Stand and Site Conditions Associated with the Abundance and Distribution of Black Spruce and Balsam Fir Advance Growth in Northeastern Ontario

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ABSTRACT

Advance growth is frequently abundant in certain forest ecosystems in northeastern Ontario. Protecting such growth by careful harvesting methods is attractive for a number of reasons, and offers the potential for lower-cost regeneration of suitable stands. However, forest managers must be able to identify stands with abundant advance growth prior to their harvest.

To evaluate stand and site conditions associated with the abundance and distribution of advance growth, 85 stands located throughout northeastern Ontario were surveyed using replicated, fixed-area plots. These data were combined with information collected during previous research on an additional 320 stands. Stand and site factors associated with black spruce (*Picea mariana* [Mill.] B.S.P.) and balsam fir (*Abies balsamea* [L.] Mill.) advance growth, and relationships of advance growth abundance to forest ecosystem classification (FEC) site types, were explored using multiple regression and other analytical techniques.

Stand and site conditions related to the abundance of black spruce advance growth included the total basal area of the stand, stand productivity, percent black spruce in the stand, stand age, the abundance of tall woody shrubs in the understory, the abundance of *Sphagnum* spp. mosses, and the abundance of forest floor materials that inhibit or reduce layering. Black spruce advance growth was most abundant in nutrient-poor, black spruce-dominated stands having a low basal area, few tall woody shrubs in the understory, and abundant *Sphagnum* mosses on the forest floor.

Stand and site conditions related to the abundance of balsam fir advance growth included stand productivity, stand age, species composition, soil moisture regime, and the nature of materials on the forest floor. Balsam fir advance growth was most abundant in medium to rich, fresh to moist, conifer-dominated mixedwoods, especially stands with balsam fir, white spruce (*Picea glauca* [Moench] Voss), and/or hardwood components. Mixtures of materials on the forest floor, including mosses, debris, decomposed logs, needle litter, leaf litter, and exposed mineral soil, were also associated with balsam fir advance growth.

The FEC site types provided a useful framework for understanding the distribution of black spruce and balsam fir advance growth in forested ecosystems in northeastern Ontario. Nutrient-poor, black spruce-dominated peatlands, including Site Types 11, 12, and 14, had the highest stocking and density levels of black spruce advance growth. Mesic, mixed coniferous upland spruce–fir sites, including Site Types 6a, 6b, and 6c, had the highest stocking and density levels of balsam fir advance growth.

Stand and site factors associated with advance growth are discussed here in relation to forest inventory, to FEC information, and to aerial photographs. Keys are provided to assist forest managers in recognizing stands with the capability to support abundant black spruce advance growth. These keys are intended for use mainly as forest level planning aids.

RÉSUMÉ

La régénération préétablie est souvent abondante dans certains écosystèmes forestiers du nord-est de l'Ontario et elle mérite, pour plusieurs raisons, d'être protégée lors de la récolte. Notamment, elle peut servir à régénérer à moindre coût des peuplements adéquats. Toutefois, les gestionnaires forestiers doivent, pour ce, être capables de reconnaître les peuplements où elle est abondante.

Pour évaluer les conditions des peuplements et des sites liés à l'abondance et à la distribution de la régénération préétablie, 85 peuplements répartis dans tout le nord-est de l'Ontario ont été échantillonnés en utilisant des placettes à surface fixe, avec répétitions, et les données obtenues ont été combinées à celles recueillies antérieurement dans 320 autres peuplements. Les facteurs des peuplements et des sites associés aux régénérations préétablies d'épinette noire (Picea mariana [Mill.] B.S.P.) et de sapin baumier (Abies balsamea [L.] Mill.) ont été examinés, et les relations entre l'abondance de la régénération préétablie et les types de sites de la classification des écosystèmes forestiers (CEF) ont été recherchées par la technique de régression multiple et d'autres techniques d'analyse des données.

Les résultats indiquent un rapport entre l'abondance de la régénération préétablie d'épinette noire et les paramètres suivants des peuplements et des sites : surface terrière totale du peuplement, productivité du peuplement, pourcentage d'épinettes noires dans le peuplement, âge du peuplement, abondance des plantes arbustives de grande taille dans le sous-étage, abondance des sphaignes et abondance de matières au sol susceptibles d'inhiber ou de réduire le marcottage. La régénération préétablie d'épinette noire s'est révélée plus abondante dans les peuplements pauvres en substances nutritives, dominés par l'épinette noire et se caractérisant également par une faible surface terrière, peu de plantes arbustives de grande taille dans le sous-étage et l'abondance des sphaignes au sol.

Dans le cas de la régénération préétablie du sapin baumier, les paramètres influant sur son abondance comprennent la productivité du peuplement, l'âge du peuplement, la composition spécifique, le régime d'humidité du sol et la nature des matières au sol. Cette régénération s'est révélée plus abondante dans les peuplements mixtes sur site moyen à riche, à sol frais à humide, dominés par les conifères, et spécialement les peuplements où sont présents le sapin baumier, l'épinette blanche (Picea glauca [Moench] Voss) et/ou des feuillus. Des mélanges de matières au sol, telles que mousses, débris, billes décomposées, litière d'aiguilles, litière de feuilles et sol minéral exposé, étaient également associés à la régénération préétablie de sapin baumier.

Les types de sites de la CEF ont fourni un cadre utile pour comprendre la distribution de la régénération préétablie d'épinette noire et de sapin baumier dans les écosystèmes forestiers du nord-est de l'Ontario. Pour la régénération préétablie de l'épinette noire, les densités les plus élevées ont été observées dans les tourbières pauvres en substances nutritives où dominait l'épinette noire, incluant les types de sites 11, 12 et 14, tandis que pour celle du sapin baumier, elles se trouvaient sur les sites mésiques, secs, à peuplement résineux mélangés d'épinettes et de sapins, incluant les types 6a, 6b et 6c.

Les caractéristiques des peuplements et des sites liées à la régénération préétablie sont examinées en considérant l'inventaire forestier, l'information de la CEF et les photographies aériennes. Des clés sont fournies pour aider les gestionnaires forestiers à reconnaître les peuplements susceptibles de contenir une régénération préétablie d'épinette noire abondante. Ces clés sont destinées à être utilisées principalement comme outils de planification à l'échelle de la forêt.

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INTRODUCTION

Black spruce (*Picea mariana* [Mill.] B.S.P.) is the most important commercial tree species in northeastern Ontario in terms of total volume harvested (Arnup et al. 1988) and, because of its superior pulping characteristics, it will continue to play an important role in the economy for some time. Consequently, the regeneration of black spruce after harvesting receives considerable attention, and methods to ensure new growth are continually evolving. In northeastern Ontario, balsam fir (*Abies balsamea* [L.] Mill.) is of less commercial importance. However, as wood supply situations change and mill technologies evolve, this species may be utilized more extensively in the future.

Forest managers are constantly looking to develop lower cost management strategies. Natural regeneration of black spruce, through the protection of advance growth, offers a potential to integrate regeneration with harvesting. This should result in lower costs than would artificial regeneration methods. Although most well drained productive sites in northeastern Ontario require artificial reforestation methods in order to maintain a black spruce cover type, many poorly drained transitional and peatland sites can be regenerated with prescribed natural treatments.

Black spruce advance growth originates as seedlings, which develop sexually from seed dispersal, and as layers, which result when the lower branches of a tree forms roots after becoming embedded in organic material (Stanek 1961, 1968). Most studies indicate that the majority of the advance growth occurring in the understory of black spruce stands originates from layering (Heinselman 1959, Frisque and Vezina 1977, Walsh and Wickware 1991). Even-aged, fire-origin stands originate from seedlings. In the absence of fire, or other disturbance agents, stand openings develop in overmature stands. Under these conditions layering provides a means of continuous reproduction (Sims et al. 1990, Walsh and Wickware 1991). Layering is most prevalent on wet, nutritionally poor sites where rapid *Sphagnum* spp. growth covers the lower living branches.

Although balsam fir can reproduce by layering, most balsam fir advance growth originates as seedlings (Bonner 1941). Balsam fir will germinate and become established on many types of seedbeds, including mineral soil, rotten wood, mosses, and shallow duff or litter, provided there is sufficient moisture (Bell 1991). Balsam fir advance growth is frequently abundant in a variety of mature stand types on upland sites (Harvey and Bergeron 1989). Since balsam fir is shade tolerant, a reserve of established seedlings is typically present even under dense canopies (Roe 1953).

Protecting advance growth by careful harvesting methods is attractive for a number of reasons. Costs of seed and seedling production, site preparation, and tree planting are reduced. Preservation of advance growth retains the locally adapted gene pool on the site. The height growth of black spruce advance growth compares favorably with that of planted stock (Doucet and Boily 1986). Since advance growth usually has an initial height and size advantage over planted or seeded trees, tending needs are reduced and the stand rotation period is shortened (Archibald and Arnup 1993).

The distribution and abundance of advance growth can be related to specific stand and site conditions. In the Clay Belt, the abundance of black spruce advance growth on peatlands was found to be related to site type, stand basal area, speckled alder (*Alnus rugosa* [Du Roi] Spreng.) cover, *Sphagnum* moss cover, and percent black spruce in the stand (Groot 1984). Walsh and Wickware (1991) reported similar relationships between black spruce advance growth distribution and stand and site factors, although they found that overall abundance levels of advance growth in north central Ontario were generally less than those reported for the Clay Belt. This may be due to regional climatic differences, since the Clay Belt is more humid than the north central part of the province (Chapman and Thomas 1968).

The distribution and abundance of balsam fir advance growth is also related to site conditions. In Quebec, balsam fir seedling densities were found to be highest on dry to mesic, balsam fir, herb and moss site types on well to imperfectly drained tills (Côté and Belanger 1991). Low seedling densities were associated with hardwood-dominated stands, with abundant tall woody shrubs in the understory, and with abundant deciduous leaf litter on the forest floor (Harvey and Bergeron 1989, Côté and Belanger 1991).

There is a need for integrating these research results into harvest and silvicultural planning. The ability to identify the location and extent of areas having a high potential for advance growth is needed by forest managers for broad-scale planning. This requires methods for generating an inventory of advance growth conditions or, alternatively, a mechanism for stratifying existing forest inventories. For more detailed planning purposes, a better understanding of the distribution of advance growth within individual forest stands is needed so that specific prescriptions for the preservation of advance growth can be determined and implemented.

In northeastern Ontario, the distribution and abundance of advance growth in relation to stand and site factors has not been studied outside the northern Clay Belt. A forest ecosystem classification (FEC) system that extends the original FEC work in the Clay Belt (Jones et al. 1983) to the remainder of northeastern Ontario has recently been completed (McCarthy et al. 1995). There is a need to extend the advance growth survey conducted in the Clay Belt (Groot 1984) to the remainder of northeastern Ontario, and to synthesize knowledge of advance growth within the framework of the most recent FEC system.

The objectives of this project are threefold:

1. To determine stand and site conditions associated with the abundance and distribution of advance growth in northeastern Ontario;

2. To synthesize information on advance growth abundance and distribution within the framework of the FEC system for northeastern Ontario; and

3. To develop practical tools for predicting the abundance and distribution of advance growth in black spruce ecosystems so as to assist forest managers with inventory and planning applications.

METHODS

Advance Growth Survey

In the Clay Belt advance growth survey (Groot 1984), sample plots were established in 30 stands. For this study, advance growth survey plots were established in 85 forest stands. These stands were distributed geographically across northeastern Ontario in order to gain an equitable representation of different forest stand types and site conditions. The sampled stands included a range of site types, age classes, tree species composition, stocking, understory, and seedbed conditions.

