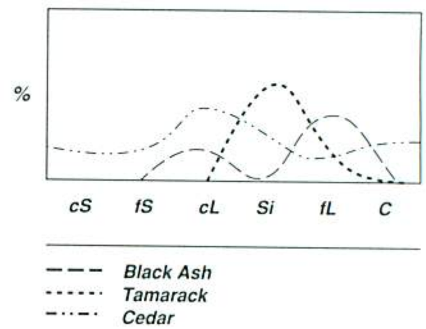




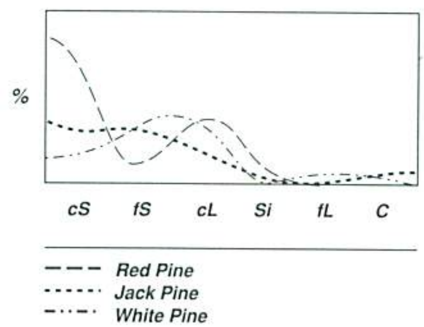
Texture Class Groupings

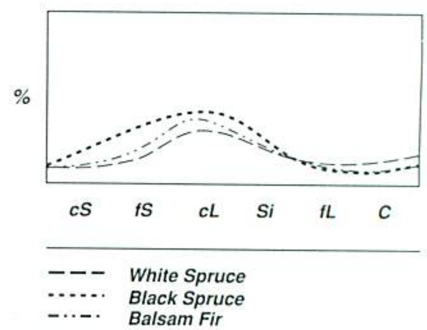
cS - *coarse sandy*
fS - *fine sandy*
cL - *coarse loamy*
Si - *silty*
fL - *fine loamy*
C - *clayey*





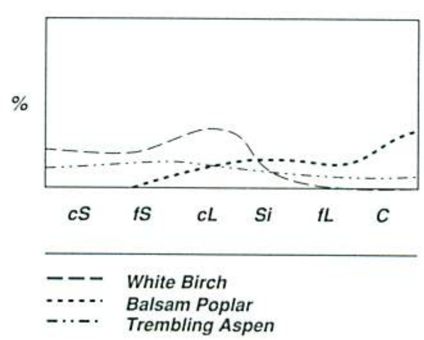
Texture of C Horizon

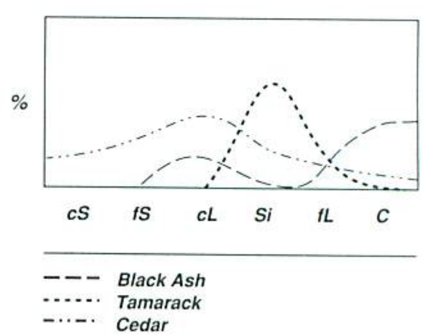




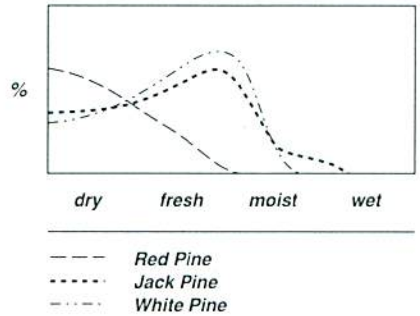
Texture Class Groupings

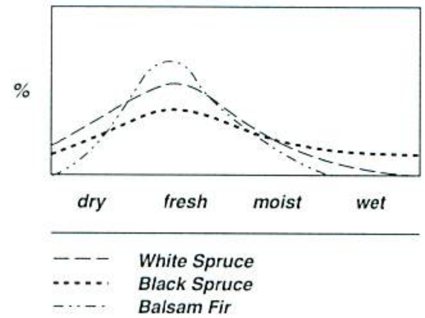
cS - *coarse sandy*
fS - *fine sandy*
cL - *coarse loamy*
Si - *silty*
fL - *fine loamy*
C - *clayey*

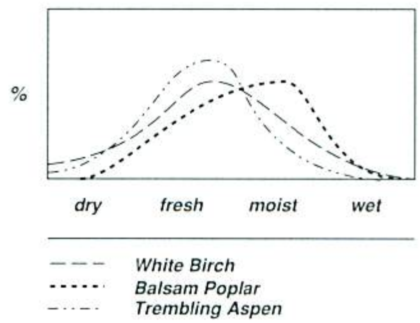


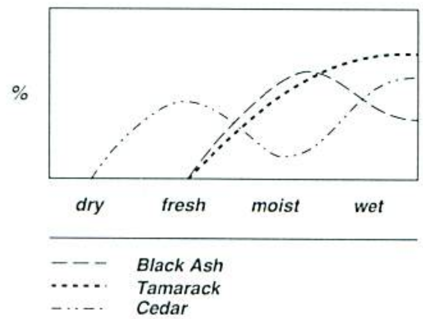


Soil Moisture Regime

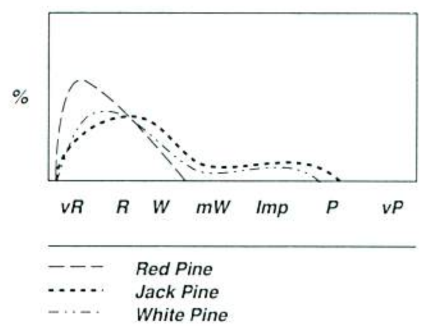


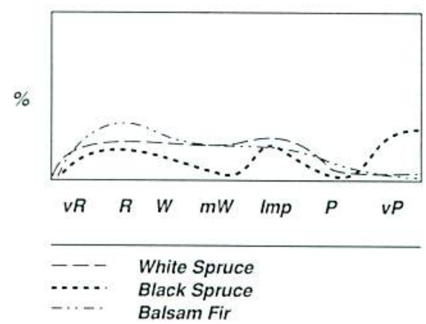






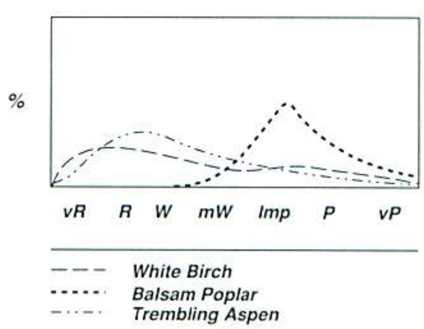
Soil Drainage

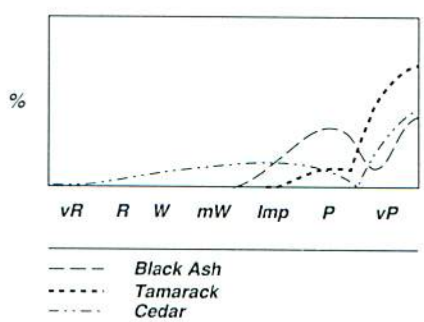




Drainage Classes

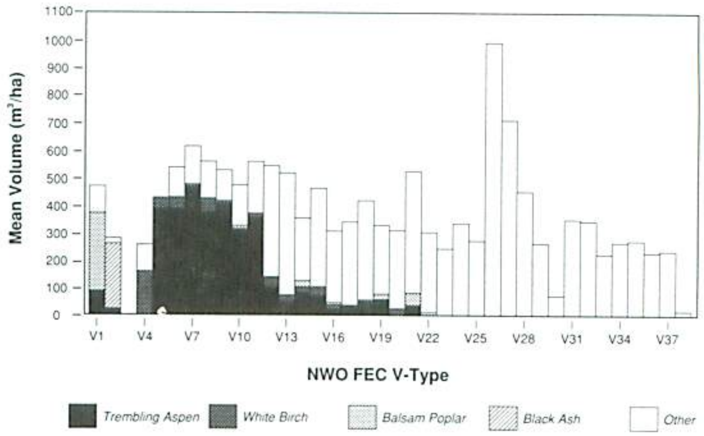
- *vR* - *very rapid*
- *R* - *rapid*
- *W* - *well*
- *mW* - *moderately well*
- *Imp* - *imperfect*
- *P* - *poor*
- *vP* - *very poor*





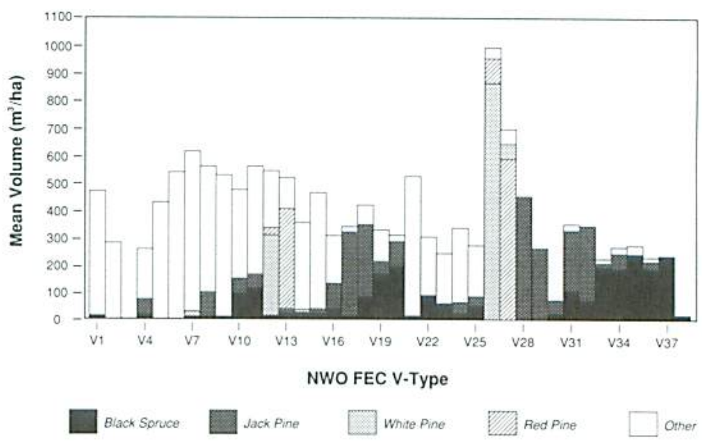
Summary of Species Volumes

Trembling Aspen, White Birch, Balsam Poplar and Black Ash



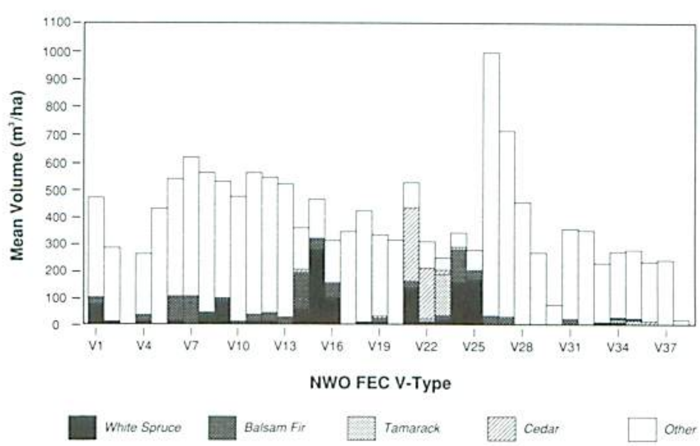
Summary of Species Volumes

Black Spruce, Jack Pine, White Pine and Red Pine



Summary of Species Volumes

White Spruce, Balsam Fir, Tamarack and Cedar



Tree Species 3.

Balsam Fir	*Abies balsamea*
White Spruce	*Picea glauca*
Black Spruce	*Picea mariana*
Tamarack / Eastern Larch	*Larix laricina*
Jack Pine	*Pinus banksiana*
Red Pine	*Pinus resinosa*
White Pine	*Pinus strobus*
Eastern White Cedar	*Thuja occidentalis*
Balsam Poplar	*Populus balsamifera*
Trembling Aspen	*Populus tremuloides*
White Birch / Paper Birch	*Betula papyrifera*
Black Ash	*Fraxinus nigra*

Balsam Fir

3.1.

Abies balsamea (L.) Mill.
Pinaceae (Pine Family)

Description: Balsam fir is a small to medium-sized tree at maturity that is widespread in the NC Region as both an overstory and understory species in dry to moist forests. It is typically symmetrical in form, with a narrow, pyramidal crown. It occurs primarily in uneven-aged stands. In the overstory, balsam fir is typically found in mixed associations with other species, and often occurs in several age classes within one stand.

Balsam Fir

Associated Stand Conditions

NWO FEC Vegetation Types *(76 NWO FEC plots)*:

Balsam fir occurs as a dominant species in mixed conifer stands, often with white spruce as a co-dominant (Bakuzis and Hansen 1965, Sims et al. 1989). Balsam fir dominated stands include balsam fir mixedwood Vegetation Types (**V14**, **V16**), and conifer Vegetation Types characterized by white spruce - balsam fir overstories (**V24**, **V25**). The mixedwood Vegetation Types typically have moderately to poorly developed herb and shrub layers, patchy to continuous feathermoss mats, and are associated with well-drained, fresh, upland soils. The conifer Vegetation Types have variable understory conditions ranging from shrub rich to shrub poor and are associated with deep, fresh to moist mineral soils. Balsam fir - trembling aspen co-dominated stands (**V6**, **V7**) are also common.

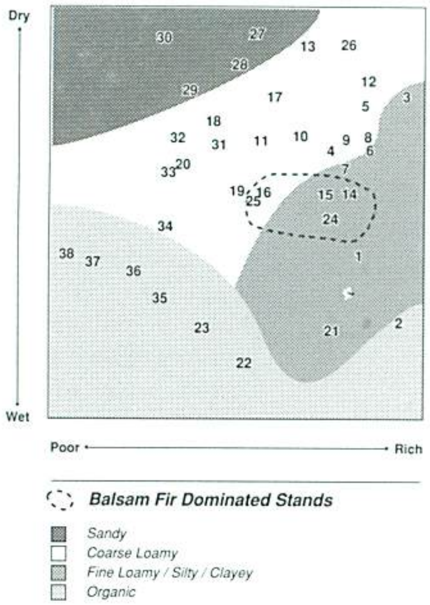
Overstory: White spruce is the most common co-dominant overstory species occurring with balsam fir in all Vegetation Types except the trembling aspen Vegetation Types (**V6**, **V7**). In these V-Types, balsam fir often occurs in a secondary canopy, usually with lower overall cover and abundance than aspen. Black spruce, jack pine and white birch are commonly associated with balsam fir. Balsam poplar occurs infrequently in the overstory of balsam fir mixedwood Vegetation Types.

Shrubs: Most balsam fir stands in the NC Region have moderately to poorly developed herb and shrub layers. Cover and abundance of herb and shrub understories can generally be related to the degree of shading by, and density of, the overstory. Where shrub layers develop, balsam fir shrubs are typically abundant. Other common shrub associates include: *Aralia nudicaulis*, *Acer spicatum*, *Rubus pubescens*, *Linnaea borealis*, *Sorbus decora* and *Rosa acicularis*. Occurring with less frequency are *Diervilla lonicera*, *Populus tremuloides*, *Amelanchier* spp., *Corylus cornuta*, *Vaccinium myrtilloides*, black spruce, *Gaultheria hispidula* and *Ribes* spp.

Herbs: *Maianthemum canadense*, *Clintonia borealis*, *Streptopus roseus*, *Cornus canadensis*, *Trientalis borealis* and *Viola renifolia* are the most common associates in the herb layer of balsam fir dominated stands in the NC Region. Occurring less frequently are: *Mitella nuda*, *Aster macrophyllus*, *Galium triflorum*, *Coptis trifolia*, *Petasites palmatus*, *Anemone quinquefolia*, *Lycopodium annotinum* and *Fragaria virginiana*.

Mosses and Lichens: *Pleurozium schreberi* and *Ptilium crista-castrensis* occur with high frequency in balsam fir stands. Other mosses occurring less frequently are: *Hylocomium splendens*, *Plagiomnium cuspidatum*, *Dicranum polysetum*, *D. fuscescens*, *Mnium* spp. and *Rhytidiadelphus triquetrus*. Total feathermoss ground cover averages 40-50% in balsam fir dominated stands where the overstory coniferous component is high, and about 10-20% in more open balsam fir stands with herb and/or shrub rich understories. Ground lichens are typically sparse and/or absent.

NWO FEC Vegetation Type Ordination showing distribution of Balsam Fir dominated stands and associated soil conditions in the NC Region.



Silvics

Growth Habit: Balsam fir is a small to medium-sized conifer, averaging less than 15 m in height. It is characterized by a dense, symmetrical, spire-like crown. Needles are 2-3 cm long, flattened, with a blunt or minutely notched tip, and two longitudinal white bands beneath; they are spirally arranged on the stem but twisted at the base of each needle, giving the spray a flattened appearance. Main branches on balsam fir are usually distinctly whorled, whereas finer branchlets are opposite and arranged in flat sprays. Dead branches are often maintained for many years on the bole below the live crown. Branching extends to low levels on the bole except in very dense stands. The trunk has a slight taper and the greyish bark is smooth with raised resin blisters on younger trees, becoming brownish and scaly with age (Scoggan 1978, Fernald 1979). The rooting system is spreading and shallow, rendering the tree vulnerable to windthrow if major roots become exposed or damaged (Hosie 1969).

Shade Tolerance: Balsam fir is very tolerant of shade and can survive at low light levels for long periods of time, up to 50 years or more (Roe 1950, Bakuzis and Hansen 1965). Trees are capable of responding to release late into life; the rate of recovery is partly related to the period of supression (Hatcher 1960) but shade tolerance can also be influenced by climatic and soil fertility factors. Based on a detailed survey of Minnesota forests, balsam fir was given a ranking of 2.0 on a 5-unit scale (1=least to 5=greatest) for light requirements; for moisture, nutrient and heat requirements, rankings were 3.6, 2.0 and 1.4, respectively (Bakuzis and Hansen 1959).

Climatic Range: Balsam fir grows well in the cold, moist climate associated with the Boreal Forest Region (Rowe 1972). Within the NC Region, temperature does not appear to be limiting except along the northern boreal / tundra transition. Within balsam fir's range in the NC Region, mean annual precipitation ranges from 610 to 760 mm (Anon. 1987a).

Frost Resistance: Because balsam fir flushes relatively early in the season, seedlings are moderately susceptible to frost; saplings and mature balsam fir are frost resistant.

Flood Tolerance: Both seedlings and mature trees are intolerant of prolonged flooding longer than a few weeks, but are tolerant of flooding for shorter periods. Prolonged submergence of roots by flooding lasting more than 6 weeks may kill mature trees (Ahlgren and Hansen 1957).

Fire Tolerance: Balsam fir is very susceptible to fire, particularly on drier soils and in overmature stands. The thin resinous bark, shallow rooting habit, waxy needles and poor self-pruning habit all contribute to the high flammability of balsam fir. In many stands, however, moist soils, well-developed understory components, and a mixed overstory composition may act to ameliorate the hazard and incidence of fire. Balsam fir stands killed by spruce budworm in the NC Region can pose extreme fire hazards (Stocks 1985, 1987).

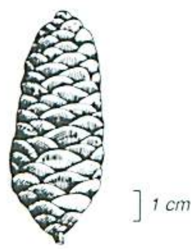
Successional Status: Balsam fir is a sub-climax to climax species that is capable of regenerating beneath its own cover. It is a relatively short-lived tree species, but does achieve ages up to 150 years. Fungus-induced defects, which increase beyond age 90 are common in the NC Region (Basham and Morawski 1964).

Vegetative Reproduction: Vegetative reproduction is by layering, which may occur when lower branches contact moist soil surfaces. Balsam fir vegetative reproduction occurs only occasionally in the NC Region; by far, the most common mode of reproduction is through seed dispersal. Layering of balsam fir is not a primary mode of reproduction in northern Minnesota (Roe 1950) or western Quebec (Hatcher 1960), except perhaps in very local areas.

Sexual Reproduction:

Flowering: Male and female flowers occur on the same tree. Female flowers are upright fleshy cones with broadly rounded cone scales, and first appear towards the end of May. Male flowers are tiny, short-lived, cone-like flowers which hang from the bases of the previous year's leaves. Pollination is by wind.

Fruit: The fruits of balsam fir are winged seeds enclosed by the woody scales of mature female cones. Seeds mature in one season. Seed production may occur as young as 15 years (Schopmeyer 1974) and is abundant after 30 years.



Crop Cycle: Abundant seed crops are produced every 2 to 4 years with light seed crops in intervening years.

Crop Abundance: Cones are most abundant on open-grown, dominant trees. Quantities vary, depending on climatic and other factors.

Seed Viability: The optimum age for seed production is around 40 years. Seed viability also peaks at this age, decreasing thereafter (Benzie 1960). Few viable seeds are stored in the forest floor longer than one year. Viability averages 30% in natural stands.

Seed Dispersal: Seeds ripen during late August or early September with dispersal beginning a few days thereafter. Ripening continues until early spring. Although balsam fir seeds disseminate to a maximum distance of 160 m, most seeds fall directly beneath the tree. Rodents are only minor agents for seed dispersal.

Germination: Germination occurs from late May to early July on fresh to moist substrates (Bakuzis and Hansen 1965). Low levels of germination may occur on litter layers greater than 8 cm in depth. Highest germination under natural conditions occurs beneath a forest cover with 80% or less crown closure. High regeneration success occurs on seedbeds consisting of mixed organic humus material and mineral soil (Place 1955).

Seedling Survival and Growth: Principle causes of seedling mortality for balsam fir are reported to be high ground-surface temperatures, drought and frost heaving. Mortality is frequently high during late July and August, when drought conditions are most likely to occur (Stoeckeler and Skilling 1959, Bakuzis and Hansen 1965). During fall and winter, mortality may result from smothering by hardwood leaf litter, physical damage by ice and/or snow, or extreme cold. Establishment and early growth rates depend upon the amounts and types of vegetative competition. *Pteridium aguilinum*, *Rubus pubescens* and *Acer spicatum* are some of the major competitors for young balsam fir (Roe 1950, Vincent 1956). Seedbed substrates that have supported *Kalmia anqustifolia* may inhibit primary root growth and development of young balsam fir (Thompson and Mallik 1989).

In an attempt to understand the spruce budworm's role in forest succession, regeneration was documented over a 10-year period on several northern Ontario (including a site near Black Sturgeon Lake in the NC Region) and Quebec forest sites that previously supported balsam fir stands killed by spruce budworm. Ghent et al. (1957) found no common trends for regeneration or early vegetational succession among the sites; re-establishing balsam fir often competed with young black spruce seedlings for similar microsites.

Height Growth: Height growth is initiated at the end of May or early June, when height growth for most other tree species in the NC Region has ended. Typically height growth ends in late July or early August. Radial growth begins towards the end of May and terminates in late August or early September.

Height growth for seedlings is greatest in dense shade up to about 8 years of age, but afterwards young saplings require nearly full light for optimum development. Growth rates are best for trees with a crown ratio (i.e., proportion of total tree height in live crown) of 0.7 or better. Growth rates of up to 6 cm DBH per year are achieved by productive trees on fresh to moist silt loams and stony loam tills. Heights of 15 m in 50 years may be achieved (Bakuzis and Hansen 1965).

Balsam fir seedlings are reported to be inherently slow-growing during the first 5 or 6 years. Zon (1914) reported balsam fir seedlings under full light reaching 30 cm in 5 years and 90 cm in 9 years and considered such growth slow. On favourable sites in Quebec, an average of 4.8 years was required for seedlings to grow to 30 cm in full sunlight (Hatcher 1960). Once well established, average height growth of up to 30 cm per year is achieved under optimal growing conditions; height increments for less vigorous trees may average only 1 cm per year. Understory trembling aspen and white birch competition is usually not severely limiting to balsam fir height growth (Johnston 1977a). Under full light, balsam fir grows at a rate comparable to any spruce species with which it is associated (Hatcher 1960).

In a study of the growth of balsam fir advance growth after logging in Quebec, younger and smaller seedlings responded faster and better to release than older and taller seedlings; a direct relationship was demonstrated between seedling height growth before release and height growth subsequent to release (Hatcher 1964).

Root Development: Balsam fir develops a shallow, wide-spreading root system. Seedlings frequently develop a heavy central root, which initially appears to be a taproot but then splits at the bottom of the humus into a number of laterals that remain in the organic layer (Bakuzis and Hansen 1965). Root grafts are common among balsam fir (Johnston 1977a).

Stand Development: Although certain associations of shrubs, herbs and mosses may be correlated with the general site quality of balsam fir stands, no firm relationships have been established in the NC Region. In balsam fir mixedwood stands, *Viburnum / Oxalis* and other species-rich understories may be associated with productive soils. Mixed stands of balsam fir with other conifers that support *Cornus / Maianthemum* dominated understories may be associated with intermediate-quality soils. Feathermoss carpets with shrub and herb poor conditions under pure balsam fir stands may be associated with less productive soils. Balsam fir - white birch stands that develop on floodplains in central Newfoundland are highly productive (Damman 1964).

Balsam fir's tendency to develop into uneven-aged stands is in part due to the species' shade tolerance and its quick response when released (Roe 1950). Suppressed balsam fir in the understory grow quickly when openings and clearings, created by blowdown, disease or other perturbations, develop in mature and overaged stands (Bakuzis and Hansen 1965). Baskerville (1961) examined the response of 40- to 50-year-old balsam fir in northwestern New Brunswick to four levels of crown release, and determined that increased basal area resulted, but the degree of release had little influence on the rate of growth; a stronger correlation was found with initial breast-height diameter, crown width, competition and other factors.

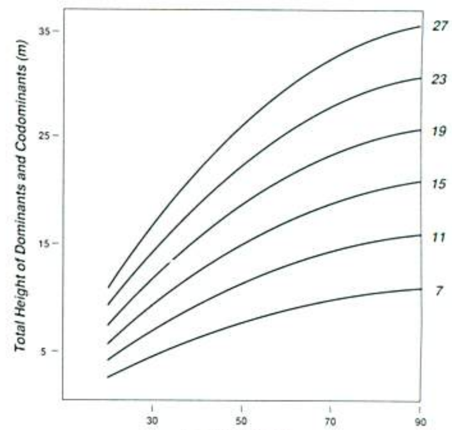
Conifer dominated stands with a high component of balsam fir tend to develop on sites with imperfect drainage. The characteristic shallow rooting habit of balsam fir on these sites renders trees vulnerable to windthrow (Johnston 1977a). Balsam fir stands with a high hardwood component occur on better drained sites. In northern Ontario, root rot may contribute to significant reductions in growth by balsam fir; over a 3 year period, infected trees had average height and radial increments decreased by 13.5 and 10.9%, respectively (Whitney and MacDonald 1985).

Based on a study in the Thunder Bay area, NC Region, Burgar (1961) indicated that merchantable wood volume production of the average white spruce tree was approximately 35% more at age 25, 40% more at age 60, and 110% more at age 90 than that of the average balsam fir tree at the same ages.

In Quetico Park, near the southwestern corner of the NC Region, Walshe (1980) noted that although balsam fir is an abundant understory component, it rarely occurs in the overstory as a dominant species.

Site Index Curves for Balsam Fir

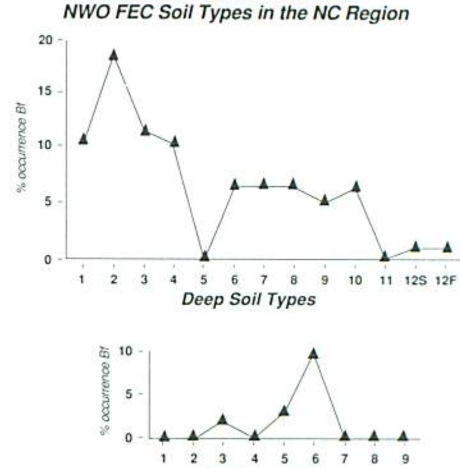
(adapted from Gevorkiantz (1956) and Carmean and Hahn (1981), prepared for the northern Lake States, USA)



Associated Soil Conditions

NWO FEC Soil Types (*76 NWO FEC plots*): Balsam fir dominated stands occur on a wide range of mineral soils in the NC Region, including deep, fresh, fine sands, coarse sands, coarse loams, silts and clays (**S1**, **S2**, **S3**, **S4**, **S6**) and deep, moist to wet sands, coarse loams, fine loams and clays

Distribution of Balsam Fir across NWO FEC Soil Types in the NC Region



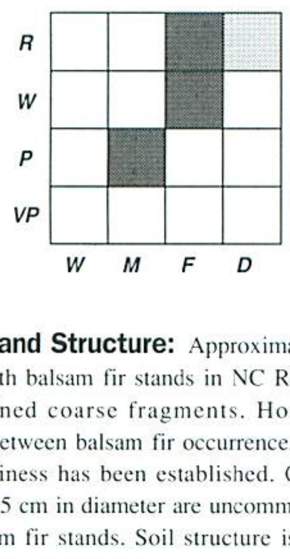
(**S7**, **S8**, **S10**). Balsam fir occurs less frequently on shallow soils, primarily on coarse loamy parent materials (**SS6**).

Deposition: Balsam fir dominated stands in the NC Region occur primarily on morainal and lacustrine materials, with minor occurrences on glaciofluvial outwash deposits. They are most commonly associated with brunisolic, podzolic and gleysolic soil profiles.

Texture: Balsam fir dominated stands are found most frequently on soils with a coarse loamy parent material; more than half of the balsam fir dominated NWO FEC plots in the NC Region were on soils with coarse loamy C horizon textures. A and B soil horizons are typically coarse loamy, fine sandy or silty textures.

Drainage and Moisture Regime: Balsam fir dominated stands in the NC Region occur mainly on rapidly to imperfectly drained soils. They occur less frequently on poorly drained or very rapidly drained soils, and are not found on very poorly drained soils. Balsam fir stands in the NC Region occur mainly on fresh to moderately moist soils. Balsam fir is not found as an overstory component on wet soils.

Correlation of Soil Drainage and Moisture Regime Classes for Balsam Fir



Stoniness and Structure: Approximately 50% of soils associated with balsam fir stands in NC Region NWO FEC plots contained coarse fragments. However, no clear relationship between balsam fir occurrence, cover or density and soil stoniness has been established. Coarse fragments greater than 25 cm in diameter are uncommon in soils of NC Region balsam fir stands. Soil structure is typically single grained or subangular blocky.

Site Position: Balsam fir stands are commonly found on level terrain or upper to mid-slope positions in the NC Region. Balsam fir dominated stands are only occasionally found on lower or toe slope positions.

Litter Layer: LFH layers beneath balsam fir stands in the NC Region are moderately thick (6 to 15 cm) to thin (1 to 5 cm). Fibrimor and humifibrimor forest humus forms are typically associated with balsam fir dominated stands in the NC Region.

Soil Fertility Requirements: Optimum growth for balsam fir is believed to occur on soils with pH values between 4.0 and 6.0 (Bakuzis and Hansen 1965); however, further studies of soil productivity / soil nutrient status are needed. Balsam fir stands in the NC Region are primarily associated with brunisolic, podzolic and gleysolic soils. Balsam fir is occasionally found on organic soils, as well as on gravelly sands, but on these soils growth is slow and trees typically have poor form. In a series of replicated fertilization trials, Krause et al. (1977) found that balsam fir generally responded poorly to the addition of nitrogen. Growth of a pure balsam fir stand could not be improved by separate applications of either nitrogen, phosphorus or potassium (Krause 1970). Increased soil acidity and high aluminum levels may seriously limit ectomycorrhizal formations associated with balsam fir (Entry et al. 1987).

Insects, Diseases and Other Damaging Agents

Insects:

Spruce Budworm (*Choristoneura fumiferana* Clem.): Balsam fir is a preferred food source for the spruce budworm and may be subject to intense budworm infestations when it occurs, in particular, in dense or pure stands (Rose and Lindquist 1977). As a damaging agent, spruce budworm reduces tree growth, kills individual trees as well as entire stands, and can cause significant yield reductions in subsequent rotations (Basham 1984, MacLean 1985, Seymour 1985). Typically, spruce budworm damage will affect tree growth after 2 years of serious infestation. Severe outbreaks often occur in mature stands after several years of early summer drought. Trees weakened by budworm defoliation are often attacked and killed by a variety of other insect pests (Belyea 1952). Extensive root mortality resulting from root starvation typically follows budworm defoliation. Bacterial or insecticide applications can control infestations; current efforts in budworm management include protection planning, model development for damage detection and forecasting, and defoliation-based growth forecasting (MacLean 1990).

Diseases:

A variety of root rot fungi cause widespread damage and mortality to balsam fir throughout northern Ontario. Based on an 11-year survey, it was determined that 16% of dominant or co-dominant balsam fir were killed or experienced premature windthrow as a result of root rot, and levels were generally higher in northwestern than in northeastern Ontario (Whitney 1989). Root rot in balsam fir became significant (about 20% of total crop trees dead or windthrown) at 51 to 60 years of age, and scaled cull in living trees reached 16% (Whitney 1989).

Shoestring Root Rot (*Armillaria ostoyae (Romagn.)* Herink.): *Armillaria* enters trees through roots or basal wounds. Drought or nutrient stressed trees have a greater potential for infection. A variety of root rots are abundant in mature balsam fir in northern Ontario (Whitney and MacDonald 1985). Tree mortality resulting directly from *Armillaria* is relatively low in balsam fir, but such infections contribute to reduced growth and increased windthrow (Whitney 1976).

Brown Cubical Butt Rots (*Polyporus balsameus* Pk., *Merulius himantioides* Fr., *Coniophora puteana* (Schum. ex. Fr.) Karst.): These three butt rot fungi infect individual trees through root or basal wounds, weakening the tree and leading to decreased wood quality and increased incidence of windthrow. Stands should be harvested at younger rotations to minimize losses from these infections.

Trunk Rot Fungus (*Haematostereum sanguinolentum* (Alb. and Schw. ex Fr.) Pouz.): *Haematostereum* enters balsam fir through stubs and broken tops, and causes decay in upper portions of living trees. Balsam fir cull losses from trunk and top rot are more than twice those from butt rot.

Nectria spp.: *Nectria* canker causes dieback in balsam fir. It is not considered an economically important stem disease.

Other:

Windthrow: When balsam fir is found on shallow, moist soils, there may be a considerable windthrow hazard, especially for stands more than 50 years old. Black spruce and balsam fir are generally more susceptible to wind damage than trembling aspen, jack pine or white birch (Fleming and Crossfield 1983).

Management Considerations

Balsam fir is important in the pulpwood and sawlog industries of the NC Region, and is also grown for the Christmas tree market. The wood is light, soft, weak, somewhat brittle, white in color and odorless (Hosie 1969).

Although only 30% of seeds typically germinate, natural regeneration of balsam fir is a viable and practical method of regeneration on moist seedbeds. Mineral-humus soil mixtures form the best seedbeds for balsam fir; consequently, scarification should only mix the mineral / humus layers, and not remove or bury the humus entirely.

Balsam fir is a shade-tolerant species. Timing and degree of competition control is not as critical to its survival and growth as for most other tree species in the NC Region. Because of its shade tolerance, balsam fir could be managed under an uneven-aged system and the viability of the stand maintained. Even-aged silviculture may be more appropriate in mature stands where residual tree quality would decline if trees were not harvested. Balsam fir is subject to windfall, especially on shallow soils with moist moisture regimes.

Decay is rapid in older stands and the risk of spruce budworm infestation rises with increased area of uniform balsam fir cover. Harvesting should occur as early in the rotation as possible (Burns 1983). To minimize losses to spruce budworm, the management goal may be to decrease the percentage of balsam fir within a management area by harvesting balsam fir early for pulp, before trees decline in quality (Johnston 1977a). In order to prevent root rot losses from exceeding 35% of crop-tree volume, Whitney (1989) suggests that balsam fir in northern Ontario be harvested before reaching 65 years of age; this is considerably earlier than the pathological rotation age of 70-80 years suggested by Bakuzis and Hansen (1965).

Stripcuts allow for natural regeneration and assist in maintaining local seedbed conditions for optimal regeneration. For balsam fir, stripcuts should be narrow, not exceeding 60 m. A shelterwood may also create a suitable environment for natural regeneration.

Balsam fir dominated stands are used to some extent by many wildlife species. Deer and moose use balsam fir dominated stands for winter shelter (Euler 1979, Racey et al. 1989a). Mature or older stands, especially those with a diverse understory, may provide good habitat for a variety of small mammals, including martens, fishers, voles and snowshoe hares.

White Spruce

3.2.

Picea glauca (Moench) A. Voss
Pinaceae (Pine Family)

Description: White spruce is a medium to large-sized (averaging 17 m high, up to 28 m), evergreen conifer at maturity with a fairly symmetrical, conical crown, a tapered bole, branches that spread and droop slightly, and a regular branching pattern that often extends to the ground. It is very shade tolerant and often occurs as an understory or sub-dominant overstory species (Hosie 1969). White spruce is a transcontinental species of conifer that is found throughout the NC Region as an occasional stand element in mixed stands. It very rarely grows in pure stands. As a tree, it occurs primarily on fresh to moist soils and is commonly associated with balsam fir, trembling aspen and black spruce (Stiell 1976, Anon. 1980, Arnup et al. 1988). As an understory species, it is relatively common, occurring on a somewhat wider range of soil/site conditions.

White Spruce

Herbs: *Maianthemum canadense*, *Cornus canadensis* and *Aster macrophyllus* are the most common herbs beneath white spruce stands in the NC Region. *Trientalis borealis*, *Clintonia borealis*, *Streptopus roseus*, *Galium triflorum*, *Mitella nuda*, *Petasites palmatus*, *Anemone quinquefolia* and *Viola renifolia* are common in the white spruce mixedwood Vegetation Type (**V15**).

Mosses and Lichens: *Pleurozium schreberi*, *Rhytidiadelphus triquetrus*, *Ptilium crista-castrensis*, *Mnium* spp., *Plagiomnium cuspidatum* and *Dicranum* spp. occur with low frequency and cover beneath white spruce stands. In the NC Region, total moss cover averages from 16% beneath coniferous stands (**V24**, **V25**) to very scattered, low cover (<2%) under white spruce mixedwoods (**V15**). Lichens are sparse beneath white spruce dominated stands in the NC Region.

Associated Stand Conditions

NWO FEC Vegetation Types (*76 NWO FEC plots*): White spruce is a dominant species in mixed conifer (**V24**, **V25**) and balsam fir / white spruce mixedwood (**V15**, **V16**) Vegetation Types.

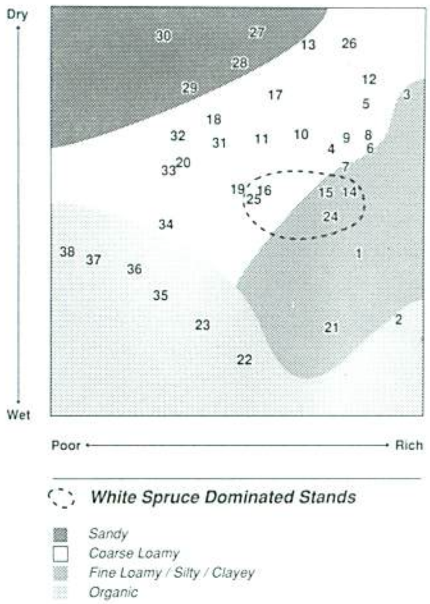
Overstory: White birch, balsam fir and trembling aspen are common overstory associates of white spruce in the NC Region. Black spruce and balsam poplar occur less frequently as associates of white spruce.

Shrubs: Balsam fir, *Acer spicatum*, *Aralia nudicaulis*, *Linnaea borealis*, *Corylus cornuta*, *Diervilla lonicera* and *Amelanchier* spp. are common in the shrub rich understories of white spruce dominated stands in the NC Region. As well, trembling aspen, *Sorbus decora*, *Rosa acicularis* and *Ribes* spp. are frequently encountered in the understory of the white spruce mixedwood Vegetation Type (**V15**).

Silvics

Growth Habit: White spruce is characterized by a trunk with pronounced taper and a symmetrical, conical crown. Needles are thick, stiff, sharp, about 2 cm long, 4-sided in cross-section, and green to bluish-green in colour, often with a powdery coating; needles are spirally arranged on the stem. Branches typically extend to the ground in relatively open stands but, in dense stands, the crown may occupy about half of a tree's height. Finer branchlets of white spruce are hairless with persistent, raised, woody leaf bases The trunk bark is light greyish-brown, flaky or scaly, and the inner bark is silvery-white to reddish (Scoggan 1978). Sometimes white spruce trees have deep sinker roots and/or a shallow tap root, but the root system is usually a shallow, platy and fibrous mat. Self-pruning of branches in white spruce is poor.

NWO FEC Vegetation Type Ordination showing distribution of White Spruce dominated stands and associated soil conditions in the NC Region.



White spruce and black spruce may sometimes be difficult to distinguish; black spruce has smaller cones, shorter needles, hairy branchlets and olive-green inner bark. When crushed in the hand, the odor emitted by white spruce needles is sharp and spicy, whereas black spruce is fragrant (Brayshaw 1960). In the seedling stage, white spruce may be distinguished from black spruce by its pubescent terminal shoot and ciliate needle margins (Jablanczy 1964).

Shade Tolerance: White spruce is a very shade tolerant species in the NC Region, and will survive for long periods suppressed in the understory. However, although seedlings will grow well in 45% full sunlight up to about age 5, after age 10, they require virtually full sunlight for continued optimum growth, along with minimal root competition (Stiell 1976, Arnup et al. 1988). Logan (1969) reported that after 9 years, optimum height growth of white spruce seedlings was attained under both 45% and 100% sunlight. In British Columbia, Krajina (1969) notes that shade tolerance of white spruce is variable and dependent upon site moisture; shade tolerance is considered to be higher on drier sites and lower on mesic sites. Based on a detailed survey 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; for moisture, nutrient and heat requirements, rankings were 2.8, 2.2 and 1.5, respectively (Bakuzis and Hansen 1959).