Candidate stands were identified by examining land resource inventories (soil maps, surficial geology maps, and the Ontario forest resource inventory [FRI]), FEC databases, and aerial photographs. Field reconnaissance was conducted to confirm conditions on the ground prior to establishing survey plots. Figure 1 shows the general location of the 85 forest stands in which the plots are located. Detailed locational information and FRI stand listings for the surveyed stands are included in Appendix 1.

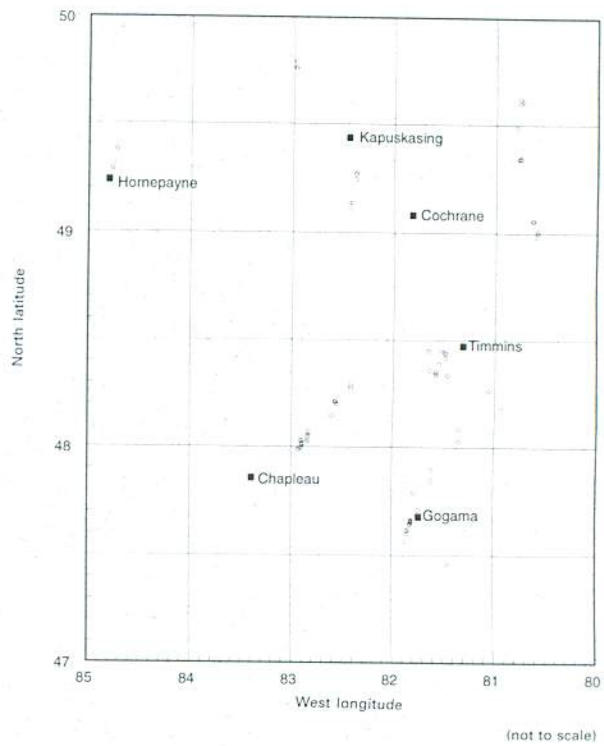


Figure 1. General locations of the stands sampled for the advance growth survey.

The advance growth survey plots consisted of four 10-m x 10-m subplots, spaced 100 m apart on a linear transect. Within each subplot, detailed information was recorded on soil conditions, FEC site types, stand features, understory shrubs, seedbeds, and advance growth. Soil information was recorded using standard methods described by the Ontario Institute of Pedology (1985). The soil features recorded included depth to bedrock, sequence and thicknesses of organic and mineral soil horizons, dominant mineral soil texture, depths to mottles and gley colors, moisture regime, depth of organic matter, and forest humus form. FEC keys were used to allocate each subplot to a site type. Stand mensurational data collected within the subplots included the species and diameter at breast height (DBH) of all trees greater than 10 m in height, and the heights and ages (at stump height) of three dominant or codominant trees. Also, two sweeps using a BAF2 prism were conducted adjacent to the subplots. Trees were counted by species to provide estimates of species composition and basal area in the stand.

The percentage cover of shrubs in the understory, by species, and the percentage cover of seedbed types and unvegetated substrates on the forest floor were estimated visually. Forest floor substrate categories included the percentage cover of mounded *Sphagnum* mosses, flat *Sphagnum* mosses, feathermosses, other mosses, logs

(>7 cm), debris (twigs and branches <7 cm), coniferous needle litter, deciduous leaf litter, exposed bedrock, surface stones, exposed mineral soil, and water.

Advance growth was recorded individually for each of one hundred 1-m x 1-m quadrats within each subplot. Within each quadrat, advance growth stems were counted by species within four height classes. The four height classes were: 0 to 10.0 cm, 10.1 to 50.0 cm, 50.1 to 200.0 cm, and 200.1 cm to 10 m. As previously indicated, stems greater than 10 m in height were not considered to be advance growth but were recorded with the stand information.

Data Sources

Data for this study were obtained from three different sources:

1. The advance growth survey subplots (n = 340) established in 85 forest stands located throughout northeastern Ontario, as described previously.
2. Advance growth survey data for 70 additional stands (provided by Art Groot, Canadian Forest Service, Great Lakes Forestry Centre). This consisted of two subsets of data. Detailed data on advance growth stocking and density, as well as on stand and site features, were provided for 30 stands from the Clay Belt advance growth survey. These plots were sampled using methods previously described by Groot (1984). Data from an additional 40 stands were provided from the survey of stand structure in peatlands. These plots were sampled by methods described by Horton and Groot (1987). Information on advance growth stocking, stand factors, and selected site factors was available from these latter plots.
3. FEC plots established in 250 stands located in the Ontario Clay Belt, surveyed during the early 1980s, were used to prepare the Clay Belt Classification System (Jones et al. 1983). The advance growth present in these plots was measured by using twenty-five 4-m^2 quadrats, within which tree seedlings and saplings up to 10 m in height were counted by species and by height classes. Using this data, estimates of advance growth stocking and density were calculated by tree species. This data set contained detailed soil, understory vegetation, and seedbed information, but little stand mensurational data (age measurements only).

Since the variables measured and the survey methods used were somewhat different among these three data sets, several subsets of the entire data set were created that had variables and measurement techniques in common. These data subsets were used in the various analyses conducted on the advance growth data for this project.

Data Analyses

For each survey plot, advance growth stocking estimates were generated based on 1-m^2 and on 4-m^2 plot sizes. Total density of advance growth, and density of advance growth by height classes were calculated for each tree species (as stems per ha). For each subplot, the following stand variables were calculated: average stand age (i.e., the mean age of the dominant trees in the main canopy), maximum age (i.e., the age of the oldest tree measured in the plot), total stand density, density by tree species, total stand basal area, basal area by tree species, total basal area of hardwood species, total basal area of coniferous species, and the percentage of total stand basal area by tree species.

In general, advance growth levels, stand factors, and site factors varied more among stands than within stands. Hence, the four subplots that were located within each forest stand were aggregated to provide a stand-level data set. Since each stand contained four plots, estimates of advance growth levels and stand mensurational features were based on a plot area of 400 m^2, the same as in the data sets provided by the Canadian Forest Service. Average values for soil and site variables were calculated from the measurements recorded in the four individual subplots.

Standard data reduction techniques were used to generate descriptive statistics (i.e., mean, range, and standard error) for advance growth levels within FEC site types, and within other groups of stands that were defined by classes of stand age, total stand basal area, *Sphagnum* moss cover, and percentage of black spruce basal area. Differences in mean advance growth stocking and density levels among FEC site types, and among the stand groups, were tested using Tukey-Cramer honestly significant difference tests and independent sample t-tests. Bartlett tests for homogeneity of group variances and one-way analyses of variance were conducted for each permutation.

Relationships among stand and site factors, and advance growth levels, were initially explored using simple correlation (i.e., Spearman rank-correlation coefficient). Interactive multiple step-wise regression by forward selection was used to select variables for modeling advance growth levels using stand and site factors. Based on these initial analyses, the data set was stratified into three site type groups, since advance growth levels appeared to be related to different factors under different site conditions. These groups were:

1. Lowlands—all stands associated with FEC site types on organic soils, i.e., Site Types 11 (black spruce–Labrador-tea [*Ledum groenlandicum* Oeder]), 12 (black spruce–speckled alder), 13 (conifer–speckled alder), and 14 (black spruce–leatherleaf [*Chamaedaphne calyculata* (L.) Moench]).

2. Black spruce-dominated uplands—all stands associated with FEC Site Types 5a (black spruce–feathermoss–fine soil), 5b (black spruce–feathermoss–medium soil), 8 (black spruce–feathermoss–*Sphagnum*), and 9 (conifer–moist soil).

3. Upland mixedwoods, jack pine (*Pinus banksiana* Lamb.) stands, and shallow soils, i.e., all stands associated with Site Types 1 (very shallow soil), 2a (jack pine–coarse soil), 2b (jack pine–very coarse soil), 3a (mixedwood–medium soil), 3b (mixedwood–coarse soil), 4 (jack pine–black spruce–coarse soil), 6a (mixedwood–fine soil), 6b (conifer mixedwood–medium soil), 6c (hardwood mixedwood–coarse soil), 7a (hardwood–fine soil), 7b (hardwood–medium soil), and 10 (hardwood–moist soil).

A variety of linear and nonlinear models to predict advance growth levels from stand and site factors was tested using the entire data set and the site group data subsets. In general, the multiple linear models were the most satisfactory. The effects of stand and site factors appeared to be additive, and the effects of interactions between stand and site factors were small in comparison with the effects of the primary factors. To provide an independent test of the multiple linear models, multiple discriminant analysis was performed using the same site and stand factors as in the regression models to predict classes of advance growth abundance levels. Important ecological relationships between advance growth abundance and distributions, and stand and site factors, could be inferred from the results of these analyses. To demonstrate relationships between advance growth abundance and stand and site factors, advance growth levels were summarized by ranges of important stand and site factors.

A key to assist forest managers in recognizing stands with abundant black spruce advance growth when viewing aerial photographs was also prepared. Stands in which the advance growth survey plots were located were examined on black and white, 1:20 000 scale aerial photographs (i.e., standard FRI photography). Each stand was described using a set of features identifiable on the photos. These features included position on the slope, tree species composition, degree of canopy closure, gray tone, and stand pattern. A data set of photo attributes and advance growth stocking levels (measured in the field for each surveyed stand) was then created. Multiple discriminant analyses was used to determine which photo features best discriminated stands with abundant advance growth. These features were then used to build an hierarchical key to allocate stands into one of three black spruce advance growth stocking classes.

RESULTS AND DISCUSSION

In this report, the abundance and distribution of advance growth are discussed in terms of two different measures, stocking and density. Stocking is a measure of the distribution of advance growth. To estimate stocking, a series of quadrats of equal size are established within the area to be surveyed. Stocking is defined as the proportion (or percentage) of these quadrats within which at least one advance growth stem is present. Stocking can be expressed at different scales, depending on the size of the individual quadrats used to measure advance growth occurrence. Since 2-m x 2-m quadrats are commonly used to measure stocking in regeneration assessments conducted by government and industry in Ontario, the advance growth stocking levels presented in this report are based on a plot size of 4 m^2, unless stated otherwise. Density is a measure of the abundance of advance growth, and is defined as the total number of advance growth stems per unit area (usually stems per ha).

This report focuses on the abundance and distribution of black spruce and balsam fir advance growth. Advance growth of other coniferous species, including white spruce (*Picea glauca* [Moench] Voss.), jack pine, eastern white pine (*Pinus strobus* L.), eastern white cedar (*Thuja occidentalis* L.), and larch (*Larix laricina* [Du Roi] K. Koch), were also recorded in the sampled stands. However, advance regeneration of these species was encountered infrequently and had low abundance levels. Hence, analyses of the distribution and abundance of these species in relation to site types, stand factors, and site factors could not be conducted.

Abundance and Distribution of Advance Growth by FEC Site Types

Previous research has indicated that the abundance and distribution of advance growth is related to stand factors (tree species composition and canopy structure), and to site factors (abundance of forest floor substrates suitable for layering and seeding, and abundance of understory vegetation that inhibits layering or competes with established seedlings and layers). FEC site types are defined as mappable, management-oriented groupings of vegetation occurring on specific ranges of soil conditions (McCarthy et al. 1995). Since the site types integrate a number of stand and site factors, they should provide a useful framework for understanding the distribution of advance growth across the forested landscape.