Climatic Range: White spruce grows well in the cold, moist climate associated with the Boreal Forest Region (Rowe 1972). White spruce grows throughout the NC Region where mean July temperatures range from 16°C to 19°C, and winter temperatures may fall below -40°C; by comparison, throughout its natural range, white spruce occurs in areas with mean July temperatures ranging from 14°C to 21°C and with winter minimums as low as -57°C. The mean date of last spring frost varies from May 30 to June 15 and the date of the first fall frost varies from September 2 to 20 throughout the commercial range of white spruce in northern Ontario (Arnup et al. 1988).

Frost Resistance: White spruce has a low to moderate resistance to frost; it flushes earlier than black spruce and consequently is more susceptible to early spring frosts. Frost frequently damages flowers and early shoot growth in spring, especially in low-lying areas and depressions, and young seedlings are frequently damaged (Clements et al. 1972). However, white spruce can withstand severe winter temperatures.

Flood Tolerance: White spruce has a moderate tolerance to flooding. It grows relatively well on imperfectly drained alluvial floodplains (Gardner 1983) but is less tolerant of prolonged flooding than black spruce. Seedlings are tolerant of flooding, but seedling vitality and survival are reduced after prolonged flooding (Ahlgren and Hansen 1957, Zinkan et al. 1974). Grossnickle (1987) showed that cold-stored black spruce and white spruce seedlings planted on cold, flooded soils in spring will develop an undesirable water-relations pattern, with reduced root growth and possibly increased mortality. White spruce seedlings have displayed patterns of increasing tolerance tof flooding with increasing age (Lees 1964). White spruce trees experience mortality after long periods of flooding (Ahlgren and Hansen 1957).

Fire Tolerance: White spruce is often associated with mixedwood stands that are not highly susceptible to fire. Stands damaged by spruce budworm, however, are particularly susceptible to fire.

Successional Status: White spruce represents a climax species, and readily reproduces under its own shade.

Vegetative Reproduction: Seed production is the primary reproductive mechanism for white spruce in northern Ontario. Layering rarely occurs in white spruce in northern Ontario although elsewhere it is sometimes the primary reproductive strategy (Sutton 1968). Layering in white spruce occurs in open stands growing on nutritionally poor and wet, moss-dominated organic soils; layers develop where lower limbs are retained for extended periods of time and moss and litter accumulate to cover these limbs. Roots are subsequently initiated from dormant buds near terminal bud scars of the branches.

Sexual Reproduction:

Flowering: White spruce is monoecious, with male and female flowers occurring on the same tree, usually on different branches. 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). Flower bud initiation commences in July the year before flowering (Alden 1985). Flowering occurs for 3 to 5 days in late May to early June prior to the flushing of vegetative buds. Date of flushing becomes later with increased age. Pollination is by wind.

Fruit: White spruce female cones are about 3.5-5.0 cm long, cylindrical, and have smooth-margined, woody cone scales that enclose the winged seeds (Schopmeyer 1974). Mature cones are pendant and ripen during mid-August to late September of the year of development to release seeds. In closed stands, moderate cone production begins at age 30 or earlier, with optimum production at age 60 or older.

Crop Cycle: Excellent seed crops are produced every 10 to 12 years, with most stands yielding few to many cones every 2 to 3 years (Alden 1985).

Crop Abundance: Cone crops vary greatly in abundance from year to year, and from area to area. 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 trees at the narrowest spacing (Caron et al. 1990).

Seed Viability: Approximately 310,000 viable white spruce seeds are obtained per hL of cones (370 viable seeds per gram). Seeds require stratification or overwintering to induce germination. Seeds are generally viable for 1 year, but if conditions remain extremely dry, they may maintain their viability for up to 2 years (Alden 1985, Anon. 1986a). In a survey of 3 Ontario plantations over 2 years, Fogal and Alemdag (1989) found that the number of sound seeds per cone varied from 0 to 162; however there were large year-to-year and location-to-location differences in the amount of viable seed produced. The authors provide a technique for constructing regression equations, using 3 variables (sound seeds per section, cone length and cone diameter), for locations and crop years to aid in the determination of the number of sound seeds per cone (Fogal and Alemdag 1989).

Seed Dispersal: Seeds drop by gravity within a few days of maturation during late summer or early fall. They may be dispersed a short distance by wind or water, usually not more than 100-200 m (Fowells 1965).

Germination: Germination occurs during mid-June to late July, when seedbed temperatures are between 18°C and 24°C and there is sufficient soil moisture. Good seedbeds include exposed, humus-rich mineral soils, decayed wood and mineral/organic soil mixtures. Particularly on alluvial soils, white spruce seeds that fall among thick mats of grass in the autumn may become suspended and, as dead blades of grass dry out in the spring, germinants may dessicate and die before their roots penetrate the soil (Eis 1981). Zasada and Norum (1986) advocate prescribed burning on interior Alaska flood plains for fuel reduction and site preparation prior to white spruce planting; they found that subsequent mechanical site preparation was required to provide the mineral soil exposure necessary for adequate, well-distributed regeneration from seed.

Seedling Survival and Growth: Frost heaving is a common and serious problem for white spruce seedlings growing on exposed silty or fine loamy mineral soils (Stiell 1976). This condition may be mitigated by maintaining the surface litter layer in cutover and seeded or planted areas. However, significant amounts of deciduous leaf litter on the forest floor may smother or crush young white spruce seedlings (Gregory 1966). White spruce is a mesic species that requires well or moderately well drained soils for germination and early growth (Fowells 1965, Nienstaedt 1982). Some genetic stock of white spruce may be poorly adapted to calcareous soil conditions (Teich and Holst 1974, Perala 1987).

A sparse overstory may provide partial shade while serving to increase local humidity and soil moisture for seedling growth. Young white spruce seedlings prefer full sunlight for optimum growth but are more tolerant of low light than black spruce (Sutton 1968, 1969). Good growth occurs during the first 5 years in as little as 45% sunlight (Logan 1969). After about age 10, full sunlight and minimal root competition is required if the tree is to achieve optimum growth.

White spruce commonly suffers a period of post-planting depression known as *check* that may last from 2 to 15 years (Stiell 1976). Typical symptoms of check are short, greenish-yellow needles, poor retention of needles that are 2 or more years old, small buds and very slow growth (Sutton 1975). Check results not from direct physical damage, but rather from the tree's inability to exploit the rooting zone (Sutton 1968).

Height Growth: Diameter and height growth, and root and shoot weights are all reduced under low light intensities. Height growth by seedlings is initially slow and indeterminate. In juvenile stages, the tree is capable of flushing and growing continuously if favorable environmental conditions are maintained (Stiell 1976).

In the spring, white spruce typically flushes 5 to 10 days before black spruce. This new growth, however, is susceptible to late-spring frost damage. Regrowth of damaged leaders rarely occurs following frost damage (Sutton 1968). Nienstaedt and King (1982) report a strong positive correlation between late budbreak and rapid height growth for white spruce. During wetter years, height growth is greater on warm soils. However, soil temperatures during drier years often do not correlate well with height growth.

Weed competition is one of the main factors that affects early height growth of white spruce; height growth is significantly improved by controlling competing woody and herbaceous vegetation (Stiell 1976). Based on studies of several forest sites in British Columbia, Eis (1981) noted that herbaceous vegetation slowed the rate of growth by white spruce seedlings planted immediately after logging for a few years, but did not cause significant mortality and failure of regeneration. Sutton (1972) found that after 7 years, the height growth of white spruce did not respond to fertilization or irrigation, but increased significantly from 114 cm on plots without weed control to 155 cm on plots with weed control. In the northern interior of British Columbia, two of the most aggressive and serious competitors for white spruce are *Calamagrostis canadensis* and trembling aspen (Herring 1989). In the northern Lake States, dense 15- to 20-year-old plantations are sometimes weeded and 30- to 50-year-old stands are often row-thinned; early plantations were typically planted with trees too closely spaced (Rauscher 1987).

First year height growth of white spruce was significantly affected by season of planting, but not by handling technique (Vyse 1983). Ackerman and Johnson (1962) reported that after 5 years, the current annual height growth of white spruce was still affected by month of planting. Based on 20-year measurements, Ball (1990) noted that site preparation by *straight-blading* of plantations in west-central Manitoba created long-lasting and deleterious growth consequences for white spruce, even though it resulted in improved early survival of seedlings (Waldron 1964).

Root Development: White spruce is moderately resistant to windthrow. Mature and overmature trees may be subject to windthrow, especially on shallow, organic and poorly drained silty or clay rich soils where rooting depth is restricted. Roots of white spruce require good soil aeration. Root form and rooting depth is highly variable in response to soil texture, drainage and moisture regime, soil fertility, and the existence of impermeable soil layers (Sutton 1968, 1969).

Roots are often concentrated in the upper 30 cm of the soil but they are typically deeper than roots of black spruce on similar soils. The root system of mature trees is typically composed of shallow, wide-spreading laterals that are tough and pliable (Hosie 1969). Roots are often most abundant along the boundary of the organic LFH layer and underlying mineral soil.

A regimen of root pruning and wrenching modified the morphology of white spruce transplants by decreasing the height and increasing the root system size (Buse and Day 1988); this approach may improve establishment and growth of outplanted white spruce stock.

Stand Development: The best growth of white spruce often occurs along streams and lakes, where moisture and nutrients are not limiting. White spruce achieves good growth on fresh sandy loams (**S3**), calcareous silts and silt loams (**S4**, **S9**), and other silt-rich soils (Perala 1987). It is a minor and usually unproductive species on dry sandy soils or wet clay soils. White spruce can tolerate a wide range of soil moisture conditions but performs poorly on dry or poorly drained soils. White spruce responds moderately well to release or thinning. No differences in dominant height were observed 10 and 20 years after thinning a 35-year-old white spruce plantation near Petawawa (Stiell 1980). Advance growth will display rapid growth following overstory removal (Johnson 1986). White spruce matures between ages 75 and 125 but, in the absence of fire or disease, typically survives from 150 to 200 years.

White spruce will outgrow and outperform black spruce and balsam fir in later stages of stand development, but initial growth may be relatively slow (Berry 1971). Based on a study in the Thunder Bay area, NC Region, Burgar (1961) indicated that merchantable wood volume production of the average white spruce tree was approximately 35% more at age 25, 40% more at age 60, and 110% more at age 90 than that of the average balsam fir tree at the same ages. White spruce - balsam poplar ecosystems on floodplains represent some of the most productive sites in the southern Yukon Territories, with site indices at 100 years of more than 22 m (Stanek and Orloci 1987).

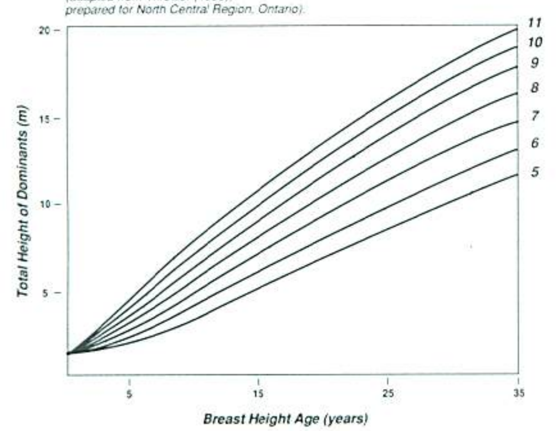
In mixedwood stands, white spruce may remain suppressed in the understory until the hardwood overstory component becomes decadent (Johnson 1986, Arnup et al. 1988). In order to release supressed white spruce, Froning (1980) and Yang (1989) recommend careful harvesting in mixedwood stands. In the Quetico Park area of the NC Region, Walshe (1980) notes that although white spruce is common in the understory, it is rarely a dominant overstory component.

White spruce is a tolerant species that may remain suppressed for years. For this reason, site index curves are somewhat difficult to prepare, interpret and apply properly. Growth and stand development may be highly variable, depending on stand history and stand composition. White spruce is also subject to considerable genetic variation, which may serve to locally modify normal growth patterns, reproductive cycles and other characteristics.

Thrower (1986, 1987) prepared breast height site index curves for plantation white spruce in the NC Region using growth intercepts; projected site indices ranged from 5 to 11 m at age 35. Results suggested that estimates of white spruce plantation yields could then be extrapolated using polymorphic curves prepared by Berry (1971, 1978) for white spruce near Petawawa, Ontario. Willcocks et al. (1990) provide preliminary total-volume and merchantable-volume yield tables for plantation white spruce.

Site Index Curves for Plantation White Spruce at 15 years

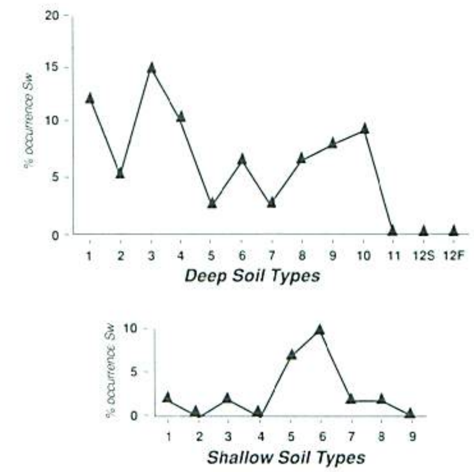
(adapted from Thrower (1986); prepared for North Central Region, Ontario)



Associated Soil Conditions

NWO FEC Soil Types *(76 NWO FEC plots)*: White spruce dominated stands in the NC Region are most commonly found on deep, fresh, coarse loamy (**S3**) soils. They also commonly occur on deep, fresh coarse sand (**S1**), deep, fresh silt (**S4**) and deep, moist fine loam or clay (**S10**) Soil Types. White spruce also occurs with low frequency on shallow, coarse loamy soils (**SS6**). White spruce dominated stands do not occur on wet organic soils or very shallow soils. As an understory species, however, white spruce is found across a wider range of soil/site conditions.

Distribution of White Spruce across NWO FEC Soil Types in the NC Region

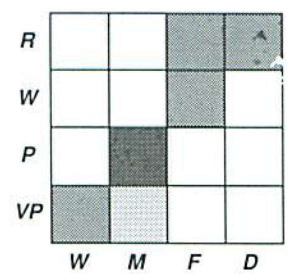


Deposition: White spruce dominated stands in the NC Region occur primarily on morainal and lacustrine deposits, and less commonly on glaciofluvial outwash deposits. Soil profiles are usually brunisolic or podzolic.

Texture: White spruce stands occur predominantly on coarse loamy parent materials in the NC Region, but are also associated with coarse to fine sandy, fine loamy, silty and even clayey C horizon textures. A and B horizons vary from coarse or fine loamy soils to silty soils.

Drainage and Moisture Regime: White spruce in northern Ontario typically occurs on rapidly to imperfectly drained soils (Arnup et al. 1988). In the NC Region, white spruce is less common on very rapidly or poorly drained

Correlation of Soil Drainage and Moisture Regime Classes for Black Spruce



soils, and does not occur on very poorly drained soils. White spruce dominated stands in the NC Region commonly occur on fresh and, less frequently, moderately moist or moderately dry soils. White spruce stands do not develop on very dry or wet soils. However, mottling in soil profiles under white spruce dominated stands occurs relatively frequently; about 1/3 of the NWO FEC plots in the NC Region had mottles in the profile. Gley colors are not commonly encountered under white spruce stands in the NC Region.

Stoniness and Structure: Coarse fragments, mostly as cobbles, are commonly encountered in soil profiles under white spruce dominated stands in the NC Region. Soils beneath white spruce dominated stands are predominantly single grained in structure; occasionally, subangular blocky and platy structures are encountered.

Site Position: Most white spruce dominated stands in the NC Region occur on level terrain or at upper through toe slope positions.

Litter Layer: In the NC Region, LFH layers beneath white spruce dominated stands typically range from 6 to 15 cm thick; organic (O) horizons are rarely encountered. Typically, forest humus forms are humifibrimors and fibrimors.

Soil Fertility Requirements: White spruce is a more nutrient demanding species than black spruce and requires moderate fertility for optimum growth. Although it tolerates a wide range of soil acidity, optimum growth occurs between pH 5.0 and 7.0 (Wilde et al. 1965, Sutton 1969, Arnup et al. 1988). About 1/3 of the NWO FEC soil profiles under white spruce had free carbonates within 100 cm of the surface.

Insects, Diseases and Other Damaging Agents

Insects:

Spruce budworm (*Choristoneura fumiferana* Clem.): Outbreaks of spruce budworm affect stand growth after 2 years of serious infestation; mortality of 60% or more may result. Infestations are more common and destructive in stands containing a large component of balsam fir (Rose and Lindquist 1977). In mature stands, serious outbreaks often occur after several years of early-summer drought.

White Pine Weevil (*Pissodes strobi* Peck): White pine weevil causes some damage to white spruce stands. Larvae attack and kill leaders during late May to mid-July, affecting tree form.

Diseases:

Shoestring Root Rot (*Armillaria ostoyae* (Romagn.) Herink.): Stress caused by dry or nutrient poor soils increases the probability of root rot infection. Inoculum of *Armillaria* can persist in the soil for up to 10 years. Root rot is generally understood to affect a minor component of mature stands but becomes more serious in overmature stands (Whitney 1976). It may cause significant damage in young plantations, especially where mortality is not evenly distributed over the stand (Whitney 1988).

Based on the results of an 11-year survey in northern Ontario, 6% of dominant or co-dominant white spruce were killed or experienced premature windthrow as a result of root rot (Whitney1989). The degree of root rot (stain and decay) is highly correlated with the number of dead and windfallen trees, stand age, and root decay at ground level (as a percentage of basal area) for a 10-tree sample (Whitney 1989).

Trunk and Butt Rot (*Inonotus tomentosus* (Fr.) Gilbert. and *Phellinus pini* (Brot.: Fr.) A. Ames): Trunk and butt rot may cause significant stem decay in white spruce stands, particularly in trees more than 140 years old. Infections may enter trees through stem wounds caused by logging (Basham 1990).

Other:

Seedling Injury: Common sources of injury to and mortality of white spruce seedlings include frost heaving, flooding, summer heating, sun scorching, physical damage from ice loading and deep snow, and smothering by vegetation (Sutton 1969).

Wildlife Browse: In young plantations, leader browsing by snowshoe hare and other animals may cause significant damage. During winter and early spring in south-central Alaska, snowshoe hares strongly preferred white spruce dominated stands with canopy covers of 25-75% (MacCracken et al. 1988). Seedlings and young trees in plantations may be damaged or killed by small rodents, typically by stem girdling; the grassy vegetation often found on sites supporting regenerating white spruce also provides preferred cover and food for voles (Kennedy et al. 1989).

Windthrow: In mature and overmature stands, windthrow may cause considerable mortality.

Management Considerations

White spruce is a valuable timber species, used for both pulpwood and lumber in the NC Region. The wood is light, soft, resilient, straight-grained and white, with little colour contrast between sapwood and heartwood (Hosie 1969).

In many instances, white spruce may be managed most effectively using a *mixed forest objective*; rarely does white spruce form pure stands naturally (Nienstaedt 1982). Natural regeneration success is often inconsistent for white spruce and unreliable and, consequently, artificial regeneration is usually required if a high component of white spruce is desired in new stands. Genetically improved white spruce planting stock should be used when possible (Sutton 1982); white spruce has exceptional potential for genetic improvement, calling for further research and breeding trials (Rauscher 1987).

In the Upper Great Lakes Region of the United States, white spruce is favored in planting for sawlog and pulp production. As well, it is used to increase forest diversity, regenerate balsam fir stands destroyed by spruce budworm, and restock river-bottom and valley areas, including areas previously occupied by elm stands destroyed by Dutch elm disease (Rauscher 1987).

Because of nutrient and moisture demands by the shallow root systems of white spruce, site preparation prior to planting should be conducted carefully. Care should be taken to not expose bare mineral soil, but rather to either reduce LFH layers to less than 8 cm or to effectively mix organic materials with surface mineral soils. Developing roots of seedlings typically concentrate along the boundary of the organic LFH layer and the underlying mineral soil.

Competition control can significantly improve juvenile survival and growth (Stiell 1976, Eis 1981). White spruce seedlings are particularly susceptible to frost damage. Although shade tolerant, white spruce achieves optimum growth in full sunlight after about age 10. White spruce demands more nutrients than black spruce and requires moderate fertility for optimum growth (Sutton 1969). White spruce responds moderately well to release or thinning. Advance growth will grow rapidly after removal of the overstory.

White spruce dominated stands are used to some extent by many wildlife species. Deer and moose use white spruce dominated stands for winter shelter (Euler 1979, Arnup et al. 1988). Mature or older white spruce dominated stands with a diverse understory may provide good habitat for a variety of small mammals, including martens, fishers, voles and snowshoe hares.

Black Spruce 3.3.

Picea mariana (Mill.) BSP.
Pinaceae (Pine Family)

Description: At maturity, black spruce is a small to medium-sized evergreen conifer, averaging 15 m in height, with a narrow, compact, conical crown, straight stem form and often fine branching. Black spruce branches often droop, with upturned ends, and the top of the crown may develop a characteristic club-like shape with age. The root system is shallow and spreading, and lower branches and roots readily layer. Black spruce is widespread and common in temperate North America, growing in both pure and mixed stands (Westveld 1953, Horton and Lees 1961, Damman 1964, Vincent 1965). With its long wood fibers, it is highly valued in Ontario as a pulpwood species (Anon. 1980, Arnup et al. 1988). In the NC Region, black spruce grows on a wide range of soil and site conditions from dry, shallow, upland mineral soils to wet, lowland organic soils. Black spruce is a very common species in both the overstory and understory of many forest stands in the NC Region. On upland soils, it grows in pure stands or in association with jack pine, trembling aspen, balsam fir, white birch and white spruce. On lowlands, it is commonly found in pure stands but may also occur in overstory associations with tamarack and eastern white cedar.

Black Spruce

Associated Stand Conditions

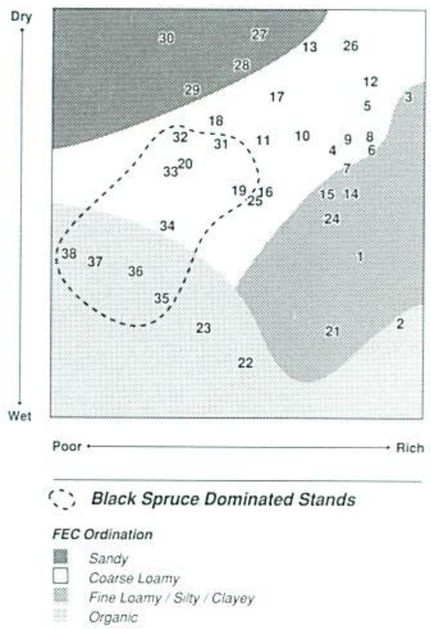
NWO FEC Vegetation Types *(454 NWO FEC plots)*: Black spruce is the dominant overstory species in four black spruce / feathermoss Vegetation Types (**V31**, **V32**, **V33**, **V34**). Jack pine is a common associate in these stands, particularly when located on fresh, coarse loamy, upland mineral soils (Sims et al. 1989). Understory conditions in **V31**, **V32**, **V33** and **V34** are variable in both species composition and abundance, but black spruce is typically present as a shrub. Black spruce is also the dominant overstory species in four black spruce / Sphagnum Vegetation Types (**V35**, **V36**, **V37**, **V38**) on moist to wet, organic soils. Shrub and herb layers are variable, ranging from herb and shrub rich to poor.

Black spruce is the dominant overstory tree species in two black spruce mixedwood Vegetation Types (**V19**, **V20**). It is a common associate in the overstory of 13 other NWO FEC Vegetation Types, most notably the two mixedwood Vegetation Types **V10** and·**V11**, and is present as an overstory component in more than half of the 38 Vegetation Types defined by the NWO FEC system (Sims et al. 1989)

Overstory: Jack pine is the most common associate of black spruce dominated stands on upland mineral soils. It occurs as a minor associate in most upland Vegetation Types in which black spruce is dominant. Balsam fir occurs as a minor associate in the overstory of both upland and lowland communities. Tamarack and white cedar may be present in varying frequencies on organic soils. White birch and trembling aspen are frequent associates on upland mineral soils; occasionally either or both species also occur in black spruce dominated lowland Vegetation Types.

Shrubs *Gaultheria hispidula*, black spruce, *Vaccinium myrtilloides*, *V. angustifolium*, *Ledum groenlandicum*, *Linnaea borealis* and balsam fir occur in upland and lowland Vegetation Types in which black spruce is dominant. *Alnus rugosa*, *Rubus pubescens*, *Oxycoccus microcarpus*, *Kalmia polifolia*, *Chamaedaphne calyculata* and *Sorbus decora* are frequent in lowland Vegetation Types in the NC Region. *Aralia nudicaulis*, *Diervilla lonicera*, *Rosa acicularis* and *Amelanchier* spp. are restricted to upland black spruce-jack pine / shrub rich / feathermoss stands.

NWO FEC Vegetation Type Ordination showing distribution of Black Spruce dominated stands and associated soil conditions in the NC Region.



Herbs: *Cornus canadensis* and *Maianthemum canadense* are ubiquitous beneath black spruce dominated stands in the NC Region. *Equisetum sylvaticum*, *Coptis trifolia*, *Smilacina trifolia*, *Mitella nuda*, *Viola renifolia* and *Petasites palmatus* are restricted in distribution to lowland Vegetation Types dominated by black spruce. *Clintonia borealis*, *Carex trisperma* and *Trientalis borealis* are frequent in black spruce dominated stands on both lowland and upland soils. *Aster macrophyllus* and *Streptopus roseus* are usually restricted to mixedwood Vegetation Types with black spruce in the overstory.

Mosses and Lichens: *Pleurozium schreberi*, *Dicranum polysetum*, *Ptilium crista-castrensis* and *Hylocomium splendens* are ubiquitous in black spruce dominated stands of the NC Region. *Sphagnum nemoreum*, *S. girgensohnii*, *S. magellanicum*, *S. angustifolium* and *Aulacomnium palustre* are restricted to lowland black spruce Vegetation Types. Total moss cover ranges from 49% to 90% in upland stands and from 79% to 94% in lowland black spruce dominated stands. *Cladina rangiferina* occurs occasionally in upland black spruce stands but rarely in lowlands.

Silvics

Growth Habit: Black spruce is a slow growing, long-lived tree. Its growth form is straight and relatively uniform, and it is often finely branched. Taper is least in better-growth stands of black spruce, including stands of **V19**, **V20**, and **V33** on coarse loamy soils, and greatest on stands with poorer growth on organic soils, including **V36**, **V37** and **V38**. Black spruce is a characteristically shallow-rooted species with a narrow crown form; the top of the crown often forms a club-like shape.

Needles are stiff, thick and sharp, less than 2 cm long, distinctly 4-sided in cross-section, and dark bluish-green, often with a powdery coating; needles are arranged spirally on the stem. Black spruce branchlets are densely covered with a brownish, velvety hair, and have persistent, raised, woody leaf bases (Hosie 1969). Outer trunk bark is dark greyish-brown and flaky, but inner bark has a distinctive dark olive-green coloration (Scoggan 1978, Fernald 1979). White spruce, which is sometimes difficult to distinguish from black spruce, has hairless branchlets and a lightly colored inner bark, as well as larger, more cylindrical cones and longer needles. The bark of white spruce twigs also tends to be more pale, often almost yellow.

Vegetative buds of black spruce swell during mid-April to late May, and open by the middle of June after the serious risk of frost has passed. Height growth occurs from mid-June to early August. Radial growth begins about 2 weeks earlier than height growth and ends in late August (Arnup et al. 1988). Black spruce is a poor natural self-pruner, except when it occurs in dense stands. It often grows in an even-aged community, reflecting a post-fire stand origin (Westveld 1953, Horton and Lees 1961, Viereck 1983, Foster 1986). Growth response is associated with gradients in photoperiod, temperature and local soil/site conditions.

Shade Tolerance: Black spruce has an intermediate tolerance to shade. It grows best in full sunlight but is capable of surviving for long periods at low light intensities (Klinka et al. 1982). Seedling survival is often increased if partial shade is available to provide shelter and modify seedbed temperatures and moisture loss. Black spruce seedlings may survive under as low as 10% of full sunlight, but will grow poorly (Logan 1969). Black spruce is somewhat more shade tolerant than white spruce (Arnup et al. 1988). In very densely stocked stands, the shade is often so great that black spruce may regenerate only after the stands are substantially reduced by natural thinning (Krajina 1969). Based on a detailed survey of Minnesota forests, black spruce was given a ranking of 3.5 on a 5-unit scale (1=least to 5=greatest) for light requirements; for moisture, nutrient and heat requirements, rankings were 4.5, 1.2 and 1.0, respectively (Bakuzis and Hansen 1959).

Climatic Range: Black spruce grows across a range of temperature regimes in the NC Region, occurring on cooler-than-average lowland areas as well as warmer-than-average shallow, dry upland sites. The mean frost-free period for the commercial range of black spruce in northern Ontario varies from 80 to 112 days, intermediate compared to its overall natural range of below 60 to over 140 days (Fowells 1965). Bud burst, shoot elongation and radial increment in black spruce will all continue at low temperatures between 3°C and 8°C. Precipitation levels also vary widely across the range of black spruce in the NC Region, being higher near Lake Superior and eastward, and lower in the western part of the Region. Total annual precipitation across black spruce's range in northern Ontario ranges from 635 to 864 mm (Chapman and Thomas 1968, Anon. 1987a); across its entire botanical range, precipitation ranges from less than 250 mm near the Northwest Territories treeline to over 1400 mm in eastern Quebec (Fowells 1965).

Frost Resistance: Black spruce is resistant to frost damage because it flushes up to 2 weeks later than white spruce and balsam fir growing in the same area on similar soils. By delaying leaf flush, black spruce successfully avoids most spring frosts but young shoots are still susceptible to late frosts that occur in early to mid-June (Stathers 1989).

Flood Tolerance: Both seedlings and mature trees are intolerant of prolonged flooding longer than 48 days, but are highly tolerant of flooding for shorter periods of time. Prolonged submergence of roots by flooding lasting more than 6 weeks may kill mature trees (Ahlgren and Hansen 1957, Fowells 1965). In a long-term study of 3 flooded sites in northern Minnesota, Ahlgren and Hansen (1957) found that black spruce and balsam fir displayed improved flood resistance, better crown recovery and less reduction of terminal growth than white spruce, white pine, red pine or jack pine. To adapt over the longer term to changing water-table conditions, black spruce is capable of developing adventitious roots from its stem and surface roots. Such a mechanism is useful, for example, along stream levees where flooding periodically buries surface roots, or where seasonal water levels gradually shift.

Seedling vitality and survival are reduced after prolonged flooding (Ahlgren and Hansen 1957, Zinkan et al. 1974). Grossnickle (1987) showed that cold-stored black spruce and white spruce seedlings planted on cold, flooded soils in spring will develop an undesirable water-relations pattern, with reduced root growth and possibly increased mortality.

Fire Tolerance: During spring, summer and fall, fire hazard ratings are lower in stands older than 30 years than in young stands of 3 to 30 years of age. Fire hazard is greatest in mixed spruce-fir stands, and lowest in spruce dominated mixedwood Vegetation Types (**V10**, **V11**). Crown and surface fires may readily kill or damage black spruce. By killing competing vegetation and reducing dry litter, fire often creates an improved seedbed for black spruce regeneration. Black spruce seeds are retained in semi-serotinous cones, where they are protected and remain viable for several years. Following fire, trees may slowly disseminate these seeds over a period of 2 to 4 years (Arnup et al. 1988), although Wilton (1963) found that about half of seeds fell within 60 days after a relatively hot fire in Newfoundland.

Successional Status: Black spruce is frequently classified as a pioneer species. After a disturbance such as fire, it often readily develops into even-aged stands. It also grows as a mid-successional species in mixed upland stands. Balsam fir tends to increase in abundance in older black spruce stands growing on more fertile soils (including Vegetation Types **V31**, **V35** and **V36** on **S2** and **S3** soils), whereas black spruce maintains its dominance on nutrient poor soils (including stands of **V37** on deep organic **S12F** soils). In upland conifer stands (**V32**, **V33**), in the absence of fire, black spruce may remain over time as a major stand component, often accompanied by balsam fir and jack pine. Viereck (1983) suggests that the amount of organic matter in the forest floor that is removed by fire may in part determine the successional sequence for black spruce stands following fire, although other important factors include pre-burn vegetation type and age, severity and time of year of the burn, parent material, climate, and weather patterns following fire.

Vegetative Reproduction: Black spruce reproduces both by layering and seed production. Layering is a common form of black spruce reproduction, especially on wet organic soils, but layering may also account for up to half of reproduction on mineral soils in boreal areas (Hosie 1969). Layering occurs when lower branches come in contact with and are covered by accumulating moss or litter on the forest floor (Stanek 1961). If sufficient moisture exists, these branches develop roots from dormant buds near the terminal bud scars of branchlets, and shoot growth initiates. Once established, layered trees develop into new individuals in the stand.

Sexual Reproduction:

Flowering: Black spruce is monoecious with male and female flowers forming on different branches of the same tree, at the end of the previous year's growth. Flower primordia are usually initiated during the season preceding the year of seed production. Male flowers are tiny, cone-like, deciduous and short-lived, whereas female flowers are red, erect cones with numerous spirally-arranged scales (Scoggan 1978). Bud development starts during late July or early August, and is more prolific during years with warm, dry springs and summers.

Trees as young as 10 years of age can produce flowers and seed cones, and trees as young as 14 years produce cone crops large enough to provide adequate pollen for within-plantation fertilization (Caron and Powell 1989). Abundant flower and cone production does not typically occur until trees are 40 to 50 years old (Haavisto et al. 1988). The optimum age for cone production is about 150 years. Flowering occurs from mid-May to late June, varying with local climate and other factors. Pollen is shed by mid-June and is wind borne.

Fruit: Small, winged seeds are enclosed by the woody scales of the mature female cone (Schopmeyer 1974). Cones are about 1.5-3.0 cm long, semi-serotinous, egg-shaped to roundish, and have cone scales that are toothed or frayed along their margins. Most cones are concentrated in upper parts of the tree crown, and mature from late August to mid-September. Ripened cones open periodically late in the winter after development to release seeds. Cones may persist on branches for several years, often remaining in a partially opened state (Vincent 1965).

Crop Cycle: One out of approximately every 4 years is a heavy seed-crop year for black spruce. Young plantation trees may be predisposed to produce large numbers of cones every second year, although the pattern may be modified by climatic factors (Caron and Powell 1989). Black spruce is a dependable seed producer each year, with few failures.

Crop Abundance: A mature black spruce tree may produce an average of 1146 seed cones in a good seed-bearing year, but numbers vary greatly from year to year (Haavisto 1975). Healthy female cones from mature black spruce contain about 50 to 110 viable seeds per cone (Haavisto et al. 1988). Average seed yields for black spruce stands in Ontario are 494,200 seeds per ha (Skeates and Haavisto 1987).

Seed Viability: Black spruce cones mature in early September. Seeds remain viable for extended periods, up to 18 years in storage and about 4 years when retained in cones in the natural setting. Wilton (1963) reported that 50% of viable seeds remained in cones 1 year after ripening, and about 15% remained after 5 years. Seed viability in the field, however, begins to decline quickly after approximately 4 years (Fraser 1976). Consequently, for seed-extraction purposes, collection of cones older than 4 years from standing timber and 3 years from logging slash is not recommended (Haavisto 1975). Most black spruce seeds remain viable after fire, and the semi-serotinous cones open in extreme heat to release seeds. Once on the ground, black spruce seed viability decreases with time and is typically lost within 10 to 16 months (Fraser 1976, Anon. 1986a).

Seed Dispersal: Seed dispersal extends a distance of 2 or 3 tree heights, typically about 80 m downwind and 40 m upwind, with about half of the seeds shed during winter. Some seeds continue to disperse throughout subsequent years, but most viable seeds are dispersed from cones within the first 4 years. In one lowland stand, Haavisto (1978) noted that 75% of annual viable seedfall occurred in early spring.

Germination: Black spruce seeds require a moist but unsaturated seedbed, with available moisture within 1 to 2 cm of the surface. Tolerance of young seedlings to drying and desiccation is very low (Thomas and Wein 1986), due in part to the shallow, slow-growing root system. The highest regeneration success occurs on a mixture of organic humus material and mineral soil. Survival is increased in areas where slash or a light vegetation cover may provide partial shade to reduce evaporation and ameliorate seedbed temperatures (Arnup et al. 1988).

Black spruce rarely regenerates successfully on loose, uncompacted feathermoss, which dries out and often dies following overstory removal (Place 1955, Jeglum 1981, 1984). Seeds can germinate on Sphagnum moss but survival is usually possible only if the Sphagnum is compacted or a slow-growing species (Haavisto 1979). Burned duff is also a suitable seedbed for regenerating black spruce seedlings (Place 1955, Vincent 1965, Foote 1983, Jeglum 1984). Litter provides a poor seedbed; it is difficult for seeds to penetrate, and leaves them prone to desiccation (Jeglum 1984).

Seedling Survival and Growth: Seedling survival is greatest on a mixture of organic humus material and mineral soil (Place 1955, Jeglum 1979). Seedling losses from frost heaving and desiccation may occur on finer textured soils (Racey et al. 1989a). Acceptable survival has been documented on burned duff, but the percentage depends in part upon the severity of the burn and the resulting local climate, particularly on ground surface temperatures (LeBarron 1948). Very low survival by black spruce in northern Minnesota, less than 7%, was observed during dry years on undisturbed duff and feathermoss seedbeds (Johnston 1977b).

Height Growth: Average black spruce seedling growth rates are 3 cm during year one, 5-13 cm during year 2, and 20-38 cm during year 3 (Arnup et al. 1988). Black spruce seedlings grow faster than those of white spruce but slower than aspen, tamarack and jack pine seedlings in the same area on similar soils. Seedlings can develop and survive under as little as 10% full sunlight but optimum growth is observed when seedlings grow in the open. Height growth is variable, depending in part on local climate and the nature of the rooting medium; however, black spruce is capable of achieving heights up to 28 m within 90 years. Stands with a site index of 7.5 m at age 50 are considered the minimum acceptable for commercially viable stands (Johnston 1977b). Black spruce growth is indeterminate during the first several years, with elongation and radial growth continuing as long as environmental variables are favorable. Indeterminate growth diminishes with time, and ceases when seedlings are 5 to 10 years old (Logan and Pollard 1975). Annual growth is subsequently controlled by preformed overwintering buds.

Root Development: Roots of young seedlings rarely penetrate deeper than 5 cm during the first year. Within the first few years, however, black spruce seedlings develop strong, fibrous, lateral roots. These laterals fan out and extend into rock crevices or remain in the humus layer, permitting seedlings to adapt readily to shallow or restricted rooting spaces (Robinson 1974, Arnup et al. 1988). Surface roots require some aeration and in upland soils are often concentrated at the interface of the organic humus (LFH) layer and underlying mineral soil (A horizon). In organic soils, surface roots are typically scattered throughout the organic mat in a zone above the mean annual water table (Vincent 1965). Winter shoot damage has been linked to reduced root vigor of containerized black spruce (Columbo and Glerum 1984).

The shallow rooting habit of black spruce renders individual trees prone to windthrow (Heinselman 1957a, Robinson 1974). Sometimes older trees develop sinker roots that may improve windfirmness. Roots exhibit a relatively high demand for nitrogen, which the trees may draw from decaying feathermosses and decomposing litter (Weetman and Timmer 1967, Weetman 1968).

Ectomycorrhizal fungi occur naturally in the soils of most boreal forest ecosystems and can enhance tree growth in a number of ways, including the extension of tree root absorptive systems and the production of plant growth regulators and secondary metabolites; in addition, these fungi can provide their hosts with resistance to a variety of serious feeder-root diseases, and they may help to detoxify allelochemicals and decrease competitive interactions among plants (Perry et al. 1987, Kropp and Langlois 1990). Ectomycorrhizae are commonly associated with black spruce growing on mineral soils, but are rarely associated with black spruce on organic soils. Black spruce seedlings planted on routine reforestation sites may also benefit from inoculation (Gagnon et al. 1988, McAfee and Fortin 1989), but further investigations are needed. Leachates from the leaves of *Rubus* spp. have a demonstrated allelopathic effect on ectomycorrhizae associated with black spruce (Cote and Thibault 1988).

Black spruce readily develop adventitious roots along the buried stems of seedlings, saplings and older trees in both organic and mineral soils. Prolonged submergence of roots by flooding for more than 48 days may kill seedlings and mature trees. Flooding of shorter duration is usually tolerated. Partially decomposed organic matter of *Kalmia angustifolia* has inhibitory effects on primary-root growth in black spruce (Mallik 1987).