Figure 2 shows the mean percentage stocking levels, and one standard deviation unit about the mean, for black spruce advance growth by FEC site types. Table 1 shows the differences in the mean black spruce advance growth stocking levels among site types using Tukey-Cramer

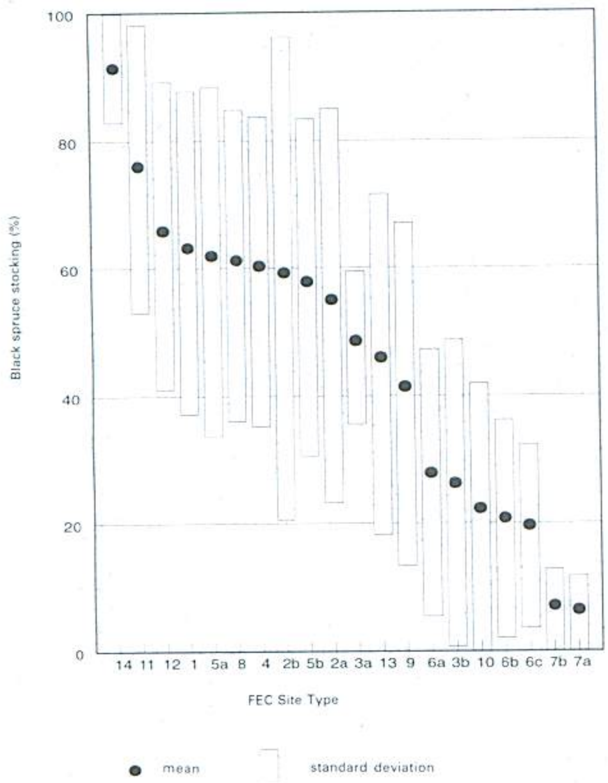


Figure 2. Percentage stocking to black spruce advance growth by northeastern Ontario FEC site type.

honestly significant difference tests. The highest mean stocking levels to black spruce advance growth were found in wet, nutrient-poor peatland sites (Site Types 11 and 14). Fresh to moist, herb-poor, black spruce-dominated upland sites (Site Types 4, 5a, 5b, and 8); dry, herb-poor upland sites (Site Types 1, 2a, and 2b); moist to wet, herb-rich mixed coniferous sites (Site Types 9 and 13); and herb-poor, black spruce–speckled alder sites (Site Type 12) had intermediate stocking levels. Fresh to moist mixedwood or hardwood sites (i.e., Site Types 3b, 6a, 6b, 6c, 7a, 7b, and 10) had the lowest levels of stocking to black spruce advance growth. Although the mean stocking level for Site Type 3a was intermediate, the sample size was small (four stands). A generalized relationship between black spruce advance growth stocking and the FEC site types is illustrated schematically in Figure 3.

The distribution of balsam fir advance growth by site types appears to be the opposite of the distribution of black spruce advance growth. Figure 4 shows the mean percentage stocking levels, and one standard deviation unit about the mean, for balsam fir advance growth by FEC site types. Table 2 shows the differences in mean balsam fir advance growth stocking levels between site types using Tukey-Cramer honestly significant difference tests. In general, balsam fir stocking levels are more variable within site types compared to the stocking levels for black spruce.

Table 1. Multiple comparison tests for differences of mean percent stocking between FEC site types, for black spruce advance growth.

Site type	Sample size	Mean stocking (%)	Site type: 14	11	12	1	5a	8	4	2b	5b	2a	3a	13	9	6a	3b	10	6b	6c	7b	7a
14	16	91.4	–																			
11	107	75.6	–	–																		
12	66	65.2	**	–	–																	
1	39	62.5	**	–	–	–																
5a	21	61.1	**	–	–	–	–															
8	68	60.5	**	**	–	–	–	–														
4	46	59.5	**	**	–	–	–	–	–													
2b	15	58.4	**	–	–	–	–	–	–	–												
5b	9	57.0	**	–	–	–	–	–	–	–	–											
2a	14	54.1	**	**	–	–	–	–	–	–	–	–										
3a	4	47.5	–	–	–	–	–	–	–	–	–	–	–									
13	64	44.9	**	**	**	–	–	*	–	–	–	–	–	–								
9	65	40.2	**	**	**	**	–	**	*	–	–	–	–	–	–							
6a	30	26.3	**	**	**	**	**	**	**	*	–	–	–	–	–	–						
3b	17	24.7	**	**	**	**	**	**	**	**	–	–	–	–	–	–	–					
10	29	20.6	**	**	**	**	**	**	**	**	*	**	–	**	*	–	–	–				
6b	11	19.1	**	**	**	**	**	**	**	**	–	–	–	–	–	–	–	–	–			
6c	7	17.9	**	**	**	**	**	**	**	–	–	–	–	–	–	–	–	–	–	–		
7b	6	5.0	**	**	**	**	**	**	**	**	**	**	–	**	**	–	–	–	–	–	–	
7a	22	4.3	**	**	**	**	**	**	**	**	**	**	*	**	**	**	–	–	–	–	–	–

Tukey–Cramer HSD: ** p = 0.01;
* p = 0.05; and
– = nonsignificant.

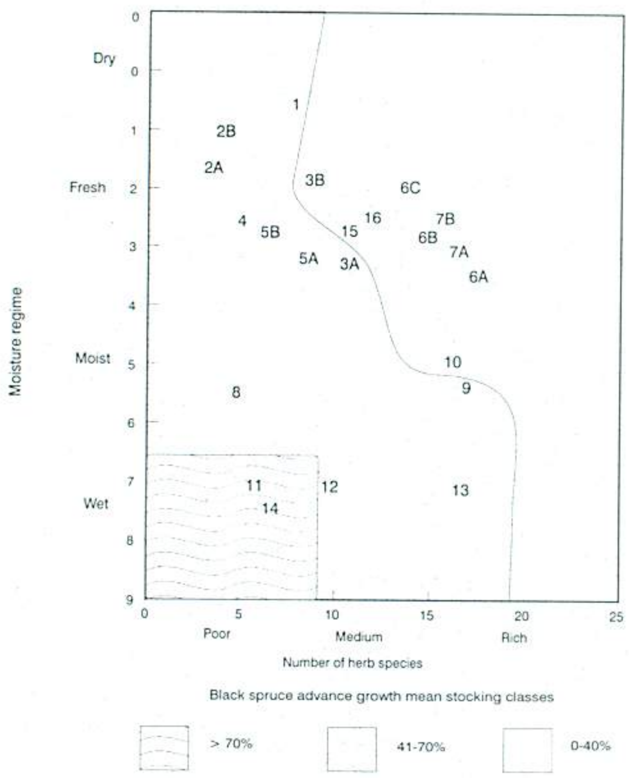


Figure 3. Diagram showing the general relationship between black spruce advance growth stocking and the northeastern Ontario FEC site types.

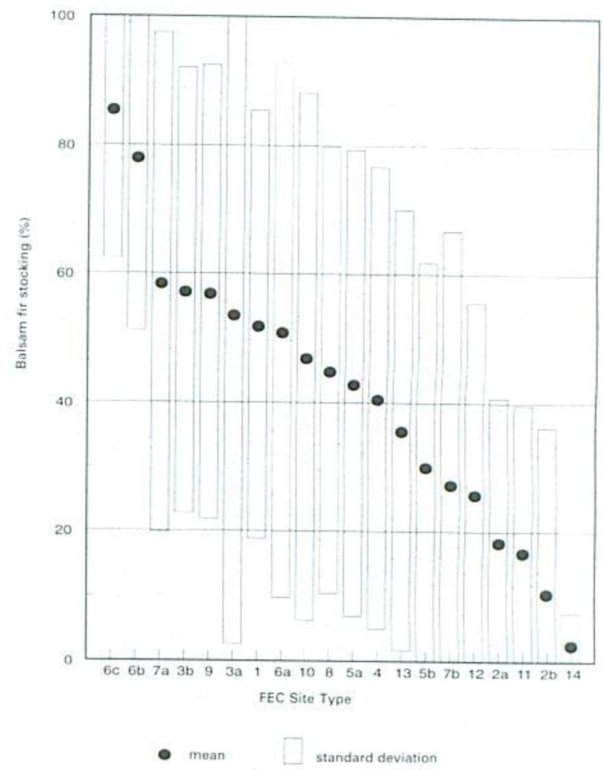


Figure 4. Percentage stocking to balsam fir advance growth by northeastern Ontario FEC site type.

Table 2. Multiple comparison tests for differences of mean percent stocking between FEC site types, for balsam fir advance growth.

Site type	Sample size	Mean stocking (%)	Site type: 6c	6b	7a	3b	9	3a	1	6a	10	8	5a	4	13	5b	7b	12	2a	11	2b	14
6c	7	85.7	–																			
6b	11	78.2	–	–																		
7a	22	58.6	–	–	–																	
3b	17	57.4	–	–	–	–																
9	65	57.1	–	–	–	–	–															
3a	4	53.8	–	–	–	–	–	–														
1	39	52.1	–	–	–	–	–	–	–													
6a	30	51.2	–	–	–	–	–	–	–	–												
10	29	47.2	–	–	–	–	–	–	–	–	–											
8	68	45.1	–	–	–	–	–	–	–	–	–	–										
5a	21	43.1	–	–	–	–	–	–	–	–	–	–	–									
4	46	40.8	*	*	–	–	–	–	–	–	–	–	–	–								
13	64	35.8	**	**	–	–	*	–	–	–	–	–	–	–	–							
5b	9	30.2	*	*	–	–	–	–	–	–	–	–	–	–	–	–						
7b	6	27.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–					
12	66	25.9	**	**	**	*	**	–	*	*	–	–	–	–	–	–	–	–				
2a	14	18.6	**	**	*	–	*	–	–	–	–	–	–	–	–	–	–	–	–			
11	107	17.0	**	**	**	**	**	–	**	**	**	**	*	*	*	–	–	–	–	–		
2b	15	10.7	**	**	**	**	**	–	**	**	*	*	–	–	–	–	–	–	–	–	–	
14	16	2.8	**	**	**	**	**	–	**	**	**	**	**	**	*	–	–	–	–	–	–	–

Tukey–Cramer HSD: ** p = 0.01;
* p = 0.05; and
– = nonsignificant.

The highest mean stocking levels for balsam fir advance growth occurred in herb-medium to herb-rich, mixed conifer stands with a high balsam fir component, on fresh to moist soils (Site Types 6b and 6c). Fresh to moist mixedwood and hardwood sites (Site Types 3a, 3b, 6a, 7a, 9, and 10), and fresh to moist black spruce-dominated upland sites (Site Types 4, 5a, and 8), and sites on very shallow soils (Site Type 1) had intermediate stocking levels. Wet, black spruce-dominated peatland sites (Site Types 11, 12, 13, and 14) and herb-poor, jack pine- or black spruce-dominated upland sites on dry to fresh coarse soils (Site Types 2a, 2b, and 5b) had the lowest stocking levels to balsam fir. The mean stocking level for Site Type 7b was low (28 percent) but the sample size was small (six stands). A generalized relationship between balsam fir mean stocking levels and FEC site types is illustrated schematically in Figure 5.

The mean values, and standard deviations about the means, for black spruce and balsam fir advance growth density by FEC site types are shown in Figures 6 and 7, respectively. The differences in mean density levels between site types, using Tukey-Cramer honestly significant difference tests, for black spruce and balsam fir advance growth, are summarized in Tables 3 and 4, respectively.

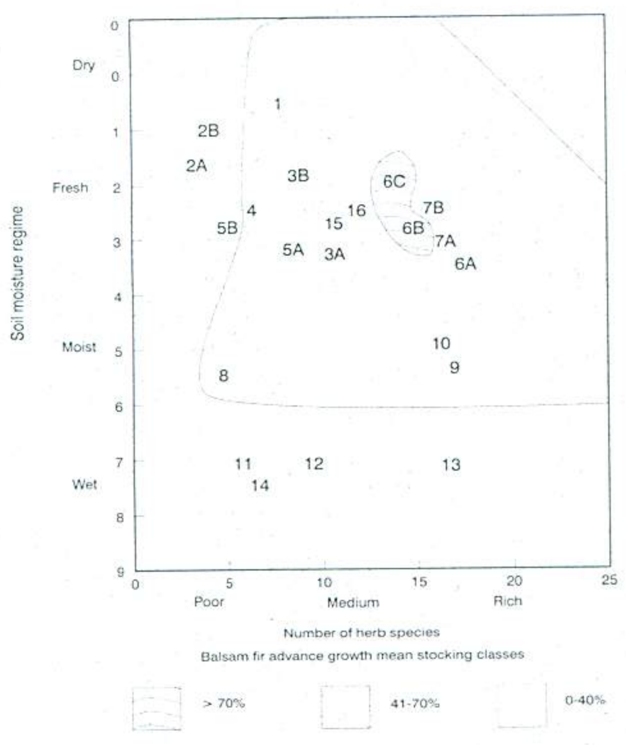


Figure 5. Diagram showing the general relationship between balsam fir advance growth stocking and the northeastern Ontario FEC site types.