Stand Development: Many black spruce dominated stands on organic soils are uneven-aged (Anon. 1981b, Arnup et al. 1988). In lowland areas, these stands are less likely to have arisen initially after a major fire and are often less prone to cyclical forest fires. In the absence of major disturbances, layering may perpetuate these stands for hundreds of years (Groot 1984). In such stands, layering provides a means of continuous reproduction as clearings and stand openings develop. On organic soils, black spruce stands often have an irregular, clumped distribution (Haavisto 1979, Jones et al. 1983).

Even-aged stands often develop on mineral soils after major burns. Crown and surface fires can readily kill mature stands of black spruce. The shallow rooting habit renders black spruce susceptible to ground fires (Lutz 1955, Rowe and Scotter 1973, Burns 1983, Zasada et al. 1983, Foster 1986). Black spruce, however, regenerates well after light fires, as seeds are released by the semi-serotinous cones and burned surfaces provide good seedbeds for germination and growth (Damman 1964). Even-aged stands on upland soils sometimes exhibit considerable variation in tree heights and diameters.

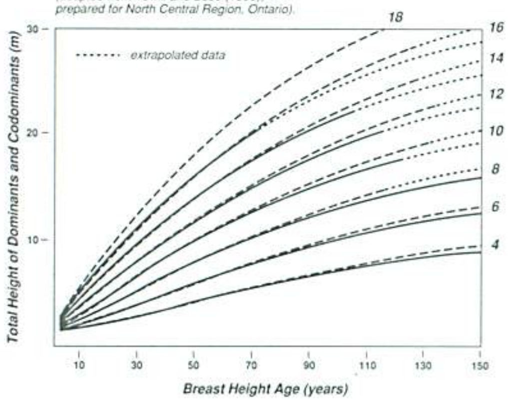
Heinselman (1957b) described several developmental phases for black spruce dominated stands in northern Minnesota: an initial 10-year *establishment phase* of very slow growth; a 10- to 50-year *canopy development phase* of continuing overstory development, accompanied by the expansion of a feathermoss ground cover; and, between 50 and 120 years, a *maturation phase*, when overstory growth slows and black spruce and balsam fir seedlings become abundant in the understory. Senescence sets in between 70 and 150 years, depending on site productivity, stand health, stand density, local climate and other factors (Heinselman 1957b). Ten years after the initiation of senescence, as much as 1/2 of the total stand volume may be lost in black spruce stands (Smith et al. 1987); harvest plans should be adjusted to accommodate black spruce stands that show such significant and rapid volume declines.

Faster-growing stands of black spruce on productive soils tend to deteriorate more rapidly and at a younger age than slower-growing stands on less favorable soils. Growth rates on organic soils have been correlated with nutrients and groundwater aeration, with lower growth rates occurring on oxygen-deficient, nutrient-poor soils (Jeglum 1974). Stands on nutrient-poor organic soils often have continuous feathermoss or Sphagnum mats, and sparse shrub layers composed mainly of scattered ericaceous shrubs. A number of preliminary experiments in northern Ontario have shown that peatland black spruce responds well to site drainage (Stanek 1968, Payandeh 1978, 1989, Haavisto and Wearn 1988). Near Cochrane, Ontario, an operational-scale drainage trial of a black spruce dominated peatland has recently been undertaken; this project is providing additional and new information on growth and yield responses, vegetational changes, and hydrological and environmental effects (Berry and Jeglum 1988, Haavisto and Wearn 1988, Jeglum 1990).

Buse and Baker (1990) developed a preliminary site-quality key for black spruce in the NW Region, which assigns a site index to key soil parameters. The highest (best) site indices are associated with moderately deep, coarse loamy mineral soils and deep, structured clay soils; the lowest site indices are associated with very shallow, dry soils, deep stagnant organic soils, or deep silt loam and loam soils with neither mottles or gleying within 40 cm of the surface.

Site Index Curves for Upland (----) and Lowland (——) Black Spruce

(adapted from Towill and Buse (1990); prepared for North Central Region, Ontario).

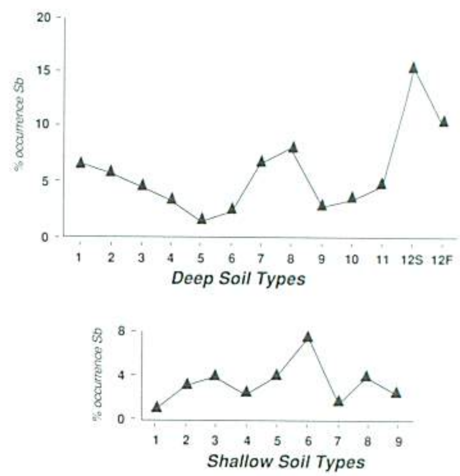


Towill and Buse (1990) produced polymorphic site-index curves for upland and lowland black spruce stands in the NC Region. In a similar manner, Buse and Baker (1990) prepared polymorphic site-index curves for upland and lowland black spruce in the NW Region. Willcocks et al. (1990) provide a preliminary set of growth curves for plantation black spruce in the NC Region, with tables showing estimated merchantable volumes for stands at various spacings.

Associated Soil Conditions

NWO FEC Soil Types *(454 NWO FEC plots)*: Black spruce dominated stands occur on a variety of NWO FEC Soil Types. They occur with highest frequency on deep (more than 40 cm thick) organic soils, shallow, coarse loamy tills, dry to fresh coarse and fine sands, and moist sands. Of the 454 NWO FEC plots that were black spruce dominated stands, 1/3 were on deep soils with organic surface horizons (**S12S**, **S12F**, **S11**), 1/3 were shallow soils with loamy A and B horizon textures (**SS6**), and 1/3 were deep mineral soils ranging from dry to fresh, medium and fine sands (**S1**, **S2**) to moist, coarse loams (**S8**).

Distribution of Black Spruce across NWO FEC Soil Types in the NC Region

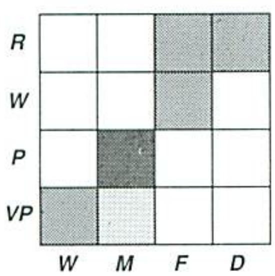


Deposition: Black spruce dominated stands occur on soils originating from all major modes of deposition found in the NC Region. Most commonly, however, black spruce stands are located on morainal soils, including shallow deposits over bedrock, and on organic soils. Black spruce is also frequently found in mixed and pure stands on glaciofluvial and lacustrine deposits. Black spruce stands typically occur over brunisolic, podzolic or gleysolic mineral-soil profiles or fibrisolic organic-soil profiles.

Texture: Black spruce stands commonly develop on organic soils; however, of the 454 NWO FEC plots sampled, 2/3 were on mineral soils with a variety of soil textures. Black spruce dominated stands in the NC Region are commonly found on mineral soils with coarse loamy, fine sandy, silty and coarse sandy B horizons. Occasionally, B horizon textures are clays and fine loams. Parent material textures are most commonly coarse loams and fine sands. However, black spruce stands are frequently found on silts, silt loams and clays and occasionally on coarse sandy parent materials.

Drainage and Moisture Regime: Black spruce dominated stands in the NC Region are found on very rapidly to very poorly drained soils, with lowland black spruce / Sphagnum stands occurring on poorly to very poorly drained soils and black spruce / feathermoss and mixedwood stands mainly on moderately well to rapidly drained soils. The wide ecological tolerance of black spruce to moisture is reflected in its broad range of distribution across dry to wet soils (Lowry 1972). In the NC Region, black spruce dominated stands are found on all soil moisture regime classes.

Correlation of Soil Drainage and Moisture Regime Classes for Black Spruce



Stoniness and Structure: No trend in stoniness is apparent under black spruce dominated stands in the NC Region. Most often, these stands develop on stone-free soils; however, they are commonly found on soils with a wide range of coarse fragment contents. Soil structure is predominantly single grained and blocky, but occasionally platy, amorphous and granular soil structures are encountered.

Site Position: The majority of black spruce dominated stands in the NC Region are located on level sites. Less frequently, they are found on upper, mid-slope and other slope positions. Better growth is correlated with black spruce stands on middle and lower slopes with well drained, fresh to very fresh, coarse to fine loamy soils (Racey et al. 1989a).

Litter Layer: Black spruce dominated stands in the NC Region are typically associated with LFH layers ranging from 6 to 15 cm thick, and less frequently with organic (O) horizon deposits more than 40 cm thick. Occasionally, stands are located on LFH layers ranging up to 25 cm thick. Common forest humus forms include fibrimors, humifibrimors and fibric peatymors.

Soil Fertility Requirements: Black spruce is tolerant of low fertility and high acidity (LeBarron 1948, Westveld 1953). Stand growth has been demonstrated to improve with drainage, fertilization and liming, all of which serve to increase available soil nutrients. Peatland soils supporting poorly growing black spruce may have a groundwater pH of 3.6 or lower (Jeglum 1974, Jeglum et al. 1974, Brown 1981). Often, there may be higher levels of potassium and phosphorus in the standing crop of black spruce than in the soils in which the stands are growing (Gordon 1983). Black spruce has lower nutritional requirements than white spruce (Arnup et al. 1988).

Availability of nitrogen has been correlated to black spruce growth, particularly on organic soils (Hatcher 1963, Vincent 1965, Vallee and Lowry 1970, Lowry 1972, Munson and Timmer 1989a,b). In a 10-year growth-response study, a 65-year-old upland black spruce stand in Quebec responded significantly to several thinning and urea-fertilization treatments (Weetman 1975). For a variety of replicated fertilization trials on semi-mature black spruce stands, Krause et al. (1977) recorded significant growth responses following nitrogen additions. In the NC Region, near Nipigon, a nitrogen (N), phosphorus (P) and potassium (K) fertilization study was conducted on a 100-year-old upland black spruce stand (Foster et al. 1986). Results indicated that N fertilization provided a significant ($p=0.05$) diameter growth response; the best 10-year response was to 224 kg N/ha, which produced 7.4 m^3/ha more wood than controls. Addition of K and PK to the N provided some additional growth response, but not a significant ($p=.05$) amount.

Occasionally, black spruce stands in the NC Region occur on calcareous soils; about 1/5 of the NWO FEC plots dominated by black spruce occurred on soil profiles with free carbonates within 100 cm of the surface.

Insects, Diseases and Other Damaging Agents

Black spruce is relatively free of insect and disease pests, especially on lowland organic soils.

Insects:

Spruce Budworm (*Choristoneura fumiferana* Clem.): This insect rarely defoliates black spruce, preferring balsam fir and white spruce. However, damage can be extensive if black spruce is growing among infested balsam fir and white spruce. Spruce budworm may destroy flowers in early spring and considerably reduce cone crops in an area (Rose and Lindquist 1977). Significant effects on growth are evident after 2 years of heavy infestation. Insecticide or bacterial applications can control infestations.

White Pine Weevil (*Pissodes strobi* Peck): White pine weevil rarely causes significant damage to black spruce stands. Larvae attack and kill leaders during late May to mid-July, affecting tree form. Adult weevils hibernate in forest litter and emerge when maximum daily temperatures exceed 15°C. To control populations, infected trees may be hand-pruned about mid-July, and infested leaders destroyed.

Yellow-headed Spruce Sawfly (*Pikonema alaskensis* Roh.): The yellow headed spruce sawfly rarely causes damage to the current year's foliage. Eggs are laid singly along needle edges. Young larvae feed in colonies, stripping one branch before moving on. Larvae spin oval, paper-like cocoons in humus or on twigs.

Sawyer Beetles (*Monochamus* spp.): Trees on the edges of cutovers are most susceptible to sawyer beetle attack. Limiting the extent of slash piles near living trees is a management practice that helps to reduce damage. In areas where modified harvesting is practised, the removal of excess slash is especially important to control this insect; if serious infestations occur, sawyer beetles may contribute to the death of seed-tree groups within 2 years (Howse 1984).

Diseases:

Needle Rusts (*Chrysomyxa ledi* (Alb. and Schw.) de Bary and *C. ledicola* (Peck) Lagerh.): Rusts defoliate but generally do not severely injure stands. The alternate host for these two rusts is *Ledum groenlandicum*. Rusts occasionally cause defoliation, stunting and death of small trees.

Tomentosus Root Rot (*Inonotus tomentosus* (Fr.) Gilbertson): Tomentosus root rot results in small openings in stands, and is more common in stands older than 100 years of age on organic sites. It can lead to significant wind breakage and windthrow (Whitney 1972, Johnston 1977b). About 11% of dominant or co-dominant black spruce are killed or experience premature windthrow as a result of various butt and root rots in northern Ontario (Whitney 1989).

Shoestring Root Rot (*Armillaria ostayae* (Romaqn.) Herink): Shoestring root rot does not extend up the bole. It occasionally kills a few trees, creating small openings. Stand mortality is typically less than 2% but can reach 40% or more on dry, sandy soils. Shoestring root rot is more common on well drained, sandy soils and less common in areas with excess moisture. When stands are being reestablished in areas previously infected, intensive site preparation should be conducted to break up and expose infected materials; this procedure may help lower the likelihood of reinfection in the new stand. Direct seeding, the use of container stock, or the planting of a less susceptible species should all be considered as options for managing previously infected areas (Whitney 1976).

Other Root and Butt Rots (e.g., *Coniophora* spp. and *Haematostereum spp.*): Damage by root rots in black spruce was equivalent to a loss of 42% of the current annual increment between 1977 and 1981. About 90% of root rot mortality between 1977 and 1981 occurred in black spruce, with the most damage developing in overmature stands (Gross 1985). Effective measures to control root and butt rot in natural stands and large plantations are unknown. As a preventative measure, infected trees should be harvested before extensive rot and related blowdown occurs.

Heart Rot (*Phellinus pini* (Brot. ex Fr.) A. Ames): Heart rot develops as a red pocket-rot in the trunk. Black spruce is less affected by heart rot than most other Ontario tree species (Basham 1990). Heart rot typically affects upland stands between 20 and 100 years of age and lowland stands between 100 and 130 years. The main point of entry is through broken tree tops and trunk wounds.

Other:

Windthrow: Windthrow is a serious damaging agent of black spruce dominated stands, especially older stands (Arnup et al. 1988). In the NC Region, windthrow may cause considerable mortality in both upland and lowland stands, especially near breaks in the landscape, or along edges of roadways and harvested areas (Fleming and Crossfield 1983). Where black spruce stands have been harvested using a stripcut method, the majority of volume loss typically occurs near the edges of strips, with the exposed corners sustaining the most damage (Elling and Verry 1978, Fleming and Crossfield 1983). Black spruce and balsam fir are generally more susceptible to wind damage than trembling aspen, jack pine or white birch (Fleming and Crossfield 1983).

Black Spruce Dwarf Mistletoe (*Arceuthobium pusillum* Peck.): Dwarf mistletoe is a parasitic plant species that causes deformation or *witch's broom*, which may result in stunted growth and eventual death. It is more common in the southwestern corner of the NC Region, and mortality is highest among seedlings and saplings.

Management Considerations

Black spruce, with its long wood fibers that add strength to paper, is highly valued as a pulpwood species, and is consequently the most important species in terms of value and volume cut in the NC Region (Anon. 1988). Black spruce is also widely used for sawlog production. The wood is moderately light, soft, relatively strong, resilient, white and straight-grained (Hosie 1969).

Black spruce is the most intensively regenerated species in the NC Region of Ontario, and extensive container and bareroot stock plantations are established annually. Black spruce requires well aerated surface layers for successful root survival and function (Jeglum 1974). Seedlings should not be planted too deeply into saturated zones. Seedling survival often depends upon the development of strong lateral root systems and, when planting, it should be confirmed that lateral root development will not be impeded.

Black spruce requires a fresh to moist seedbed. Organic material in the LFH layer and the mineral soil A horizon is an important source of nitrogen for growth, and a mixture of humus and mineral soil material is a preferred seedbed. On shallow sandy upland soils, up to 3/4 or more of the soil nutrient reserves in the rooting zone occur in the LFH (humus) layer and, thus, careful maintenance of this layer is critical. The presence of ectomycorrhizae on uplands has a significant effect on growth potential for black spruce. Nitrogen-fixing alder in moderate abundance may also benefit the growth of black spruce (LeBarron 1948, Vincent 1964b).

In some areas, black spruce advance growth may provide a considerable contribution to restocking an area for future harvest (Vincent 1964a, Fraser 1966, Groot 1984, Wickware et al. 1990). If suitable seedbed conditions are provided, direct seeding of black spruce is a viable regeneration option (Winston 1973, Richardson 1973, Fleming et al. 1987). Black spruce initially grows slowly, and competition control may be required (Bell 1990).

Grasses, sedges, aspen and shrubs such as alder can overtop and retard the early growth of black spruce (Haavisto 1979, Hamilton and Yearsley 1988). Rapidly growing Sphagnum can outcompete young seedlings. Black spruce seedlings will grow best in full sunlight if the seedbed does not dry out or overheat excessively. Slow growth is demonstrated under full shade; however, black spruce is very shade-tolerant and can persist under low light levels for many years. It is resistant to insect damage such as that from spruce budworm if grown in pure stands. It is resistant to 2,4-D if the herbicide is applied after buds have formed in late July (Bell 1990). Black spruce responds well to release and thinning during early developmental stages, i.e., between 10 and 50 years of age (Weetman 1975).

Provenance tests indicate that apical growth extension is genetically controlled in black spruce. Transporting stock from north to south may reduce growth rates as a result of early cessation of growth by the northern provenances (Morgenstern 1978). Similarly, moving stock north may lead to frost damage as southern provenances continue to grow in response to longer photoperiods. Upland versus lowland genetic adaptations may occur to some extent in black spruce (Fowler and Mullin 1976, Lee 1984). To better understand some of the genetically-controlled relations of black spruce to various soil/site parameters, further research is required.

Black spruce dominated mixed forests are used to some extent by many wildlife species; pure black spruce stands have lower value for wildlife. Deer, moose, caribou, black bears and hares feed on understory vegetation in black spruce stands, especially during winter months (Euler 1979, Cumming 1987, Arnup et al. 1988, Morash and Racey 1990). Lowland stands of black spruce are favored as thermoregulation areas and late-winter shelter by moose (Racey et al. 1989a). Spruce grouse spend their full life cycle within black spruce stands (Johnston et al. 1977b), mostly in upland areas (Arnup et al. 1988).

The common rotation age for black spruce is 70 to 80 years (Robinson 1974, Arnup et al. 1988). Rotation ages could be adjusted to reflect variations in growth patterns under different site conditions. As black spruce reaches senescence earlier on better soils, shorter rotations seem appropriate. Payandeh (1978, 1990) showed that black spruce on lower site classes of some peatland sites develop more slowly, extending the optimum rotation and yielding greater heights and volumes than Plonski's (1974) site-index curves suggest.

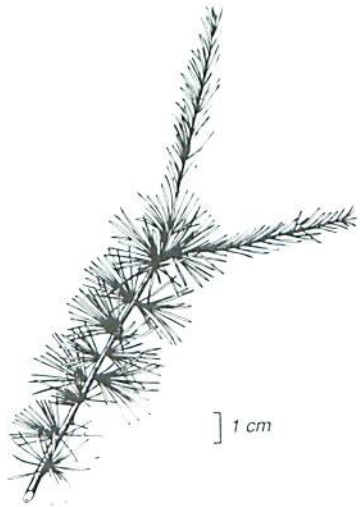
Tamarack/ Eastern Larch

3.4.

Larix laricina (Du Roi) K. Koch
Pinaceae (Pine Family)

Description: Tamarack is a medium-sized (at maturity averaging 18 m in height), deciduous conifer with a sparse, open crown and a characteristically ragged, irregular appearance. Branches have numerous dwarfed, stubby, and spur-like lateral branchlets and the thick trunk bark is grey to reddish-brown and scaly. Tamarack is native to cool temperate regions in Canada. It has one of the widest geographic ranges of all North American gymnosperms, extending from Alaska to Newfoundland and into the northern and northeastern United States (Roe 1957, Fowells 1965). Tamarack occurs infrequently throughout the NC Region, primarily on wet, poorly drained, usually organic, soils.

Tamarack/Eastern Larch



Associated Stand Conditions

NWO FEC Vegetation Types (*12 NWO FEC plots*): Tamarack is often associated with black spruce in northwestern Ontario (Sims et al. 1989). A dense understory of shrubs and herbs may develop under the canopy. In the NC Region, tamarack occurs as a dominant overstory component in the tamarack (black spruce) / speckled alder/ Labrador tea Vegetation Type (**V23**).

Overstory: Black spruce is a common co-dominant species with tamarack. Balsam fir, white spruce and eastern white cedar are also occasionally present in the overstory.

Shrubs: *Alnus rugosa*, *Ledum groenlandicum*, *Rubus pubescens*, *Gaultheria hispidula*, black spruce, *Linnaea borealis*, balsam fir, *Ribes triste*, *Rosa acicularis* and *Lonicera villosa* are common shrub species in tamarack dominated stands in the NC Region.

Herbs: *Cornus canadensis*, *Trientalis borealis*, *Maianthemum canadense*, *Viola* spp., *Equisetum sylvaticum*, *Coptis trifolia*, *Mitella nuda*, *Smilacina trifolia*, *Galium triflorum* and *Dryopteris austriaca* are common herb species associated with tamarack stands.

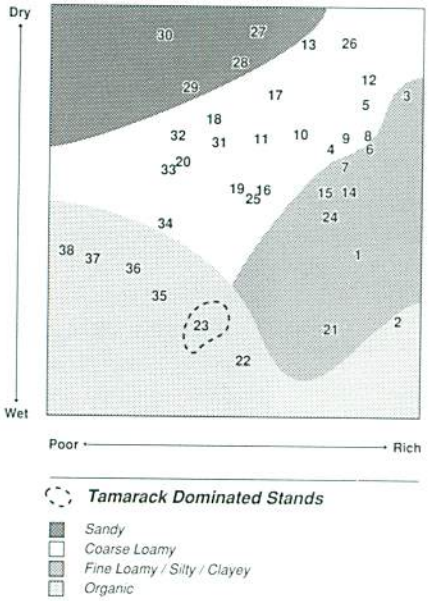
Mosses and Lichens: Total moss cover averages about 50% in tamarack dominated standsof the NC Region. Two feathermoss species, *Pleurozium schreberi* and *Ptilium crista-castrensis*, along with *Sphagnum girgensohnii* and *S. nemoreum*, are common. *Dicranum polysetum* is occasionally present. Lichens are sparse to absent under tamarack dominated stands in the NC Region.

Silvics

Growth Habit: Tamarack is a straight, slender tree with a narrow pyramidal crown that occupies from 1/3 to 1/2 of the bole in closed stands (Scoggan 1978). Needles are soft, flexible, very slender, 2-3 cm long and light green (turning yellow in fall and dropping off); needles are spirally arranged on the current year's twigs, and occur in clusters of 10-20 on dwarf lateral branchlets. Sylleptic shoots, lateral shoots arising from components not previously contained in a resting scaly bud, occur frequently in tamarack (McCurdy and Powell 1987). The bark of tamarack is thin, smooth and grey when young, becoming reddish-brown and scaly in mature trees (Hosie 1969). Tamarack is a moderate self-pruner and is considered to be a short to moderately long-lived species, typically surviving 150 to 180 years. It is tolerant of high soil acidity, low soil temperatures and a wide range of climatic and soil moisture conditions.

Tamarack grows on a wide range of soils, from deep, wet organic to coarse-textured mineral soils. The best growth occurs on rich, moist, well drained loamy soils along streams, lakes, swamps or seepage zones or on shallow, well decomposed organic deposits overlying mineral horizons

NWO FEC Vegetation Type Ordination showing distribution of Tamarack dominated stands and associated soil conditions in the NC Region.



(Beeftink 1951). Tamarack readily develops adventitious shoots to replace damaged foliage. Adventitious roots develop where organic soils accumulate and bury original root systems.

Shade Tolerance: Tamarack is very shade intolerant, and consequently is rapidly outcompeted, especially on mineral soils (Duncan 1954). During early stages of growth, up to about 4 years of age, tamarack can survive under moderate shade. It subsequently requires nearly full sunlight for continued growth and development. Based on a detailed survey of Minnesota forests, tamarack was given a ranking of 5.0 on a 5-unit scale (1=least to 5=greatest) for light requirements; similarly for moisture, nutrient and heat requirements, rankings were 5.0, 1.0 and 1.0, respectively (Bakuzis and Hansen 1959).

Climatic Range: Tamarack tolerates a wide range of moderate to cold temperature regimes throughout the Boreal Forest Region (Rowe 1972). It grows up to 68°N latitude, occupying cool, moist to wet soils throughout its range. Tamarack tolerates wide variations in precipitation, from dry subarctic Alaskan sites with a mean annual precipitation of 170 mm, to eastern Canadian wetlands where mean annual precipitation reaches 1400 mm (Fowells 1965).

Frost Resistance: Tamarack is very resistant to frost. It occupies low-lying habitats and wet soils on which late spring and early-fall frosts are frequent (Krajina et al. 1982).

Flood Tolerance: Tamarack is very tolerant of short to medium duration flooding (Baker 1949); however, prolonged flooding may cause widespread mortality in stands. Young tamarack trees are less tolerant to flooding (Fowells 1965), but tamarack of all ages are physiologically adapted for growth under waterlogged conditions (Garcia-Novo and Crawford 1973). Tamarack responds well to drainage (Trettin and Jones 1989).

Fire Tolerance: The tolerance of tamarack to fire is moderate, although in the seedling stage, particularly on upland soils, tolerance is low. Mature upland stands have thick bark and an excellent self-pruning habit. On organic soils, tamarack is more vulnerable to damage by ground fires because of its shallow rooting habit.

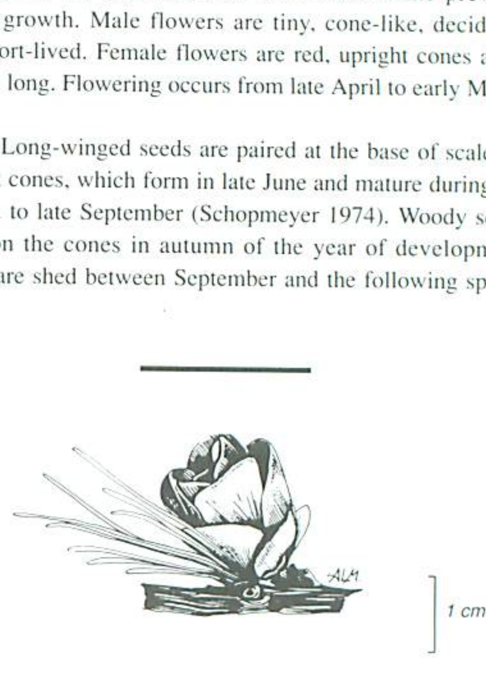
Successional Status: Tamarack is a pioneer to early successional species. It is a colonizer in open peatlands. It is often succeeded by or coexists with black spruce, which is more shade tolerant.

Vegetative Reproduction: Layering of tamarack may occur but it is not a significant means of natural reproduction. Farmer et al. (1986) describe a greenhouse mist-propagation approach to rooting vegetative cuttings of tamarack, and recommend the technique for production of containerized planting stock.

Sexual Reproduction:

Flowering: Male and female flowers develop separately on the same tree. Male and female strobili arise from buds that develop on the leafless dwarf branchlets of the previous year's growth. Male flowers are tiny, cone-like, deciduous and short-lived. Female flowers are red, upright cones about 1-2 cm long. Flowering occurs from late April to early May.

Fruit: Long-winged seeds are paired at the base of scales on upright cones, which form in late June and mature during late August to late September (Schopmeyer 1974). Woody scales open on the cones in autumn of the year of development. Seeds are shed between September and the following spring.



Cones are usually produced on young shoots of vigorous trees and may persist on the trees for 2 to 5 years.

Crop Cycle: Good seed crops occur at 3- to 6-year intervals with some seeds produced during intervening years.

Crop Abundance: Cones develop on trees as young as 12 years of age but abundant seed production begins at age 40 and continues to age 150. Optimum production has been recorded at age 75. Tamarack can produce up to 20,000 cones per tree with up to 300,000 viable seeds (Fowells 1965). In closed stands, production may range from 1,235,000 to 2,964,000 seeds per hectare.

Seed Viability: Seed viability is moderate to high (up to 85% viability). For 50-year-old tamarack near Thunder Bay, Ontario, germination of collected and cone-extracted seed varied from 0 to 86%, with the best germination occurring in late August (O'Reilly and Farmer 1988).

Seed Dispersal: Seeds ripen in late August and disperse soon after (early September to end of October). Seed dispersal is usually restricted to a distance of about twice the height of the seed-bearing tree.

Germination: Internal dormancy of seeds is broken during the first winter after dispersal. Germination occurs from late May to mid-June, and is greatest when surface temperatures reach 18°C to 20°C. An optimum seedbed is a moist mineral or organic soil surface, free of shrub competition but with a sparse cover of herbs or grass (Duncan 1954, Roe 1957). Sphagnum moss may overgrow and outcompete small tamarack seedlings.

Seedling Survival and Growth: Tamarack seedlings require abundant light (Logan 1966, Brown et al. 1988). Seedling mortality is high during the first 6 to 8 weeks, as small seedlings are subject to drought, flooding and inadequate light. On organic soils, seedlings may grow less than 5 cm per year for the first 8 years. On well drained sites in full sunlight, seedlings may grow up to 30 cm per year for the first 3 years, followed by rapid growth (up to 80 cm per year) until crown closure is reached. Tamarack seedlings inoculated with an ectomycorrhizal fungus [*Laccaria laccata* (Scop. ex Fr.) Berk and Br.] and grown for 6 months had significantly greater root lengths, total dry weights, and lower shoot:root ratios than untreated seedlings (Chakravarty and Chartarpaul 1990).

Height Growth: Some shoots on tamarack are elongated and arranged in a long spiral. Most shoots are dwarfed and occur in dense whorls. Needles on dwarf shoots develop early in spring before long shoots are evident. Height growth in tamarack begins after the first needles have reached full development in June, and continues until mid-August to early September, depending upon location, soils and climate. Radial growth begins earlier than height growth and also ceases earlier, typically in early August. Height growth is regulated by moisture and aeration. On well drained soils in the NC Region, tamarack is a fast-growing conifer.

In a study of tamarack from different seed sources, 2-year-old seedlings displayed distinctly different height growth and dates for bud set (Pauley 1965). In view of tamarack's wide geographic range, ecotypes or geographic races may exist (Schopmeyer 1974). Cheliak et al. (1988) describe tamarack as having a high genetic diversity, comparable to that of other species of woody perennials with extensive transcontinental ranges. Using a discriminant analysis approach, they delineated a broad east-west pattern to this diversity in Ontario (Cheliak et al. 1988).

Root Development: Tamarack has a shallow, compact root system that is concentrated in the upper 30 cm of soil. Taproot development is rare on mineral soils, where tamarack tends to produce a plate-like rooting structure, and absent on organic substrates (Fowells 1965). On river levees or organic soils, tamarack can develop new adventitious roots from the stem when original roots are buried below the surface layers of the soil. The root system provides moderate windfirmness (Hosie 1969).

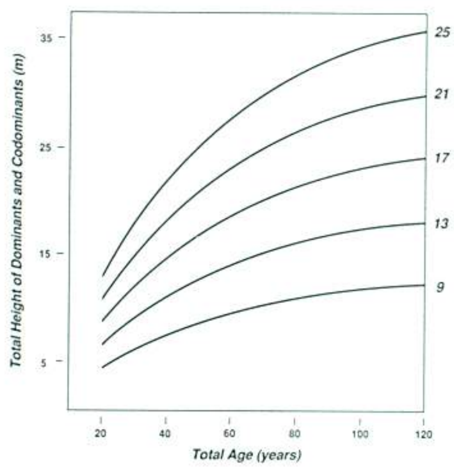
Stand Development: Tamarack is often a pioneer species in peatlands. Prolonged high water levels resulting from beaver activity or other factors may cause considerable local mortality and decreased growth of tamarack. Stands on shallow organic soils (**SS9**) are particularly vulnerable to root damage and windthrow. In mixed forest stands, tamarack must obtain sufficient sunlight, and normally must be present as an overstory component to persist (Duncan 1954). Tamarack is an excellent self-pruner with clear boles for 1/2 to 1/3 of tree height for 25- to 30-year-old trees. Trees whose tops experience dieback after sawfly defoliation or flooding may produce numerous adventitious shoots along the main stem (Roe 1957).

Height growth is initially rapid, with height increases of up to 0.4 m per year until stand closure occurs (around 25 to 30 years), but this then slows to 0.2 to 0.3 m per year as trees attain heights of 15 m or more. Recently, the potential of tamarack as a commercial species has been seriously considered, especially for short-rotation pulpwood plantations, because of its sometimes superior early growth rates compared to species such as black spruce (Fayle 1979, Hall 1986). In addition, tamarack has favorable wood properties, ease of seedling production, a good survival rate, low susceptibility to most pest infestations, and a wide ecological range (Vallee 1983). Genetic and breeding studies are underway to determine methods for improving growth and yield potentials of tamarack (Boyle et al. 1989).

Sixty-five years after ditching a forested, nutrient-rich peatland in northern Minnesota, productivity of tamarack increased 55% and average stem diameter increased 145% within 5 m of ditches; there was no apparent effect of ditching further than 80 m from ditches or at diameters beyond 20 m (Trettin and Jones 1989). In Newfoundland, Richardson (1981) reported that height growth of young tamarack seedlings was consistently greater on drained sites within 5 m of ditches.

Site Index Curves for Tamarack

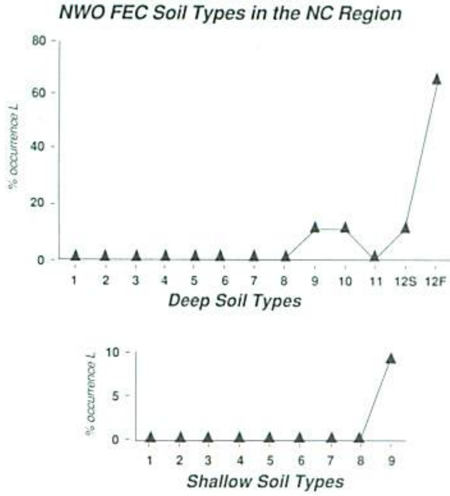
(adapted from Gevorkiantz (1957a) and Carmean et al. (1989); prepared for northern Minnesota, USA).



Associated Soil Conditions

NWO FEC Soil Types (*12 NWO FEC plots*): Tamarack dominated stands in the NC Region are found mainly on deep organic soils associated with a Sphagnum cover of less than 25% (**S12F**). Less frequently, they occur on moist to wet silty, fine loamy and clayey soils, and on shallow organic soils.

Distribution of Tamarack across NWO FEC Soil Types in the NC Region

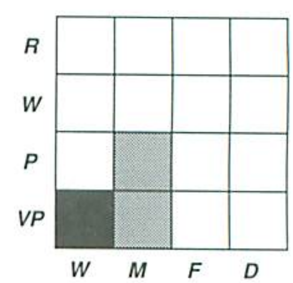


Deposition: In the NC Region, tamarack dominated stands occur mainly on organic deposits. Underlying landforms may be bedrock, morainal tills, and lacustrine or glaciofluvial deposits. Typically, tamarack stands are found on fibrisolic or mesisolic organic soil profiles or on gleysolic mineral-soil profiles.

Texture: Tamarack in the NC Region most frequently occurs on organic soils, but is also found on silt, silt loam, very fine sandy clay loam and medium sand parent materials. Mineral-soil surface textures (A and B horizons, when present) are usually fine-textured materials, ranging from fine sands to very fine sandy clay loams.

Drainage and Moisture Regime: Tamarack occurs on very poorly or imperfectly drained soils. Tamarack stands in the NC Region occur on soils with very moist to wet moisture regimes. Stands occurring on mineral soils often have gley colors and mottles at shallow depths, typically within 50 cm of the mineral soil-surface.

Correlation of Soil Drainage and Moisture Regime Classes for Tamarack



Stoniness and Structure: Coarse fragments are typically absent in soils under tamarack stands in the NC Region. Mineral soils beneath tamarack dominated stands are primarily single grained in structure.

Site Position: Tamarack is typically found on level or depressed sites in the NC Region.

Litter Layer: In the NC Region, tamarack stands most commonly grow on deep organic deposits, more than 40 cm thick. On mineral soils, LFH layers range from moderately thick (6 to 15 cm) to thick (16 to 25 cm). Fibric peatymors and mesic peatymors are the most common forest humus forms under tamarack dominated stands in the NC Region.

Soil Fertility Requirements: Soil fertility requirements for tamarack are defined as *low* in Minnesota but as *very high* in British Columbia (Krajina et al. 1982). Within its range in Alaska, Hulten (1968) called tamarack a *decided calcophile*; however, it only rarely occurs in the NC Region on soil profiles with free carbonates in the top 100 cm. Throughout northern Ontario, tamarack develops successfully on nutrient-poor, granitic, fine sandy soils but optimum growth appears to occur on neutral to slightly alkaline sites (pH of 6.6 to 7.6). On organic soils, tamarack is typically associated with nutrient-rich and well aerated fen and swamp wetlands (Jeglum et al. 1974). For northern Minnesota peatlands, Tilton (1978) correlated low levels of foliar N and P levels in tamarack with reduced stemwood radial growth and generally poor site fertility.

Insects, Diseases and Other Damaging Agents

Insects:

A more detailed description of common insect pests of tamarack is given by Rose and Lindquist (1980).

Larch Sawfly (*Pristiphora erichsonii* Hartig): Larch Sawfly is a serious pest of tamarack. Larvae feed on tamarack needles from June to August and often defoliate entire trees. Sawfly populations periodically reach epidemic levels and defoliate stands over large areas for several successive years until parasites, predators or flooding of cocoon sites cause population declines. Tamarack typically die after 8 successive years of sawfly defoliation. Full grown larvae overwinter in cocoons in the soil. Adult sawflies emerge from May to August and lay eggs on the tamarack shoots (10-30 eggs per shoot).

Larch Casebearer (*Coleophora laricella* Hubner): This European insect defoliates tamarack during late May and early June. Defoliation can reduce growth and cause tree mortality if infestations continue over 2 or 3 successive years. Adult casebearers are tiny moths that emerge from May to August and lay egg masses on needles. Hatched larvae bore into and feed on tamarack needles. For control, insecticides can be applied to young feeding larvae throughout the summer.

Eastern Larch Beetle (*Dendroctonus simplex* Leconte): Langor and Raske (1989) have recently described the species, which occurs throughout the natural range of tamarack in North America, as being a potentially serious pest for tamarack, and one that has caused widespread mortality in the Atlantic provinces of Canada. No significant outbreaks have been recently recorded in Ontario.

Diseases:

Heart Rot (*Phellinus pini* (Brot. ex Fr.) A. Ames), Butt Rot (*Phaeolus schweinitzii* (Fr.) Pat.) and Root Rot (*Armillaria ostayae* (Romagn.) Herink): Rots generally cause minor damage to tamarack, but are more abundant in stands occurring on wet, organic soils.

Other:

Animal Damage: Porcupines feed on the inner bark during winter, girdling tamarack stems and reducing growth or sometimes killing individual trees.

Management Considerations

Tamarack is occasionally logged for railway ties, poles, posts, pilings, boxes, crates, boat-building and pulpwood (Hosie 1969). The wood is moderately hard and heavy, decay-resistant, somewhat oily, frequently spiral-grained, and white (sapwood) to yellowish-brown (heartwood) in color (Hosie 1969).

Tamarack in the NC Region typically occurs in even-aged natural stands, either alone or in mixed stands associated with black spruce. Tamarack is frequently found along streams, lakes, swamps or seepage zones or on shallow, well decomposed organic deposits overlying mineral horizons. Tamarack is a shallow-rooting species that requires a continuously moist rooting medium; it is tolerant of saturated soils but not of widely fluctuating water tables. The best growth occurs on rich, moist, well drained loamy soils, but the species is more commonly found on acidic and near-neutral organic soils.

Tamarack is frost tolerant and thus a suitable species for growing in depressions and frost pockets. It requires full sunlight for optimum regeneration and early development, and may be best adapted to clear or shelterwood cutting, with subsequent competition control as required. The species experiences rapid early juvenile growth and, with optimum growing conditions, a relatively short rotation period. It is considered to be a short- to moderately long-lived species. Tamarack has potential as a commercial species for pulpwood, because of better early growth rates than black spruce on similar sites (Hall 1986). Some characteristics of wood quality for tamarack in the NC Region are described by Yang and Hazenberg (1987); growth of juvenile wood decreases from lower to higher latitudes, whereas the proportion of latewood shows the reverse trend (Yang and Hazenberg 1987).