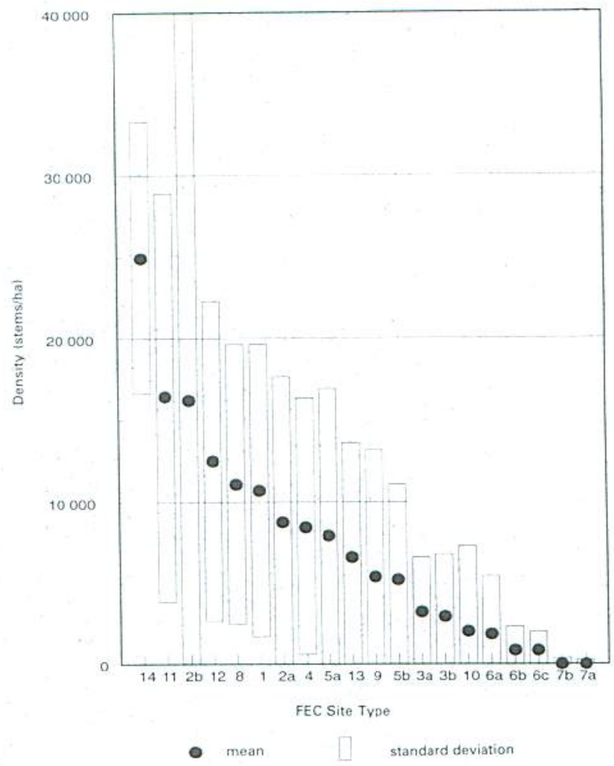


Figure 6. Density of black spruce advance growth by northeastern Ontario FEC site type.

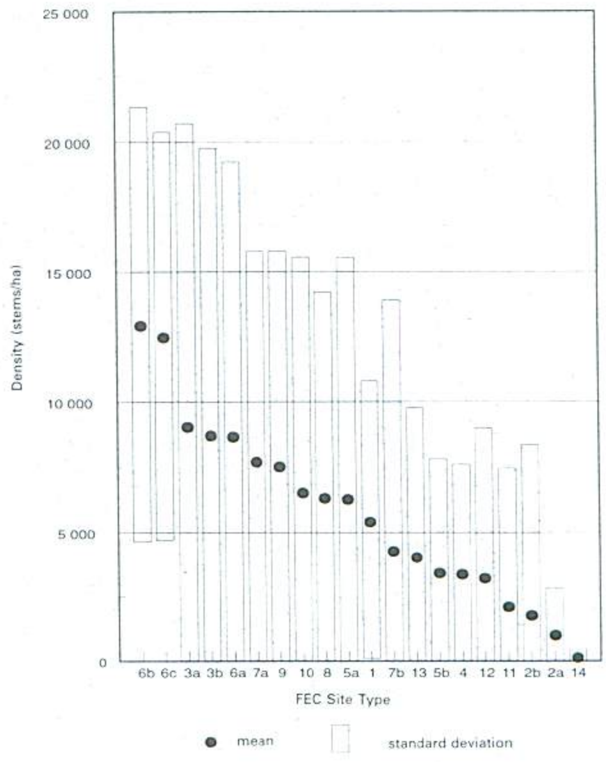


Figure 7. Density of balsam fir advance growth by northeastern Ontario FEC site type.

Table 3. Multiple comparison test for differences of mean density, for black spruce advance growth between FEC site types.

Site type	Sample size	Density (stems/ha)	Site type																			
			14	11	2b	12	8	1	2a	4	5a	13	9	5b	3a	3b	10	6a	6b	6c	7b	7a
14	16	24 931	–																			
11	107	16 372	–	–																		
2b	66	16 135	–	–	–																	
12	39	12 473	**	–	–	–																
8	21	11 053	**	–	–	–	–															
1	68	10 665	**	–	–	–	–	–														
2a	46	8 764	**	–	–	–	–	–	–													
4	15	8 446	**	**	–	–	–	–	–	–												
5a	9	7 926	**	*	–	–	–	–	–	–	–											
13	14	6 585	**	**	*	–	–	–	–	–	–	–										
9	4	5 396	**	**	**	**	–	–	–	–	–	–	–									
5b	64	5 244	**	–	–	–	–	–	–	–	–	–	–	–								
3a	65	3 250	**	–	–	–	–	–	–	–	–	–	–	–	–							
3b	30	2 940	**	**	**	*	–	–	–	–	–	–	–	–	–	–						
10	17	2 036	**	**	**	**	**	*	–	–	–	–	–	–	–	–	–					
6a	29	1 873	**	**	**	**	**	*	–	–	–	–	–	–	–	–	–	–				
6b	11	875	**	**	**	*	–	–	–	–	–	–	–	–	–	–	–	–	–			
6c	7	857	**	**	*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–		
7b	6	104	**	**	*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	
7a	22	68	**	**	**	**	**	**	–	*	–	–	–	–	–	–	–	–	–	–	–	–

Tukey–Cramer HSD: ** p = 0.01;
* p = 0.05; and
– = nonsignificant.

Table 4. Multiple comparison tests for differences of mean density, between FEC site types, for balsam fir advance growth.

Sample type	Density size	(stems/ha)	Site type																			
			6b	6c	3a	3b	6a	7a	9	10	8	5a	1	7b	13	5b	4	12	11	2b	2a	14
6b	11	12 977	–																			
6c	7	12 536	–	–																		
3a	4	9 063	–	–	–																	
3b	17	8 751	–	–	–	–																
6a	30	8 723	–	–	–	–	–															
7a	22	7 753	–	–	–	–	–	–														
9	65	7 576	–	–	–	–	–	–	–													
10	29	6 566	–	–	–	–	–	–	–	–												
8	68	6 375	–	–	–	–	–	–	–	–	–											
5a	21	6 332	–	–	–	–	–	–	–	–	–	–										
1	39	5 444	–	–	–	–	–	–	–	–	–	–	–									
7b	6	4 292	–	–	–	–	–	–	–	–	–	–	–	–								
13	64	4 078	*	–	–	–	–	–	–	–	–	–	–	–	–							
5b	9	3 439	–	–	–	–	–	–	–	–	–	–	–	–	–	–						
4	46	3 410	**	–	–	–	–	–	–	–	–	–	–	–	–	–	–					
12	66	3 240	**	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–				
11	107	2 135	**	*	–	*	**	–	**	–	*	–	–	–	–	–	–	–	–			
2b	15	1 808	**	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–		
2a	14	1 021	**	*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	
14	16	145	**	*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Tukey–Cramer HSD: ** p = 0.01;
* p = 0.05; and
– = nonsignificant.

The density of black spruce advance growth is more variable within site types, compared to the stocking levels, probably because layered advance growth tends to occur in clumps. The mean density values for black spruce advance growth for site types with high stocking levels range from 15 000 to 20 000 stems per hectare. For site types with intermediate stocking levels, mean density values range from 5 000 to 15 000 stems per hectare. For site types with the lowest stocking levels, mean densities are generally less than 5 000 stems per hectare. In Site Type 7, the mean densities are less than 200 stems per hectare.

For balsam fir advance growth, the mean density levels are somewhat lower than for black spruce. Site types associated with the highest balsam fir stocking levels had mean density levels ranging from 10 000 to 15 000 stems per hectare. Site types with intermediate stocking levels to balsam fir advance growth had mean density values ranging from 5 000 to 10 000 stems per hectare. Site types with low stocking levels had mean density values less than 5 000 stems per hectare.

The relative proportions of advance growth within different height classes were similar among site types for black spruce (Fig. 8) and for balsam fir (Fig. 9). On all sites, the greatest proportion of black spruce advance growth occurred in the smaller size classes (i.e., 50 cm or less in height, *see* Figure 8). Nonetheless, a considerable amount of larger advance growth was present in some stands. The mean density of advance growth stems greater than 50 cm in height exceeded 3 000 stems per hectare in the peatland site types, and averaged approximately 1 500 stems per hectare in the black spruce-dominated upland site types.

Figure 10 shows the relationship between black spruce advance growth stocking when measured with 1-m^2 quadrats, versus stocking when measured with 4-m^2 quadrats. Assuming that the advance growth stems were randomly distributed, the relationship between stocking measured with 1-m^2 quadrats versus 4-m^2 quadrats would be:

Equation 1: $\text{stocking}[4] = 1 - (1 - \text{stocking}[1])^4$

where:

stocking [4] = stocking based on 4-m^2 quadrats, and
stocking [1] = stocking based on 1-m^2 quadrats.

Very few points fall on the curve defined by Equation 1 (*see* Figure 10), illustrating the clumped distribution of the black spruce advance growth. A nonlinear regression derived the following relationship between the two stocking measures:

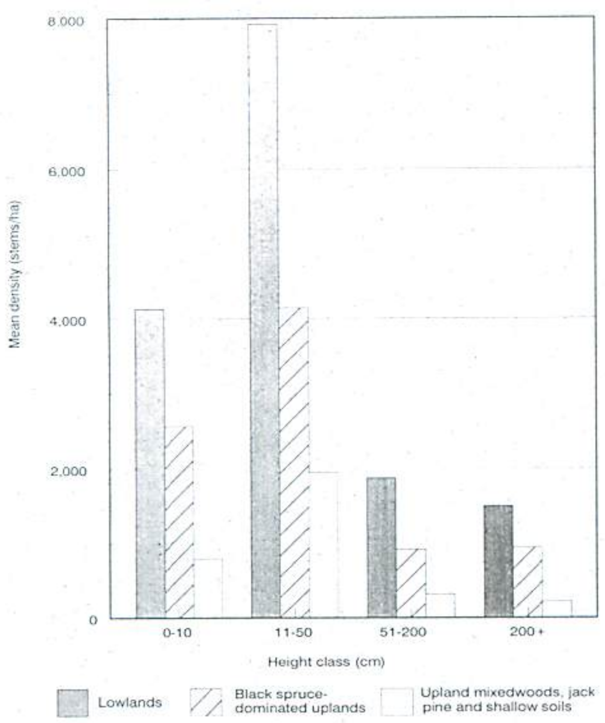


Figure 8. Mean density of black spruce advance growth by height class and site type group.

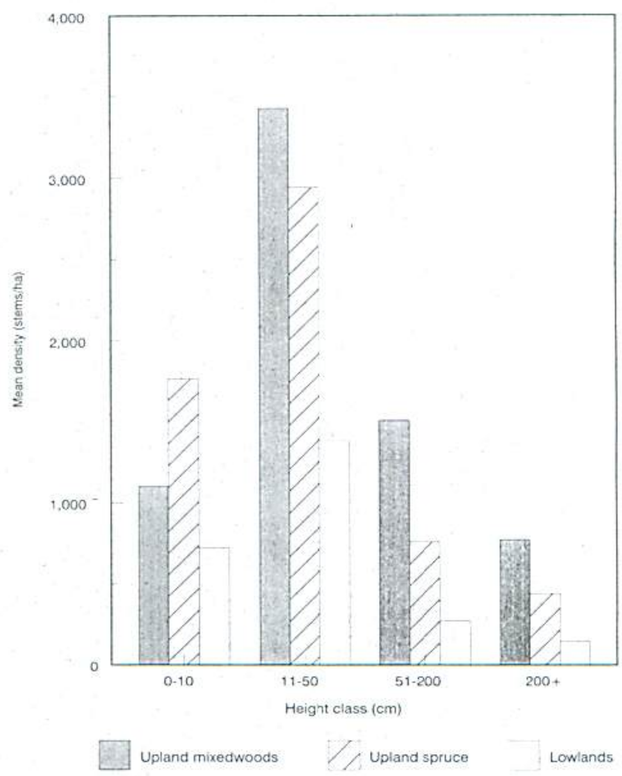


Figure 9. Mean density of balsam fir advance growth by height class and site type group.