The larch sawfly causes significant defoliation and mortality to tamarack growing endemically throughout northern Ontario. Even moderate defoliation may result in top die-back, poor form and reduced growth rates for individual trees. In Michigan, the sawfly has severely decimated this species and few old-growth individuals remain (Barnes and Wagner 1981).

Tamarack stands have generally low value for wildlife. Deer, moose, caribou, black bears and hares feed on understory vegetation in tamarack stands, especially during winter months (Euler 1979, Arnup et al. 1988). Buckner (1966) describes population dynamics of several shrew species at 3 tamarack-dominated peatland sites in southeastern Manitoba.

Jack Pine

3.5.

Pinus banksiana Lamb.
Pinaceae (Pine Family)

Description: Jack pine is a medium to large-sized (averaging 19 m high, up to 30 m), evergreen conifer at maturity with a sparse, variable crown and spreading or ascending branches. It is a two-needled, early successional pine that is native to central and eastern Canada and north-central and northeastern United States. It is well adapted to the colonization of dry and burned-over areas (Fowells 1965, Cayford and McRae 1983). Jack pine is the third most important commercial species in the NC Region in terms of volume harvested (Davison 1984), and the second most important species provincially (Anon. 1988). It is commonly encountered in the NC Region, occurring frequently on dry to fresh, sandy or coarse loamy soils. It typically comprises even-aged, post-fire forests either as monospecific stands or as pure coniferous stands with black spruce. Jack pine also occurs in mixedwood stands, in association with trembling aspen and other species.

Jack Pine

Associated Stand Conditions

NWO FEC Vegetation Types (*257 NWO FEC plots*): Jack pine is the dominant or co-dominant species in jack pine mixedwood Vegetation Types (**V17**, **V18**) and jack pine coniferous Vegetation Types (**V28**, **V29**, **V30**, **V31**, **V32**). Black spruce is often associated with jack pine in coniferous stands. Jack pine is the dominant overstory species in three herb and shrub rich Vegetation Types (**V17**, **V28**, **V31**) and four herb and shrub poor Vegetation Types (**V18**, **V29**, **V30**, **V32**). Jack pine stands are often characterized by a predominantly ericaceous shrub layer and a feathermoss ground cover. Herb and shrub poor understory conditions in jack pine stands may be correlated with dry, nutritionally poor soils that support a low site class of jack pine (Ohmann et al. 1978).

Overstory: Black spruce, trembling aspen and white birch are frequent overstory associates of jack pine in the NC Region. Balsam fir and white spruce occur less commonly.

Shrubs: Black spruce, *Vaccinium myrtilloides*, *V. angustifolium*, *Linnaea borealis*, *Aralia nudicaulis* and *Diervilla lonicera* are common understory shrub species in jack pine dominated Vegetation Types in the NC Region. Balsam fir, trembling aspen, *Gaultheria hispidula*, *Amelanchier* spp., *Rosa acicularis*, *Alnus crispa*, *Rubus pubescens*, *Corylus cornuta*, *Ledum groenlandicum* and *Arctostaphylos uva-ursi* occur with lower frequencies.

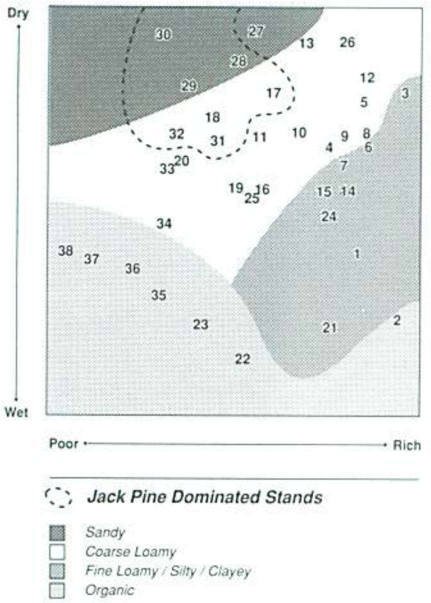
Herbs: *Maianthemum canadense*, *Cornus canadensis* and *Clintonia borealis* are the most common herbs in jack pine dominated stands in the NC Region. *Aster macrophyllus*, *Trientalis borealis*, *Melampyrum lineare*, *Streptopus roseus* and *Viola* spp. occur less frequently.

Mosses and Lichens: *Pleurozium schreberi*, *Dicranum polysetum* and *Ptilium crista-castrensis* are common ground layer mosses in jack pine dominated stands. *Hylocomium splendens* is also found, but less frequently. *Cladina rangiferina* is common beneath jack pine. *Cladina mitis* and *C. stellaris* are found less frequently.

Silvics

Growth Habit: Jack pine is a medium to large-sized (averaging 19 m high, up to 30 m), evergreen conifer with a sparse, variable crown and spreading or ascending branches. Breast-height diameters range typically from 12 to 38 cm. In closed stands, the live crown becomes greatly reduced, often covering less than 1/5 of the height of the tree (Hosie 1969). Needles are straight or slightly curved, stiff, twisted, sharply

NWO FEC Vegetation Type Ordination showing distribution of Jack Pine dominated stands and associated soil conditions in the NC Region.



pointed, and 2.0-3.5 cm long; light yellowish-green needles occur in clusters of two and have a persistent basal sheath. Branchlets of jack pine are yellowish-green. The trunk bark is reddish-brown on young stems, becoming dark brown and flaky or platy with age (Scoggan 1978). Jack pine is a moderately long-lived tree, reaching ages of 90 to 160 years.

Jack pine is characterized by rapid juvenile growth and annually displays two distinct flushes of extension growth separated by periods of inactivity. Although the species has an extensive geographic range, some of the best examples of well-developed jack pine occur within the NC Region, northwest of Lake Superior (Fowells 1965, Davison 1984).

Shade Tolerance: Jack pine is a shade intolerant species (Sterrett 1920, Anon. 1986b). It requires full sunlight at all stages of its life cycle to achieve optimum growth. However, the best initial survival of seedlings occurs on microsites with less than 4 hours of direct sunlight daily. Based on a detailed survey of Minnesota forests, jack pine was given a ranking of 5.0 on a 5-unit scale (1=least to 5=greatest) for light requirements; for moisture, nutrient and heat requirements, rankings were 1.0, 1.1 and 1.9, respectively (Bakuzis and Hansen 1959).

Climatic Range: The natural range of jack pine is characterized by long, frigid winters and short, warm to cool summers with low rainfall (Anon. 1986b). Jack pine is tolerant of air temperature extremes ranging from -40°C to +35°C, but different provenances are adapted to local temperature ranges; provenance trials across latitudinal and climatic gradients frequently display considerable winter damage. The number of frost-free days across the natural range of jack pine varies from 50 to 180 days (Fowells 1965). Date of flushing generally corresponds to the time when spring soil temperatures rise above 4.4°C. Jack pine is tolerant of a broad range of precipitation regimes. It is highly tolerant of, and well adapted to, summer droughts in excess of 30 days.

Frost Resistance: Jack pine is very frost resistant. It generally does not flush early, thus minimizing the potential for damage by spring frosts.

Flood Tolerance: Jack pine has a moderate tolerance to flooding, with tolerance decreasing with increasing duration of flooding. Jack pine roots are intolerant of prolonged flooding but can tolerate short-term inundation (Ahlgren and Hansen 1957). All young jack pine under 2 cm were killed, and 55% of jack pine 2 to 4 m tall were killed, by a 4-month flood in a northern Minnesota plantation (Benzie 1977a). Seedlings are tolerant of flooding, but seedling vitality and survival are reduced after prolonged flooding (Ahlgren and Hansen 1957, Zinkan et al. 1974).

Fire Tolerance: Jack pine is well adapted to periodic fires (Ahlgren 1959, Beaufait 1960, Cayford and McRae 1983, Anon. 1986b). It typically develops as even-aged stands after fire. The serotinous cones open after forest fires, and jack pine germinates readily on burned ground surfaces. The species is well-adapted, particularly as a monoculture, to colonization of and growth on dry, burned-over areas (Ahlgren 1959, Chrosciewicz 1983). Plantations are vulnerable to fire because of the flammable, dry sites on which they tend to occur and the porous needle litter, which dries out rapidly beneath stands.

Successional Status: Jack pine is an early to mid-successional species. In the absence of fire, it is eventually replaced by hardwoods and balsam fir. It is well adapted as a fire-origin species, with heavily scaled, serotinous cones that open readily only when subjected to very high or excessively low temperatures.

Vegetative Reproduction: Jack pine does not readily reproduce vegetatively in the natural forest. However, using standard horticultural practices, it can be easily grafted to potted stock.

Sexual Reproduction:

Jack pine is a prolific early producer of serotinous cones. Cone production occurs as early as 3 years of age, with production initiated, on average, in closed stands between 10 and 25 years. Seed viability is high for the first 6 years.

Flowering: Primordia for staminate flowers are laid down several weeks before those for pistillate flowers. Male and female flowers are separate on the same tree, and appear during mid- to late May. Male flowers are tiny, cone-like, deciduous, short-lived, and develop at the base of the current year's growth. Female flowers are erect cones with numerous spirally arranged scales (Fernald 1979). The date of flushing for jack pine fluctuates, depending on local climatic conditions, but occurs between mid-May and early June. Pollination is by wind.

Fruit: Winged jack pine seeds are enclosed by the woody scales of the mature female cone (Schopmeyer 1974). Cones are erect, egg-shaped to conical, straight or curved, and 3-5 cm long. Cones ripen during the fall of their second year. They are serotinous, usually remaining closed and persistent on the tree for years. Jack pine cones may remain closed for up to 25 years. Jack pine is an early and proficient seed producer and trees may begin to bear cones at 3 to 5 years of age, with significant seed production attained by age 10 (Roe 1963).

Crop Cycle: Jack pine seed production is continuous with good seed production every 3 or 4 years.

Crop Abundance: Jack pine seed production is abundant (Baker 1980, Anon. 1986b). On average, from 300 to 500 cones are produced per tree. However, production may rise as high as 1,200 cones per tree. The greastest production occurs in stands ranging in age from 70 to 80 years. Approximately 50 winged seeds are produced in each 73-scaled cone (Schantz-Hansern 1941).

Seed Viability: Jack pine seed viability is relatively high, ranging between 24 and 95%. Seeds are ripe when about 1/2 of the cone has turned brown. Viability is highest during the first 6 years but some seeds remain viable for up to 25 years. Even seeds from the oldest cones play a role in natural regeneration (Cayford and McRae 1983).

Seed Dispersal: A small percentage of cones will open at temperatures as low as 27°C but most require the higher temperatures associated with fire or exposed ground surfaces that receive full sunlight (i.e., greater than 50°C). Some cones will also open at very low temperatures (less than -50°C). The effective range of dispersal is about twice the tree height.

Germination: Seeds germinate within 15 to 60 days of dispersal when air temperatures are above 17°C and moisture is adequate. The greatest germination is observed during spring, between April and June (Anon. 1939, Chrosciewicz 1960) on seedbeds of either exposed mineral soil or a mixed substrate of mineral soil and surface humus (LFH) layers. Seeds have no requirement for stratification (Anon. 1986b). White birch leaf litter inhibits the germination and growth of jack pine, white pine and red pine seedlings (Ahlgren and Ahlgren 1981).

Seedling Survival and Growth: Seedlings are vulnerable to heat (temperatures above 50°C), drought, freezing, frost heaving, insect and rodent damage, and being smothered beneath fallen leaf or grass litter (Jameson 1961). Recently transplanted young seedlings often experience a period of moisture stress that disrupts physiological processes; for example, Grossnickle (1988a, b) demonstrated a close relationship between changes in minimum daily plant water potential and leaf conductance in newly planted jack pine. Improved seedling survival is observed where microsites endure less than 4 hours of direct sunlight per day (Beaufait 1960). High seedling survival occurs on microsites where jack pine is established on bare mineral soil or a mixed mineral soil and humus seedbed. Low survival (20%) is associated with undisturbed LFH layers less than 1.5 cm thick. The greatest mortality of jack pine seedlings occurs during the first and second growing seasons (Chrosciewicz 1983). Cayford and McRae (1983) note that dead standing trees in a fire-killed stand may provide important partial shade for regenerating jack pine seedlings.

Height Growth: Eighty percent of height growth occurs between mid-May and the end of June (Belyea et al. 1951). If moisture conditions are favorable, a second period of elongation occurs during late summer. Growth by natural jack pine seedlings is relatively slow during the first 3 years, followed by more uniform and rapid growth up to about age 40 (Anon. 1986b). Height growth of planted stock averages 30 to 140 cm per year, depending on site conditions, stock health and climate. Height increment is reduced where vertical root development is restricted by soil conditions. Jack pine responds extremely well to thinning and release during juvenile and intermediate stages of development (Smith 1984, Weetman and Fournier 1984, Anon. 1986b).

Fifteen years after a jack pine plantation was established in southern Manitoba, spacing effects were examined (Bella and DeFrancheschi 1980); at wide spacings, height growth was reduced, but diameter increment in terms of basal area was more than 100% greater than that observed at narrow spacings.

Root Development: Jack pine root development requires temperatures above 4.4°C in the upper 10 cm of soil. Growth may cease entirely if temperatures fall below 7°C for 6 successive days. Roots are intolerant of prolonged flooding but can tolerate short-term flooding. Tap roots develop in natural seedlings (Cheyney 1932, Bannan 1949). On a sandy soil in upper Michigan, seedling roots grew 13-25 cm in the first year and reached 25-33 cm deep, with a 60-cm spread, by year 2; by year 7, tap roots were up to 60 cm deep, and lateral roots were up to 4.9 m long (Fowells 1965). Rooting space is usually defined and established during the first 7 years in regenerating jack pine plantations established from seed. Tap roots develop in about 25% of planted container stock seedlings, and rarely develop in planted bare root stock. Bannan (1949) found that jack pine consistently produced a tap root with a deeper rooting system than either white spruce, black spruce or balsam fir growing on the same soil.

Ectomycorrhizal fungi associated with the roots of boreal conifers enhance tree growth by extending tree absorptive systems, producing plant growth regulators and secondary metabolites, and providing host resistance to feeder-root diseases (Kropp and Langlois 1990). A survey was conducted of the ectomycorrhizal flora associated with several mature jack pine stands in northeastern Alberta (Danielson 1984); the results indicated that no single species or small group of species dominate jack pine root systems, making selection of a suitable inoculum for planting stock somewhat difficult (Danielson 1984). Research is continuing, but several ectomycorrhizal inocula have already been found to have beneficial effects on the growth of outplanted jack pine stock (Navratil et al. 1981, Gagnon et al. 1987, McAfee and Fortin 1989).

Stand Development: Wiltshire (1982), Lenthall (1986) and Carmean and Lenthall (1989) prepared site index curves for jack pine in the Thunder Bay area. Schmidt (1986) and Schmidt and Carmean (1987) summarized some soil/site relations for jack pine stands in the Thunder Bay area. Site indices increased with soil depth, decreased with an increase in coarse fragment content in the C horizon, decreased with increased slope on glaciofluvial landforms, and increased with decreasing pH and increasing thickness of the A horizon on lacustrine landforms.

LeBlanc and Towill (1989a,b) related jack pine productivity in the NC Region to key soil characteristics and to NWO FEC Soil Types. The best growth occurs on deep, moist silts and silt loams (**S9**), fresh silty clays, sandy clays or clays (**S6**) and fresh fine sandy, coarse loamy and silty soils (**S2**, **S3**, **S4**). The poorest growth occurs on very shallow (<5 cm) soils over bedrock (**SS1**, **SS2**) (LeBlanc and Towill 1989a).

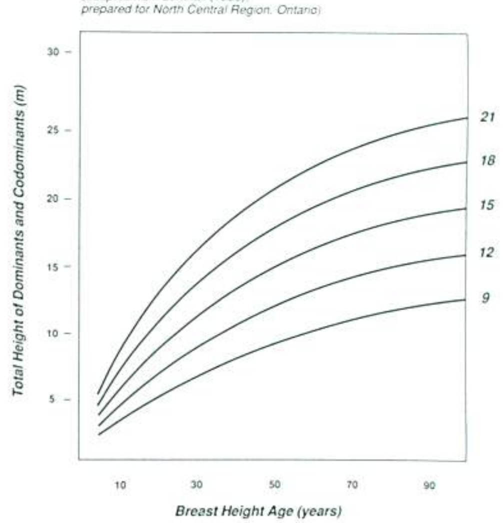
Where a seed source is present, early stand growth is rapid after major disturbances (fire, windthrow, harvesting). Growth levels off at an early age (about 40 to 50 years) on dry, shallow, coarse-textured soils, but continues to 60 or 80 years on deeper, fresh soils. Jack pine stands on shallow soils in northern Minnesota are generally less productive than those growing on deeper soils (Green and Grigal 1979).

Waves of mortality have been recorded in jack pine stands between years 15 and 30 as a result of inter-tree competition. Many young jack pine stands would likely benefit from selective thinning during this period. For a 45-year-old northern Ontario jack pine stand, a light, low thinning had no effect on 10-year growth, but urea fertilization resulted in a significant growth response (Groot et al. 1984).

Stand decline often begins shortly after maturity is attained. Young jack pine are relatively resistant to disease; stands less than 60 years often have less than 1% cull. On productive soils, decline has been observed as early as age 60; percentage cull increases progressively during subsequent years (Benzie 1977a). Jack pine may develop undesirable branch and stem forms when open-grown and, thus, stand density should not be decreased excessively by thinning (Shea 1981).

Site Index Curves for Jack Pine

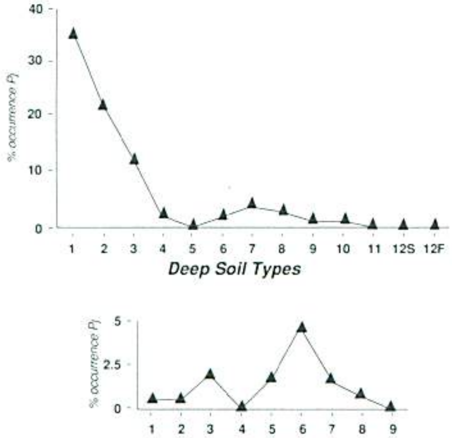
(adapted from Lenthall (1986), prepared for North Central Region, Ontario)



Associated Soil Conditions

NWO FEC Soil Types *(257 NWO FEC plots)*: Jack pine dominated stands in the NC Region occur frequently on deep, dry to fresh, coarse sandy soils (**S1**) and deep, fresh, fine sandy to coarse loamy soils (**S2**, **S3**). They occur less frequently on shallow, coarse loamy soils (**SS6**). Jack pine is typically not a dominant tree species on organic or finer textured silt and clay mineral soils.

Distribution of Jack Pine across NWO FEC Soil Types in the NC Region

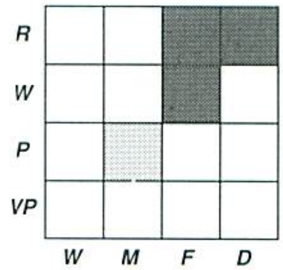


Deposition: Jack pine is mainly found on glaciofluvial and morainal till deposits in the NC Region. Jack pine stands are less frequently associated with lacustrine soils, and are not associated with organic landforms. Soil profiles are most commonly brunisolic or podzolic.

Texture: Jack pine dominated stands in the NC Region occur almost exclusively on coarse loamy, fine sandy and coarse sandy B horizon textures. Parent material (C horizon) textures are also predominantly coarse sandy, fine sandy and coarse loamy.

Drainage and Moisture Regime: Soils under jack pine dominated stands in the NC Region are predominantly rapidly drained, very rapidly drained or well drained; jack pine dominated stands do not occur on very poorly drained soils. Mottles and gley colors rarely occur in soil profiles under jack pine dominated stands. Soils associated with jack pine dominated stands are most commonly moderately fresh, fresh, moderately dry or dry. Jack pine dominated stands in the NC Region do not occur on soils with a wet moisture regime. Better growth of jack pine stands in the NC Region is associated with fresh to very fresh, well to moderately well drained, coarse loamy soils on upper slopes and level positions (Schmidt 1986, Racey et al. 1989a).

Correlation of Soil Drainage and Moisture Regime Classes for Jack Pine



Stoniness and Structure: Gravel and cobbles are often present in soil profiles under jack pine dominated stands in the NC Region. These stands are typically found on structureless soils although, occasionally, subangular blocky soils are encountered.

Site Position: Jack pine dominated stands are typically found on level or upper to mid-slope positions in the NC Region.

Litter Layer: LFH layers beneath jack pine stands in the NC Region generally range between 6 and 15 cm thick, less frequently between 1 and 5 cm. Fibrimors or, less frequently, humifibrimors are the most common forest humus forms.

Soil Fertility Requirements: Jack pine has low requirements for soil fertility (Fowells 1965). However, repeated fertilization combined with control of ground vegetation in a 40-year-old jack pine stand in Quebec produced a sustained increase in jack pine growth over 10 years (Weetman and Fournier 1984). Nitrogen fertilization has resulted in increased growth by jack pine (Krause et al. 1977, Morrison and Foster 1990). Wilde et al. (1964) define optimum soil pH for jack pine as 4.8 to 7.0. Schmidt (1986) found that the highest site indices for jack pine in the Thunder Bay area occurred on lacustrine soils with a B or C horizon pH of 4.8 to 5.3.

Jack pine in the NC Region is rarely associated with calcareous (within 100 cm of surface) soil profiles; according to Fowells (1965), jack pine will grow satisfactorily on calcareous soils only if a normal mycorrhizal association is present. In British Columbia, jack pine is not found on limestone substrata or soils rich in calcium (Krajina 1969).

Insects, Diseases and Other Damaging Agents

Insects:

More than 58 insect species are associated with jack pine. Of these, approximately half cause significant damage or reduction in tree growth and 5 are considered serious management problems (Howse 1984, Rose and Lindquist 1984).

Jack Pine Budworm (*Choristoneura pinus pinus* Free.): This major pest causes considerable jack pine mortality. The heaviest feeding by jack pine budworm occurs in treetops, causing deformed or multiple leaders and dieback. The tiny budworm overwinters under bark scales and begins feeding in spring on male flowers and developing shoots. Infestations appear greatest in stands with heavy male-cone crops. The pest is especially associated with open stands more than 40 years old. Moths emerge in July or early August. Outbreaks usually last 2 to 4 years, then decline rapidly. Insecticide or bacterial applications will control infestations.

Swaine Jack Pine Sawfly (*Neodiprion swainei* Midd.): This is the most destructive sawfly in eastern Canada. Adult sawflies emerge in late June or early July. Eggs hatch in early August and larvae feed until October. Cocoons are spun in soil beneath the trees. Poorly productive (site class 3) jack pine stands growing on shallow soils (e.g., NWO FEC Vegetation Type **V30**) are very susceptible to sawfly damage.

Sawyer Beetle (*Monochamus* spp.): Adults feed on the bark and twigs of mature and immature jack pine along the edges of harvested areas or on fire-damaged trees. The greatest damage occurs when considerable logging slash is present.

Eastern Pine Shoot Borer (*Eucosma gloriola* Heinr.): This shoot borer occurs frequently in jack pine plantations. According to Howse (1984), more than 39% of jack pine stands in Ontario were infested during the previous 10 year period. Only 10% of leaders were damaged, with most damage occurring on trees less than 6 m in height (Howse 1984). Larvae feed in June and July and pupate in the soil, with moths emerging the following May. Large-scale chemical control measures have been unsuccessful or too costly (Howse 1984).

White Pine Weevil (*Pissodes strobi* Peck): White pine weevil has been observed in 35% of jack pine plantations in Ontario. Average leader mortality is less than 1%. Weevils, the most common pests of pines in Ontario, attack and kill young leaders and thus affect tree form. Damage is greatest in poorly stocked plantations on trees less than 10 m in height. Adult weevils hibernate in soil litter, emerging in spring when daily air temperatures exceed 15°C. Larvae feed until July. One preventative method is to hand prune infested trees about mid-July, and destroy the leaders. Pesticides applied at 3- to 4-year intervals provide control.

Diseases:

Jack pine is relatively resistant to serious damage by disease (Hepting 1971); stands less than 60 years old typically have less than 1% cull as a result of disease. Several diseases occur on jack pine but they are considered to be relatively minor management concerns in the NC Region.

Scleroderris Canker (*Ascocalyx abietina* (Lagerb.) Morelet): This fungus causes mortality of trees with poor vigour. The first symptom is a red discoloration of needle bases in spring. Needles of infected trees are shed by fall of the second year. There is some variation in susceptibility among different provenances (Yeatman 1984).

Sweetfern Blister Rust (*Cronartium comptoniae* Arth.): Symptoms of this disease include the presence of large, resinous cankers, which may be most prominent in June and July (Gross 1976). Seedlings are killed by the girdling effect of cankers. Infection rarely rises 2 m above the ground. Cull averages 11% of merchantable volume of cankered trees (Gross et al. 1978) and there may be a decline of 20% in cubic-volume growth. To minimize infection, avoid planting jack pine in frost pockets and outside of its natural range.

Western Gall Rust (*Endocronartium harknessii* (J.P. Moore) Y. Hirats.): This rust causes round stem galls on young pines and branch galls on jack pine throughout its life cycle. It occasionally contributes to seedling mortality.

Shoestring Root Rot (*Armillaria ostoyae* (Romaqn.) Herink): Root and butt rots frequently kill jack pine, particularly seedlings and juvenile stands. *Armillaria* root rot is usually present on about 1% of trees in a stand (McGauley and Gross 1984). However, poor planting procedures, unfavorable climates or adverse site conditions will often increase the incidence.

Needle Cast (*Davisomycella ampla* (J. Davis) Darker): Needle cast kills all foliage except the current year's needles, reducing growth. Dead needles are shed in the year following infection.

Heart Rot (*Phellinus pini* (Brot. ex Fr.) A. Ames): Heart rot is common in the heartwood of living jack pine in northwestern Ontario; *Phellinus* is the most commonly associated fungus (Basham 1966).

Management Considerations

Jack pine is a valuable commercial species, used for construction lumber and pulpwood in the NC Region, as well as for railway ties, poles, pilings and specialty products. Jack pine wood is moderately hard and heavy, lacks strength and ranges in color from white (sapwood) to brown (heartwood) (Hosie 1969).

Jack pine does not germinate well under its own shade. In areas of higher precipitation, and on fine-textured soils, successful jack pine regeneration may occur beneath moderate shade. In the NC Region, jack pine is particularly suited to even-aged management and regeneration in clearcuts (Davison 1984). Mechanical site preparation and prescribed burning create seedbeds that are similar to those that develop from naturally occurring disturbances. Surface temperatures are typically elevated on open sites, causing serotinous cones to open and seeds to germinate. Near-surface soil temperatures rise in early spring on open sites, stimulating root activity and leader growth.

Many young jack pine stands may benefit from selective thinning or fertilization (Weetman and Fournier 1984, Anon. 1986b). In a study of several young jack pine stands in northeastern Ontario, precommercial thinning resulted in little height growth response but significant diameter growth (Smith 1984). Although thinning at a more advanced age (e.g., greater than 22 years) may be beneficial, it will not optimize growth within the stand since the opportunity to avoid a period of reduced, unproductive growth resulting from competition may be lost. In general, jack pine stands in northern Ontario respond positively to mineral fertilizers, with volume gains of up to 20 m^3/ha over 10 years (Morrison and Foster 1990).

Jack pine dominated stands are used to a moderate extent by many wildlife species. Caribou feed on ground vegetation in jack pine stands, especially during winter months, and moose, deer and grouse make occasional use of jack pine dominated stands for cover and browse (Euler 1979, Arnup et al. 1988, Racey et al. 1989a, Morash and Racey 1990).

Where local climates are sufficiently mild and soils are warm early in spring, forest managers may choose to convert jack pine cutovers to more productive red pine stands. In the NC Region, jack pine is often managed on very dry and nutritionally poor soils where no other native species can effectively grow.

Forest managers may assign shorter rotation periods of 40 to 50 years to jack pine on soils with shallow effective rooting zones, where stands will begin to stagnate and decline at an early age. Intermediate rotation ages of 50 to 70 years are appropriate for deeper, more productive soils. Longer rotation ages of over 70 years are assigned to soils of intermediate productivity where growth is slow and steady for an extended period of time (Anon. 1986b).

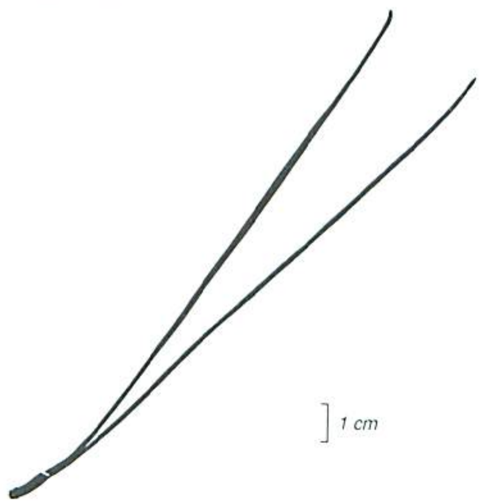
Red Pine

Pinus resinosa Ait.
Pinaceae (Pine Family)

3.6.

Description: Red pine is a tall, evergreen conifer averaging 23 m in height at maturity, with a sparse, oval crown and a straight, limbless trunk with little taper. Red pine grows in pure, even-aged stands and uneven-aged mixed stands in association with white pine, jack pine and/or trembling aspen. In Ontario, it occurs throughout much of the Boreal Forest Region but is more common in the Great Lakes - St. Lawrence Forest Region (Rowe 1972). The northern boundary of its commercial range occurs just north of Lake Nipigon, Ontario (at 52°N) and extends southwest into the general area of Atikokan (Haddow 1948). Red pine has a limited distribution in the NC Region, occurring mainly in the Quetico - Atikokan area and south of Thunder Bay near the United States border. It occurs infrequently, usually in small, localized stands on dry to fresh, rapidly drained, sandy or coarse loamy, often stony, soils. Genetic variation is reflected in growth rates, survival, photoperiod response and wood quality.

Red Pine



Associated Stand Conditions

NWO FEC Vegetation Types (*17 NWO FEC plots*): Red pine occurs as the dominant tree species in two NWO FEC Vegetation Types: red pine conifer (**V27**) and red pine mixedwood (**V13**). Red pine conifer stands (**V27**) typically exhibit a sparse understory with a thick ground cover of needle litter. Red pine mixedwoods (**V13**) are characterized by a more diverse understory, although shrub abundance is variable in both Vegetation Types.

Overstory: White birch and trembling aspen occur as co-dominants in red pine mixedwood stands. Jack pine, balsam fir, white pine, black spruce and large-toothed aspen are less frequent associates.

Shrubs: *Vaccinium myrtilloides* and *V. angustifolium*, *Diervilla lonicera*, *Aralia nudicaulis*, *Linnaea borealis*, balsam fir and *Amelanchier* spp. are common in the shrub layer of red pine dominated stands. Black spruce, *Corylus cornuta*, *Acer spicatum* and trembling aspen frequently occur in the shrub layer of red pine mixedwoods.

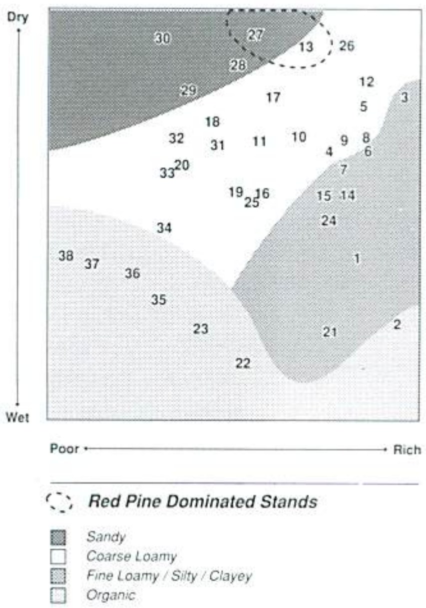
Herbs: *Maianthemum canadense* and *Cornus canadensis* are common in the herb layer of red pine stands in the NC Region. *Oryzopsis asperifolia* is common in red pine conifer stands (**V27**). *Aster macrophyllus* and *Clintonia borealis* are common in red pine mixedwood stands (**V13**).

Mosses and Lichens: *Dicranum polysetum* and *Pleurozium schreberi* are common in red pine dominated stands. In the NC Region, total moss cover is typically low in red pine mixedwood stands (14% cover) and moderate in red pine conifer stands (37%). *Cladina rangiferina* occurs with low cover in red pine conifer stands.

Silvics

Growth Habit: Red pine is a tall slender tree with little trunk taper and a limbless bole of up to 3/4 of the height of the tree in closed forest stands. However, in open stands, leafy branches may be retained over the whole height of the tree, and the trunk may be noticeably tapered (Hosie 1969). The tree has a dense, symmetrical, oval crown. Red pine needles are straight, slender, flexible, sharp-pointed, and 10-15 cm long; the shiny, dark green needles occur in clusters of two, and have a persistent basal sheath. Branches are usually spreading and upturned with foliage tufted at the ends. Branches do not self-prune in open-grown trees. Branchlets are stout, shiny and orangish; the trunk bark is reddish, flaky, becoming furrowed into thick plates with age (Scoggan 1978, Fernald 1979).

NWO FEC Vegetation Type Ordination showing distribution of Red Pine dominated stands and associated soil conditions in the NC Region.



Shade Tolerance: The shade tolerance of red pine is low. Red pine is more shade intolerant when it grows under drier and warmer conditions. Seedlings can grow well in up to 45% full sunlight up to age 5, but require full light for maximum growth in subsequent years (Anon. 1986c). Based on a detailed survey of Minnesota forests, red pine was given a ranking of 4.5 on a 5-unit scale (1=least to 5=greatest) for light requirements; similarly for moisture, nutrient and heat requirements, rankings were 1.1, 1.6 and 2.1, respectively (Bakuzis and Hansen 1959).

Climatic Range: The northern distribution of red pine is determined by a deficiency of summer heat, and roughly parallels the 2°C mean annual isotherm (Anon. 1974). Cold temperatures restrict development at all ages. Excessive heat is restrictive, particularly to the development of young seedlings. Red pine can tolerate low to moderate rainfall levels and summer droughts that may exceed 30 days.

Frost Resistance: Red pine is prone to frost damage. Frost may kill or severely damage newly flushed growth. Frost damage often occurs in depressions or along breaks in natural slopes where air drainage is limited (Benzie 1973, 1977b). Radiation frost damage may also occur on exposed, dry, sand flats where rapid, natural cooling occurs at night. Severe frost damage occurs on dry soils when temperatures fall rapidly over a short period of time. Frost desiccation of red pine occurs in spring, when flushing begins before root activity (Chapeskie et al. 1988).

Flood Tolerance: Red pine is characterized by a very low flood tolerance at all stages of growth. Red pine does not tolerate a lack of good soil aeration, even for short periods of time.

Fire Tolerance: Mature trees have thick, insulating bark and elevated crowns that enable stands to survive ground fires. Young plantations are vulnerable to fire because of the flammable, dry sites on which they tend to occur, branching that is close to the ground, and the porous needle litter which dries out rapidly beneath stands. Because of red pines's fire-resistant bark, crown-scorch is the usual limitation to a tree's survival (Van Wagner 1971). Fire usually prepares an excellent seedbed for red pine seeds. Suitable natural regeneration of red pine occurs on such burned surfaces, provided there is sufficient moisture for successful germination (Chapeskie et al. 1988).

Successional Status: Red pine is an early to late successional species. It typically becomes established during early successional stages of vegetation development in an area. Because it is long-lived and grows large, and is able to resist cyclical patterns of fire, red pine often persists in the overstory into a late successional stage.

Vegetative Reproduction: Red pine does not reproduce vegetatively.

Sexual Reproduction:

The reproductive strategy of red pine depends on successful seed dispersal. Nutrition is a key factor that influences successful flower and cone production. Cone production is rare near the northern edge of red pine's geographic range.

Flowering: Red pine is monoecious, with male and female flowers occurring on the same tree, usually on different branches. Male flowers are tiny, cone-like, deciduous and short-lived, developing at the base of the current year's growth. Female flowers are cones with numerous spirally arranged scales. Flowering occurs in late May or early June before flushing of vegetative buds and about 2 weeks earlier than white pine flowering. Pollination and fertilization occur during late May to mid-July. Conelets require two summers to mature.

Fruit: Winged seeds are enclosed by the woody scales of mature female cones (Schopmeyer 1974). Cones are egg-shaped to somewhat conical, straight, essentially stalkless and 4-8 cm long. Cones open to release seeds in the autumn of the year following initial formation, and fall from the tree by the following spring. Cones ripen from mid-August to mid-September.

Crop Cycle: Good seed crops occur every 3 to 7 years, with abundant crops occurring every 10 to 12 years (Anon. 1986a). Normally, at least some seed production occurs annually (Fowler and Lester 1970). Seed production is significantly reduced towards the northern edge of red pine's geographic range.

1 cm

Crop Abundance: Red pine produces 0.5 hL of cones per tree in good seed years (Anon. 1986c) with approximately 20 viable seeds per cone out of an average of 45 seeds. Each tree produces, on average, 50 to 200 cones, or about 4,000 viable seeds per tree. At Petawawa, Ontario, Stiell (1988) recorded cone yields from a single tree of 1,025 and 792, in 1970 and 1984, respectively. In overstocked red pine stands, seedfall is very low and many trees do not produce cones.

Seed Viability: Seed viability is variable, ranging from 14 to 65%. Less than half of all cone scales contain viable seeds. Viable seeds may be produced by trees as young as 12 years, but the best seed production is by trees of 50 to 150 years.

Seed Dispersal: Seeds ripen during mid-August to October of the second year after fertilization, with dispersal commencing a few days after ripening, and continuing into autumn. Most seeds are dispersed within a month of ripening with only a low percentage remaining on the tree for 2 or 3 years (Fraser 1965). Seeds disperse up to a maximum of 300 m but most fall within a radius equal to half of tree height (Fowells 1965).

Germination: Successful germination occurs on moist mineral soil where early summer precipitation is greater than 100 mm and temperatures are around 16°C. Red pine regenerates successfully where disturbance, such as fire, has prepared a mineral-soil seedbed (Benzie 1973, Ahlgren 1976). At the northern edge of its range, germination may occur on north-facing aspects where surface soils are fine-textured, provided competition is minimal. Little or no germination occurs if dense shrub and herb competition exists, surface litter layers or burned ground surfaces (ash layers) are thick, or ground surface temperatures exceed 33°C. Norby and Kozlowski (1980) report inhibition of red pine radicle elongation and seedling growth by extracts of *Aster macrophyllus* and *Rubus idaeus* var. *strigosus*, as well as other species. In germination tests using a variety of natural litters, red pine germinated and grew poorly in its own and several other litters, reflecting its requirement of mineral soil seedbeds for natural seedling establishment (Ahlgren and Ahlgren 1981).

Seedling Survival and Growth: Seedling mortality occurs in exposed areas as a result of high surface temperature and drought. Abrupt temperature fluctuations in the fall may kill young seedlings, especially on dry sites. Seedlings develop poorly under low light and moisture conditions associated with abundant grass or herb covers, dense shrub layers or dense hardwood canopies (Horton and Brown 1960, Anon. 1986c). Germination is most successful at around 25% full sunlight. Flooding, smothering and root competition can decrease seedling survival. Growth is best on acidic, well aerated soils. Young red pine are susceptible to root damage and perform poorly on calcareous soils. Red pine transplants typically have a faster initial growth than seedlings (Horton and Bedell 1960).

Root penetration by red pine is not as rapid as for white pine and therefore seedlings are less tolerant of competition (Stiell 1978). On some sites, complete release of red pine seedlings from shrubs and other low competition may be required by the end of the third growing season (Benzie 1977b). Survival is often low under *Corylus cornuta*, perhaps because of allelopathic influences. Containerized red pine seedlings subjected to moisture stress will have reduced survival and growth (Becker et al. 1987).

Height Growth: Optimal height growth occurs on sites that receive up to 6 hours of direct sunlight daily. Red pine tends to be very uniform in height growth. Average height increment is 30 cm per year for the first 60 years under favorable conditions. In natural stands, saplings may reach 1.3 m within 4 to 6 years. Mature individual trees average 30 to 60 cm DBH (up to 152 cm DBH) and 25 m in height (up to 46 m for old-growth individuals) (Chapeskie et al. 1988).

The length of the terminal shoot is determined the preceding summer by the number of needle internodes laid down in the winter bud. Water stress during the spring can limit elongation. Normally only one annual whorl is produced. Occasionally, a second flush of lammas growth occurs in summer under moist, warm conditions. Thrower (1986) has successfully used early height growth as a method to predict site quality of red pine plantations.