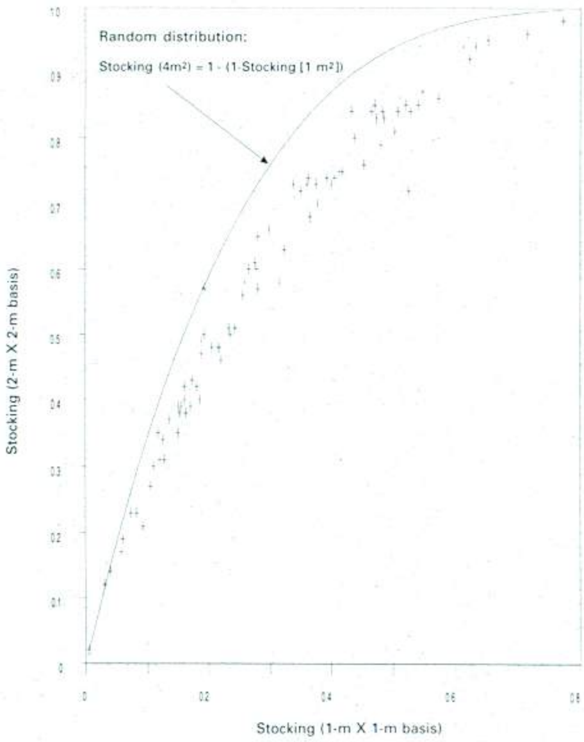


Figure 10. Scatterplot of black spruce advance growth stocking measured with 1-m^2 plots versus stocking measured with 4-m^2 plots.

Equation 2: stocking [4] = $1 - (1 - \text{stocking}[1])^{2.788}$
Adjusted $R^2 = 0.978$

For balsam fir, the relationship between the two stocking measures was similar:

Equation 3: stocking^4 = $1 - (1 - \text{stocking}[1])^{2.875}$
Adjusted $R^2 = 0.980$

The clumped distribution of advance growth may be related to clusters of layers originating from branches of individual parent trees, to the distribution of receptive seedbeds and substrates conducive to layering, to openings in the canopy, or to a combination of factors. Equations 2 and 3 can be used to convert between stocking estimates of advance growth that were measured using the two different quadrat sizes.

Stand and Site Factors Associated with the Abundance and Distribution of Advance Growth

Simple correlation was used initially to explore relationships between advance growth stocking and density measures for black spruce and balsam fir, and 35 stand and site variables. Since the factors included class level variables (e.g., moisture regime), continuous variables (e.g., total basal area), and variables measured as percentages (e.g., percentage cover of *Sphagnum* moss), a rank-correlation method was chosen (Spearman's Rho). Spearman rank-correlations between the advance growth stocking and density measures, and the stand and site variables, are summarized in Table 5. The table is structured so that factors that are positively correlated with black spruce stocking appear at the top; variables negatively associated with black spruce stocking appear at the bottom of the table.

In general, the correlation coefficients between density, stocking measured with 1-m^2 or 4-m^2 plots, and the stand and site variables were of similar magnitude, although the correlation coefficients associated with stocking were slightly higher than those for density. Black spruce advance growth was positively correlated with the total amount of moss cover, the amount of *Sphagnum* moss cover, and the percentage of black spruce basal area in the stands. Black spruce stocking was negatively correlated with the amount of unvegetated surface (i.e., litter, debris, logs, rocks, etc.), deciduous litter, and debris on the forest floor; with the total basal area of the stand; and with the abundance of hardwoods in the stand. In other words, black spruce advance growth tended to be most abundant in relatively pure black spruce stands with few or no hardwood trees present, in open stands with low basal area and with a relatively continuous moss cover on the forest floor, and in stands with high levels of *Sphagnum* mosses.

The relationships between balsam fir stocking and density with the stand and site factors was opposite to the relationships between black spruce advance growth and the stand and site factors. Black spruce advance growth was associated with relatively pure black spruce stands with few hardwoods and high *Sphagnum* moss cover. On the other hand, balsam fir advance growth was associated with mixedwood or hardwood stands; with low *Sphagnum* moss cover; and with abundant needle and leaf litter, logs, and debris on the forest floor.

To further explore these relationships, the sampled stands were subdivided into three site-type groups: lowlands, black spruce-dominated uplands, and mixed upland stands (mixedwoods, jack pine stands, and shallow soils). Spearman rank-correlation coefficients between advance growth stocking estimates and the 35 stand and site variables, for each of the three site groups, are summarized in Table 6. The correlations between black spruce and balsam fir stocking, and the stand and site variables, differ among the three site groups. In general, the correlation coefficients are somewhat higher than when all stands and all site types are combined (*see* Table 5). This suggests that relationships between advance growth stocking and stand and site factors may be better explained by stratifying the data into site type groups.

Since the highest correlations were associated with different factors in different site type groups, the abundance and distribution of advance growth appears to be related to different stand and site factors on different site types. For example, black spruce stocking was most strongly related to *Sphagnum* moss cover on black spruce-dominated uplands, somewhat less related to *Sphagnum* cover on lowlands, and unrelated to *Sphagnum* cover on mixed uplands. This is likely because most lowland sites were associated with abundant *Sphagnum* moss cover, thereby providing ample opportunities for layering. Black spruce-dominated uplands were usually associated with lower levels of *Sphagnum* moss cover, which may then become a limiting factor. On upland stands, little or no *Sphagnum* cover is present. Therefore, advance growth may develop on different seedbeds; for example, moist feathermoss mats. Note that black spruce stocking is positively correlated with feathermoss cover in the mixed uplands, but negatively correlated with feathermoss cover in both lowlands and black spruce-dominated uplands.

Table 5. Spearman rank-correlation coefficients for advance growth measures versus stand and site variables (all stands, n = 85).

	Density		Stocking, 1 m^2		Stocking, 4 m^2	
Stand and site variables	Black spruce	Balsam fir	Black spruce	Balsam fir	Black spruce	Balsam fir
All mosses	0.565	-0.504	0.605	-0.555	0.588	-0.574
All sphagnum	0.466	-0.248	0.513	-0.294	0.502	-0.321
Percent black spruce	0.462	-0.211	0.486	-0.233	0.491	-0.242
Mounded sphagnum	0.416	-0.284	0.461	-0.340	0.456	-0.364
Ericaceous shrubs	0.441	-0.286	0.459	-0.309	0.454	-0.319
Flat sphagnum	0.391	-0.199	0.434	-0.230	0.422	-0.255
Organic depth	0.354	-0.408	0.405	-0.452	0.409	-0.482
Percent coniferous	0.362	-0.347	0.386	-0.367	0.374	-0.371
Moisture regime	0.241	-0.342	0.282	-0.382	0.267	-0.407
Black spruce tree density	0.099	-0.449	0.154	-0.497	0.159	-0.513
Water	0.057	-0.186	0.132	-0.224	0.136	-0.231
Oldest age	0.191	0.084	0.090	0.060	0.111	0.058
Mean age	0.159	-0.017	0.072	-0.033	0.096	-0.035
Conifer tree density	0.036	-0.463	0.088	-0.509	0.088	-0.522
Depth to rock	0.076	-0.249	0.089	-0.291	0.086	-0.323
Total tree density	-0.019	-0.430	0.029	-0.473	0.029	-0.487
Unvegetated surface	-0.514	0.505	-0.552	0.559	-0.541	0.577
Total basal area	-0.453	-0.067	-0.510	-0.063	-0.507	-0.058
Deciduous litter	-0.456	0.304	-0.481	0.336	-0.449	0.345
White spruce tree density	-0.405	0.195	-0.410	0.228	-0.408	0.263
Percent hardwood	-0.362	0.347	-0.386	0.367	-0.374	0.371
Hardwood tree density	-0.357	0.338	-0.382	0.357	-0.367	0.360
Debris	-0.324	0.289	-0.334	0.290	-0.344	0.287
Logs	-0.271	0.317	-0.336	0.346	-0.339	0.374
Coniferous litter	-0.283	0.372	-0.278	0.401	-0.290	0.412
Black spruce basal area	-0.213	-0.125	-0.258	-0.134	-0.258	-0.136
Exposed bedrock	-0.198	0.277	-0.247	0.300	-0.234	0.314
Feathermoss	-0.206	0.026	-0.203	0.036	-0.194	0.045
Other woody shrubs	-0.170	0.181	-0.160	0.217	-0.144	0.233
Balsam fir tree density	-0.146	-0.111	-0.144	-0.093	-0.134	-0.080
Surface stones	-0.138	0.203	-0.116	0.187	-0.112	0.226
All tall shrubs	-0.153	-0.013	-0.109	-0.049	-0.106	-0.061
Mineral soil	-0.080	0.051	-0.083	0.088	-0.077	0.104
Speckled alder	-0.078	-0.100	-0.023	-0.153	-0.022	-0.173
Other mosses	0.033	0.018	-0.016	-0.006	-0.014	-0.014

Note that the critical value for significance at p = 0.05 (95% level) is approximately 0.17.

Several multiple linear regression models were developed that predicted the abundance and distribution of black spruce and balsam fir advance growth using stand and site factors. Mathematical formulae and statistical output for the multiple linear regression models are included in Appendix 2.

Regression models that were developed using information from the individual subplots (n = 340) were less satisfactory than the models that used information aggregated within stands (n = 85). This may be attributed to factors of scale, as well as to spatial and temporal variation in stand and site features. A single 10-m x 10-m plot may not provide sufficiently accurate estimates of stand and site features. Within a forest stand, tree species composition, canopy closure, basal area, and other features exhibit spatial variation and introduce variation into the data when measured at a single point. The overall stand condition is captured better by larger plots, and/or by multiple samples.

Table 6. Spearman rank-correlation coefficients between advance growth stocking estimates and stand/site variables, by site type groups.

	Black spruce stocking			Balsam fir stocking		
Stand/site variable	Lowlands	Black spruce-dominated uplands	Mixed uplands	Lowlands	Black spruce-dominated uplands	Mixed uplands
All mosses	0.628	0.313	0.779	-0.347	-0.604	-0.515
Percent black spruce	0.572	0.320	0.395	-0.298	-0.168	0.015
All sphagnum	0.549	0.729	0.108	-0.279	-0.005	-0.022
Flat sphagnum	0.468	0.586	0.042	-0.198	0.120	-0.091
Ericaceous shrubs	0.360	0.274	0.588	-0.209	-0.204	-0.068
Mounded sphagnum	0.331	0.699	0.176	-0.218	-0.490	-0.073
Organic depth	0.283	0.192	0.373	-0.566	-0.119	-0.178
Moisture regime	0.268	0.179	-0.354	-0.536	-0.076	0.239
Percent coniferous	0.227	-0.119	0.767	-0.237	-0.102	-0.312
Depth to rock	0.153	-0.030	-0.251	-0.243	-0.118	-0.177
Mean age	0.108	-0.035	-0.194	0.155	0.169	0.139
Oldest age	0.078	-0.042	-0.128	0.195	0.307	0.308
Mineral soil	0.000	-0.262	0.119	-0.029	0.272	-0.172
Total basal area	-0.761	-0.182	-0.380	0.283	-0.484	-0.227
Unvegetated surface	-0.566	-0.211	-0.748	0.349	0.587	0.510
All tall shrubs	-0.548	0.013	-0.070	-0.031	0.004	0.246
Black spruce basal area	-0.540	0.061	-0.175	0.178	-0.399	-0.153
Coniferous litter	-0.486	0.010	0.006	0.326	0.413	0.196
Logs	-0.452	-0.169	-0.252	0.351	0.280	0.420
Speckled alder	-0.448	0.067	0.055	-0.150	-0.085	0.013
Debris	-0.406	-0.183	-0.345	0.157	0.192	0.400
White spruce tree density	-0.400	-0.359	-0.442	0.119	0.421	0.228
Other woody shrubs	-0.390	-0.036	0.148	0.323	0.036	0.194
Deciduous litter	-0.369	-0.339	-0.705	0.114	0.171	0.463
Balsam fir tree density	-0.315	-0.292	0.208	-0.118	-0.339	-0.349
Feathermoss	-0.307	-0.528	0.552	0.131	-0.378	-0.349
Other mosses	-0.246	0.093	0.222	0.205	-0.078	-0.172
Hardwood tree density	-0.243	0.226	-0.730	0.238	0.010	0.300
Percent hardwood	-0.227	0.119	-0.767	0.237	0.102	0.312
Total tree density	-0.197	0.100	0.190	-0.297	-0.606	-0.577
Surface stones	-0.159	-0.279	0.085	0.216	0.293	0.005
Conifer tree density	-0.142	0.050	0.273	-0.340	-0.592	-0.595
Water	-0.136	0.178	0.146	-0.059	-0.010	-0.317
Black spruce tree density	-0.017	0.166	0.246	-0.358	-0.611	-0.529
Exposed bedrock	na	na	-0.393	na	na	0.495

Note that the critical value for significance at p = 0.05 (95% level) is approximately 0.17.

Stand features also vary with time. Field measurements capture the stand condition only at the time of measurement. For example, if stand conditions become more favorable for advance growth establishment through break-up of the canopy with age, there will be a lag period while the advance growth develops. Conditions that appear to be favorable for advance growth when measured today may have been very different a year ago. Therefore, multiple plots located within a stand may reduce the variation associated with temporal variation in the canopy. Temporal variation is also likely to be a source of unexplained variation in the data, regardless of how measurements were taken.

Finally, some factors that influence the abundance and distribution of advance growth may function at the scale of stands or forested landscapes. As such, these are better captured with multiple samples. Such factors may include genetic disposition, cone and seed crops, disturbance history (e.g., fires, disease, and insect attacks), moisture regime, and bioclimatic effects.

The stand-level data set was used to develop regression models to predict advance growth stocking and density for all stands and site types combined, and for each of the three site type groups. The multiple regression models for black spruce advance growth stocking and density are summarized in Table 7. In general, the variation in advance growth stocking can be better explained in terms of stand and site variables than can the variation in advance growth density, as shown by the adjusted R^2 values for the multiple regressions. Also, for both stocking and density measures, the variation in the data set can be better explained by stratifying the stands into site type groups. For black spruce, 70 to 80 percent of the variation in stocking could be explained on the basis of stand and site factors within site type groups. About 40 to 60 percent of the variation of advance growth density could be explained on the basis of stand and site factors within the same site type groups.

Based on the stand and site variables included in the regression models, and the sign of the associated

Table 7. Summary of multiple regression models for black spruce advance growth stocking and density.

	Advance growth stocking			Advance growth density		
Stand group	Stand/site variable	Relationship	Adjusted R-squared	Stand/site variable	Relationship	Adjusted R-squared
All stands	Organic depth	+	0.614	Mean tree age	+	0.395
(n = 85)	Moisture regime	-		Total density	+	
	Total density	+		Total basal area	-	
	Total basal area	-		Total moss	+	
	Debris	-		Basal area x tall shrubs	-	
	Total *Sphagnum*	+				
	Total moss	+				
	Speckled alder	-				
Lowlands	Total basal area	-	0.668	Mean tree age	+	0.593
(n = 39)	Percent black spruce	+		Total density	+	
	Deciduous leaf litter	-		Total basal area	-	
	Total *Sphagnum*	+		Tall woody shrubs	-	
Black spruce-	Maximum tree age	+	0.771	Percent black spruce	+	0.621
dominated	Percent black spruce	+		Debris	-	
uplands	Total *Sphagnum*	+		Tall woody shrubs	-	
(n = 20)	White birch density	+		Total *Sphagnum*	+	
	White birch density	+				
Upland	Moisture regime	-	0.864	Moisture regime	-	0.456
mixedwoods,	Mean tree age	-		Total moss cover	+	
jack pine, and	Total basal area	-		Willow	+	
shallow soils	Feathermoss	-				
(n = 26)	Total moss cover	+				
	Willow	+				

coefficients, some general ecological relationships between the abundance and distribution of black spruce advance growth and stand and site factors can be inferred. Overall, black spruce advance growth was associated with nutrient-poor, high density but low basal area stands on wet, organic soils, with abundant moss (especially *Sphagnum* moss) cover, and low levels of speckled alder. Advance growth tended to be somewhat more abundant in older stands.

On lowland site types, abundant black spruce advance growth was associated with nutrient-poor, high density, low basal area, pure or relatively pure black spruce stands with abundant *Sphagnum* moss cover, few tall woody shrubs, and little deciduous leaf litter. Advance growth density (not stocking) tended to be somewhat higher in older stands.

In black spruce-dominated upland site types, black spruce advance growth was associated with older, pure or relatively pure black spruce stands, with abundant *Sphagnum* moss cover, few tall woody shrubs, and little debris on the forest floor. In these site types, both stocking and density were positively related to the density of white birch. In this survey, white birch appeared to be associated with openings caused by blowdown or mortality in the canopies of older stands.

On upland mixedwoods, jack pine, and shallow soil site types, black spruce advance growth was associated with stands with low basal area; with abundant moss cover (generally conifer-dominated stands); and with nutrient poor, shallow soils over bedrock. The shallow, poor soils are associated with willow (*Salix bebbiana* Sarg.) cover. The negative correlation with moisture regime also appeared to be related to the abundance of advance growth on shallow soils. Although these sites were classed in the field as dry, they contained numerous local depressions in the bedrock. These depressions collect water and were often occupied by *Sphagnum* mosses. On the shallow sites, the black spruce advance growth was often found in these moist pockets.

Table 8 summarizes the multiple linear regression models developed to predict stocking and density of balsam fir advance growth. Since balsam fir advance growth is relatively rare on peatland sites, regression models were developed for all stands combined; for all upland stands; and for the upland mixedwood, jack pine, and shallow soil site types. In general, less variation in advance growth stocking and density could be explained by the stand and site factors than for black spruce advance growth. With balsam fir stocking, stratifying the data set did not improve the predictive capability of the models, indicating that

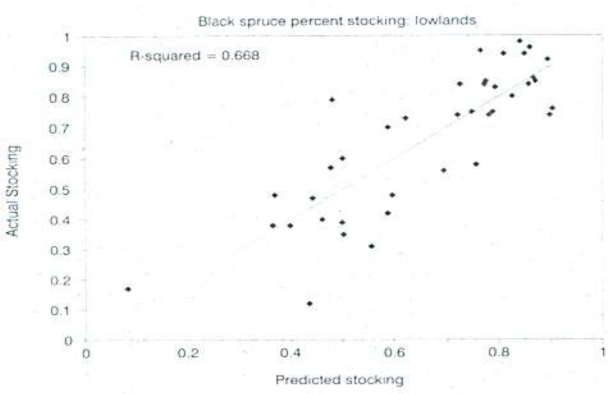
Table 8. Summary of multiple linear regression models for balsam fir advance growth stocking and density.

	Advance growth stocking			Advance growth density		
Stand group	Stand/site variable	Relationship	Adjusted R-squared	Stand/site variable	Relationship	Adjusted R-squared
All stands (n = 85)	Organic depth	-	0.556	Organic depth	-	0.335
	Total density	-		Maximum tree age	+	
	Balsam fir density	-		Black spruce density	-	
	Coniferous litter	+		Balsam fir density	-	
	Logs	+		Ericaceous shrubs	-	
	Ericaceous shrubs	-				
All upland stands (n = 46)	Total density	-	0.432	Total density	-	0.380
	Debris	+		Debris	+	
	Coniferous litter	+		Ericaceous shrubs	-	
	Total *Sphagnum*	+				
	Mineral soil	-				
Upland mixedwoods, jack pine and shallow soils (n = 26)	Organic depth	-	0.403	Organic depth	-	0.712
	Total density	-		Moisture regime	+	
	Coniferous litter	+		Total density	-	
	Hardwood density	+				
	Debris	+				
	Bedrock	-				
	Mineral soil	-				
	Total moss cover	+				

balsam fir advance growth stocking was related to similar stand and site factors across all site types.

Based on the stand and site variables used in the different models, and the sign of their coefficients, some general ecological relationships of balsam fir advance growth abundance and distribution with stand and site variables can be inferred. Balsam fir advance growth was associated with open, older, mixedwood stands; with thin organic horizons (i.e., upland humus forms) on deep, fresh to moist soils; and with mixed forest floor materials, consisting of mosses, debris, coniferous litter, and logs. This is consistent with the fact that balsam fir is a nutrient-demanding species that prefers moderately rich to rich, mesic (fresh to moist) sites.

Figure 11 shows the actual black spruce stocking levels, and the stocking levels predicted by the multiple regression equations, for the lowland and upland mixedwood site groups. In both cases, the residuals are relatively well behaved (i.e., they are uniformly distributed about the regression line). The errors associated with the stocking predictions from the regression models were fairly high



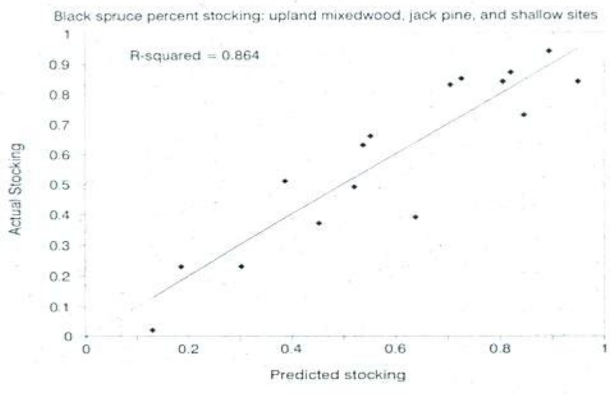


Figure 11. Actual percentage stocking values for black spruce advance growth, versus stocking values predicted by the multiple regressions, for lowland sites, and for upland mixedwood, jack pine, and shallow soil sites.

(in the order of plus or minus 20 percent stocking). Hence, these equations cannot be used to predict with precision the stocking of black spruce advance growth in any particular stand. However, more general models to predict advance growth abundance and distribution, based on stocking classes and on classes of site types and stand features, may prove to be feasible.

To test the ability to predict classes of stocking to black spruce advance growth using the stand and site variables, a multiple discriminant analysis was conducted on the stand level data set. Results of this analysis are summarized in Table 9. Stands were grouped into three classes of black spruce advance growth stocking (based on 4-m^2 quadrats): high (>70 percent stocking), medium (40–70 percent stocking), and low (0–40 percent stocking). Most of the variation in stocking class was explained by the first discriminant axis (*see* canonical correlations, Table 9), which was most strongly related to the amount of *Sphagnum* moss cover and the total basal area of the stands (*see* canonical loadings, Table 9). The second discriminant axis was most strongly related to the amount of black spruce in the stand, and to the amount of debris on the forest floor.

Using the stand and site factors listed in Table 9, the discriminant model was able to correctly predict the stocking class 76 percent of the time (*see* Table 10). The "high" stocking class (i.e., >70 percent stocking) was correctly discriminated from the other stocking classes

Table 9. Results of multiple discriminant analysis to differentiate black spruce advance growth stocking classes.