Rapid height growth occurs in the absence of overhead cover and competition. Logan (1966) found that red pine can achieve full height growth at 43% of full sunlight until age 5, but requires full sunlight to attain maximum height after 6 years of age. Red pine seedlings in the shade of *Corylus cornuta* grew 4 cm in height the second year after planting, but seedlings in full sunlight grew 15 cm (Strothmann 1967). Height growth of red pine has been correlated with soil moisture supply and total nitrogen. Improved growth of red pine has been observed when the water table is within 1.2 to 2 m of the surface. A 42% reduction in height growth occurred in a 46-year-old red pine stand growing on an exposed sandy soil that was heavily wind eroded (Farrish 1987).

Height growth of red pine is unaffected over a wide range of spacings, except on poor sites, or in extremely open or dense stands (Stiell 1985). Stiell and Berry (1977) reported that red pine planted at wide spacings consistently grew more in average height than stock planted at close spacings; however, dominant height (tallest 10%) of the stand was not significantly related to spacing.

Root Development: Red pine's tap root grows from 12 cm to over 3 m long. This root develops well in loose soil and poorly in coarse-textured, compacted, saturated or strongly stratified fine over coarse-textured soils (Brown and Lacate 1959). Container stock of red pine rarely develop tap roots. Natural root development is moderately deep and wide-spreading, with abundant root grafting (Bannan 1949, Hosie 1969). Most root elongation occurs during the spring and early fall, and there is typically a period of reduced growth during summer.

Root development may be modified by soil moisture regime and temperature. Vertical sinker roots often develop from lateral roots and may extend to 4.5 m in depth. Root mortality occurs if soils are saturated for more than 3 months of the year. Poor root development by red pine has been observed on unstructured clays. Roots tend to expand up to age 15, afterwards becoming denser. Dement and Stone (1968) found that height growth of intolerant red pine was reduced on poorly drained sites, an indication that the site was limiting to the inherently deep-rooting tendency of red pine. Fayle (1978) also concluded that red pine seedlings need to develop a deep vertical root system for good top growth.

Red pine roots tend to penetrate soils that would divert white pine roots. Red pine roots will often grow around cobbles and stones, and penetrate small cracks in the bedrock under shallow soils; white pine roots tend instead to develop an extensive lateral network above such restrictions (Horton and Brown 1960). In these situations, red pine may be able to exploit moisture at deeper levels than white pine (Merchant et al. 1989).

Stand Development: Red pine is relatively uniform in terms of its growth and development. Trees survive up to 350 years, although rotation ages range from 80 to 110 years. Shrubs under red pine stands on very dry soils may intercept and use a large proportion of the available soil moisture, causing moisture stress in the trees and, consequently, reducing wood yields (Stiell 1970). The best growth by red pine occurs on well to moderately drained, fresh to very fresh, coarse loamy soils. Growth may be very poor on soils deficient in potassium (Anon. 1986c). Good growth and development has been observed on soils that have stratified bands of finer textured soil.

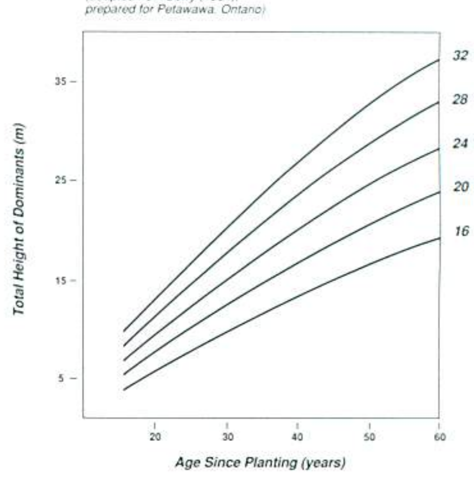
Red pine productivity has been observed to be *better* on deep, dry to fresh outwash sands and deep ablation tills, *intermediate* on moderately shallow tills, and *poor* on clays and clay loam lacustrine deposits. Initial growth of natural seedlings is slow, especially if they are shaded (Stiell 1978). Growth of seedlings is normally less than 25 cm during the first 4 years, but increases to between 0.3 and 0.6 m per year for the next 10 to 20 years (Thrower 1986). Radial growth continues for up to 200 years, although maximum average stand height is normally reached by 60 to 120 years of age. Red pine stands are often succeeded by stands comprising more shade-tolerant species such as white pine, black spruce, white spruce and balsam fir. Butson et al. (1987) described the age and size distributions of 3 disjunct populations of red pine near Lake Nipigon, Ontario.

In the Quetico Park area of the NC Region, red pine and white pine are more common than in most other portions of the Region; these two species are dominant in about 8% of the forests within the park (Walshe 1980).

Red pine has a higher productive capacity than white pine up to about 60 years (Stiell 1978). In 25 paired plantations in the Lake States, red pine consistently outproduced jack pine (Alban 1978). Red pine exhibits a good response to thinning from time of crown closure up to about age 60 (Lundgren

Site Index Curves for Plantation Red Pine

(adapted from Berry (1984); prepared for Petawawa, Ontario)

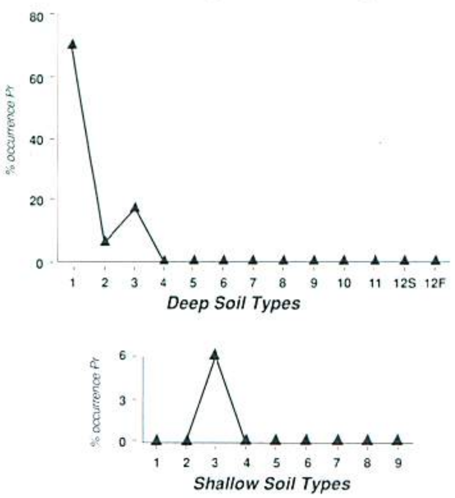


1965, 1981, Beckwith et al. 1983). Red pine is generally considered to be a poor self-pruner; it will respond well to artificial pruning treatments and to release from competing vegetation (Stiell 1959). Stand volume increment and yield for red pine is strongly correlated with site quality and degree days above a threshold temperature. Growth and yield decline significantly below 2400 growing degree days. Rotation ages should also be modified depending on soil depth, soil texture and moisture regime.

Associated Soil Conditions

NWO FEC Soil Types (*17 NWO FEC plots*): Red pine occurs mainly on dry to fresh, non-calcareous, upland mineral soils. In the NC Region, red pine stands occur most frequently on deep, coarse sandy soils (**S1**) and less frequently on deep, coarse loamy soils (**S3**) and fine sandy soils (**S2**). The red pine conifer Vegetation Type (**V27**) mainly develops on coarse-textured, drier soils (**S1**, **S2**) while the red pine mixedwood Vegetation Type (**V13**) occurs on fresh, coarse loamy soils (**S3**).

Distribution of Red Pine across NWO FEC Soil Types in the NC Region

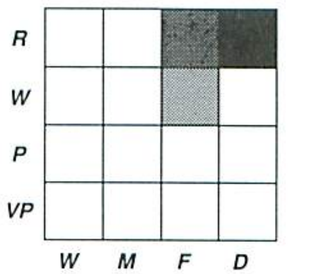


Deposition: Red pine dominated stands in the NC Region most commonly develop on morainal soils and glaciofluvial sands. Less frequently, red pine stands occur on stratified deposits such as tills overlying glaciofluvial sands and glaciofluvial sands overlying tills. Brunisolic or, occasionally, podzolic soil profiles develop under red pine dominated stands in the NC Region.

Texture: Red pine dominated stands in the NC Region occur most frequently on soils with coarse loamy or coarse sandy B horizon textures, and coarse sandy parent (C horizon) materials. Surface textures (A horizons) are predominantly fine sands and silt loams. In the Algonquin Region of Ontario, red pine was found to be most productive on deep sands with loamy material in at least the surface layers, and on shallow to moderately deep silty sand tills (Merchant et al. 1989). It was least productive on very shallow soils and soils with very fine textures and (Merchant et al. 1989). Red pine growth rates generally appeared to be more affected by soil depth and less by high coarse fragment content than white pine (Merchant et al. 1989).

Drainage and Moisture Regime: In the NC Region, red pine stands are found on very rapidly to rapidly drained soils, and occasionally on well drained soils; red pine is not suited to poorly drained soils (Stiell 1978). Red pine stands occur predominantly on soils with moderately dry or fresh moisture regimes. Normally, red pine stands in the NC Region are too well drained and too dry for the development of mottles or gley colors in soil profiles.

Correlation of Soil Drainage and Moisture Regime Classes for Red Pine



Stoniness and Structure: Considerable coarse fragment content is common in soils supporting red pine dominated stands; over half the NWO FEC plots supporting red pine had greater than 50% coarse fragment content. Gravel and cobble sized fragments are most commonly encountered. Single grain structure is most common.

Site Position: Red pine dominated stands occur mainly on level and upper to mid-slope positions in the NC Region. In the Algonquin Region of Ontario, growth of red pine was better on gentle slopes than on steep slopes (Merchant et al. 1989).

Litter Layer: Most red pine stands in the NC Region are associated with litter layers ranging from 6 to 15 cm thick. Common forest humus forms are fibrimors and humifibrimors.

Soil Fertility Requirements: Red pine has relatively low nutrient and moisture requirements for survival and growth (Burns 1983). Red pine grows well on rapidly drained, acidic (pH 4.5 to 6.0) soils. None of the NWO FEC soil profiles in the NC Region were calcareous within 100 cm of the surface; Chapeskie et al. (1988) noted that red pine height growth and vigor frequently decline where free carbonates are located within 60 cm of the surface. If competition is controlled, best growth is on soils where the surface texture's silt plus clay content ranges between 10 and 40%. Flower production is related to soil nutrient regime. Height growth of red pine may be correlated with total nitrogen of the surface layers and with soil moisture regime. Two years after fertilization with magnesium and potassium, Gagnon (1965) recorded significant growth improvements for a 20-year-old red pine plantation.

Insects, Diseases and Other Damaging Agents

Red pine is relatively free of serious pests and disease problems.

Insects:

The most serious insect damage to red pine is to seed production during the second year of cone development (Rose and Lindquist 1984).

European Pine Shoot Moth (*Rhyacionia buoliana* Schiffermuller): The European pine shoot moth is an introduced pest that can stunt the growth of young red pine in plantations. Larvae feed on the buds and developing shoots, turning needles brown and killing new shoots. This can lead to development of *witch's broom* as laterals begin to develop after the death of the leader. Red pine growing on dry hilltops appear to be more vulnerable to this pest.

Jack Pine Budworm (*Choristoneura pinus pinus* Free.): Although jack pine is the preferred target species, jack pine budworm can cause widespread damage to red pine, particularly when red pine grows in mixed stands with jack pine. Budworms overwinter under bark scales, and in spring feeds on male flowers and developing needles. Moths emerge in July or early August.

Red Pine Cone Beetle (*Conophthorus resinosae* Hopkins): Black adult beetles bore into the bases of cones during mid-May to mid-July. White larvae feed on seeds and scales; when cones are scarce, larvae attack young, growing shoots. In late July new adult cone beetles emerge, feeding on and damaging small growing shoots of red pine.

White Pine Weevil (*Pissodes strobi* Peck): This borer attacks terminal shoots of red pine and white pine growing together. The weevil feeds from the terminal shoot downward, destroying up to 2 years growth and creating crooked, forked trees.

Diseases:

Fomes Root Rot (*Heterobasidion annosum* (Fr.) Bref.): This root rot fungus enters through freshly cut stumps in thinned red pine stands, infecting them during the first 10 to 14 days after harvest. Root grafting may contribute to its spread. Foliage turns yellow, growth is stunted and increased windthrow occurs. Both borax and sodium nitrite provided excellent protection of red pine stumps against this fungus in an Ontario thinning operation (Myren 1981).

Scleroderris Canker (*Ascocalyx abietina* (Lagerb.) Schlapfer-Bernhard): Fungal spores are deposited on pine needles or buds. The disease spreads through buds, needles, branches and the main stem during summer, fall and winter and, by spring, needles turn brown. Fungal development results in main-stem cankers that may girdle trees. Smaller trees and trees in depressions and frost pockets are more susceptible to damage. The fungus may cause extensive damage to the current year's shoots and loss of tree vigor in very young stands (e.g., trees 2 m or less in height).

Shoestring Root Rot (*Armillaria ostoyae* (Romaqn.) Herink): *Armillaria* affects trees of low vigor. It causes the development of discolored and undersized foliage, and leads to widespread senescence of branches. Wood in the root-collar area becomes decayed, and white mycelial fans develop underneath the bark. *Armillaria* spreads readily underground, where it penetrates roots. The infection can remain active in the soil for many years, making plantation establishment somewhat risky and difficult. There is some evidence that red pine and jack pine are less susceptible to the disease than either black spruce or white spruce (Whitney 1988).

Management Considerations

As a timber species, red pine is used for sawn lumber, poles, pilings and railway ties. Structurally, the wood is somewhat heavier and harder than that of white pine, and the porous sapwood readily absorbs preservatives. The wood of red pine is relatively light, yellowish white (sapwood) to reddish-brown (heartwood) in color, moderately hard and straight-grained (Hosie 1969).

Red pine is an ideal plantation species, and potentially provides a higher yield than any other species growing in the NC Region (Carmean 1987). Red pine responds well to moderate thinning (Lundgren 1965, 1981, Beckwith et al. 1983). However, because of red pine's root-grafting habit, stem-applied herbicides can kill trees other than target trees and disease can spread from infected stumps to surviving trees (Bell 1990). Thinning can increase cone production. A recommended spacing is equivalent to one half the height of average dominant and co-dominant trees. Managers should avoid underplanting, as seedlings rarely persist more than 10 years in the shade (Benzie 1977b).

Site preparation should be designed to remove thick, insulating LFH layers. Site preparation that effectively mixes humus and upper mineral-soil layers can create warm, moist and protected seedbeds. Good initial root growth and water uptake is important for red pine seedling survival and growth. Red pine is very sensitive to depth of planting, so care must be taken not to plant seedlings too deep or too shallow (Benzie 1977b, Chapeskie et al. 1988). Potassium and magnesium deficiencies have been observed in red pine growing on excessively cultivated or severely burned sites. Red pine is well adapted to slightly acidic sites, ranging from pH 5.2 to 6.5 (Wilde et al. 1965). Free carbonates within 60 cm of the soil surface are correlated with decreased root growth in seedlings.

Red pine stands often have high recreation value. Understory development in large, old-growth stands may be controlled to enhance the aesthetic value (Benzie 1977b). In general, red pine stands are considered poor habitat for game birds and animals; older stands, in particular, may provide important cover and nesting sites for many species of wildlife.

White Pine

3.7.

Pinus strobus L.
Pinaceae (Pine Family)

Description: White pine is a large (averaging 22 m high at maturity), evergreen conifer with a characteristically wide-spreading, asymmetrical crown that is often irregularly shaped by the effects of prevailing wind. The trunk has little taper and is often branchless for more than 1/2 its height in closed stands. In northern Ontario, white pine grows mainly in the Great Lakes - St. Lawrence Forest Region (Haddow 1948, Horton and Brown 1960, Rowe 1972). In the NC Region, white pine typically occurs on deep, dry to fresh, rapidly drained, non-calcareous coarse upland soils. It occurs infrequently and usually achieves its best growth on deep, fresh, sandy or loamy soils. This species produces valuable softwood lumber that exibits low shrinkage and a uniform texture.

White Pine

Associated Stand Conditions

NWO FEC Vegetation Types (*15 NWO FEC plots*): White pine is dominant in both the white pine conifer Vegetation Type (**V26**) and in the white pine mixedwood Vegetation Type (**V12**).

Overstory: White pine grows in pure stands or, more commonly, in association with other conifers and hardwoods. White birch, balsam fir and trembling aspen are common overstory co-dominants in mixedwood stands in the NC Region. In white pine conifer stands, balsam fir and red pine are common associates, with white spruce, cedar, black spruce and white birch occurring less frequently. In mixedwoods, up to 10 associated species can occur in the canopy, including white spruce, cedar, black spruce, large-toothed aspen, jack pine and red maple.

Shrubs: Balsam fir, *Acer spicatum*, *Aralia nudicaulis*, *Linnaea borealis*, *Corylus cornuta*, *Diervilla lonicera* and *Amelanchier* spp. are common in the typically shrub rich understory of white pine dominated stands. *Lonicera canadensis* and trembling aspen are also frequently encountered in the shrub layer of white pine mixedwoods.

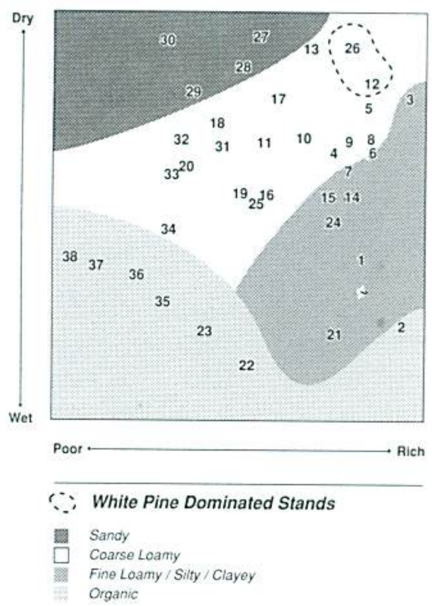
Herbs: *Maianthemum canadense*, *Cornus canadensis*, *Aster macrophyllus* and *Polypodium vulgare* are common herbs in white pine stands in the NC Region. *Trientalis borealis*, *Clintonia borealis*, *Streptopus roseus* and *Oryzopsis asperifolia* are associated with these species in white pine mixedwood stands.

Mosses and Lichens: *Pleurozium schreberi* and *Dicranum polysetum* occur with low frequency and cover beneath white pine stands in the NC Region. Total moss cover averages about 12% beneath coniferous stands and is insignificant in the herb and shrub rich understory of white pine mixedwood stands. Lichens are sparse beneath white pine dominated stands in the NC Region.

Silvics

Growth Habit: White pine is a large tree, averaging 22 m in height and growing up to 36 m. It is an evergreen conifer with a wide-spreading, often irregularly shaped crown. White pine needles are straight, very slender, flexible, soft, and 3-13 cm long; the bluish green and often somewhat whitened needles occur in clusters of five, without a basal sheath. In the upper part of the tree, branches often ascend irregularly and in response to the influences of the prevailing wind (Hosie 1969). The trunk has little taper and, in closed stands, is limbless up to 1/2 to 2/3 of tree height (Scoggan 1978). White pine have thin, smooth, greyish-green bark when young, and deeply-furrowed, thick (up to 5 cm) bark on mature trees. The aggressive root system of white pine is capable of anchoring trees to rock by penetrating crevices under very shallow soils.

NWO FEC Vegetation Type Ordination showing distribution of White Pine dominated stands and associated soil conditions in the NC Region.



White pine has one flush of height growth each year that produces an annual whorl of lateral branches at the end of leading shoots (Bell 1990). Occasionally a second flush is produced by lammas growth in late-summer. This second growth is often related to the occurrence of late-summer rains after drought. The length of the terminal shoot is determined by the number of needle internodes laid down in the previous year. Moisture stress and the effects of competing vegetation can limit elongation.

White pine exhibits vertical differentiation of the crown canopy into dominant and co-dominant, intermediate and suppressed classes. White pine can grow well at relatively high densities. It is a moderately efficient self-pruner that tends to retain dead branches for extended periods of time, especially in dry microclimates.

Shade Tolerance: White pine exhibits intermediate shade tolerance. It is, however, more shade tolerant than its common associate, red pine. Based on a detailed survey of Minnesota forests, white pine was given a ranking of 2.8 on a 5-unit scale (1=least to 5=greatest) for light requirements; similarly for moisture, nutrient and heat requirements, rankings were 1.7, 2.1 and 2.0, respectively (Bakuzis and Hansen 1959).

Climatic Range: White pine occurs across a range of climatic conditions, but its establishment and growth is favored by moderate temperatures and low precipitation (Anon. 1973). The northern botanical limit of white pine occurs where the mean length of the frost-free season drops below 2400 degree days. Air and soil temperatures greater than 33°C can significantly impede successful germination and growth of white pine (Horton and Bedell 1960). Sun scald can damage the thin bark of young white pine. White pine seedlings are more vulnerable than red pine to moisture stress.

Frost Resistance: White pine is susceptible to frost damage, especially during the initiation of the spring foliage flush. Planting of white pine should be avoided in low-lying areas. Frost damage to young seedlings results in deformities and reduced growth potential, or senescence. Severe frost damage occurs on dry soils when temperatures fall rapidly over a short period of time. Blister rust and *Scleroderris* canker are more widespread in areas where cool, moist air develops.

Flood Tolerance: White pine is characterized by a low flood tolerance in all stages of growth. Seedlings are particularly susceptible to flooding.

Fire Tolerance: Mature trees have an insulating bark and elevated crowns that enable stands to survive ground fires. Young plantations are vulnerable to fire as a result of the flammable, dry sites on which they tend to occur and the porous needle litter, which dries out rapidly beneath stands. Fire provides an excellent seedbed for white pine seeds.

Successional Status: White pine is a long-lived, fire-climax or subclimax species. Regeneration and perpetuation in nature is dependent upon seed supply. Stand disturbance, often by fire, is usually required for successful regeneration. White pine is more tolerant of competition than is red pine.

Vegetative Reproduction: White pine does not regenerate vegetatively under natural conditions.

Sexual Reproduction:

Flowering: Flower initials are laid down in the bud in the year before flowering. Cone primordia are visible during the late spring of the year of flowering. White pine is monoecious, with male flowers developing on lower branches in late May and female flowers developing in the upper 1/3 of the crown approximately 2 weeks later. Male flowers are tiny, cone-like, deciduous and short-lived, appearing at the base of the current year's growth. Female flowers are cones with numerous spirally arranged scales (Fernald 1979). Pollination is by wind and occurs from mid- to late June. Both cross-pollination and self-pollination can produce fertile seeds; however, inferior progeny are often produced through self-pollination. The amount of pollen produced declines with age after 150 years.

Fruit: White pine produces winged seeds that are enclosed by woody scales of the mature female cone (Schopmeyer 1974). Cones are cylindrical, approximately 10-15 cm long when ripened, and hang down from short stalks. Depending on weather conditions, cones mature in September or October of the year of development, open to release seeds, and then fall from the tree. White pine cones ripen three to four weeks after those of red pine.

Crop Cycle: A good cone crop occurs every 3 to 5 years, with production of viable seed beginning at 15 to 20 years of age and continuing to about 250 years (Anon. 1986a). The optimum age for cone production occurs between 50 and 150 years. Only small quantities of seeds tend to be produced between good seed crops.

Crop Abundance: Approximately 1.8 hL of cones are produced per tree, equivalent to an average of 80,000 viable seeds per tree. This is about double the viable seed production of red pine.

Seed Viability: The viability of eastern white pine seeds is about 75%.

Seed Dispersal: Seed dispersal is most effective within a distance about equal to the height of the tree. Wind can carry seeds considerable distances, especially if seed trees are located on ridges. Most seeds are dispersed within one month after cones mature (Fowells 1965).

Germination: Germination is best on moist mineral soil and mineral soil mixed with humus material (Candy 1939). For successful germination, white pine seed requires moist soils and soil surface temperatures of 20°C to 30°C. White pine seeds will also germinate on rotten wood, burned ground surfaces and *Polytrichum* spp. moss (Ahlgren 1959, 1976, Chapeskie et al. 1988). Some germination will occur on the litter layer under the canopy of a mature forest. White pine seeds display some embryo dormancy, which is broken by natural stratification in autumn and early spring (Chapeskie et al. 1988). White birch leaf litter inhibits the germination and growth of jack pine, white pine and red pine seedlings (Ahlgren and Ahlgren 1981).

Seedling Survival and Growth: Seedlings grow relatively slowly for the first 5 years. Seedlings will survive in sunlight as low as 45% and will thus survive underplanting if overhead shade and lateral competition is maintained at moderate levels (Logan 1966). Seedlings are susceptible to droughts, flooding, extreme cold and browsing by animals (Horton and Brown 1960, Roberts 1989).

Height Growth: White pine is the tallest conifer in eastern Canada reaching heights of 36 m and diameters of 1.8 m. During the first 40 to 60 years, red pine will exceed white pine height growth; beyond these ages, the relationship is reversed (Chapeskie et al. 1988). White pine may demonstrate faster and more consistent growth on stratified soils (i.e., soils that are layered near the surface because of more than one landform deposit). White pine is characterized by low height increments during the first 5 years. However, annual increments of greater than 30 cm are produced in subsequent years if shading by competing vegetation is minimal and weevil damage does not occur (Cooke and Barrett 1985). Nonetheless, it is rarely planted in the NC Region because of its susceptibility to the white pine blister rust fungus (*Cronartium ribicola*) and the white pine weevil (*Pissodes strobi*).

Root Development: White pine has a vigorous, deep rooting system that renders it highly resistant to windthrow (Hosie 1969). Its extensive root system may penetrate to a depth of 3 or 4 m. A taproot with numerous branched laterals develops in early years. This taproot is not always retained in mature white pine, but sinker roots that develop on laterals will anchor the tree in its absence (Brown and Lacate 1959). Because of extensive root grafting, large areas of the root system may be shared by several trees (Bormann 1966). The extent and character of white pine root systems are influenced by physical and chemical properties of the soil. For example, in areas of variable soil depths, white pine may share root systems to draw moisture from deeper soils.

White pine's lateral rooting system tends to be more extensive than red pine's, and roots may spread over restrictions (Horton and Brown 1960). Consequently, white pine is perhaps better adapted than red pine for growth on shallow soils or soils with compacted or stratified subsurface layers (Merchant et al. 1989).

Stand Development: White pine performs poorly on very dry sites and very moist to wet sites (Leak et al. 1988). Growth is best on fresh fine sands, sandy loams and well drained silt loams (**S2**, **S3**). If growth commences before soils thaw, moisture stress is common, especially on coarse to medium sandy soils (**S1**). White pine tends to occur in mixed coniferous stands, often with red pine, on ablation tills over bedrock, on ridge tops and south-facing slopes, and on loamy sands to silty very fine sands. It grows poorly on cool wet clay and clay loam soils although it performs better than red pine on these sites provided that frost and disease problems are absent (Stiell 1978).

White pine produces one flush of height growth each year with an annual whorl of lateral branches formed at the end of leading shoots. Occasionally, a second flush of lammas shoots is produced in late summer. The length of the terminal shoot is determined by the number of needle internodes laid down in the previous year's bud. Moisture stress and vegetation competition can limit elongation of the internodes. Stem elongation begins in late May and continues for 6 to 8 weeks, with most growth occurring within the first 2 or 3 weeks. In white pine plantations, annual height growth reaches its maximum rates just prior to crown closure (Chapeskie et al. 1988). White pine is not very prone to growth stagnation because it is moderately shade tolerant and its canopy is differentiated into dominant and less dominant positions. The species responds well to release from vegetation competition (Stiell 1959) and thinning (Spurr et al. 1957, Della-Bianca 1981, Andison et al. 1984), even at an early age (Gillespie and Hocker 1986). White pine is a moderate to poor self-pruner, regardless of its spacing (Stiell 1959, Leak et al. 1988).

Heinselman (1973) described white pine communities in northern Minnesota, where the oldest trees were 323 to 368 years old. Old-growth stands occur in the general Quetico-Atikokan area of the NC Region (Walshe 1980). The age structure of one stand in the Atikokan-Ignace area, with some individual white pine trees over 180 years, is described by Holla and Knowles (1988).

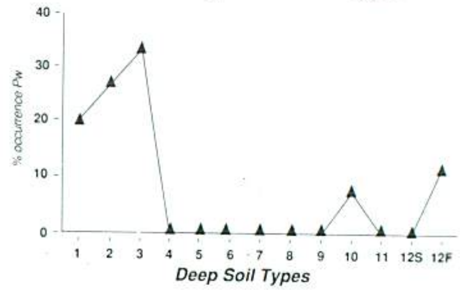
Growth curves developed for white pine in the NE Region are provided by Leale (1986). Their application in the NC Region still requires testing. Curves are based on stem analysis at 1 m intervals on trees of mean basal area growing in mature, well-stocked stands. Associated soil and site conditions are documented by Leale (1986) and Kershaw (1988).

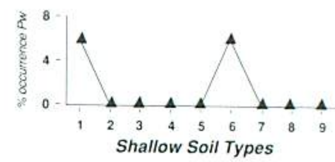
Associated Soil Conditions

NWO FEC Soil Types (*15 NWO FEC plots*): White pine occurs as a dominant species on deep, fresh, coarse and fine sands (**S1**, **S2**) and coarse loams (**S3**); it is found less frequently on shallow, fresh, coarse loamy soils (**SS6**).

Deposition: In the NC Region, white pine dominated stands mainly develop on morainal materials and, less frequently, on shallow tills over bedrock. White pine dominated stands in the NC Region are most commonly associated with brunisolic, podzolic and luvisolic soil profiles.

Distribution of White Pine across NWO FEC Soil Types in the NC Region

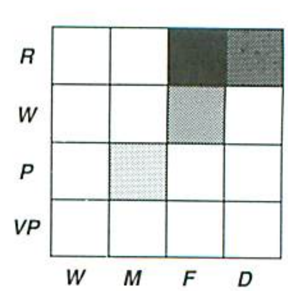




Texture: White pine dominated stands in the NC Region occur mostly on coarse loamy parent materials, with silty fine sands and loamy very fine sands the dominant textures for A and B horizons. Less frequently, white pine occurs on soils with an A and B horizon silt loam texture underlain by coarse loam or fine sand parent materials. Rarely, white pine is found on clay soils or soils with a fine loamy B or C horizon texture. In the Algonquin Region of Ontario, white pine growth rates were highest on deep sands with loamy material in at least the surface layers, and on shallow to moderately deep morainal silty sands (Merchant et al. 1989). Poorest productivity was recorded on soils with very fine textures, and on very shallow soils (Merchant et al. 1989).

Drainage and Moisture Regime: Soils in the NC Region supporting white pine are very rapidly to rapidly drained or, occasionally, well drained. White pine dominated stands occur mainly on soils with moderately dry to fresh moisture regimes. Mottles and gley colors are not normally encountered in soil profiles under white pine dominated stands.

Correlation of Soil Drainage and Moisture Regime Classes for White Pine



Stoniness and Structure: Coarse fragments may or may not be present under white pine stands in the NC Region. In the Algonquin Region of Ontario, a soil coarse fragment content greater than 50% was associated with lower productivity by white pine (Merchant et al. 1989). Soils beneath white pine stands in the NC Region are often subangular blocky, a common structure for coarse loamy tills.

Site Position: White pine dominated stands are most frequently found on level and upper to mid-slope positions in the NC Region.

Litter Layer: LFH layers beneath white pine in the NC Region are typically 6 to 15 cm thick; occasionally, thin (1 to 5 cm) LFH layers are encountered. Common forest humus forms are fibrimors and humifibrimors.

Soil Fertility Requirements: White pine has moderate to low fertility requirements, but is generally more demanding than red pine (Wilde et al. 1965). Optimum pH ranges from 4.7 to 7.3. Unlike red pine, white pine is tolerant of calcareous soil conditions.

Insects, Diseases and Other Damaging Agents

Insects:

White Pine Weevil (*Pissodes strobi* Peck): Weevils are a major pest for white pine; weevil damage can reduce stem quality and stand value in white pine plantations by 20 to 60%. Susceptible locations for weevil infestation include unshaded areas with low relative humidity and high temperatures. The trees most affected by weevils are white pine between 2 to 6 m tall with a thick leader (exceeding 4 mm in diameter). Adult weevils reside in the forest-floor litter close to the bole and emerge in early spring. Feeding and oviposition occur rapidly and are largely confined to the bark of the preceding year's growth. The leader is girdled and assumes a characteristic *shepherd's crook* (Rose and Lindquist 1984).

Diseases:

White Pine Blister Rust (*Cronartium ribicola* Fisch. ex Rabh.): White pine blister rust can cause heavy mortality and loss of tree vigor in young, developing stands. The locations most vulnerable to infestation are lower slopes, north-facing slopes and depressions, which may trap and maintain cool, moist conditions. The fungus attacks the living bark and cambium. Spores transmit the disease to the alternate host, gooseberry or wild currant (*Ribes* spp.), and then back to white pine (Hepting 1971).

Heart Rot (*Phellinus pini* (Brot. ex Fr.) A. Ames): Heart rot can cause very significant growth and value losses in over-mature stands. Trees on shallow soils with restricted rooting are especially vulnerable to this infection. Decay is most prevalent in the butt region. The pathogen enters the trunk through external wounds such as logging scars, root injuries or weevilled branch stubs, and causes distinctive white pockets of rot.

Other:

Wildlife Browse: Browsing by deer and snowshoe hares may cause significant damage to young white pine plantations during fall and winter.

Management Considerations

White pine is a valuable timber species. Although the natural population is now much depleted, it is still preferred for softwood lumber products, partly because of its low shrinkage and uniform texture. Wood is light, moderately strong, soft and creamy-white (sapwood) to yellow (heartwood) in color (Hosie 1969).

In the overstory, white pine is usually found in mixed associations with other species. In the NC Region, white pine is common but not widespread, with the highest concentrations in the Quetico Park general area. Management objectives for white pine may include maintaining it in a mixed stand composition (Horton and Brown 1960).

White pine is severely restricted in commercial planting because of its susceptibility to blister rust and the white pine weevil. White pine can survive and develop with moderate levels of competition. Weevil damage is typically highest in open stands, where leader diameters are wide; as well, susceptibility to weevil damage decreases with increased stand height (Chapeskie et al. 1988).

White pine stands, particularly old-growth stands, may have high recreation value, and may provide important shelter and nesting sites for many species of wildlife.

Eastern White Cedar 3.8.

Thuja occidentalis L.
Cupressaceae (Cypress Family)

Description: At maturity, eastern white cedar is a small to medium-sized (up to 12 m) evergreen tree with a dense, layered, conical crown, arching branches, a strongly tapered and usually twisted trunk, and reddish-brown, fibrous bark. Eastern white cedar is distributed throughout the northeastern United States, New Brunswick, Quebec, Ontario and eastern Manitoba. It grows well on fresh to moist, neutral to alkaline soils (Brown 1981, Barnes and Wagner 1981). In the NC Region, eastern white cedar is found infrequently on wet, organic soils and moist, well to rapidly drained mineral soils.

Eastern White Cedar

Associated Stand Conditions

NWO FEC Vegetation Types

NWO FEC Vegetation Types (*38 NWO FEC plots*): In northwestern Ontario, eastern white cedar occurs in both pure and mixed stands (Sims et al. 1989). Black spruce is a major co-dominant species on wet organic soils (**V22**) whereas balsam fir, white birch, white spruce and trembling aspen are often found with cedar on moist to moderately dry soils (**V21**). In the NC Region, cedar typically occurs at the base of slopes and on lowlands.

Overstory: Pure stands of cedar are often densely canopied, sometimes thicket-like. Black spruce is the most common co-dominant species on lowland organic soils whereas balsam fir is the most common co-dominant on upland mineral soils. White birch, tamarack, balsam fir, white spruce and black ash may occur in the canopy of **V22** stands. In **V21** stands, white birch, white spruce, trembling aspen, black spruce, balsam poplar and black ash are common associates.

Shrubs: In the NC Region, balsam fir is the most common species in the shrub layer of cedar stands. *Alnus rugosa*, eastern white cedar and *Ledum groenlandicum* are common on organic soils; *Acer spicatum* and eastern white cedar are present in the shrub layer of upland stands, but are rarely abundant. *Gaultheria hispidula*, *Rubus pubescens*, *Linnaea borealis*, *Cornus stolonifera*, black spruce, *Rosa acicularis* and *Vaccinium myrtilloides* occur on wet organic soils; *Aralia nudicaulis*, *Sorbus decora*, *Lonicera canadensis* and *Ribes triste* are mainly restricted to **V21** stands.

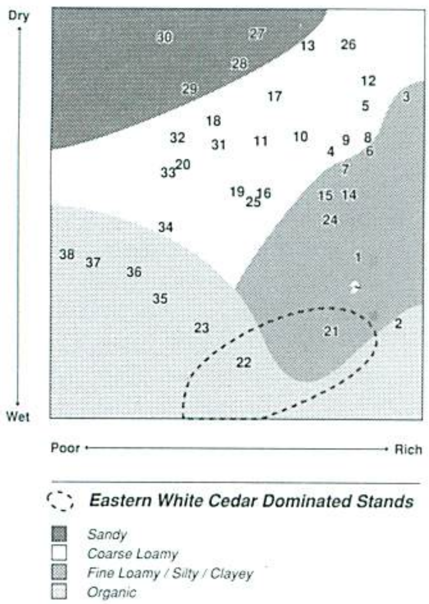
Herbs: *Trientalis borealis*, *Cornus canadensis*, *Mitella nuda*, *Maianthemum canadense*, *Viola renifolia*, *Galium triflorum* and *Clintonia borealis* are common in cedar dominated stands. *Carex disperma*, *Equisetum sylvaticum*, *Carex vaginata* and *Coptis trifolia* are often present in **V22** stands. *Aster macrophyllus* and *Gymnocarpium dryopteris* generally occur in **V21** stands.

Mosses and Lichens: *Pleurozium schreberi*, *Rhytidiadelphus triquetrus*, *Hylocomium splendens*, *Ptilium crista-castrensis* and *Dicranum* spp. occur beneath cedar dominated stands. Usually there is only sparse to moderate moss cover. Other mosses commonly present are *Sphagnum girgensohnii*, *S. nemoreum*, *Mnium* spp., *Plagiomnium cuspidatum* and *Drepanocladus uncinatus*. Ground lichens are usually absent beneath cedar dominated stands in the NC Region.

Silvics

Growth Habit: Eastern white cedar is a small to medium-sized, slow-growing conifer that may take 80 to 100 years to reach 18 cm diameter on wet organic soils. When open-growing, the narrow, spire-like crown extends to the ground. Scale-like leaves are 2-paired, 4-ranked, 2-4 mm long, opposite, closely overlapping, appressed, with rows of overlapping leaves covering the stem and side pairs of leaves keeled and partly folded over them; top and bottom leaves have prominent resin glands. Branches of eastern white cedar

NWO FEC Vegetation Type Ordination showing distribution of White Cedar dominated stands and associated soil conditions in the NC Region.



bend downwards before gradually arching up at the tips. The bark is thin, reddish-brown, often shredded and, with age, narrowly ridged. The tapered trunk is often twisted, rugged, and swollen or broadened at the base (Hosie 1969). Cedar is a long-lived tree, sometimes surviving to 400 years of age.

Shade Tolerance: Eastern white cedar is very shade tolerant. Based on a detailed survey of Minnesota forests, cedar was given a ranking of 1.2 on a 5-unit scale (1=least to 5=greatest) for light requirements; for moisture, nutrient and heat requirements, rankings were 4.2, 2.3 and 1.3, respectively (Bakuzis and Hansen 1959).

Climatic Range: Eastern white cedar occurs across a wide range of moderate to cold temperature regimes throughout the Boreal Forest Region (Rowe 1972), and occupies cool, moist to wet soils throughout its range. The northern limit of cedar extends to the northern edge of the boreal forest, and the southern limit, in the Lake States, corresponds to a mean annual temperature isotherm of 10°C. Annual precipitation within its range in the NC Region varies from 560 to 760 mm (Anon. 1987a); however, cedar often occupies sites that are more humid and cooler than the regional average.

Frost Resistance: Eastern white cedar has a high resistance to frost (Godman 1958). It occupies low-lying positions prone to late-spring and early-fall frosts without displaying significant symptoms of frost damage. It can withstand physical damage from heavy ice loads.

Flood Tolerance: Cedar is very tolerant of frequent, well-aerated flooding (e.g., running water) for short periods of time (Ahlgren and Hansen 1957). Growth decreases, however, if aeration is restricted. Mortality can occur if aeration is decreased for a lengthy period as a result of a rise in the water table, or if flooding extends for an entire growing season (i.e., 2 months or more).

Fire Tolerance: Cedar dominated stands are found most often on very poorly drained soils; consequently fire is often not a major threat. However, pure stands of cedar often establish following fire (Barnes and Wagner 1981) The tree's flammable, shaggy bark and shallow rooting habit render it susceptible to damage from fires (Fowells 1965).

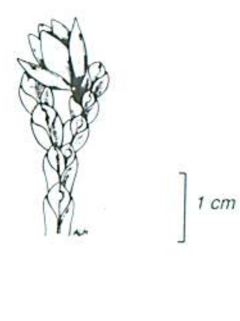
Successional Status: Eastern white cedar is a climax species on organic soils (**V22**), and an intermediate or sub-climax successional species in mixedwood stands on mineral soils (**V21**).

Vegetative Reproduction: Layering, principally by lower branches, and the formation of vertical stems from windthrown trees, are common methods of reproduction on organic soils (Godman 1958). Often, as old trees tip over and lie flat in a swamp, branches grow upright, take root and form a row of living trees along the buried trunk. In lowland areas, up to 60% of cedar regeneration results from layering (Nelson 1951). Seedlings as young as 5 years can successfully regenerate by layering. Rarely, sprouts will also arise from roots or stumps.

Sexual Reproduction:

Flowering: Flowering occurs in late April or early May with cone formation in late June and maturation in mid-August. Male and female flowers develop separately on the same tree. Male flowers are tiny, short-lived and deciduous, and develop at the tips of branchlets. Female flowers are small cones with 4 to 6 pairs of opposite scales.

Fruit: The fruits of eastern white cedar are upright, small, egg-shaped cones, which mature after one season but remain attached to the tree until the following spring. Seeds are two-



winged with two cotyledons and are enclosed by the woody scales of the mature female cone (Schopmeyer 1974). Cones are small (about 1 cm long), erect and oval.

Crop Cycle: Eastern white cedar is characterized by dependable annual seed production. Abundant crops are produced every 3 to 5 years, with light to medium crops in intervening years (Fowells 1965).

Crop Abundance: Seed production occurs in trees as young as 30 years of age, but peaks after age 75 (seeds are occasionally produced on trees as young as age 6). Approximately 9 litres of cones are produced per tree; each cone has 4 to 6 pairs of scales and two seeds per scale.

Seed Viability: The viability of seeds from eastern white cedar is unknown.

Seed Dispersal: Eastern white cedar has a short seeding range, up to 60 m. Cones open to release seeds in the year after initial development. Dispersal begins in mid-September, 7 to 10 days after cone ripening, and ends in November. Wind is the primary agent for dispersal and the effective maximum seeding range is about 50 to 70 m (Fowells 1965).

Germination: Seeds display slight dormancy, but germination normally begins in late May or early June. Cedar requires a moist substrate for successful germination (Barnes and Wagner 1981). Northern exposures are often the most favorable, particularly if there is a light slash cover and a seedbed of burned organic soil. Seeds will germinate successfully on neutral to alkaline soils, rotten wood, decayed litter, compacted moss, peat and burned organic surfaces (Nelson 1951, Godman 1958, Johnston 1977c). Thick feathermoss or dense slash cover retard germination.

Natural seeding, especially on burned surfaces, may result in new stands that are too dense for optimum growth. Conversion of a cutover white cedar stand to black spruce is usually easily accomplished. Johnston (1977c) indicates that broadcast burning is a preferred technique for site preparation after logging of white cedar stands in northern Minnesota.

Seedling Survival and Growth: Clearcut or shelterwood harvesting usually prepare sufficient seedbeds for regeneration (Johnston 1977c). A taproot is developed during the first few years of growth, but this is replaced in subsequent years by a fibrous root system. Drought accounts for up to 1/3 of the observed mortality in young cedar seedlings. Survival and growth is best at 50% full sunlight but seedlings will tolerate full shade; the best seedling height growth is at 45% of full sunlight (Logan 1969).

Height Growth: Eastern white cedar responds well to release at all ages. Height growth commences in late May or early June and ceases in late August. Radial growth begins shortly after height growth starts, and ends about 2 weeks after height growth stops.

Growth rates are highly variable. Heights of dominant white cedar trees at 50 years vary from at least 12.2 m on the best sites to less than 4.5 m on the poorest (Johnston 1977c).

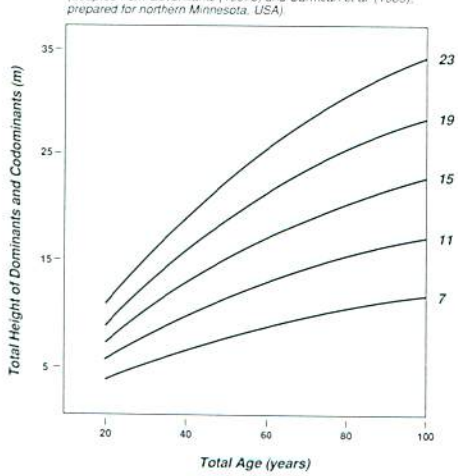
Root Development: Cedar is a shallow-rooted species that is moderately prone to windthrow. A tap root is produced by young seedlings but this gradually develops into a dense, fibrous root system after a few years (Fowells 1965). Root grafts are common and these help to improve windfirmness. The shallow roots are easily exposed and disturbed, even by trampling, creating sites for infection or physical damage. The trunk is swollen at the base and often two or three secondary limbs of about equal size develop from one base (Hosie 1969).

Stand Development: Annual height growth of eastern white cedar ranges from less than 6 cm on wet organic soils up to 21 cm on upland seepage sites (Johnston 1977c). Within its range, cedar has a remarkable ability to persist on a range of site conditions, including organic lowland soils and well drained upland mineral soils. Studies in northern and eastern Wisconsin have attributed this inherent adaptability to ecotypic variation (Habeck 1958).

Clearcut harvesting of white cedar stands may provide adequate natural regeneration, but a more effective management approach may be to harvest cedar stands in narrow stripcuts. A cost-effective strategy for stand management advocated in the north-central United States is to harvest by means of narrow stripcuts or patch-cuts to encourage natural regeneration (Johnston 1977c, Ohmann et al. 1978).

Site Index Curves for Eastern White Cedar

(adapted from Gevorkiantz (1957b) and Carmean et al. (1989), prepared for northern Minnesota, USA)



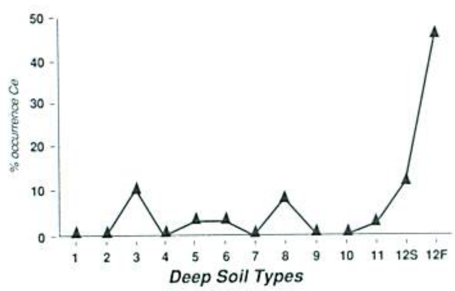
Lowland cedar would likely respond to drainage and fertilization treatments, although research is needed to determine the growth responses. Eastern white cedar responds well to thinning at all ages (Johnston 1977c). Spacing will improve timber quality for most end uses. To minimize site damage, harvesting of cedar on wet, organic soils may be deferred until winter. Rotation lengths vary from 80 to 145 years, depending on site and product objectives (Ohmann et al. 1978).

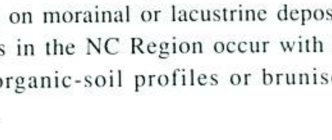
A few stands of very large trees occur on lime-rich greenstone sites in Quetico Park, near the southwestern corner of the NC Region; some trees have diameters (DBH) up to 100 cm (Walshe 1980).

Associated Soil Conditions

NWO FEC Soil Types *(38 NWO FEC plots)*: Cedar dominated stands in the NC Region occur on a wide range of soils, including deep coarse loams, silt and clay rich soils, shallow silt and clay rich soils, and organic soils. Most stands in the NC Region occur on organic soils, with Sphagnum constituting less than 25% of the moss cover.

Distribution of Eastern White Cedar across NWO FEC Soil Types in the NC Region



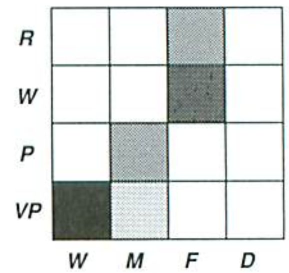


Deposition: Cedar dominated stands occur most frequently on deep fibric or mesic organic deposits. They are found infrequently on morainal or lacustrine deposits. Typically, cedar stands in the NC Region occur with fibrisolic and mesisolic organic-soil profiles or brunisolic mineral-soil profiles.

Texture: Most cedar stands in the NC Region occur on organic soils. However, where mineral soils are encountered, A and B horizon textures are predominantly coarse loams and silty fine and very fine sands. Cedar stands occur on a wide range of soil parent material textures.

Drainage and Moisture Regime: Cedar dominated stands are found most often on very poorly drained soils. However, cedar will occur on a wide range of soil drainage conditions, including well and rapidly drained soils. Cedar dominated stands in the NC Region occur predominantly on soils with moderately wet, fresh or very moist moisture regimes.

Correlation of Soil Drainage and Moisture Regime Classes for Eastern White Cedar



Stoniness and Structure: A significant coarse fragment content is rarely associated with cedar dominated stands in the NC Region. Soils beneath cedar stands are predominantly single-grained in structure. Some blocky and amorphous structured soils occur.

Site Position: Eastern white cedar stands tend to occur on low-lying, level terrain in the NC Region. A small percentage of stands are on upper- and mid-slope positions.

Litter Layer: Organic soils more than 40 cm deep commonly support cedar stands in the NC Region. Mineral soils generally have LFH layers from 6 to 15 cm thick. Typical forest humus forms associated with cedar dominated stands in the NC Region are fibric peatymors, fibrimors and mesic peatymors.

Soil Fertility Requirements: Eastern white cedar grows best on neutral or alkaline soils. Cedar is occasionally present on calcareous soils in the NC Region; about 1/5 of the time, cedar stands in NWO FEC plots occurred on soil profiles with carbonates within 100 cm of the soil surface. Growth improves on organic soils as depth of peat decreases and internal drainage improves. Cedar performs best on well decomposed wood and sedge peat, and poorest on Sphagnum dominated and acidic organic soils. Growth is improved on mineral soils where significant seepage occurs. Cedar is only rarely found on deep, dry upland soils that are acidic.

Insects, Diseases and Other Damaging Agents

Insect and disease damage to eastern white cedar is minor. A summary of common insect pests of cedar is given by Rose and Lindquist (1980).

Insects:

Carpenter Ant (*Camponotus herculeanus* L., *C. pennsylvanicus* DeGeer): Carpenter ants feed on the partially decayed heartwood of living trees. Mature trees are most affected by these insects.

Northern Cedar Bark Beetle (*Phloeosinus canadensis* Swaine): Cedar bark beetles attack damaged, weakened or dying trees. Extensive feeding results in flagging and the browning of foliage. No effective control measures are known; however, damage is minimal.

Arborvitae Leafminer (*Argyresthia thuiella* Packard): This green leafminer may cause foliar scorching and mortality in trees on very poor soils, including drought-stressed trees on dry, shallow soils. Leafminer adults emerge in late May to early July. Parasites often kill the larvae. Pruning and destruction of infested twig tips in early spring will control infestations.

Diseases:

Brown Cubical Butt Rot (*Polyporus balsameus* Pk. and *P. schweinitzii* Fr.): Brown cubical rot tends to attack trees growing in cedar stands on the drier portions of wet, organic soils. Weakened trees are particularly prone to windthrow.

White Stringy Butt Rot (*Poria subacida* (Pk.) Sacc.): This butt rot affects mature stands and trees growing on drier lowland soils.

Other:

Wildlife Browse: Red squirrels frequently eat cedar flower buds and clip cone-bearing branches, but damage generally is minor. Porcupine often partially or completely girdle individual tree stems, significantly weakening and sometimes killing trees in local areas. Eastern white cedar is an important winter browse species for hares and deer (Verme 1961). Sometimes browse lines approximately 2.1 m wide are clearly evident through cedar dominated stands in areas that support winter concentrations of deer. Moose occasionally browse on cedar in winter (Fowells 1965).

Management Considerations

A minor commercial species, cedar is occasionally cut in the NC Region for fence posts, rails, shingles and specialty lumber products. The wood is decay-resistant but does not endure mechanical wear. The wood of eastern white cedar is very light, soft, of low strength, and white (sapwood) to light brown (heartwood) in color (Hosie 1969).

Clearcutting may provide adequate natural regeneration, but a more effective management approach may be to harvest cedar stands in narrow stripcuts, and then broadcast burn to prepare new seeding or planting sites (Johnston 1977c). Winter harvesting of cedar on wet, organic soils effectively minimizes site damage.

In the NC Region, cedar grows well on neutral or slightly alkaline mineral soils, but is found on a wide range of soil/site conditions. The wide site adaptability may, in part, be a result of the possible existence of white cedar ecotypes (Habeck 1958).

Cedar is an important winter browse and cover species for snowshoe hares and white-tailed deer, as well as for many other edge and interior forest-dwelling wildlife species (Ohmann et al. 1978). Scheduling the harvest of cedar stands during winter may provide important browse for deer (Verme 1961). Insect and disease problems associated with eastern white cedar are minor.

Balsam Poplar

3.9.

Populus balsamifera L.
Salicaceae (Willow Family)

Description: Balsam poplar is a medium to large-sized (at maturity averaging 20 m high, up to 30 m), broadleaved hardwood tree with a narrow, open crown of thick, ascending branches, and stout, hairless, reddish-brown branchlets with large (15-25 mm long), sticky, fragrant, sharp-pointed buds. It tolerates a wide variation in climate and grows from Newfoundland to Alaska and south to the lower end of Lake Michigan. Balsam poplar is found on a wide range of sites with adequate moisture, but does not occur on deep organic soils or very dry soils.

Balsam poplar occurs infrequently throughout the NC Region, mainly on fresh to moist, fine-textured, often calcareous, soils. It is most commonly found in small, localized, mixed stands, often in association with trembling aspen, black spruce or white spruce, balsam fir and/or white birch (Anon. 1981a, Viereck et al. 1983, Anon. 1986d, Leak et al. 1988). In the NC Region, balsam poplar occurs on alluvial bottoms, river flats, sandbars, lake margins, rivers and lower slope and depressional landscape positions where there is a significant amount of moisture or seepage. In Quetico Park, balsam poplar is scarce, and restricted to lime-rich, fine textured soils (Walshe 1980).

Balsam Poplar

Associated Stand Conditions

NWO FEC Vegetation Types *(21 NWO FEC plots)*: Balsam poplar is associated with the balsam poplar hardwood and mixedwood NWO FEC Vegetation Type (**V1**). It is a minor element in the black spruce mixedwood / herb rich Vegetation Type (**V19**). The understory of balsam poplar dominated stands in the NC Region is typically herb and shrub rich. Soils range from fresh to moist mineral soils of mainly fluvial and lacustrine origin.

Overstory: Balsam poplar is most commonly found in small, localized, mixed stands. Trembling aspen is the most common co-dominant overstory species. Balsam fir, white spruce, white birch and black spruce are occasionally present in the overstory.

Shrubs: *Aralia nudicaulis*, *Rubus pubescens*, balsam fir, *Rosa acicularis*, *Ribes triste*, *Actaea rubra*, *Cornus stolonifera*, *Alnus rugosa*, *Rubus strigosus*, *Acer spicatum* and *Amelanchier* spp. are common understory shrubs in balsam poplar dominated stands in the NC Region.

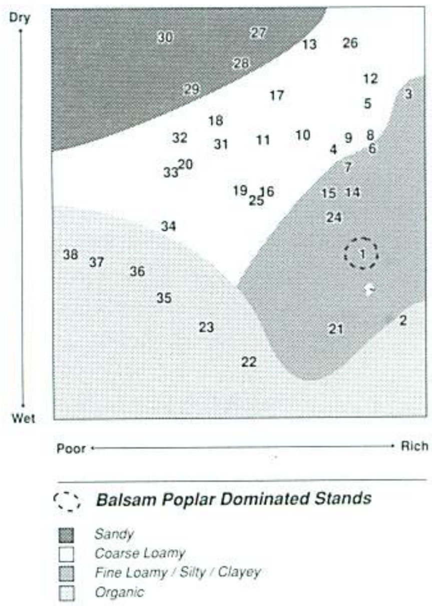
Herbs: *Mitella nuda*, *Galium triflorum*, *Viola* spp., *Maianthemum canadense*, *Streptopus roseus*, *Aster macrophyllus*, *Petasites palmatus*, *Equisetum* spp., *Clintonia borealis*, *Carex* spp., *Cornus canadensis*, *Trientalis borealis*, *Fragaria virginiana*, *Aster ciliolatus*, *Mertensia paniculata*, *Viola renifolia* and *Anemone quinquefolia* are common species in the relatively diverse herb layer of balsam poplar dominated stands.

Mosses and Lichens: Moss cover is very low in balsam poplar dominated stands, averaging 7% in NWO FEC plots in the NC Region. Those mosses which occur most frequently include *Pleurozium schreberi* and *Plagiomnium cuspidatum*. Ground lichens are typically absent from balsam poplar dominated stands in the NC Region.

Silvics

Growth Habit: Balsam poplar is a rapidly growing, medium to large-sized deciduous tree (averaging 20 m in height) with a narrow, open crown of thick, stout and ascending branches. Leaves are alternate, simple, about 8-13 cm long, ovate to ovate-lanceolate, with a long tapering apex and a finely toothed margin; they are dark, bronzy-green

NWO FEC Vegetation Type Ordination showing distribution of Balsam Poplar dominated stands and associated soil conditions in the NC Region.



above and pale beneath, often stained rusty-brown with resin, and supported by a short (3-4 cm long), round, smooth petiole. Juvenile balsam poplar have thin, smooth, greenish bark that becomes grey and deeply furrowed into long V-shaped ridges with age (Scoggan 1978). The species typically lives longer than trembling aspen and is an excellent self-pruner. Long, straight boles for 10 to 18 m are not uncommon. Twigs are stout, with large, pointed, resinous buds.

In the leafless condition, balsam poplar may be readily separated from trembling aspen by bud characteristics. Balsam poplar has 12- to 20-mm-long terminal buds that are bright reddish brown, glabrous and covered with a fragrant resin; trembling aspen buds are 6 to 10 mm long, reddish brown, glabrous and lustrous, and lack fragrant resin (Maini 1966).

Shade Tolerance: The shade tolerance of balsam poplar is low, similar to that of trembling aspen. The best growth and development occurs in full sunlight (Roe 1958, Fowells 1965). Based on a detailed survey of Minnesota forests, balsam poplar was given a ranking of 3.5 on a 5-unit scale (1=least to 5=greatest) for light requirements; for moisture, nutrient and heat requirements, rankings were 3.7, 2.7 and 2.1, respectively (Bakuzis and Hansen 1959).

Climatic Range: Balsam poplar is tolerant of a wide range of temperature and precipitation conditions. Across its commercial range in Ontario, mean January temperatures range from -11°C to -13°C and July temperatures from 26°C to 32°C (Anon. 1987a). Balsam poplar tolerates a wide range of variation in distribution and abundance of precipitation. Throughout its botanical range, annual precipitation varies from 170 to 1390 mm. Although it is distributed throughout the Canadian prairies in relatively dry areas, balsam poplar does require continuous sources of soil moisture, especially during the establishment phase.

Frost Resistance: Balsam poplar is frost resistant and becomes established in areas where frost remains in the soil well into June (Roe 1958). Cycles of flowering and leaf flush vary with temperature, thus adapting the species to variations in annual climatic patterns.

Flood Tolerance: Balsam poplar is highly tolerant of flooding (Haeussler and Coates 1986). Trees will produce new roots as required after flooding, especially when surface silt depositions occur.

Fire Tolerance: Young balsam poplar have relatively thin bark and are easily killed by fire. However, mature trees have a thick, fire-resistant bark; Lutz (1955) noted that of the tree species in the northern boreal forest, balsam poplar is perhaps the most resistant to destruction by fire. Balsam poplar dominated stands often have relatively low fuel loadings. Fire-killed trees sucker copiously from shallow roots and fire improves seedbed conditions for balsam poplar on upland mineral soils.

Successional Status: Balsam poplar is a pioneer to early successional species.

Vegetative Reproduction: Both seeding and suckering are important means of reproduction for balsam poplar. Vegetative suckering is probably the most common means of reproduction in the NC Region. Balsam poplar regenerates from basal (stump) sprouts, buried branch parts and root suckers (Coates and Haeussler 1986). Suckers appear during late summer after harvest and may grow rapidly. Most root suckers originate and grow from roots about 1 cm in diameter that occur within the upper 2 cm of the soil, or from exposed roots. Suckering is reduced in soils with significant coarse fragment contents as opposed to fine-textured soils free of coarse fragments. Suckering is greatest when the insulating organic layer has been removed. Balsam poplar is easily propagated from rooted stem cuttings.

Sexual Reproduction:

Flowering: Balsam poplar is dioecious, with male and female catkins developing on separate trees (Brayshaw 1978). Trees flower as early as 8 to 10 ten years of age. Flowers appear and mature in April and May before leaves emerge. Pollination is by wind.

Fruit: Balsam poplar produces several capsules (5-8 mm long) on the female catkins. Capsules mature during late May to mid-June, when leaves are about 2/3 grown, and split to discharge tiny seeds with long, silky hairs.

Crop Cycle: Balsam poplar produces a good seed crop annually.

Crop Abundance: Abundant seed production is associated with balsam poplar.

Seed Viability: Balsam poplar seeds initially display high viability but typically retain this viability for only a few days after dispersal.

Seed Dispersal: Seed dispersal is by wind and water. Dispersal is concentrated within a zone of 100 to 200 m around the parent tree. A small percentage of seeds travel greater distances.

Germination: Balsam poplar seeds germinate immediately after dispersal (i.e., during late May to late June) if seedbed conditions are favorable and moisture is not limiting. Balsam poplar has no dormancy requirements. Preferred seedbeds include recently exposed mineral-soil deposits along streams or drainage channels, and mineral-soil surfaces exposed by recent fires (Roe 1958, Fowells 1965). To ensure seedling survival, seedbeds should be continuously moist for several weeks after germination (Zasada et al. 1981).

Seedling Survival and Growth: Balsam poplar seedlings are particularly susceptible to desiccation, rain damage and infections by soil fungi. Approximately one month of relatively continuous and abundant moisture after germination is necessary to ensure survival.

Height Growth: Balsam poplar grows rapidly in height during the first 40 to 50 years. On moist and fertile sites, balsam poplar may outperform trembling aspen.

Root Development: Balsam poplar has a wide-spreading, shallow root system (Hosie 1969). Propagation is chiefly by means of suckers that arise from roots near the surface of the soil.

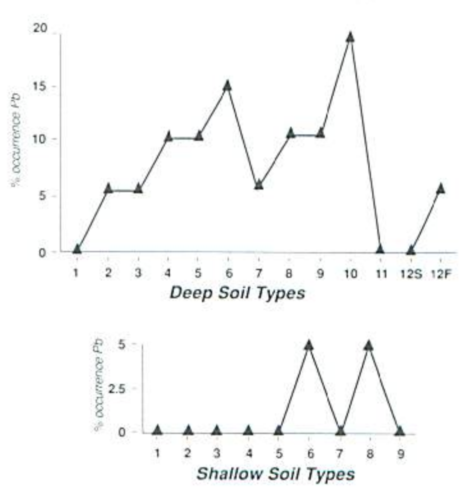
Stand Development: Balsam poplar stands frequently originate from root and stump sprouts after a major disturbance. A burn of light to moderate intensity may prepare a good seedbed and stimulate root suckering. Root suckering is often most prolific two years after burning. Stump sprouting is greatest on winter-logged areas. Moderate to severe burns may reduce or stop stump sprouting. Sprout mortality is high on summer-logged areas. Early juvenile growth is relatively rapid and balsam poplar will outcompete most other tree species in height growth. Farmer et al. (1988) present preliminary information on the genetic diversity of balsam poplar in northwestern Ontario; they found little measurable diversity along a latitudinal gradient.

Balsam poplar reaches commercial size relatively quickly compared to other boreal tree species, often within 40 years. The incidence of stem and root rot increases rapidly with age, especially after about age 70.

Associated Soil Conditions

NWO FEC Soil Types (*21 NWO FEC plots*): Balsam poplar grows mainly on fresh to moist, fine-textured, often calcareous, soils. Balsam poplar stands may be found on a wide range of NWO FEC Soil Types, but occur with highest frequency on deep, moist to wet, fine loamy and clayey soils (**S10**) and deep, fresh, clayey soils (**S6**). Balsam poplar occurs rarely on very shallow soils and does not occur on deep organic or very dry sandy soils. It does not colonize dry, sandy pine sites as trembling aspen does (Barnes and Wagner 1981).

Distribution of Balsam Poplar across NWO FEC Soil Types in the NC Region

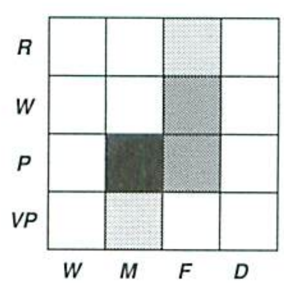


Deposition: In the NC Region, balsam poplar occurs on alluvial bottoms, river flats, sandbars, lake margins, rivers and lower-slope and depressional landscape positions where moisture or seepage is significant. Balsam poplar dominated stands are most commonly associated with lacustrine deposits, and are less commonly found on morainal or fluvial materials. They are most commonly associated with brunisolic, gleysolic and podzolic soil profiles.

Texture: Balsam poplar in the NC Region is typically associated with clayey, silty, fine loamy and, less commonly, coarse loamy parent material textures. Surface horizons under balsam poplar dominated stands in the NC Region are most commonly clayey, silty and fine and coarse loamy textures.

Drainage and Moisture Regime: Balsam poplar dominated stands in the NC Region occur on a range of soil drainage conditions but more than 1/2 of the NWO FEC plots studied were imperfectly drained. Mottling and gleying are frequently encountered in soil profiles; mottles and gley colors were observed in more than 1/2 of the NWO FEC plots supporting balsam poplar, typically at depths of between 51 and 75 cm. Gleyed horizons occur less frequently than mottling. Balsam poplar dominated stands in the NC Region occur on very fresh to very moist soils.

Correlation of Soil Drainage and Moisture Regime Classes for Balsam Poplar



Stoniness and Structure: Coarse fragments are infrequent in soils under balsam poplar dominated stands in the NC Region. Significant soil coarse-fragment content may reduce regeneration potential by lowering the numbers of root suckers. Mineral soils beneath balsam poplar dominated stands are primarily blocky in structure. Some platy, structured soils also occur.

Site Position: Most balsam poplar dominated stands in the NC Region occur on level or lower-slope and depressional landscape positions. Occasionally, these stands may occur on upper or mid-slope positions, where seepage or higher moisture conditions prevail.

Litter Layer: Balsam poplar stands in the NC Region commonly have LFH layers that range from 6 to 15 cm in thickness. Forest humus forms are mostly humifibrimors, although fibrimors and fibrihumimors are sometimes encountered.

Soil Fertility Requirements: The nutrient requirements of balsam poplar are high (Haeussler and Coates 1986). The species requires a good supply of calcium and magnesium, typically associated with lacustrine or alluvial deposits (Krajina et al. 1982). Balsam poplar often grows on calcareous parent materials in the NC Region; about 1/2 of the NWO FEC plots dominated by balsam poplar were on soils with carbonates in the upper 50 cm of mineral soil. Balsam poplar is intolerant of very acid conditions and forest humus forms that release nutrients slowly (Roe 1958).

Insects, Diseases and Other Damaging Agents

A summary of common insect pests of balsam poplar is given by Rose and Lindquist (1982).

Insects:

Forest Tent Caterpillar (*Malacosoma disstria* Hubner): Forest tent caterpillars will feed on the foliage of balsam poplar if preferred aspen foliage has been depleted. Larvae feed in groups on new foliage from May to late June. Populations of forest tent caterpillar expand year by year, then rapidly decline as a result of unfavorable spring weather, lack of food or the introduction of disease organisms.

Poplar and Willow Borer (*Cryptorhynchus lapathi* L.): This weevil, introduced from Europe, is the most serious insect pest of balsam poplar and willow and can lead to sapling mortality in 20- to 40-year-old stands. The life cycle of the poplar and willow borer takes up to 3 years to complete. Eggs are laid in holes chewed in the lower 40 cm of the stem in summer, early fall and spring. Larvae bore into the wood and tunnel upwards, thereby weakening or killing the stem.

Diseases:

Leaf Spot (*Mycosphaerella populorum* G.E. Thompson): Balsam poplar is less susceptible to leaf spot disease than trembling aspen. Leaf spot affects trees late in August but has limited influence on growth.

Shoestring Root Rot (*Armillaria ostoyae* (Romaqn.) Herink): Shoestring root rot is a common decay in mature stands, weakening trees and increasing breakage. Losses are less than those experienced by trembling aspen.

Heart Rot (*Phellinus tremulae* (Bondart.) Bondart. and Borisov): Heart rot is a common decay in mature stands but does not contribute significantly to mortality and decline in balsam poplar stands. In the Boreal Forest Region of Alberta, 61% of sampled balsam poplar had fungal infections, with *Phellinus tremulae* the most common decay encountered (Thomas et al. 1960). Although the extent of decay decreased in trembling aspen from mesic to dry soils, no similar trend was observed in balsam poplar from wet to mesic sites (Thomas et al. 1960). The incidence of decay in balsam poplar in Ontario was found to increase southward, based on a study of 38 trees at 5 locations along a broad north-south transect (Balatinecz and Peng 1987).

Management Considerations

Balsam poplar is used occasionally for pulpwood and plywood in the NC Region. The wood is light, soft and low in strength, and ranges in color from white (sapwood) to greyish-brown (heartwood) (Hosie 1969).

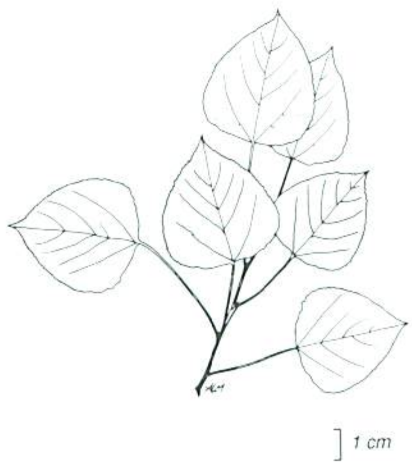
Mechanical site preparation to expose mineral soil typically results in an excellent seedbed for balsam poplar regeneration if soil surfaces remain moist. Site preparation may also promote suckering if residual balsam poplar trees are present (Zasada et al. 1981). Burning may stimulate root suckering and also prepare a good seedbed. Root suckering is often most prolific two years after a light to moderate burn (Roe 1958). Moderate to severe burns may reduce stump sprouting. Stump sprouting is greatest on winter-logged areas and sprout mortality is typically high on summer-logged areas.

Trembling Aspen 3.10.

Populus tremuloides Michx.
Salicaceae (Willow Family)

Description: At maturity, trembling aspen is a medium to large-sized (averaging 21 m high), broadleaved hardwood with a relatively small, diffuse crown, long, spreading branches, and a trunk with little taper that is essentially branchless below the crown. It is an early successional native species and occurs over a broad range of soil and climatic conditions. Stands are predominantly of sucker origin (Graham et al. 1963) and occur frequently as pure stands. In mixed stands, common associates include white spruce, black spruce, white birch, balsam poplar, jack pine and balsam fir (Bouchard and Maycock 1978, Anon. 1981a, McClain 1981, Mueggler and Campbell 1986, Anon. 1986d, Mueggler 1988, Corns 1989).

Trembling Aspen



Trembling aspen is the most widely distributed tree species in North America (Fowells 1965) and is a common forest component of both the Great Lakes - St. Lawrence and Boreal Forest Regions in Ontario (Rowe 1972). Trembling aspen is widespread and frequent in the NC Region, occurring across a wide range of soil/site conditions, particularly on upland, dry to fresh, coarse loamy soils. It is the third most important species in Ontario, in terms of annual volume harvested (Anon. 1988). The name *trembling aspen* can be attributed to its long, flattened, slender leafstalks or petioles, which permit leaves to "tremble" in the slightest breeze.

Associated Stand Conditions

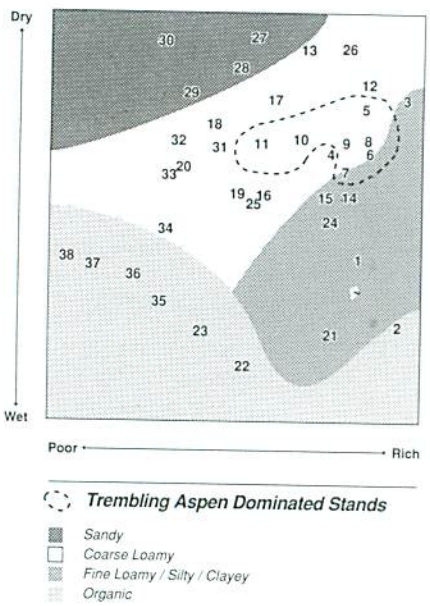
NWO FEC Vegetation Types (*299 NWO FEC plots*): Trembling aspen is the dominant or co-dominant tree species on several NWO FEC fresh, upland, shrub rich and feathermoss poor aspen mixedwood Vegetation Types (Sims et al. 1989). Co-dominant coniferous species include black spruce and jack pine (**V8, V10, V11**), balsam fir (**V6, V7**) and white spruce (**V8, V9**). It is either dominant or co-dominant in the aspen hardwood Vegetation Type (**V5**) on deep, fresh upland sites. Ericaceous shrubs are only rarely associated with aspen dominated stands (**V11**) in the NC Region.

Overstory: White birch is the most common tree-layer associate of trembling aspen in the NC Region. Jack pine is also a common overstory associate in aspen mixedwood stands and black spruce is common in shrub poor mixedwood stands. Balsam fir, black spruce and white spruce occur consistently at low frequencies as canopy associates in all but the aspen hardwood Vegetation Type (**V5**). Large-toothed aspen and red maple are infrequent associates in trembling aspen hardwood stands.

Shrubs: Balsam fir, *Aralia nudicaulis*, *Rubus pubescens*, trembling aspen, *Linnaea borealis*, *Diervilla lonicera* and *Rosa acicularis* are common shrubs in aspen dominated stands in the NC Region. *Amelanchier* spp., *Corylus cornuta*, *Acer spicatum*, *Sorbus decora*, *Lonicera canadensis*, *Ribes* spp., *Vaccinium myrtilloides*, *V. angustifolium*, black spruce, *Gaultheria hispidula* and *Alnus crispa* occur with less frequency. *Ledum groenlandicum* is a common understory shrub only in the trembling aspen - conifer / blueberry / feathermoss Vegetation Type (**V11**). Shrub layers in aspen dominated stands are typically diverse and abundant.

Herbs: *Maianthemum canadense*, *Cornus canadensis*, *Clintonia borealis*, *Aster macrophyllus*, *Trientalis borealis*, *Viola renifolia* and *Streptopus roseus* are common herbs associated with aspen dominated stands. *Galium triflorum*, *Mitella nuda*, *Anemone quinquefolia*, *Coptis trifolia*, *Epilobium angustifolium*, *Petasites palmatus* and *Viola* spp. occur with lower frequencies. *Lycopodium clavatum* and *L. annotinum* occur within aspen mixedwood stands in which jack pine and black spruce form a significant overstory component (**V10, V11**).

NWO FEC Vegetation Type Ordination showing distribution of Trembling Aspen dominated stands and associated soil conditions in the NC Region.



Mosses and Lichens: *Pleurozium schreberi* is the most common moss species in aspen dominated stands in the NC Region. The extent of *Pleurozium* ground cover varies widely, from small, scattered clumps to extensive mats. *Rhytidiadelphus triquetrus*, *Ptilium crista-castrensis*, *Plagiomnium cuspidatum*, *Dicranum* spp., *Hylocomium splendens* and *Mnium* spp. occur less frequently. Lichen ground cover is typically sparse with only *Cladina rangiferina* occurring occasionally and with low cover.

Silvics

Growth Habit: Trembling aspen is a medium to large-sized tree with an average height of 21 m (12 m to 34 m). It has a narrow, diffuse, often rounded crown and a long, branchless bole with little taper (Hosie 1969). Leaves of trembling aspen are alternate, simple, about 4-6 cm long, ovate to orbicular with a rounded or squared base, a pointed apex, and a wavy, finely toothed or almost entire margin; leaves are lustrous, dark green above, dull and pale beneath, and supported by long (3-7 cm long), laterally compressed petioles. Bark is smooth, with a waxy appearance, pale and white-green when young, becoming grey and furrowed with age. Moderately deep, wide-spreading roots extend up to 14 m from the bole. Trembling aspen is a relatively short-lived, pioneer species with rapid juvenile growth. Although individuals can survive to 200 years of age, most stands exhibit decay between 55 and 90 years. Aspen does not reproduce under its own shade but is capable of regenerating vegetatively from root suckers after light fires and disturbances.

Shade Tolerance: Trembling aspen is a shade-intolerant species that requires full sunlight for growth and survival (Stathers 1989). High light levels are required to stimulate production of root suckers, although suckers are more shade tolerant than seedlings. Based on a detailed survey of Minnesota forests, trembling aspen was given a ranking of 4.2 on a 5-unit scale (1=least to 5=greatest) for light requirements; for moisture, nutrient and heat requirements, rankings were 2.0, 2.3 and 2.1, respectively (Bakuzis and Hansen 1959).

Climatic Range: Trembling aspen is adapted to a wide range of temperature and moisture regimes, as evidenced by its wide geographic distribution (Davidson et al. 1988). It is well adapted to cold continental and boreal climates. The northern boundary of its botanical range approximates the 13°C isotherm for July (Halliday and Brown 1943). Within its commercial range in Ontario, mean July temperatures range from 16°C to 19°C, annual precipitation ranges from 635 to 864 mm and the frost-free period is 80 to 130 days (Chapman and Thomas 1968, Anon. 1987a).

Frost Resistance: Trembling aspen is very frost resistant (Stathers 1989); however, boles of trees, particularly in open-growing stands, may be susceptible to frost cracking. Frost cracks often become points of infection for destructive fungi. Young foliage is susceptible to late-spring frosts, although new foliage emerges later in the season to replace frost-damaged leaves. Suckers are more resistant to frost than are seedlings.

Flood Tolerance: Mature trembling aspen have poor to fair flood tolerance, and can survive 2-3 weeks of flooding. Vegetative reproduction is inhibited by flooding immediately after disturbance. Young seedlings or suckers are intolerant of prolonged flooding.

Fire Tolerance: Trembling aspen is adapted to sites on which fire occurs with a frequency of less than once in every 100 years (James and Smith 1977). Both young and mature trees are susceptible to fire damage, but subsequent colonization of burned areas through suckering occurs immediately after a fire (Brown and DeByle 1987). High soil temperatures associated with burned soils stimulate root suckering, and burns of moderate to severe intensity can produce more suckers than light burns (Perala 1974, Anon. 1985). Release of nutrients during the first year after a fire may stimulate suckering. Fire hazard ratings in aspen stands are generally moderate as a result of the moderately high moisture content in the foliage, the well developed herbaceous understory, and the fresh to moist soil conditions typically associated with trembling aspen stands.

Successional Status: Trembling aspen is an early successional species typically replaced by tolerant hardwoods on drier soils, and by balsam fir, white spruce and/or white pine on fertile fresh soils. It is succeeded by balsam fir, black spruce or eastern white cedar on moist soils in the absence of fire.

Vegetative Reproduction: Both suckering and seeding play a role in trembling aspen's survival and distribution; however, the predominant form of trembling aspen regeneration is through suckering, which can occur on trees of all ages. Suckering is typically induced by damage to the stem or roots. Damage results in a reduction in the production of auxins, which normally retard suckering in healthy trees. Suckers arise from adventitious or dormant buds on the roots. Suckers also occasionally develop from stump or collar sprouts. Suckers develop from roots within 3 to 10 cm of the soil surface during the growing season, when soil temperatures range between 18°C and 25°C. Soil temperatures are critical for root sucker production, and must reach 20°C for maximum production to occur (Steneker 1976).

Vegetative reproduction is inhibited by flooding immediately after disturbance. Suckers are dependent on the root system of parent plants for a few years; during this period they develop independent root systems. Suckering results in the development of extensive clones of genetically identical trees; each clone varies in general form, suckering ability, phenology, growth rate and disease susceptibility (Tubbs 1977). Trembling aspen will not propagate from woody stem cuttings (Barnes and Wagner 1981).

Sexual Reproduction:

Flowering: Dates of flowering and leaf flush vary depending on clonal origin. Trembling aspen in the NC Region flower between mid-May and early June, before leaves have emerged. Trembling aspen has unisexual flowers borne on catkins, with most trees of one area producing predominantly male or female flowers if the stand is of sucker origin (Brayshaw 1978). Male clones flower before female clones, with wind as the primary pollinating agent.

Fruit: The fruits are unicellular capsules (approximately 6 mm long) that are borne on the female catkins. Capsules split before the leaves are fully expanded in early June to discharge tiny, brown seeds with long, silky hairs (Schopmeyer 1974).

Crop Cycle: Trembling aspen produces seeds annually, with good seed crops occurring every 2 or 3 years. Fruits ripen in June as the leaves expand, about 4 weeks after initiation of flowering. Seed crops are produced by trees as young as 10 to 15 years (Doucet 1989).

Crop Abundance: Trembling aspen can produce an abundant seed crop. One 23-year-old trembling aspen tree in southern Ontario produced 1,625,000 seeds in a single season (Maini 1968).

Seed Viability: The seeds of trembling aspen are short-lived under natural conditions; the viability of fresh seed is high (95%) for only two to three weeks. Aspen seeds may be stored for 24 months or more if temperature and moisture are carefully controlled (Fechner et al. 1981). Although commercial, seed-bearing age is achieved by year 20, optimum seed crops are produced by 50- to 70-year-old trees.

Seed Dispersal: Trembling aspen seeds disperse a few days after they ripen. Seeds dispersed by wind are capable of being transported hundreds of kilometres (Maini 1968). Seed dispersal also occurs by water.

Germination: Seeds exhibit no dormancy and germinate soon after seeding. The highest germination occurs on exposed mineral soil or compacted, damp Sphagnum where there is a continuous moisture supply, good drainage and moderate soil temperatures (ranging from 5°C to 30°C). Trembling aspen seeds will germinate in the absence of light under moist conditions, but require some sunlight soon afterwards. Stands of seed origin are relatively rare, and often develop with difficulty.

Seedling Survival and Growth: Seedlings are highly vulnerable to heat damage (at temperatures above 30°C), drought and frost during the initial few days of growth, and require some sunlight for survival. Older seedlings become more tolerant and resistant. Initial stocking of suckers after harvesting or burning may vary substantially and can be as high as 200,000 stems/ha (Steneker 1976). However, tree dominance is quickly established and high stocking levels are significantly reduced during the first few years through natural mortality. At ages of 10 to 15 years, densities are often more than 10,000 stems/ha (Doucet 1989).

Height Growth: Trembling aspen is characterized by relatively rapid growth up to about 20 years of age (Kittredge 1938, Alemdag and Horton 1981). During the first year, height growth for suckers ranges from 30 cm to more than

1 m (Davidson et al. 1988). Wide-spreading lateral roots develop during years 2 and 3. Most height growth occurs between early June and mid-August. In the NC Region, radial growth begins about one week earlier and extends for 2 to 3 weeks longer.

The best height growth occurs on well drained, fresh to moist, calcareous parent materials with coarse loamy textures (Voigt et al. 1957, Strothmann 1960). On similar sites in the NC Region, site indices vary from 13.6 to 25.9 m (Buse and Towill 1990). Local variations in height growth are often mainly attributable to clonal origins and genetic differences; however, available soil moisture and spring soil temperatures are also major factors that affect height growth rates. Significant amounts of slash on a cutover may affect suckering by shading soil and lowering soil temperatures, and also by acting as a physical barrier to growth (Doucet 1979, 1989).

Root Development: Root development is strongly influenced by soil characteristics. Trembling aspen roots are usually moderately deep (1 to 2.2 m) with strong lateral roots extending up to 16 m. On fresh, coarse loamy soils, roots can extend to 2.2 m in depth. Excessive stoniness may restrict lateral root development and limit opportunities for root suckering (Brinkman and Roe 1975). Suckering normally originates from roots 0.07 to 2.2 cm in diameter (Farmer 1962) in the upper 10 cm of the soil, but can develop on roots as deep as 28 cm (Schier and Campbell 1978).

Stand Development: Trembling aspen grows rapidly after a major disturbance (fire, windthrow, harvesting). Often stands are initiated as pure stands, with other tree species becoming overstory associates at later ages. Pathological rotation is achieved by age 55, after which the incidence and extent of rot increases progressively (Shields and Bockheim 1981, Weingartner and Basham 1985). Kemperman et al. (1978) found no relationship between clonal growth and percentage defect in the Manitouwadge area; the slowest-growing trees tended to be the most defective. Waves of mortality have been recorded in the seedling and sapling stages of stand development. Trembling aspen is a very shade-intolerant species that displays moderate natural pruning in well stocked stands in the NC Region. Trembling aspen develops a clear bole up to 2/3 of its height. Climatic factors and a short growing season have been cited as contributing factors to this moderate to poor natural pruning.

Injuries that occur during a tree's early growth phases often affect its competitive position and fate in a forest stand. For example, foliar and shoot pathogens of aspen may kill young terminal shoots, thus affecting a stem's crown-class position (Perala 1984, Bates et al. 1989)

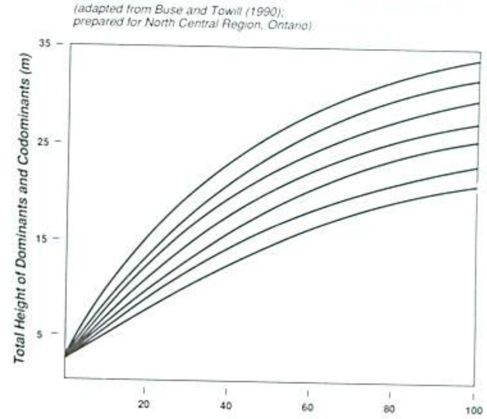
Trembling aspen remains free from heart rot longer, and stand deterioration occurs later, on calcareous as compared to acidic parent materials (Shields and Bockheim 1981). Aspen site index is lower on clays and coarse sands than on well drained, fresh to moist soils with loamy and loamy sand textures (Bedell and McLean 1952, Strothmann 1960, Heeney et al. 1980).

In normal stands, higher stem densities are present at a given age on poorer sites than on better sites. Perala (1984) noted sites that normal stands typically fit a *-3/2 self thinning rule*, which states that self thinning causes stand density to decrease as stand biomass increases, such that the logarithm of this relationship produces a graph with a constant slope of -3/2. Thus, faster growth on better sites leads to more rapid thinning and thus a higher mortality rate. Typically, most mortality occurs in smaller sized or suppressed individuals (Bates et al. 1989).

Buse and Towill (1990) developed site index curves for trembling aspen distributed over soil moisture regimes from 0 (dry) to 7 (wet) in the NC Region. Site indices ranged from 13.6 to 25.9 m, with a mean of 20.2 ± 2.2 m. Depth to gley, % clay in A and B horizons, and % clay in the C horizon were all correlated with site index. Relationships between aspen stand volume and site quality are still not well understood for the NC Region. Approximately 38% of the differences in average tree volumes were explained by genetic differences among clones in a study by Kemperman et al. (1978) in Terrace Bay District, NC Region. The study also found no clear correlations among tree volumes and measured soil factors.

Site Index Curves for Trembling Aspen

(adapted from Buse and Towill (1990); prepared for North Central Region, Ontario)

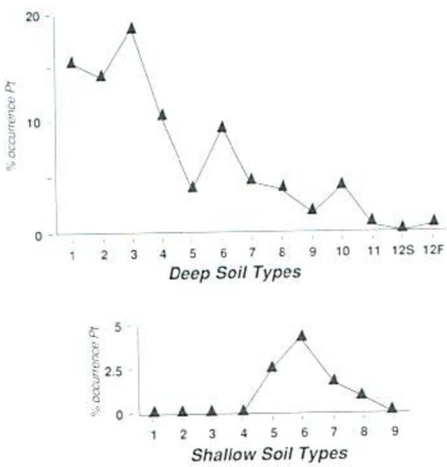


Associated Soil Conditions

NWO FEC Soil Types *(299 NWO FEC plots)*: In the NC Region, trembling aspen is often dominant on deep, dry to fresh soils with coarse loamy (**S3**), medium (**S1**) or fine sandy (**S2**), silty (**S4**) and clayey (**S6**) parent materials. It is less common on moist or shallow mineral soils and does not occur on organic soils.

Deposition: Trembling aspen dominated stands in the NC Region most commonly occur on morainal, glaciofluvial and lacustrine deposits. The most common soil profiles associated with trembling aspen stands are brunisolic, podzolic and gleysolic.

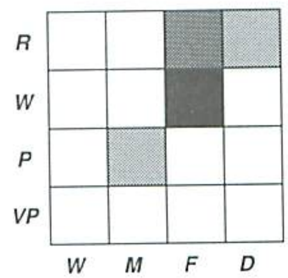
Distribution of Trembling Aspen across NWO FEC Soil Types in the NC Region



Texture: Aspen dominated stands in the NC Region are typically found on soils with a coarse loamy or fine to medium sandy parent material texture. Less frequently they are associated with coarse sandy, silty and clay textured parent materials.

Drainage and Moisture Regime: Because of its poor stomatal control, soil moisture level is a critical factor for growth of trembling aspen (Davidson et al. 1988). Aspen dominated stands in the NC Region most commonly occur on rapidly to well drained soils. Moderately well, very rapidly and imperfectly drained soils support stands of intermediate vigor (Steneker 1976). Trembling aspen is not found on very poorly drained soils in the NC Region. Trembling aspen dominated stands are most common on moderately fresh to fresh soils and occur less frequently on moist soils and moderately dry to dry soils. Aspen is not associated with wet soils. Mottling occurs in about 1/5 of the NWO FEC plots supporting aspen; gley colors are relatively rare. Aspen stands in the NC Region with better growth are often associated with fresh to moist, moderately well drained, coarse and fine loamy soils on upper and mid-slope positions (Racey et al. 1989a).

Correlation of Soil Drainage and Moisture Regime Classes for Trembling Aspen



Stoniness and Structure: Gravel and cobbles are present at low levels of abundance in the profiles of most soils that support trembling aspen dominated stands in the NC Region. Trembling aspen occurs most frequently on single-grained soils, but it is also common on soils with a blocky structure. Soil rockiness may greatly diminish aspen stand development (Fowells 1965, Burns 1983).

Site Position: Trembling aspen often occurs on level ground or upper to mid-slope positions in the NC Region. It occurs infrequently on lower or toe-slope positions.

Litter Layer: Trembling aspen dominated stands are associated with LFH layers of moderate thickness, typically 6 to 15 cm thick. Trembling aspen in the NC Region is not associated with organic soils. Forest humus forms are typically fibrimors and humifibrimors. A nurse species, trembling aspen improves humus form quality by annually providing a nutrient-rich litter-fall (Klinka et al. 1989).

Soil Fertility Requirements: Growth rates are optimal on soils with 50-60% silt plus clay content (Stoeckeler 1948, 1960) and with a moderate to high cation exchange capacity. Aspen performs best on well drained, fresh to moist soils which are porous and have some organic-matter content (Meyer 1956, Heeney et al. 1975, Perala 1977, Tubbs 1977). Poor growth occurs on dry, coarse sands with little available capillary water. Aspen also grows poorly on shallow soils over bedrock (Walshe 1980).

Aspen is considered to be a soil-improving species and it has foliage, bark, and wood that are all high in potassium, calcium, magnesium and nitrogen. Aspen will respond readily to nitrogen and NPK fertilization (Van Cleve 1973, Czapowskyj and Safford 1979, Van Cleve and Oliver 1982, Perala and Laidly 1988), and is often associated with nitrogen-rich soils (Haeussler and Coates 1986, Klinka et al. 1989). Nitrogen fertilization may significantly increase aspen foliar biomass and leaf area (Van Cleve 1973, Van Cleve and Oliver 1982). *Alnus* spp. in the understory may help improve the nutrient status of trembling aspen stands by fixing soil nitrogen, and also by improving levels of litter-layer decomposition; *Alnus crispa* leaf litter mixed with *Populus* leaf litter on the forest floor can significantly accelerate decomposition rates (Taylor and Parsons 1989).

Trembling aspen is adapted to soils with high calcium levels. Aspen occasionally occurs on calcareous soils in the NC Region; about 1/5 of the NWO FEC plots that support aspen dominated stands in the NC Region had free carbonates within 100 cm of the soil surface.

Insects, Diseases and Other Damaging Agents

Insects:

Trembling aspen is host to more than 300 different insect species, many of which cause damage (Davidson and Prentice 1968). A summary of the most common insect pests of trembling aspen is given by Rose and Lindquist (1982).

Forest Tent Caterpillar (*Malacosoma disstria* Hubner): Trembling aspen is the preferred host for the forest tent caterpillar, with outbreaks occurring at about 10-year intervals and lasting 3 to 5 years. Outbreaks typically end as a result of unfavorable weather, starvation because of high population levels or increased mortality from natural parasites and diseases. Defoliation can result in tree mortality on dry soils during periods of severe drought. Reduced radial growth (16-90%) occurs from repeated defoliation. Trees are also weakened by tent caterpillar attacks and are then more susceptible to other insect or to fungal attacks.

Large Aspen Tortrix (*Choristoneura conflictana* Walker): This is a major defoliator of aspen, second only to the forest tent caterpillar. Infestations last 2-3 years, and end as a result of starvation of the tortrix. Radial growth is reduced by this pest. In early May, larvae crawl up the tree to mine buds before opening. The dark green to black larvae subsequently feed on expanding leaves, rolling, folding and tying leaves together for feeding sites. Tiny larvae skeletonize the leaf surfaces in July and August. During epidemics, larvae also feed on balsam poplar, white birch and willow. Small, second-stage larvae overwinter in cover at the base of trees. Pupation occurs between tied leaves in mid-June. Moths are in flight from late June to mid-August.

Aspen Twinleaf Tier (*Enargia decolor* Walker): This insect causes widespread and severe defoliation in northwestern Ontario. It is the second most damaging leaf tier on trembling aspen. Larvae overwinter in the soil.

Aspen Leaf Beetle (*Chrysomela crotchi* Brown) and American Aspen Beetle (*Gonioctena americana* Schaeff.): *Gonioctena americana* is the most prevalent beetle in aspen stands in the NC Region. Both of these beetles are found annually in low numbers in most stands. They are periodically abundant on young, pole-sized aspen and on lower branches of mature trees. Adults overwinter in the soil, emerging after the first leaves reach full size. Larvae feed for one month, skeletonizing lower surfaces first, then entire leaves except veins. Defoliation typically occurs for 1- to 2-year periods.

Aspen Leafblotch Miner (*Phyllonorycter ontario* Freeman): Larvae mine the insides of leaves, causing injury and foliar browning in June to early August. In particular, the leafblotch miner attacks young trees, mostly those under 10 cm diameter at their base. Moths hibernate in stands of pine, spruce and balsam fir.

Diseases:

The causes and mechanisms of fungal decay in trembling aspen have been reviewed by Basham (1958, 1990), Thomas et al. (1960), Etheridge (1961) and others.

False Tinder Fungus (*Phellinus tremulae* (Bondart.) Bondart. and Borisov): This fungus causes 3/4 of all observed decay in trembling aspen (Basham 1958). It is a yellowish-white trunk and butt rot with black zone lines. Distinct, hoof-shaped conks develop, often with many occurring on a single tree. The fungus typically forms at old branch traces. It is most prevalent in older stands (Basham and Morawski 1964). The main entry point is through bark wounds and branch stubs. It is not unusual for decayed wood to extend 1-2 m above and below the conk. In some cases there is no external evidence associated with the rot. To decrease infections by this fungus, mechanical damage during harvesting and site preparation should be minimized, stands should be fully stocked, and harvesting should be conducted between age 50 and 80.

Hypoxylon Canker (*Hypoxylon mammatum* (Wahl.) Mill.): *Hypoxylon* canker is one of the most serious diseases associated with aspen in Canada. Poorly stocked stands are more severely damaged than well stocked stands. Clonal differences in susceptibility exist. Incidence of cankers is typically higher along stand edges. Other cankers that commonly affect trembling aspen include *Septoria musiva* Peck., *Cytospora chrysosperma* (Pers.) Fr. and *Nectria galligena* Bresad.

Shoot Blight (*Napicladium tremulae* (Frank) Sacc.): Shoot blight causes young shoots to fold, dry out at the tips, and die back.

Heart Rot (*Radulodon americanum* (Morg.) Lloyd): This infection results in a red-colored heart rot in the main bole that rarely reaches ground level. Incidence and extent of heart rot increases with increased tree diameter.

Butt Rot (*Pholiota spectabilis* Fr.): This yellow or yellow-brown, stringy butt rot is confined to roots and bases of older trees. It is not considered to be a significant rot species in the NC Region.

Leaf and Twig Blight (*Pollaccia radiosa* (Lib.) Bald. and Cif.): Leaf and twig blights are more prevalent on young regenerating seedlings and saplings, and result in the blackening and wilting of foliage early in the growing season. Newly formed shoots senesce and curl into a characteristic *shepherd's crook*. Infection is highest during years with frequent rain storms. Blights may have a serious effect on stands being managed on a short rotation. Young suckers are especially susceptible, and infections may result in growth stagnation that lasts several years (Gross and Basham 1981).

Ink Spot (*Ciborinia whetzelii* (Seav.) Seav.): Foliage is infected early in the growing season, with brown spots and holes in leaves developing by August. Young trees may be killed by severe infections.

Other:

Wildlife Browse: Beavers, porcupines, deer, moose and hares browse on aspen as a preferred food species, especially during winter months (Cumming 1987, Davidson et al. 1988). Krefting et al. (1962) note that in second-growth hardwood stands in the northern Lake States, porcupines prefer aspen with tree DBH's between 23 and 38 cm. Beavers utilize aspen poles as a preferred construction material for dams and lodges. Repeated browsing by deer and moose may deform young stems and retard height growth. Winter girdling by porcupines and snowshoe hares may create infection points for insects and disease or may kill young trees. Voles and other rodents may girdle and kill young seedlings (Stoeckeler 1955).

Management Considerations

Trembling aspen is an important commercial timber species used for pulpwood, chipboard and some sawn-lumber products. The wood fibers are increasingly being utilized in the production of fine papers. Selected logs are used for veneer and plywood. The wood of trembling aspen is moderately light, soft, relatively low in strength, and white (sapwood) to greyish white (heartwood) in color (Hosie 1969).

Aspen regenerates readily after logging, fires or other site disturbances (Maini 1968). Clearcutting of aspen stands typically gives rise to immediate establishment of a dense sucker stand that will not be subject to stagnation (Brinkman and Roe 1975). The density of regeneration is affected by several factors, including clonal variation and season of harvest. However, these will not normally have any major effect on future yield, since differences in stand density will rapidly be reduced by the death of surplus stems (Doucet 1989).

Weingartner (1980) noted that scarification before suckering begins increases both percent stocking and density of aspen suckers compared with stocking and density on unscarified sites. Heavy scarification may, in fact, trigger the greatest increase in suckering (Perala 1977). Prescribed burning also may significantly stimulate aspen suckering (Stoeckeler 1948, Schier and Campbell 1978); however, a slow-burning spring fire may effectively control aspen regeneration if it burns deeply enough to kill aspen roots and suckers (Buckman and Blankenship 1965). Strip cutting may reduce soil temperatures within adjacent leave strips and thereby lessen the extent of aspen suckering. Winter logging may result in greater numbers of aspen suckers than summer logging (Haeussler and Coates 1986, Racey et al. 1989a). Considerable root and stem decay may be associated with scarification wounds of aspen suckers as young as 3 years old; consequently, scarification at or beyond this age is not recommended (Basham 1990).

In a study of the effects of logging on soils under aspen stands in northern Michigan, Alban and Perala (1990) found that there were few short-term effects on either soil organic matter or nutrients; within about 5 years, litterfall returned to pre-harvest levels and the amounts of nutrients accumulated in the vegetation's perennial tissues were as great as those left in the logging slash (Alban and Perala 1990).

Thinning may significantly improve the growth of aspen (Steneker 1964, 1976, Perala 1978, Perala and Laidly 1988). In the northern Lake States of the United States, current recommendations are to undertake a single commercial thinning for good sites, or to conduct both a precommercial and commercial thinning for the best sites (Perala 1977, Bates et al. 1989). Thinning trials have been established in the NC Region (Weingartner 1981, 1986). Following fifth-year assessments, tree volumes in thinned plots were approximately 30% greater in 10-year-old stands and 20% greater in 15-year-old stands than in control plots; volume increases were largely reflected in diameter growth, not height growth (Weingartner 1986).

The rotation age of trembling aspen is typically 60 to 80 years (Davidson et al. 1988), but this is at least partially controlled by genetic factors. Overmature stands may deteriorate very rapidly, in as short a time as 6 years (Shields and Bockheim 1981). Managers should be aware of clonal variation in stocking within a stand, and superior clones should be favored during regeneration cuts (Perala 1977). As well, trembling aspen stands growing on poorly drained (e.g., **S9**, **S10** or **S11**) and excessively drained (e.g., **S1** or **S2**) soils should be given priority for harvest, as these stands are more susceptible to rapid deterioration (Shields and Bockheim 1981).

Trembling aspen stands provide important habitat and cover for a variety of wildlife species, including beavers, porcupines, deer, moose and hares. Moose and deer browse on aspen as a preferred food species, especially during winter (Cumming 1987, Davidson et al. 1988). Young aspen stands are very good ruffed grouse habitat (Euler 1979).

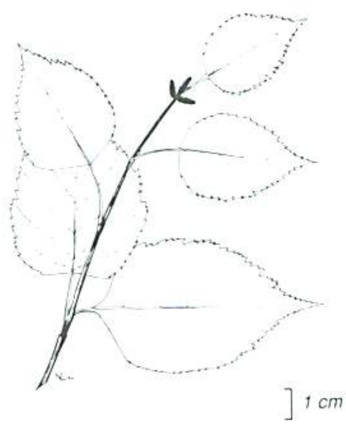
Poor aspen sites should often be converted to other species, but conversion of good sites requires considerable effort (Doucet 1989). For forest managers, pure stands of trembling aspen are extremely difficult to convert because of prolific suckering (Tubbs 1977, Davidson et al. 1988). A high level of cultivation by scarification or deep plowing is needed for effective control; better control may result if mechanical site preparation is conducted during the growing season (Haeussler and Coates 1986). Root suckers must be removed or destroyed for several consecutive years to eliminate severe aspen competition in slow-growing coniferous plantations. In some mixedwoods (e.g., **V6** and **V7**), selective and careful removal of trembling aspen overstories may favor the growth of suppressed conifers, especially balsam fir and white spruce (Johnson 1986).

White Birch / Paper Birch

Betula papyrifera Marsh.
Betulaceae (Birch Family)

Description: White birch is a small to medium-sized, small crowned hardwood tree with a mean height of 16 m at maturity. It is a short-lived, fast-growing tree with variable characteristics and numerous geographic varieties. It readily forms hybrids with other birch species, and is widespread in North America. In the NC Region, white birch is common near Lake Superior on dry to fresh, upland, coarse loamy soils, and frequently grows with aspen in pioneer to mid-successional forest stands. White birch stands often support well developed tall-shrub and herb layers (Marquis et al. 1969, Quigley and Babcock 1969, Bouchard and Maycock 1978, McClain 1981, Foster 1984, Foster and King 1986, Anon. 1986d).

White Birch/Paper Birch



Associated Stand Conditions

NWO FEC Vegetation Types (*105 NWO FEC plots*): White birch is co-dominant or dominant in the white birch hardwood and mixedwood Vegetation Type (**V4**). It is an occasional dominant in about half of the NWO FEC Vegetation Types, especially the trembling aspen dominated Vegetation Types (**V5-V11**). White birch stands are characterized by herb and shrub rich and moss poor understories. Ground lichens are sparse to absent.

Overstory: Common overstory associates of white birch include all of the most common coniferous and hardwood species in the NC Region: balsam fir, trembling aspen, white spruce, black spruce and jack pine. Large-toothed aspen is a minor associate of white birch in some aspen hardwood stands along the southwestern edge of the NC Region.

Shrubs: Balsam fir, *Aralia nudicaulis*, *Acer spicatum* and *Amelanchier* spp. are common understory shrubs beneath white birch. *Linnaea borealis*, *Vaccinium myrtilloides*, *V. angustifolium* and *Diervilla lonicera* are commonly associated understory shrubs in white birch hardwood and mixedwood stands. *Corylus cornuta*, *Sorbus decora*, trembling aspen, *Rosa acicularis*, *Lonicera canadensis*, *Ribes* spp., *Alnus rugosa*, *Rubus pubescens*, *Ribes triste*, *Actaea rubra*, *Cornus stolonifera* and *Rubus strigosus* are also common in white birch stands.

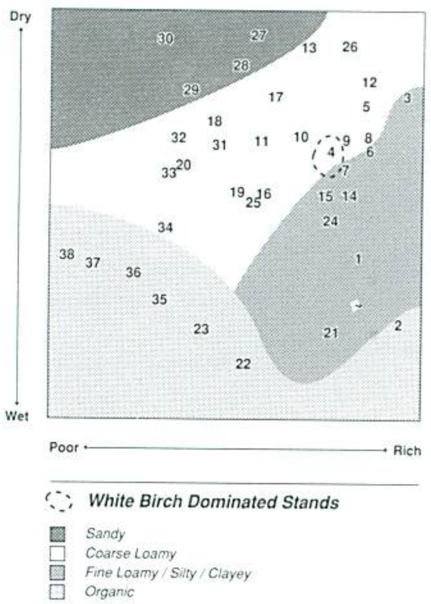
Herbs: *Maianthemum canadense*, *Cornus canadensis*, *Clintonia borealis*, *Aster macrophyllus*, *Trientalis borealis*, *Streptopus roseus* and *Lycopodium* spp. are commonly associated with white birch stands. *Viola renifolia*, *Galium triflorum*, *Mitella nuda*, *Coptis trifolia*, *Viola* spp., *Petasites palmatus*, *Equisetum* spp., *Carex* spp., *Fragaria virginiana*, *Aster ciliolatus*, *Mertensia paniculata* and *Anemone quinquefolia* are less frequently found in the understory of white birch dominated stands.

Mosses and Lichens: *Pleurozium schreberi* is common, but typically occurs in low abundance beneath white birch canopies. *Ptilium crista-castrensis* and *Dicranum polysetum* are common in low abundance in the white birch hardwood and mixedwood Vegetation Type (**V4**). *Rhytidiadelphus triquetrus* and *Plagiomnium cuspidatum* are occasionally present as mosses under white birch. Ground lichens are sparse to absent.

Silvics

Growth Habit: White birch is a small to medium-sized, broadleaved hardwood with a small, oval, open crown. In forest stands, it is frequently multi-stemmed. It often has a slender, slightly curved trunk. The crown is usually composed of many ascending branches that end in brushes of fine

NWO FEC Vegetation Type Ordination showing distribution of White Birch dominated stands and associated soil conditions in the NC Region.



branchlets (Hosie 1969). Leaves of white birch are alternate, simple, about 5-8 cm long, ovate to triangular, and have a sharply pointed apex and a coarse, more or less doubly toothed margin; leaves are thick and firm, dark green above, lighter beneath, and supported by stout petioles. The bark of white birch is very distinctive; on young stems, it is thin and reddish-brown, but with age it becomes creamy-white, and peels off easily in large, papery sheets to expose a reddish-orange inner bark (Barnes and Wagner 1981).

White birch is relatively short-lived, maturing as early as age 60. It often survives up to 140 years, but frequently displays crown dieback after maturation (Greenidge 1953). White birch is a pioneer tree species that often persists into mid-successional stages in canopy openings. White birch cannot reproduce from seed under its own shade, but can regenerate vegetatively from basal sprouts after cutting. It is characterized by moderate juvenile growth.

Betula papyrifera var. *cordifolia*, with distinctively heart-shaped leaves, grows in some locations within the NC Region, most notably near the Lake Superior shoreline in the Terrace Bay to White River areas. Damman (1964) notes that this variety has specialized habitat requirements, and normally grows in mixed stands, perhaps because it demands less light for early growth. It may achieve large dimensions and may be more suitable for veneer production.

Shade Tolerance: White birch is a shade-intolerant species (Fowells 1965). It is common as an overstory tree in seral plant communities, but only survives one generation because of its shade intolerance (Hosie 1969). In mature forests, it commonly occupies openings created by blowdown or other disturbance. White birch may have an ability to tolerate more shade in stands on rich soils than on poor soils (Damman 1964).

Early seedling growth may be better in partial shade, but is hindered by canopies exceeding 20-40% cover (Logan 1965); however, Marquis (1966) noted that white birch seedlings grown in full sunlight had larger roots, higher leaf weights, and higher root-shoot ratios than those grown in partial shade. Once established, young trees require nearly full sunlight for continued optimum growth. Based on a detailed survey of Minnesota forests, white birch was given a ranking of 5.0 on a 5-unit scale (1=least to 5=greatest) for light requirements; similarly for moisture, nutrient and heat requirements, rankings were 2.9, 2.1 and 1.7, respectively (Bakuzis and Hansen 1959).

Climatic Range: White birch tolerates a range of temperature and moisture regimes, and consequently grows across a wide geographic range in northern North America. It is extremely tolerant of cold, extending north almost to the limit of tree growth (Fowells 1965). White birch is not tolerant of high surface soil temperatures, which can cause considerable rootlet mortality and dieback. White birch grows across a range of precipitation and snow depths, but performs better in relatively humid locations where moisture conditions will not be limiting.

Frost Resistance: White birch is very frost resistant; seasonal growth often begins when minimum temperatures are still below freezing. In Alaska, white birch grows on soils where the frost layer remains in the rooting zone through to early August (Foote 1983).

Flood Tolerance: White birch displays a high tolerance to short-term flooding and imperfectly drained conditions, but is rarely found on very wet sites. Flooding may have severe effects on seedling growth and physiology (Tang and Kozlowski 1982), and trees are not tolerant of oxygen depletion in the rooting zone or soil modification that results from flooding (Comeau et al. 1989). If flooding lasts only 1-2 weeks, white birch seedlings may recover and grow faster than unflooded seedlings (Perala and Alm 1990a).

Fire Tolerance: Uniform fires of moderate to severe intensity may cause serious damage to mature birch stands (Haeussler and Coates 1986). The bark of white birch is thin and highly flammable, making individual stems susceptible to fires of even moderate intensity (Fowells 1965). However, because of the high moisture content of their canopies and the lush herb and shrub understories, mature white birch stands in the Boreal Forest tend to be less flammable than conifer stands (Van Wagner 1969). White birch forests burn only under special conditions such as in early spring before bud burst, following severe drought, or late in stand history when the proportions of conifers in the overstory may have increased; in southeastern Labrador, white birch forests typically provide an effective fire break and patterns of burns show that most forest fires pass around dense birch stands (Foster and King 1986).

Seed dispersal after fire enables white birch to readily recolonize areas. Sprouting is common on trees that are damaged or killed by fire (Hosie 1969). White birch readily germinates on thin litter layers associated with burned sites. In a study of white birch stands in Maine, burned sites did not support as much initial regeneration, but after 10 growing seasons, seedling survival on burned sites was significantly better than on disked, summer or winter logged, or control areas (Bjorkbom 1972).

Successional Status: White birch is a pioneer and early seral forest overstory species.

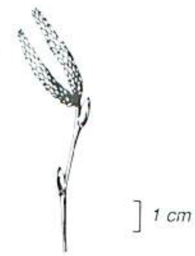
Vegetative Reproduction: White birch is capable of sprouting from the root collar and stump after logging or disturbance; it is not uncommon for 6 or 7 sprouts to appear for every cut stem (Coates and Haeussler 1986). The highest incidence of sprouting occurs in young trees; sprout vigor decreases with age (Fowells 1965); trees of 40 to 60 years of age begin to lose their ability to sprout (Perala and Alm 1990a). Sprouting is most prolific on stumps of trees cut during spring or from trees killed by fire early in the year. Sprouting may occur at the base of standing live trees that receive an increase in sunlight. Girdled trees may produce sprouts, although not as many as produced by cut stems (Coates and Haeussler 1986).

Although vegetative reproduction can be important for persistence of the species after a disturbance, regeneration by seed is the most important means of reproduction for this species.

Sexual Reproduction:

Flowering: White birch is monoecious. Flowering occurs in May before the leaves expand, with male flowers induced first. Genetic and environmental factors together govern the numbers of male and female flowers produced on a tree, and there are large year-to-year variations (Perala and Alm 1990a). Male and female flowers develop in unisexual aments (catkins), and seeds ripen from July to October. Pollination is by wind.

Fruit: White birch seeds are light, small (0.4 cm long), two-winged nutlets (samaras), borne in groups on narrow, cylindrical, 3- to 5-cm-long catkins (Schopmeyer 1974).



Crop Cycle: Seed production is continuous. A good seed crop occurs about every 1 or 2 years, depending on the location and prevailing climate (Godman and Mattson 1985). An extremely heavy seed crop one year may be followed by reduced flowering the following year (Gross 1972).

Crop Abundance: Seed production is abundant beginning at age 15, with optimum production occurring between 40 and 70 years of age; seed production ranges from 5.4 to 742 million seeds per hectare (Fowells 1965). Seed production in a 76-year-old stand of white birch was 89 million seeds per hectare (Bjorkbom et al. 1965).

Seed Viability: Seed viability is highly variable; in a burned mixedwood forest, 50% of seeds were viable the year after burning, but only 16% remained viable in year 2 (Comeau et al. 1989). In four white birch stands studied over a 5-year period in Alaska, seed viability ranged up to 41.6% in year 2 (Zasada and Gregory 1972). Viability is often highest during heavy seed years (Bjorkbom 1971) and is directly related to the amount of pollen shed (Perala and Alm 1990a). Seeds in the forest floor may remain viable for up to 2 or 3 years if moisture content is low, but viability declines rapidly under moist conditions (Schopmeyer 1974). Zasada (1971) found an average seed viability of 17%, and estimated that 300-400 white birch seeds were required to produce a single 1-year-old seedling.

Seed Dispersal: Seeds ripen during late August and September, with dispersal occurring a few days after ripening and continuing throughout the year, although most occurs between September and December (Bjorkbom et al. 1965, Bjorkbom 1971). The opening of mature female catkins is stimulated by low humidity and frost. The usual range of dispersal is within 100 m of the source tree; however, seeds are small and light, and may be wind-dispersed on crusted snow for many kilometers. Generally, less than 10% of seed is dispersed farther than 100 m (Perala and Alm 1990a). Dispersal is both by wind and water.

Germination: Germination occurs the spring following seed dispersal. Seed germination is best on partially shaded, moist, mixed mineral / organic seedbeds with moderate surface temperatures; germination is also good on disturbed mineral soil and recently burned surfaces (Bjorkbom et al. 1965, Marquis 1966, 1969, Marquis et al. 1969, Bjorkbom 1971, Tubbs 1977, Leak et al. 1988). White birch seed will sometimes germinate on humus, but rarely on leaf litter. Minimal scarification should be used to break down and incorporate forest-floor materials, especially coarse, woody debris, with surface mineral soil to form a nutrient-rich medium with a relatively high moisture-holding capacity (Perala 1989). The establishment of extensive white birch stands in southeastern Labrador requires moist and well drained soils, a nearby seed source and an open site (Foster and King 1986).

Although white birch seeds germinate best under partial shade (Logan 1965), subsequent seedling growth requires considerable sunlight (Marquis 1969, Marquis et al. 1969). In a study of the direct-seeding potential of white birch in harvested stripcuts, Horsley and Abbott (1970) recorded greater mortality of seedlings growing in full sunlight than in shaded locations. Exposure to a period of low temperature greatly improves germination rate (Comeau et al. 1989). Clautice et al. (1979) found that peak germination by white birch on ash, charred surfaces and mineral soil occurred in mid- to late July in southern Alaska.

Seedling Survival and Growth: White birch seedlings experience high levels of mortality in the 2 years after germination. Seedlings are sensitive to moisture, light and seedbed conditions (Marquis 1969, Post et al. 1969). Survival is best on rotten logs and mixed mineral / organic soils. White birch seedlings are small and have a weak radicle that cannot successfully penetrate hardwood leaf litter. Seedlings continue to survive after germination only if they receive considerable sunlight (Marquis 1966). Moisture is especially critical; seedlings may be small and poorly formed in dry locations.

Significant mortality of young seedlings may result from stem girdling by rodents, and from browsing by deer and hares (Bjorkbom 1968). Bjorkbom (1972) did not recommend planting white birch in old fields in the northeastern United States because the young trees are damaged by snow, rodents, deer and hares. An allelopathic chemical produced by the roots of *Deschampsia flexuosa* suppresses root growth of white birch seedlings (Jarvis 1964).

Control of competition by weeding and cleaning may improve the early growth and survival of white birch. However, some cover by competing vegetation may help control the extent of browsing by deer, moose and other wildlife (Perala and Alm 1990b).

Height Growth: White birch exhibits moderate juvenile growth. Height, in year 1 ranges from 6 to 14 cm, with better growth observed in full sunlight (Marquis 1966). Vegetative sprouts grow faster than seedlings during the first year and are often double the size of seedlings by year 4.

Height growth begins early in the growing season, when minimum temperatures are below freezing. Growth rates peak in mid-June. Height growth then drops off gradually for the remainder of the summer. Diameter growth begins after maximum temperatures reach 21°C and minimum temperatures are above freezing. Growth ceases before temperatures become limiting. Increases and decreases in radial growth during spring and fall are correlated with abrupt temperature changes and not with rainfall (Ahlgren 1957). White birch seedlings grow well over a range of soil temperatures, but total seedling biomass may be highest when soil temperatures are between 19°C and 30°C (Heninger and White 1974). Heavy seed crops reduce flowering and radial growth the following year, and may induce crown die back (Gross 1972).

Root Development: White birch is a relatively deep-rooting species, with stabilizing sinker roots and shallower feeder roots. Roots adapt readily to soil depth conditions and rarely penetrate compacted layers occurring at shallow to moderate depths. White birch roots are typically concentrated in the top 20- to 30-cm of soil, but the root system is *plastic*, and may readily adapt to difficult sites (Perala and Alm 1990a).

Larger roots and higher root-to-shoot ratios are produced by seedings grown in full sunlight. Considerable organic material is required for development of fine rootlets; seedlings grow faster when decayed wood and organic materials are incorporated into the mineral soil. High rootlet mortality may occur after stand disturbance. White birch roots are sensitive to increased surface temperatures and to surface compaction. Ectomycorrhizal fungi associated with the roots of birch enhance seedling and tree growth (Perala and Alm 1990a).

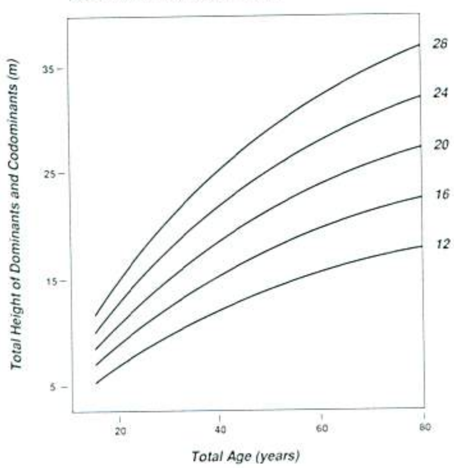
Stand Development: White birch stands frequently occur in areas with a history of fire (Krajina et al. 1982, Foster and King 1986). Burns of even moderate intensity will easily kill individual birch trees, as the bark is thin and highly flammable. The best growth by white birch occurs on well drained sandy or silty soils or soils derived from limestone (Solomon 1969). In interior Alaska, white birch is considered to be an *intermediate* species that often develops after a fire; on upland sites, it tends to occur on cooler slopes than aspen stands, and may occupy north-facing slopes, where it is successional to black spruce (Viereck et al. 1983). Damman (1964) found that some of the most productive stands in central Newfoundland were white birch - balsam fir forests.

In Quetico Park, near the southwestern corner of the NC Region, white birch is very common, and well developed birch-dominated stands often occur on moister soils just downhill from aspen-dominated stands (Walshe 1980).

Mortality is often heavy throughout the life of white birch stands. Individual trees express dominance early in life and suppressed trees die unless released. White birch is a very shade intolerant species which generally lasts only one generation before being replaced by more tolerant species. Trees mature between 60 and 75 years (Alemdag and Horton 1981, Horton 1981); the maximum age of white birch is considered to be 115 years, although ages up to 200 years have been reported (Fowells 1965). In northern Wisconsin, recommended rotation ages are 60 years on poor sites (for pulpwood) and 80 years on good sites (for sawlogs and veneer) (Cooley 1962).

Site Index Curves for White Birch

(adapted from Cooley (1958, 1962) prepared for northern Wisconsin, USA)

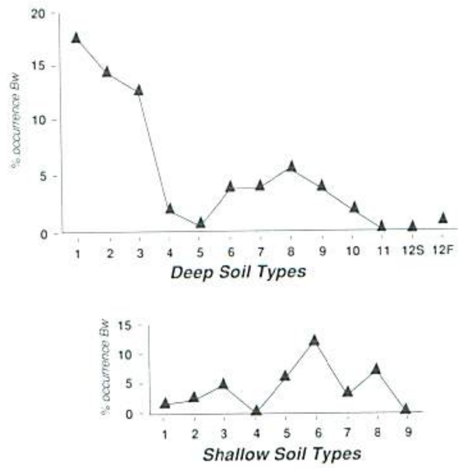


Associated Soil Conditions

NWO FEC Soil Types (*n=105 NWO FEC plots*): In the NC Region, white birch dominated stands are most frequently associated with deep, dry to fresh, coarse sandy, fine sandy and coarse loamy soils (NWO FEC Soil Types **S1**, **S2**, **S3**). Stands are also found, but with lower frequencies, on shallow sandy or coarse loamy (SS5, **SS6**), deep, moist, coarse loamy (**S8**) and shallow, moist soils (**SS8**). White birch occurs across a wide range of soil conditions; it was observed as an overstory tree species on 18 of the 22 NWO FEC Soil Types.

Deposition: White birch dominated stands in the NC Region occur frequently on deep and shallow morainal deposits. Stands occur with moderate frequency on glaciofluvial and fluvial (frequently on stratified fluvial materials) as well as lacustrine deposits. They are rare on organic soils. Soil profiles under white birch dominated stands in the NC Region are typically brunisolic, podzolic or, less frequently, gleysolic.

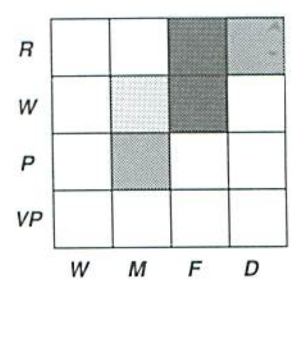
Distribution of White Birch across NWO FEC Soil Types in the NC Region



Texture: White birch dominated stands in the NC Region occur frequently on soils with coarse loamy or fine sandy B horizon soil textures. They are common on coarse sand parent materials, but are infrequently found on clay, silt and fine loamy soils.

Drainage and Moisture Regime: White birch stands in the NC Region are often found on rapid to very rapidly drained soils. Well drained, moderately well drained and imperfectly drained soils also support white birch dominated stands, but they do not occur on very poorly drained soils. White birch occurs predominantly on moderately fresh to fresh soils and less frequently on moderately dry to dry soils. White birch stands are not associated with soils with wet moisture regimes (Fowells 1965). In northern Wisconsin on sites with a 10% slope or less, the best soils for birch growth had mottles within 120 cm of the surface.

Correlation of Soil Drainage and Moisture Regime Classes for White Birch



Stoniness and Structure: Degree of stoniness is not well correlated with white birch growth or distribution. Soils associated with white birch in the NC Region are generally single grained in structure, or occasionally subangular blocky.

Site Position: White birch occurs mainly on level and upper to mid-slope positions in the NC Region. It is less frequently found on lower-slope, toe-slope and crest positions.

Litter Layer: LFH layers beneath white birch stands in the NC Region are usually 6 to 15 cm thick; occasionally, thin (1 to 5 cm) or thick (ranging up to 25 cm) LFH layers are encountered. Fibrimors and humifibrimors are the most common forest humus forms under white birch dominated stands in the NC Region.

Soil Fertility Requirements: To achieve maximum growth, white birch has moderate to high nutritional requirements (Post et al. 1969), especially for calcium and magnesium (Krajina et al. 1982). White birch is particularly sensitive to phosphorus availability (Perala and Alm 1990a). Both limited and excessive nitrogen reduce seedling growth (Bjorkbom 1973a,b). White birch responds very favorably to NPK fertilization (Comeau et al. 1989).

White birch occurs on soils ranging from acidic to highly calcareous; it has a moderate acid tolerance and can grow on acid soils with a pH as low as 4.4 (Watson et al. 1980, Haeussler and Coates 1986). White birch in the NC Region occasionally grows on calcareous parent materials; about 1/5 of the NWO FEC plots supporting white birch dominated stands had free carbonates present within the top 100 cm of the soil profile.

Insects, Diseases and Other Damaging Agents

Insects:

Bronze Birch Borer (*Agrilis anxius* Gory): The birch borer is probably the most destructive pest of birch in North America, and repeated attacks often kill trees (Rose and Lindquist 1982). Previously weakened trees are particularly vulnerable to this insect and it has been associated with extensive birch decline in North America since the 1930s (Conklin 1969). Adults emerge in June and feed on foliage in the upper crown, eventually laying eggs under the bark. On hatching, tiny white larvae tunnel through the bark, where they travel along the surface of and into the wood.

Forest Tent Caterpillar (*Malacosoma disstria* Hubner): Repeated attacks by tent caterpillars can reduce annual growth by 86% during the third year of complete defoliation. Periodic infestations have been reported since 1835. Tent caterpillars prefer trembling aspen in the northern end of their range. Tiny larvae overwinter inside clusters of eggs on twigs, emerging in spring to feed, then moving from branch to branch until late June or early July. Trees produce another crop of leaves 4 to 6 weeks later. Unfavorable spring weather, scarcity of suitable food, and an abundance of disease organisms lead to the decline of local epidemics.

Diseases:

Heart Rot (*Phellinus ignarius* (L.: Fr.) Quelet, *Pohlia obliqua* (Pers. ex Fr.) P. Karsten): These two heart rots are among the principal economic trunk rot fungi attacking white birch. Compared to other deciduous trees in Ontario, white birch is relatively resistant to stem decay; in trees less than 100 years old, decayed stem volume is typically less than 5% (Basham 1990). Infections may enter trees through branch stubs, stem or basal wounds, or root systems. To prevent rot, Marquis et al. (1969) recommended white birch be grown only on appropriate sites and that young trees be pruned when branches are small. To minimize the effect of red heart in older plantations, a partial cut is recommended to remove least vigorous, slowest-growing trees as well as trees that show signs of top death in the upper canopy (Cooley 1962).

Other:

Post-Logging Decadence: White birch bypassed during logging often exhibits decline symptoms in the first few years after harvest. Symptoms include low vigor, poor growth, dieback by twigs and branches and the premature death of trees in stands. Forest managers sometimes avoid thinning of stands by more than 1/3 of the basal area in order to minimize post-logging decadence of residual trees.

Birch Dieback: Birch dieback is characterized by premature twig and branch dieback, which spreads from the crown downward (Hyvarinen 1968). Root mortality precedes crown symptoms. Heating of the soil during the growing season and soil compaction contribute to rootlet mortality, which is then followed by twig and branch dieback. Climatic extremes and insect defoliation are considered to be major contributors to birch dieback (Greenidge 1953).

Wildlife Browse: Birch is an important food for beavers (Euler 1979). Deer and moose will also browse on birch, although it is not a preferred food. Repeated browsing by deer and moose may deform young stems and retard height growth. Small mammals can damage trees by debarking to feed on the cambium (porcupines) or clipping off twigs and stems of seedlings (snowshoe hares) (Jordan and Rushmore 1969). Porcupines may be a particular problem because they often prefer to feed on large-diameter stems as well as the dominant and co-dominant trees within a given stand (Krefting et al. 1962, Sullivan and Cheng 1989). Voles and other rodents may consume large quantities of white birch seeds (Grodzinski 1971) and girdle young seedlings (Stoeckeler 1955, Bjorkbom 1968, 1972).

Management Considerations

In the NC Region, white birch is utilized commercially for pulpwood, specialized lumber products and some veneer. The wood is moderately heavy, hard, strong and nearly white (sapwood) to pale brown (heartwood) in color (Hosie 1969).

White birch readily seeds into areas with soil disturbances caused by logging, slash burning and mechanical site preparation. Site scarification methods that mix organic and near-surface mineral-soil layers provide the best seedbeds for white birch (Marquis 1966, Perala 1989). Although white birch seeds germinate best in partial shade, subsequent seedling growth requires considerable sunlight.

The most common form of regeneration for white birch is natural regeneration from seed; it is economical and highly reliable if there is sufficient available moisture for germination and early survival (Perala and Alm 1990b). On sites where white birch seeds-in densely or has sprouted from stumps, it may readily outcompete coniferous species (Richardson 1979, Comeau et al. 1989). White birch may inhibit coniferous vegetation where areas disturbed by harvesting and silvicultural practices are located near stands of mature trees, or where residual trees are left on-site to allow seeding-in (Gregory 1966). White birch leaf litter may crush and smother white spruce seedlings, causing considerable mortality and reduced growth (Gregory 1966). However, as a nurse crop, white birch may assist regenerating conifers by stabilizing soil, improving the soil nutrient status and sheltering young trees from frost, insects and pathogens (Perala and Alm 1990b).

Early tending of white birch stands (i.e., weeding and cleaning) and intermediate thinning will improve stem quality, increase yield and shorten rotation age for sawlog production by perhaps 10 to 20 years (Ohmann et al. 1978). LaBonte and Nash (1978) reported that the value of a 24-year-old white birch stand that was cleaned and weeded more than paid for the early investment; originally composed of regenerating white birch and trembling aspen, the stand was cleaned of aspen at age 7 and converted to a higher-value birch-dominated stand (LaBonte and Leso 1989).

In the NC Region, white birch is usually harvested by clearcutting. Average rotation age is 70 to 80 years of age (Ohmann et al. 1978). Where white birch is grown for pulpwood, maximum annual yields are realized on a 45-year rotation on more productive, well drained soils, and on a 70-year rotation on wetter and very dry soils. Fertilizers may be applied to improve site quality (Perala and Alm 1990b).

Where uneven-aged management is being practised, white birch will eventually be replaced by more tolerant species. Perala and Alm (1989) suggest that shelterwood cutting for white birch may be appropriate under some circumstances; to produce shade for young seedlings, maintain soil moisture and control competition, they recommend strip-shelterwood cuts that will remove 20-40% of the crown cover. A two-stage shelterwood cut may be the best option for regenerating white birch where summer precipitation is limiting in amount or frequency (Perala 1989).

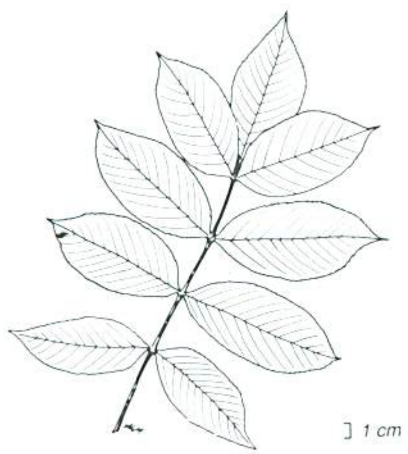
Black Ash

Fraxinus nigra Marsh.
Oleaceae (Olive Family)

3.12.

Description: At maturity, black ash is a medium-sized, broadleaved hardwood (averaging 17 m in height) with a small, open crown of large, stout, spreading and ascending branches. It occurs infrequently throughout the NC Region in small, localized stands, usually 1-5 ha in size, and grows on rich, low-lying, moist to wet, organic or fine-textured mineral soils. Black ash is more common in the Quetico - Atikokan general area.

Black Ash



Associated Stand Conditions

NWO FEC Vegetation Types (*16 NWO FEC plots*): Black ash occurs as the dominant overstory species in only one of the NWO FEC Vegetation Types (**V2**). Black ash frequently occurs in pure, relatively uniform stands in northwestern Ontario (Sims et al. 1989). It is typically characterized by a dense, rich and floristically diverse understory.

Overstory: Black ash commonly occurs in pure stands, with no co-dominant tree species. Balsam fir, trembling aspen and white birch sometimes occur as associated minor species. Occasionally, particularly near the southwestern corner of the NC Region, white spruce, white cedar, red ash (*Fraxinus pennsylvanica*) and American elm (*Ulmus americana*) are present in the overstory.

Shrubs: *Rubus pubescens*, *Acer spicatum*, balsam fir, *Ribes triste*, *Prunus virginiana*, *Cornus stolonifera*, *Alnus rugosa*, *Aralia nudicaulis*, *Corylus cornuta* and *Rubus strigosus* are commonly abundant in the understory of black ash dominated stands in the NC Region.

Herbs: *Carex* spp., *Viola* spp., *Mitella nuda*, *Athyrium filix-femina*, *Galium triflorum*, *Maianthemum canadense*, *Dryopteris austriaca*, *Circaea alpina*, *Streptopus roseus*, *Aster macrophyllus*, *Trientalis borealis* and *Equisetum sylvaticum* are among the most common species in the diverse herbaceous layer associated with black ash stands.

Mosses and Lichens: Moss cover is not abundant, averaging 20% in the NC Region. The main species are *Plagiomnium cuspidatum* and *Climacium dendroides*. Ground lichens are usually absent within black ash dominated stands in the NC Region.

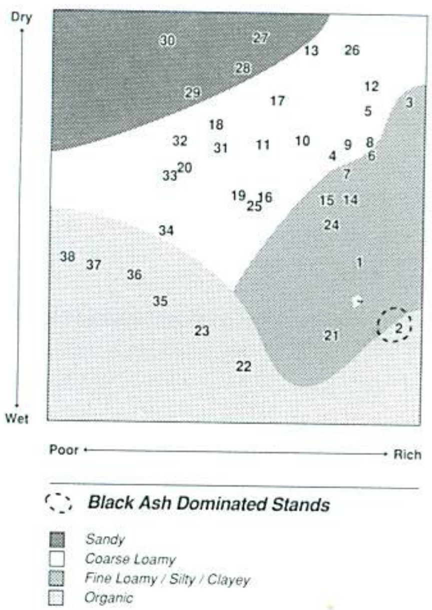
Silvics

Growth Habit: Black ash is a medium-sized tree, 12-18 m high and 30-60 cm in diameter, with a spreading, multi-stemmed crown and a shallow rooting habit. The trunk is often leaning or crooked, and when growing in a forest stand, branches are coarse and upright, forming an open, narrow crown; when open-grown, the crown is more ovoid in shape (Hosie 1969). Leaves are opposite and pinnately compound, with 7-11 leaflets. Leaflets of black ash are oval to lanceolate, finely toothed, stalkless, 7-13 cm long, tapering to a long slender tip, and blunt at the base; leaflets are glabrous, thin and firm, dark green above and lighter beneath. Bark is thin, soft, ashy grey and scaly, with corky ridges; the surface of the bark readily flakes off when rubbed by the hand (Barnes and Wagner 1981).

Black ash is relatively short-lived, maturing as early as age 60, and grows slowly. Black ash sprouts vigorously after damage by cutting, browsing or fire (Barnes and Wagner 1981).

Shade Tolerance: Black ash is initially moderately shade tolerant but becomes more intolerant with age. Black ash is more shade tolerant than yellow birch (*Betula alleghaniensis*) growing on similar soils. Based on a detailed survey of Minnesota forests, black ash was given a ranking of 1.8 on a

FEC Vegetation Type Ordination showing distribution of Black Ash dominated stands and associated soil conditions in the NC Region.



5-unit scale (1=least to 5=greatest) for light requirements; for moisture, nutrient and heat requirements, rankings were 3.9, 3.5 and 2.6, respectively (Bakuzis and Hansen 1959).

Climatic Range: The climatic range of black ash restricts its distribution to south of 50°N, and to areas where the mean annual number of growing degree days above 5°C exceeds 2200 days. Within its range in Ontario, there is a June 10 mean date for the last occurrence of spring frost and an average 160 day growing season. Black ash is not tolerant of extremely high or low temperatures, and is associated with moderate precipitation levels. Across its commercial range in Ontario, average January temperatures are 0°C to -17°C, average July temperatures are 18°C to 20°C and annual precipitation levels are 500 to 1140 mm (Anon. 1987a).

Frost Resistance: Young suckers are resistant to frost; black ash typically grows in low-lying areas subject to frequent spring frosts. The frost resistance of seedlings is unknown.

Flood Tolerance: Black ash is very tolerant of frequent, well-aerated flooding for short periods of time. Black ash often grows in low-lying areas that are annually flooded for periods of several weeks each spring. Trees may produce new roots after flooding that creates surface silt deposits. Newly outplanted seedlings can withstand temporary flooding (Lees and West 1988).

Fire Tolerance: Because this species grows in wet lowland areas, fire is rarely a major threat to black ash stands.

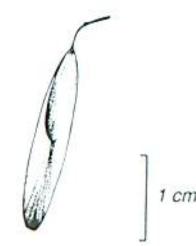
Successional Status: When it occurs in pure stands on wet organic soils (**S12S**, **S12F**, **SS9**), black ash is considered to be a climax species. In mixed stands on moderately drained mineral soils, black ash is a long-lived, sub-climax species.

Vegetative Reproduction: Black ash sprouts readily from low-cut stumps up to 30 cm in diameter. Sprouts originate from adventitious buds on the sides of the stump and root collar. Suckers will grow from the roots of cut trees.

Sexual Reproduction:

Flowering: Black ash has dioecious, rarely monoecious, flowers appearing before the leaves in late May or June. Individual flowers are inconspicuous with no petals.

Fruit: The fruits of black ash are winged, flattened, single-seeded samaras with a spicy odor. They are borne in dense terminal or lateral branch clusters, in the angles of the previous season's leaves.



Crop Cycle: Good seed crops occur at 1- to 8-year intervals with poor crops in intervening years.

Crop Abundance: Abundant seeds, with 166 seeds/100 g of fruit, are produced during good seed years (Schopmeyer 1974).

Seed Viability: Seeds exhibit dormancy, germinating in year 2 or 3 after dispersal. Black ash seeds retain their viability for up to 8 years (Schopmeyer 1974).

Seed Dispersal: Seeds ripen in late August or September, and are dispersed from October until early spring. Many of the winged seeds persist on the tree throughout the winter.

Germination: Black ash seeds require periods of warm and moist as well as cold and dry temperatures for good germination (Fowells 1965). Most seeds germinate in the second spring after seedfall. Some seeds may remain dormant for up to 8 years. Seeds will germinate in hardwood leaf litter or under 1 cm of soil but seedlings rarely survive unless germination occurs on a disturbed site where seedlings are free of competetion from adjacent vegetation (Lees and West 1988).

Seedling Survival and Growth: Seedlings grow rapidly during the first 2 weeks after germination, and may reach up to 5 cm in height. Shrub and grass control is subsequently needed to ensure survival. Growth during the first year reaches up to 15 cm, with the best survival and development believed to be at 45 to 50% full sunlight (Erdmann et al. 1987). Black ash regenerates best on disturbed mineral soils with a high water table or impeded drainage. Seedlings typically grow faster than red maple (*Acer rubrum*) seedlings found in the same location or on similar soils.

Lees and West (1988) note that the most successful method for regenerating black ash is the management of stump sprouts that arise at the butt swell of felled trees. Typically, 7 to 17 sprouts arise and grow vigorously, drawing upon the original tree's established root system. Such sprouts are more drought- and flood-tolerant than single-stem seedlings. Ash seedlings can also be grown from seeds collected in October from parent trees, but young seedlings must be handled and transplanted carefully (von Althen 1979, Lees and West 1988). Subsequent weed control and pruning may be required.

Height Growth: Black ash stump sprouts grow up to three times as tall as seedlings during the first year. Height growth varies with soil and stand conditions. For example, by age 50, trees growing in excessively wet areas may achieve heights of just 15 m, whereas trees on moist mineral soils may reach heights of 24.4 m.

Root Development: Black ash has a shallow, wide-spreading root system (Hosie 1969). Trees on wet soils are occasionally subject to windthrow.

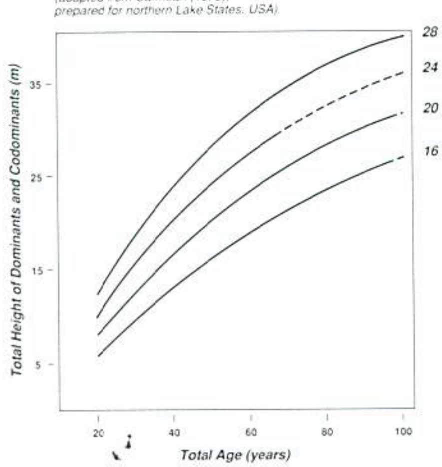
Stand Development: Black ash occurs in either even-aged or uneven-aged stands, depending upon stand history (Rudolph 1980). Most black ash stands on organic soils contain overmature and defective trees. Seedlings, saplings and sprouts tend to occur only in stand openings, often dominating the rich understory in these locations. Black ash regeneration is minimal beneath a fully closed canopy.

Clearcutting without subsequent site preparation and tending may result in inadequate natural regeneration and the loss of advance regeneration to shrub, herb and grass competition (von Althen 1979). Harvesting operations on the typically poorly drained, lower landscapes that support black ash may alter local soil drainage properties. This may elevate the water table, which can in turn reduce survival and growth of regenerating black ash.

Based on site-index comparison studies in northern Wisconsin and upper Michigan, Carmean (1979) notes that black ash has an intermediate site index (at age 50 years) range, comparable with that of American basswood (*Tilia americana*) and American elm, higher than that of American beech (*Fagus grandifolia*) and lower than that of trembling aspen. A black ash stand of exceptionally large trees, with breast-height diameters up to 66 cm, occurs on an alluvial site in Quetico Park, near the southwestern corner of the NC Region (Walshe 1980).

Site Index Curves for Black Ash

(adapted from Carmean (1978); prepared for northern Lake States, USA)

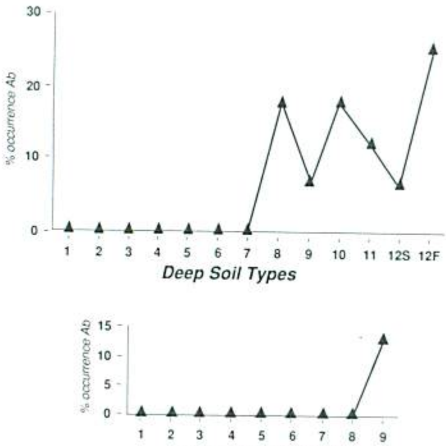


Associated Soil Conditions

NWO FEC Soil Types *(16 NWO FEC plots)*: Throughout most of its range in northeastern North America south of the 50°N, black ash typically grows on moist to wet, shallow or deep organic soils and is normally associated with treed swamps (Jeglum et al. 1974) along streams or in small, poorly drained depressions. Black ash also grows on fine sandy and loamy soils underlain by clays, where surface drainage is impeded or high water tables occur. In the NC Region, black ash occurs most commonly on deep or shallow organic soils with surface feathermoss cover (**S11**, **S12F**, **SS9**), on deep, moist to wet, coarse loamy soils (**S8**), and on deep, moist to wet, fine loamy and clay soils (**S10**). It occurs infrequently on moist to wet silty soils (**S9**) and on deep organic soils with an abundant Sphagnum cover (**S12S**).

Deposition: In the NC Region, black ash dominated stands often occur on shallow organic deposits overlying bedrock, but they are also common on stratified organic, lacustrine and morainal deposits. They are infrequent on fluvial and glaciofluvial landforms. Black ash stands in the NC Region are most frequently found on gleysolic mineral-soil profiles and humisolic or mesisolic organic-soil profiles.

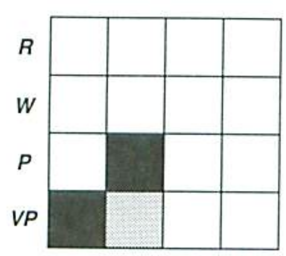
Distribution of Black Ash across NWO FEC Soil Types in the NC Region



Texture: Black ash stands in the NC Region frequently occur on organic soils or mineral soils with A horizon silty clay textures. Mineral soil C horizon (including mineral soil C horizons beneath shallower organic soils) textures range from silty clays and silty clay loams to sandy loams and silty or loamy very fine sands.

Drainage and Moisture Regime: Black ash stands develop in areas with imperfect to very poor drainage. Mottling and gleying are common soil-profile features in mineral soils beneath black ash; mottles and gley colors were present in most of the NWO FEC sample plots that supported black ash stands. Black ash stands in the NC Region occur on soils with moderately moist to very wet moisture regimes.

Correlation of Soil Drainage and Moisture Regime Classes for Black Ash



Stoniness and Structure: Coarse fragments are typically absent in soils under black ash stands in the NC Region. Mineral soils beneath black ash dominated stands are primarily blocky in structure.

Site Position: Black ash stands in the NC Region typically occur on level, low-lying or depressional landscape positions.

Litter Layer: Generally, black ash stands in the NC Region grow on deep organic deposits (greater than 40 cm thick) or on mineral soils with a well developed, 6- to 15-cm-thick LFH layer. Forest humus forms encountered under black ash stands include mesic peatymors, humic peatymors, typic moders and humifibrimors.

Soil Fertility Requirements: Soils with a moderately high nutrient status, especially those associated with fine-textured parent materials and good drainage, support better growth of black ash. Black ash is well adapted to poor drainage conditions but reduced nutrient uptake will impede tree growth on very wet soils (Rudolph 1980, Erdmann et al. 1987).

Insects, Diseases and Other Damaging Agents

There are only a few important insect and disease problems associated with black ash stands (Hepting 1971).

Insects:

Oystershell Scale (*Lepidosaphes ulmi* L.): Four species of scale insects feed on ash; all four have wide geographic ranges. They tend to be pests of small isolated clumps of trees, not of regional forests. Oystershell scale, the most common of the four, was introduced from Europe in the 1800s and spread to ash from apple orchards. Tiny, flattened crawlers 0.3 mm long hatch in early June after leaving their winter scale, and feed on twigs, branches and foliage. Occasionally this insect is a serious pest that kills younger or older trees.

Diseases:

Stem and Butt Rot (*Phellinus ignarius* (L.: Fr.) Quélet, *P. conchatus* (Pers.: Fr.) Quélet, *Armillaria ostoyae* (Romaqn.) Herink, *Inonotus glomeratus* (Peck) Murrill, *I. hispidus* (Bull.: Fr.) P. Karsten): In trees more than 100 years old, a high proportion of stem volume is often affected by a variety of fungal species; however, stem and butt rot is not considered to be a serious problem for black ash as most infections only result in stem stains and not decays (Basham 1990). Spongy white heatwood rot (*Inonotus hispidus*) is a minor disease of black ash in the northeastern United States (Fowells 1965) and may occur occasionally in the NC Region.

Other:

Wildlife Browse: Black ash sprouts and young stems are important browse for deer and other animals; minor damage to plantations may occur.

Management Considerations

Black ash is occasionally sawn in the NC Region for specialty lumber products, including interior finishing and furniture. The wood is moderately heavy, hard, moderately strong, coarse grained, and white (sapwood) to greyish-brown (heartwood) in color (Hosie 1969).

On excessively wet soils, stands are best maintained as wildlife habitat since harvesting may lead to excessive rises in the water table. Stands frequently border streams or lakes and harvesting may, in many cases, influence water quality and water temperature. It may be more suitable to harvest these stands during winter, when the ground is frozen, in order to limit site damage and soil compaction and to improve equipment operability (Lees and West 1988).

The shelterwood system is often recommended as an appropriate regeneration and harvesting method for relatively pure black ash stands on moist to wet soils (Erdmann et al. 1987). The system compensates for the infrequent good seed years and ameliorates excessive rises in the water table that may follow conventional harvesting methods. Shelterwood harvesting may provide some disturbance of the mineral soil, but it opens up areas within the stand, enhancing the chances natural regeneration. The system promotes the longer-term development of even-aged commercial stands. The final clearcut is recommended only after adequate 1-m-tall advance regeneration is present (Erdmann et al. 1987). For black ash growing in mixedwood stands on mineral soils, the single-tree selection approach for harvesting is typically followed.

Thinnings are only recommended for trees older than 110 years. Black ash stands, through crown closure and self-pruning, usually maintain good bole quality. Trees with narrow crowns should be considered for thinning, and thinning should be restricted to a relatively small radius around crop trees.

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Appendix I

Information Assessed During Development of Autecological Summaries

Vegetation Factors

- NWO FEC Vegetation Type (Sims et al. 1989)
- percent covers of individual tree species, according to their occurrence only in the tree layer
- percent covers of individual tree species, according to their occurrence in tree, shrub and ground layers
- percent covers of common understory species
- combined percent cover of all tall shrubs
- combined percent cover of all low shrubs
- combined percent cover of all herbs and graminoids
- combined percent cover of all mosses and lichens
- combined percent cover of all feathermoss species
- combined percent cover of all Sphagnum species

Site Factors

- geographic location
- slope angle
- topographic position (Ontario Institute of Pedology 1985)
- landform type (Canada Soil Survey Committee, Subcommittee on Soil Classification 1978)

Soil Factors

- NWO FEC Soil Type (Sims et al. 1989)
- percent exposed bedrock
- soil depth over bedrock
- forest humus form classification (Canada Soil Survey Committee, Subcommittee on Soil Classification 1978)
- litter type, depth and percentage ground cover (Canada Soil Survey Committee, Subcommittee on Soil Classification 1978, Sims et al. 1989)
- soil profile taxonomic classification (Canada Soil Survey Committee, Subcommittee on Soil Classification 1978)
- soil drainage (Ontario Institute of Pedology 1985)
- soil moisture regime (Ontario Institute of Pedology 1985)
- dominant surface texture (0-25 cm) (Ontario Institute of Pedology 1985)
- dominant subsurface texture (26-100 cm) (Ontario Institute of Pedology 1985)
- percent coarse fragment content (Sims et al. 1989)
- coarse fragment size class (Working Group on Soil Survey Data 1978)
- soil structure (Ontario Institute of Pedology 1985)

Appendix II

Summary of Tree Species Volumes by NWO FEC Vegetation Types

Species	Stems per hectare	Mean volume (m^3/ha)
V-Type 1 (n=23)		
• Balsam Fir	165.22	30.76
• White Spruce	130.44	70.45
• Black Spruce	60.87	8.88
• Cedar	4.35	0.67
• Balsam Poplar	373.91	269.78
• Trembling Aspen	200.00	87.25
• White Birch	52.17	6.27
• *All Species*	*986.96*	*424.93*
V-Type 2 (n=11)		
• Balsam Fir	18.18	1.45
• White Spruce	27.27	5.16
• Black Spruce	9.09	0.60
• Cedar	18.18	2.40
• Balsam Poplar	9.09	4.40
• Trembling Aspen	27.27	16.16
• White Birch	9.09	1.53
• Black Ash	763.64	252.77
• *All Species*	*881.82*	*239.00*
V-Type 4 (n=31)		
• Balsam Fir	274.19	26.91
• White Spruce	45.16	9.10
• Black Spruce	96.77	15.79
• Jack Pine	93.55	36.82
• Trembling Aspen	3.23	0.68
• White Birch	625.81	173.36
• *All Species*	*1138.71*	*239.20*
V-Type 5 (n=22)		
• Balsam Fir	4.55	0.16
• Trembling Aspen	963.64	401.91
• White Birch	159.09	31.18
• *All Species*	*1127.27*	*376.85*

Species	Stems per hectare	Mean volume (m^3/ha)
V-Type 6 (n=24)		
• Balsam Fir	466.67	90.27
• White Spruce	33.33	15.19
• Trembling Aspen	579.17	404.21
• White Birch	162.50	32.85
• *All Species*	*1241.67*	*494.34*
V-Type 7 (n=13)		
• Balsam Fir	846.15	105.26
• White Spruce	23.08	1.38
• Black Spruce	84.62	13.10
• White Pine	7.69	6.22
• Trembling Aspen	800.00	479.40
• White Birch	100.00	11.35
• *All Species*	*1861.54*	*564.44*
V-Type 8 (n=11)		
• Balsam Fir	18.18	1.05
• White Spruce	72.73	43.50
• Black Spruce	81.82	10.12
• Jack Pine	172.73	75.31
• Trembling Aspen	481.82	385.11
• White Birch	209.09	45.63
• *All Species*	*1036.39*	*492.86*
V-Type 9 (n=16)		
• Balsam Fir	93.75	12.05
• White Spruce	275.00	84.77
• Black Spruce	37.50	5.67
• Cedar	6.25	1.08
• Trembling Aspen	568.75	414.95
• White Birch	62.50	10.42
• *All Species*	*1043.75*	*399.98*

Species	Stems per hectare	Mean volume (m^3/ha)
V-Type 10 (n=16)		
• Balsam Fir	68.75	6.98
• White Spruce	50.00	3.98
• Black Spruce	412.50	79.65
• Jack Pine	100.00	49.00
• Balsam Poplar	37.50	13.92
• Trembling Aspen	575.00	315.10
• White Birch	56.25	7.21
• *All Species*	*1300.00*	*400.32*
V-Type 11 (n=9)		
• Balsam Fir	166.67	23.65
• White Spruce	33.33	10.89
• Black Spruce	566.67	99.30
• Jack Pine	133.33	46.78
• Trembling Aspen	588.89	363.55
• White Birch	66.67	15.99
• *All Species*	*1555.56*	*522.37*
V-Type 12 (n=11)		
• Balsam Fir	154.55	30.64
• White Spruce	18.18	12.55
• Black Spruce	18.18	8.06
• Red Pine	18.18	27.01
• White Pine	254.55	313.40
• Cedar	18.18	0.76
• Trembling Aspen	181.82	115.39
• White Birch	118.18	36.16
• *All Species*	*781.82*	*508.18*
V-Type 13 (n=6)		
• Balsam Fir	266.67	29.09
• Black Spruce	66.67	9.60
• Jack Pine	33.33	15.10
• Red Pine	283.33	388.12
• White Pine	16.67	4.55
• Trembling Aspen	116.67	53.21
• White Birch	216.67	19.93
• *All Species*	*1000.00*	*558.69*

Species	Stems per hectare	Mean volume (m^3/ha)
V-Type 14 (n=25)		
• Balsam Fir	772.00	141.22
• White Spruce	76.00	44.99
• Black Spruce	48.00	11.69
• Tamarack	4.00	3.36
• Jack Pine	8.00	5.02
• White Pine	20.00	9.20
• Cedar	16.00	9.03
• Balsam Poplar	40.00	15.46
• Trembling Aspen	160.00	97.63
• White Birch	80.00	21.70
• *All Species*	*1224.00*	*465.68*
V-Type 15 (n=13)		
• Balsam Fir	238.46	49.23
• White Spruce	446.15	268.23
• Black Spruce	161.54	26.30
• Jack Pine	15.39	5.88
• Balsam Poplar	7.69	3.28
• Trembling Aspen	153.85	79.18
• White Birch	84.62	36.98
• *All Species*	*1107.69*	*445.45*
V-Type 16 (n=20)		
• Balsam Fir	650.00	59.63
• White Spruce	340.00	93.01
• Black Spruce	160.00	32.19
• Jack Pine	105.00	78.17
• Cedar	25.00	1.54
• Balsam Poplar	5.00	5.85
• Trembling Aspen	50.00	17.37
• White Birch	125.00	19.27
• *All Species*	*1460.00*	*350.55*
V-Type 17 (n=16)		
• Balsam Fir	6.25	0.34
• White Spruce	6.25	0.52
• Black Spruce	100.00	9.91
• Jack Pine	1043.75	307.70
• White Pine	6.25	0.66
• Balsam Poplar	6.25	0.28
• Trembling Aspen	93.75	17.07
• White Birch	50.00	6.74
• *All Species*	*1312.50*	*265.91*

Species	Stems per hectare	Mean volume (m^3/ha)
V-Type 18 (n=12)		
• Balsam Fir	41.67	3.20
• White Spruce	25.00	3.82
• Black Spruce	516.67	72.49
• Jack Pine	641.67	280.70
• Trembling Aspen	200.00	52.39
• White Birch	58.33	10.20
• *All Species*	*1483.33*	*380.60*
V-Type 19 (n=27)		
• Balsam Fir	103.70	12.04
• White Spruce	62.96	11.24
• Black Spruce	929.63	170.90
• Tamarack	7.41	7.09
• Jack Pine	140.74	38.49
• Balsam Poplar	29.63	21.20
• Trembling Aspen	192.59	63.70
• White Birch	48.15	5.28
• *All Species*	*1514.81*	*361.39*
V-Type 20 (n=17)		
• Balsam Fir	41.18	3.28
• Black Spruce	1176.47	189.96
• Jack Pine	247.06	96.53
• Balsam Poplar	5.88	0.63
• Trembling Aspen	35.29	7.07
• White Birch	94.12	14.67
• *All Species*	*1600.00*	*330.92*
V-Type 21 (n=8)		
• Balsam Fir	137.50	22.07
• White Spruce	200.00	134.63
• Black Spruce	75.00	10.38
• Cedar	912.50	275.42
• Balsam Poplar	12.50	54.08
• Trembling Aspen	62.50	19.45
• White Birch	75.00	10.31
• *All Species*	*1475.00*	*714.79*
V-Type 22 (n=10)		
• Balsam Fir	40.00	3.72
• White Spruce	10.00	3.54
• Black Spruce	330.00	82.92
• Tamarack	50.00	14.20
• Cedar	750.00	188.41
• Balsam Poplar	30.00	7.64
• White Birch	30.00	3.30
• *All Species*	*1240.00*	*293.56*

Species	Stems per hectare	Mean volume (m^3/ha)
V-Type 23 (n=8)		
• Balsam Fir	237.50	17.64
• White Spruce	37.50	15.11
• Black Spruce	237.50	46.43
• Tamarack	400.00	154.19
• Cedar	25.00	9.20
• Black Ash	25.00	1.72
• *All Species*	*962.50*	*252.08*
V-Type 24 (n=12)		
• Balsam Fir	608.33	120.75
• White Spruce	408.33	153.14
• Black Spruce	83.33	16.65
• Tamarack	33.33	10.09
• Jack Pine	50.00	35.72
• White Birch	8.33	0.80
• *All Species*	*1191.67*	*377.95*
V-Type 25 (n=24)		
• Balsam Fir	350.00	37.33
• White Spruce	495.83	161.25
• Black Spruce	216.67	39.57
• Jack Pine	45.83	35.03
• Cedar	4.17	0.34
• White Birch	8.33	0.41
• *All Species*	*1120.83*	*290.91*
V-Type 26 (n=4)		
• Balsam Fir	150.00	33.88
• Red Pine	125.00	87.41
• White Pine	325.00	869.53
• *All Species*	*600.00*	*941.42*
V-Type 27 (n=8)		
• Balsam Fir	162.50	16.21
• Black Spruce	25.00	2.43
• Red Pine	550.00	638.65
• White Pine	125.00	50.41
• *All Species*	*862.50*	*562.80*
V-Type 28 (n=8)		
• Balsam Fir	12.50	1.08
• Black Spruce	12.50	0.41
• Jack Pine	1050.00	448.31
• Trembling Aspen	12.50	0.71
• White Birch	12.50	1.24
• *All Species*	*1100.00*	*338.32*

Species	Stems per hectare	Mean volume (m^3/ha)
V-Type 29 (n=17)		
• Black Spruce	211.76	31.25
• Jack Pine	1311.76	233.23
• *All Species*	*1523.53*	*263.60*
V-Type 30 (n=10)		
• Balsam Fir	10.00	2.18
• White Spruce	10.00	0.33
• Black Spruce	240.00	22.15
• Jack Pine	320.00	47.71
• *All Species*	*580.00*	*69.27*
V-Type 31 (n=20)		
• Balsam Fir	85.00	14.98
• White Spruce	5.00	4.95
• Black Spruce	615.00	108.00
• Jack Pine	495.00	220.93
• Trembling Aspen	5.00	0.35
• White Birch	5.00	0.60
• *All Species*	*1210.00*	*353.88*
V-Type 32 (n=34)		
• Balsam Fir	2.94	0.12
• White Spruce	5.88	1.07
• Black Spruce	702.94	73.87
• Jack Pine	929.41	269.16
• *All Species*	*1641.18*	*326.47*
V-Type 33 (n=44)		
• Balsam Fir	47.73	3.96
• White Spruce	31.82	4.28
• Black Spruce	1470.45	200.42
• Jack Pine	56.82	11.04
• Balsam Poplar	15.91	1.63
• Trembling Aspen	4.55	0.64
• White Birch	4.55	0.58
• *All Species*	*1631.82*	*218.94*

Species	Stems per hectare	Mean volume (m^3/ha)
V-Type 34 (n=29)		
• Balsam Fir	68.97	5.37
• White Spruce	17.24	4.43
• Black Spruce	1282.76	189.98
• Tamarack	37.93	8.69
• Jack Pine	148.28	52.43
• Cedar	34.48	3.31
• White Birch	10.84	2.40
• *All Species*	*1600.00*	*286.22*
V-Type 35 (n=12)		
• Balsam Fir	25.00	1.85
• Black Spruce	1175.00	245.64
• Tamarack	150.00	17.40
• Cedar	16.67	4.67
• *All Species*	*1366.67*	*249.37*
V-Type 36 (n=16)		
• Balsam Fir	43.75	2.51
• White Spruce	6.25	0.29
• Black Spruce	1493.75	191.40
• Tamarack	18.75	2.37
• Jack Pine	50.00	25.32
• Cedar	43.75	5.79
• *All Species*	*1656.25*	*261.52*
V-Type 37 (n=14)		
• Black Spruce	1557.14	230.77
• Tamarack	7.14	2.37
• *All Species*	*1564.29*	*250.99*
V-Type 38 (n=3)		
• Black Spruce	400.00	14.48
• *All Species*	*400.00*	*14.48*