Canonical correlations between stocking classes and multiple discriminant axes.

Axis 1	Axis 2
0.765	0.429

Canonical loadings (correlations between conditional dependent variables and dependent canonical factors).

Variable	Axis 1	Axis 2
Total *Sphagnum* cover	-0.547	-0.068
Total moss cover	-0.531	-0.206
Total basal area	0.447	0.286
Percent black spruce	-0.407	-0.538
Organic depth	-0.330	0.129
Total density	-0.079	0.158
Debris cover	0.310	-0.633
Tall shrub cover	0.079	-0.229
Hardwood litter cover	0.381	0.412
Maximum tree age	-0.070	-0.225

approximately 87 percent of the time. These results suggest that broader classes of stocking to black spruce advance growth could be accurately predicted using a more general model incorporating stand and site factors.

Table 10. Table of frequencies of the actual advance growth stocking classes (rows) versus the stocking classes predicted by multiple discriminant analysis (columns).

	Predicted stocking			
Actual stocking	High	Medium	Low	Total
High	26	3	5	34
Medium	2	20	4	26
Low	1	5	19	25
Total	29	28	28	85

Stocking classes: high = >70%,
medium = 40–69%, and
low = <40%.

The sampled stands were subdivided into classes of percentage black spruce basal area, percentage *Sphagnum* moss cover, stand age, and total stand basal area to examine trends in mean black spruce advance growth stocking and density levels within site type groups. Table 11 compares the average stocking and density levels of black spruce advance growth, by site type groups, between relatively pure black spruce stands (those with a 90 percent or greater component of black spruce) versus mixed stands (those with less than 90 percent black spruce). Mixed stands generally had low average stocking levels. Relatively pure, lowland black spruce stands had high stocking levels, while relatively pure black spruce stands on uplands had medium stocking levels.

Table 12 compares the mean stocking and density of black spruce advance growth in site type groups by classes of percentage *Sphagnum* moss cover. Lowland stands with more than 35 percent total *Sphagnum* moss cover had high average stocking levels, while lowland stands with less

Table 11. Comparison of mean black spruce advance growth stocking and density levels in site type groups by percentage of black spruce basal area.

	Stocking			Density (stems/ha)		
	Percent black spruce			Percent black spruce		
Site type group	50–89	90–100	t-test	50–89	90–100	t-test
Lowlands	0.46	0.73	***	7 805	15 959	***
Black spruce-dominated uplands	0.38	0.54	*	4 721	9 761	**
Mixedwood uplands, jack pine, shallow soils	0.48	0.62	ns	10 338	10 472	ns
All stands	0.45	0.66	***	8 437	13 410	***

Significance levels for independent samples t-tests: ***= significant at p = .01,
** = significant at p = .05,
* = significant at p = .1, and
ns = nonsignificant.

Table 12. Comparison of mean black spruce advance growth stocking and density levels in site type groups by classes of percentage *Sphagnum* moss cover.

	Stocking			Density (stems/ha)		
	Sphagnum cover (%)			Sphagnum cover (%)		
Site type group	0–35	>35	t-test	0–35	>35	t-test
Lowlands	0.56	0.78	***	10 900	19 277	***
Black spruce-dominated uplands	0.45	0.58	*	7 551	10 354	ns
Mixedwood uplands, jack pine, shallow soils	na			na		
All stands	0.52	0.75	***	9 828	17 939	***

Significance levels for independent samples t-tests: *** = significant at p = .01,
** = significant at p = .05,
* = significant at p = .1, and
ns = nonsignificant.

than 35 percent *Sphagnum* moss cover had medium stocking levels. Black spruce-dominated uplands with a high cover of *Sphagnum* moss had medium stocking levels, while black spruce-dominated uplands with a low *Sphagnum* cover had low average stocking levels.

Table 13 compares mean stocking and density levels of black spruce advance growth within site type groups by stand age classes. Older lowland stands (greater than 120 years old) had high average stocking levels; all upland stands and younger lowland stands (less than 120 years old) had low to medium stocking levels.

Table 14 compares the average stocking and density levels of black spruce advance growth within site type groups by classes of stand basal area. Lowland stands with a low basal area (less than 30 m^2/ha) had high average stocking levels. Upland stands with a low basal area had medium to average stocking levels, while all stands with a high basal area (>30 m^2/ha) had low to medium stocking levels.

In general, older, relatively pure black spruce stands having a low basal area, a high cover of *Sphagnum* moss on the forest floor, and growing on lowland site types had the highest stocking levels of black spruce advance growth. Upland stands that were dominated by black spruce, with high levels of *Sphagnum* moss cover and with low total basal area, had medium stocking levels. Lowland stands with high basal area, less than 90 percent black spruce, and *Sphagnum* moss cover less than 35 percent had low to medium stocking levels. Upland stands with less than 90 percent black spruce, high total basal area, and low levels of *Sphagnum* moss cover had low stocking levels.

Regional Differences in Advance Growth Abundance

Average black spruce advance growth stocking and density levels reported by Walsh and Wickware (1991) in north central Ontario were lower compared with both the average levels encountered in this survey, and with those reported

Table 13. Comparison of mean black spruce advance growth stocking and density levels in stand groups by stand age classes.

	Stocking			Density (stems/ha)		
	Stand age (years)			Stand age (years)		
Site type group	0–120	>120	t-test	0–120	>120	t-test
Lowlands	0.59	0.72	**	10 475	17 894	***
Black spruce-dominated uplands	0.46	0.51	ns	7 137	10 584	ns
Mixedwood uplands, jack pine, shallow soils	0.54	0.50	ns	11 106	9 230	ns
All stands	0.53	0.66	***	9 566	15 475	***

Significance levels for independent samples t-tests: *** = significant at p = .01,
** = significant at p = .05,
* = significant at p = .1, and
ns = nonsignificant.

Table 14. Comparison of mean black spruce advance growth stocking and density levels in stand groups by stand basal area classes.

	Stocking			Density (stems/ha)		
	Total basal area (m^2/ha)			Total basal area (m^2/ha)		
Site type group	>30	0–30	t-test	>30	0–30	t-test
Lowlands	0.45	0.81	***	6 925	20 306	***
Black spruce-dominated uplands	0.40	0.56	*	5 853	10 933	*
Mixedwood uplands, jack pine, shallow soils	0.48	0.57	ns	10 520	10 285	ns
All stands	0.44	0.71	***	7 436	16 383	***

Significance levels for independent samples t-tests: *** = significant at p = .01,
** = significant at p = .05,
* = significant at p = .1, and
ns = nonsignificant.

Table 15. Comparison of mean black spruce and balsam fir advance growth stocking and density levels for stands located within and outside the Clay Belt, by FEC site types.

	Mean Stocking			Mean Density (stems/ha)		
Site type	Stands in the Clay Belt	Stands not in the Clay Belt	P-level	Stands in the Clay Belt	Stands not in the Clay Belt	P-level
Black spruce						
8	0.57	0.63	ns	12 319	10 511	ns
11	0.80	0.72	*	20 486	13 507	**
12	0.69	0.56	ns	15 122	7 593	**
13	0.48	0.40	ns	7 066	5 884	ns
14	0.91	0.92	ns	25 036	24 700	ns
All stands	0.67	0.62	ns	15 019	11 006	**
Balsam fir						
8	0.37	0.50	ns	5 988	6 523	ns
11	0.17	0.17	ns	3 494	1 310	ns
12	0.21	0.38	ns	2 368	4 526	ns
13	0.28	0.49	*	2 438	5 992	*
14	0.02	0.04	ns	167	120	ns
All stands	0.23	0.34	**	3 127	3 957	ns

Probability levels for independent samples t-tests: ** = significant at p = .01,
* = significant at p = .05, and
ns = nonsignificant.

by Groot (1984) in the Clay Belt. Regional differences in the abundance and distribution of black spruce advance growth may exist, perhaps as a result of differing macroclimatic conditions between northeastern and northwestern Ontario. In general, northeastern Ontario has more rainfall and a higher relative humidity than does the northwestern part of the province. These conditions may be more conducive to the establishment of black spruce seedlings and layers. Within northeastern Ontario, the Clay Belt is somewhat cooler, moister, and has a higher relative humidity than does the remainder of the region (Chapman and Thomas 1968).

To test for regional differences in the abundance of black spruce advance growth, stands in the data set were divided into those occurring within the Clay Belt and those occurring in the southern and western parts of the study area, outside the Clay Belt. Table 15 summarizes the average stocking and density levels for black spruce and balsam fir advance growth, by FEC site types, for stands located within the Clay Belt versus those located within the remainder of the region (sample sizes for the site types not listed were too small to compare meaningfully). While there was a tendency for stands located in the Clay Belt to have somewhat higher average stocking levels, the differences are small in magnitude and are generally not statistically significant. Density levels for black spruce advance growth also tend to be somewhat higher in the Clay Belt, but the differences are significant only for Site Types 11 and 12.

There is a tendency for stocking and density of balsam fir advance growth to be slightly higher for stands in the south and west parts of the region, compared to stands in the Clay Belt. However, the differences are generally small in magnitude and few are statistically significant. It would appear that within northeastern Ontario, regional macroclimatic differences do not have a significant effect on the abundance and distribution of either black spruce or balsam fir advance growth. Hence, the relationships of advance growth abundance and distribution with FEC site types and with stand and site factors reported herein should be applicable throughout northeastern Ontario.

Applications

While the regression models described in the previous section are useful for understanding how the abundance and distribution of advance growth is related to stand and site factors, they are of limited usefulness to the forest manager. Forest managers need simpler tools for identifying those stands having the potential for abundant advance growth. Tools should be related to forest inventory, preharvest inspection information, or identified on aerial photographs. Stand factors that can be related to the forest inventory will assist managers in forest-level planning for the management of advance growth. Stand and site factors that can be recognized on aerial photos will assist managers in classifying the potential for advance growth in individual stands to determine if harvesting and silvicultural prescriptions to preserve advance growth are warranted.

Since stand basal area, stand age, and the percentage of black spruce in the stand are features described by the Forest Resource Inventory, the general relationships of advance growth with these factors (described in the previous section) could be used to identify FRI stands that have a high potential for black spruce advance growth. If FEC information is available, this could be used in conjunction with FRI stand information for a more refined prediction of advance growth potential. A simple key that uses FEC site types and stand factors that can be related to the FRI to predict the potential for black spruce advance growth is shown in Figure 12. Three classes of black spruce advance growth potential were identified:

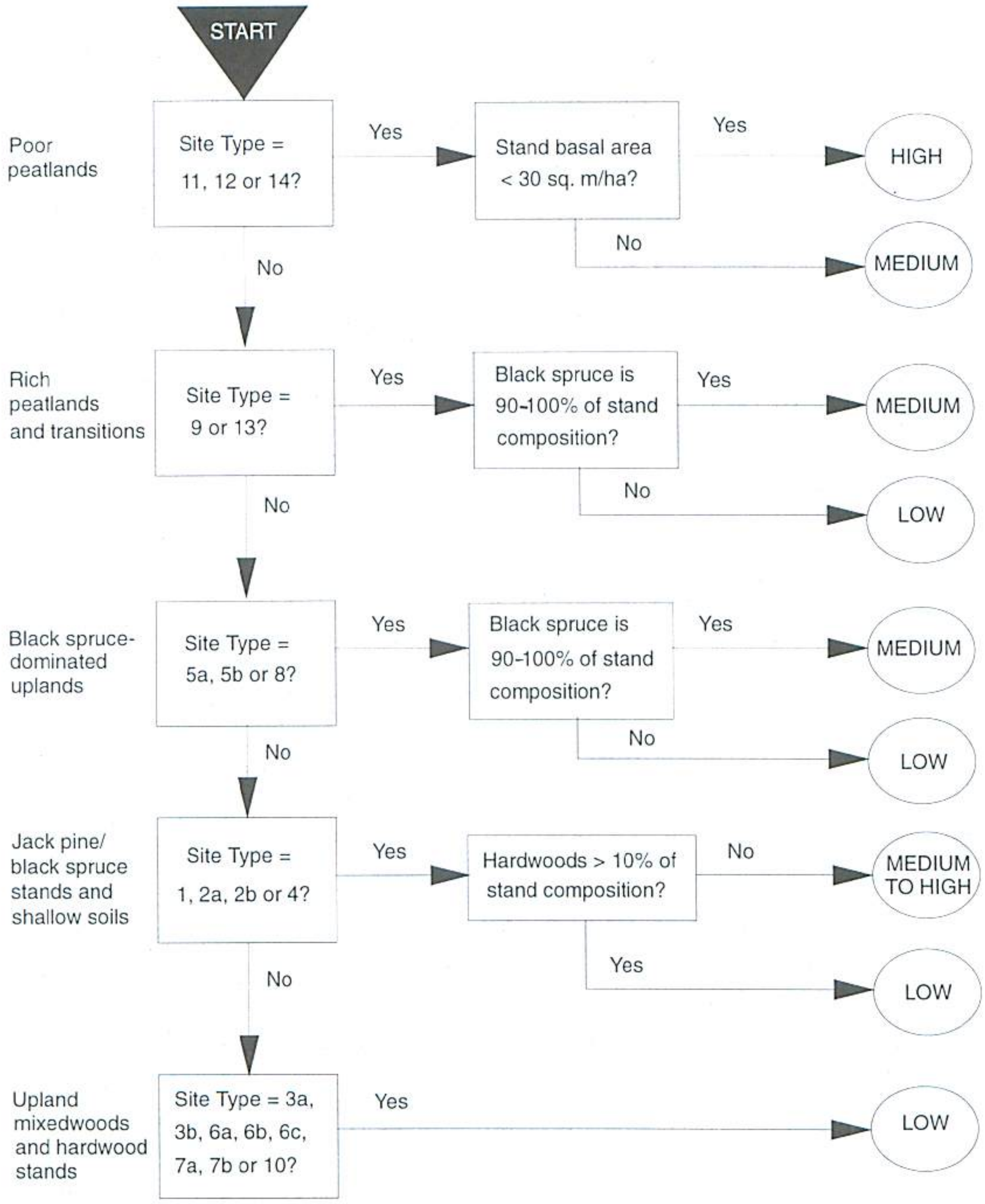


Figure 12. Forest-level key to determine the potential for black spruce advance growth using FEC site types and forest stand information.

1. High—stands with ≥70 percent stocking to advance growth;

2. Medium—stands with 40–69 percent stocking to advance growth; and

3. Low—stands with <40 percent stocking.

This key is intended for use only with forest level planning applications. Since there is considerable variation in advance growth stocking levels within site types, and errors may be associated with the FRI, predictions of advance growth potential for individual stands should be treated with caution. Field inspections should be conducted to confirm advance growth stocking levels for individual stands.

Collection of detailed field information on site and stand conditions and advance growth abundance within every stand allocated for harvesting is impractical due to cost and access constraints. Therefore, the potential to identify stands showing abundant advance growth on aerial photographs was explored. Black and white, 1:20 000 scale aerial photographs (i.e., standard FRI photographs) were obtained for each of the stands sampled in this survey. Each stand was described according to its gray tone, stand pattern, amount of canopy closure, size of canopy openings, size and number of linear drainageways, position on slope, slope complexity, grade (slope percent), tree species composition, percent black spruce, and, where visible, the appearance of the understory. Descriptions of these photo attributes are included in Appendix 3. Since aerial photo interpretation is subjective in nature, three persons described each stand independently to determine if attributes were replicable between interpreters.

As noted earlier, the stands were grouped into three classes of advance growth stocking. A multiple discriminant analysis was then used to determine if any of the aerial photo attributes were useful in discriminating advance growth stocking classes. Species composition, percent black spruce, slope grade, position on slope, number of linear drainageways, and stand pattern were significantly related to the discriminant axes, and were consistently described by all interpreters. The general relationships between these photo attributes and the stand stocking levels to advance growth are summarized in Table 16.

Based on these results, the descriptions of photo attributes were refined and an aerial photo interpretation key was developed (*see* Figure 13). A fourth interpreter then described a subset of 49 stands to test the key. Using the key, the interpreter correctly identified the stocking class for 78 percent of the stands, and correctly discriminated the "high" stocking class from the medium and low classes for 84 percent of the stands (*see* Table 17).

It would seem that the potential for black spruce advance growth can be predicted with a reasonable level of accuracy using features observable on standard FRI photographs. Hence, this key provides a method that forest managers can use to determine the potential for black spruce advance growth prior to harvesting individual forest stands. However, predictions of advance growth potential determined by using the key should be treated with due caution. Aerial photographs vary in quality, and thus add to the difficulty of interpretation of specific features. Depending on the amount of variation in the topography, many black spruce stands are quite variable in appearance. Subdividing stands into portions with a more homogeneous appearance will help in some cases, but may not be practical if the stand is extremely variable. Such stands will be difficult to describe.

Due to the likelihood of errors in predicting advance growth potential for individual stands, the aerial photo interpretation key is intended for use with forest-level

Table 16. General relationships between aerial photo attributes and black spruce advance growth stocking classes.

	Advance growth stocking class		
Photo attribute	High	Medium	Low
Pattern	Uniform Stippled	Mottled Patchy	Patchy Banded
Position on slope	Toe Depression Lowland flat	Lower Middle	Upper Crest
Percent black spruce	90–100	80–90	<80
Stand type	Conifer	Mixed conifer	Mixed hardwood and hardwood
Slope grade	Level	Gentle	Moderate to steep
Drainage pattern (Number of linear drainage corridors)	None Few	Medium	Many

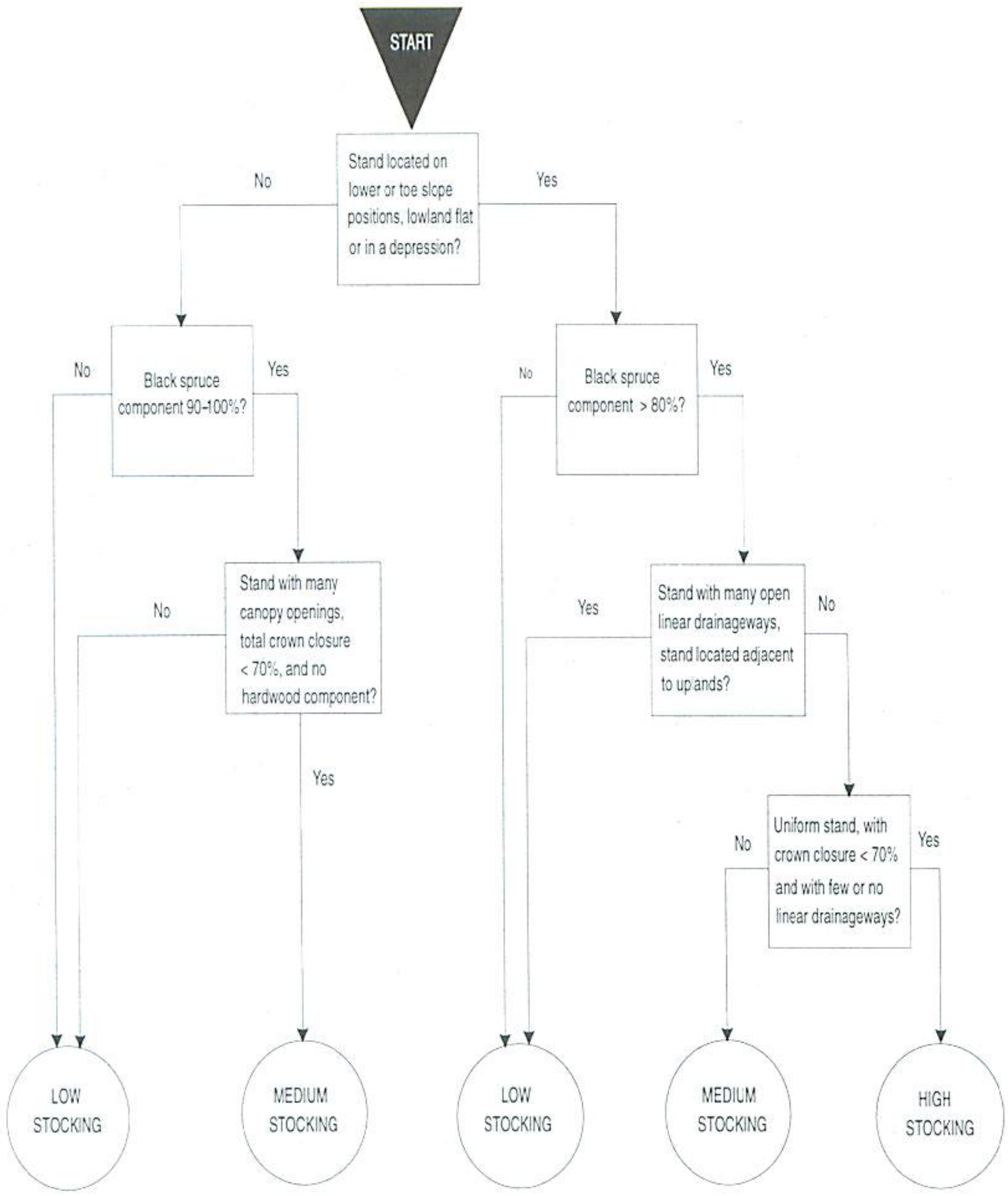


Figure 13. Key to determine the potential for black spruce advance growth for forest stands using 1:20000 scale black and white aerial photographs.

Table 17. Actual black spruce stocking classes (rows) versus the stocking classes predicted by using the aerial photo interpretation key (columns).

Actual stocking class	Predicted stocking class High	Medium	Low	Total
High	15	6	0	21
Medium	2	14	3	19
Low	0	0	9	9
Total	17	20	12	49

planning applications. Users are encouraged to conduct rigorous testing of the key prior to application. Since local conditions vary, further refinement of the key may be necessary.

CONCLUSION

The abundance and distribution of advance growth was found to be well related to specific stand and site conditions. In general, black spruce advance growth was most abundant in nutrient-poor, black spruce-dominated stands, especially those located on wet peatlands. The highest stocking and density levels of balsam fir advance growth were encountered in fresh to moist, medium to rich, spruce–fir stands.

The advance growth encountered in this survey was predominantly small in size (< 50 cm in height). Larger black spruce advance growth (i.e., larger than 2 m in height) was relatively abundant only on peatlands. Larger balsam fir advance growth (> 2 m in height) was most abundant on upland mixedwood sites.

Stand conditions related to the abundance and distribution of black spruce advance growth included:

- *Total basal area of the stand.* Advance growth stocking and density levels were highest in stands with a low basal area (less than 30 m^2/ha). High basal area in the stand, especially when combined with tall shrub cover, may also cause black spruce trees to lose their lower branches and thereby reduce the opportunity for layering.
- *Stand productivity.* Advance growth stocking and density levels were highest in low-productivity black spruce stands. These stands often have a low basal area but high density; continuous moss carpets on the forest floor; and on moist or wet sites, abundant *Sphagnum* mosses. These conditions are most suitable for layering to occur. Stands associated with richer nutrient regimes often have abundant shrubs and herbs in the understory and, hence, less moss cover and more debris and leaf litter on the forest floor. These forest floor conditions may be less conducive to layering.
- *Percent black spruce in the stand.* Advance growth stocking and density levels were highest in pure or relatively pure black spruce stands (more than 80 percent black spruce).
- *Stand age.* Black spruce advance growth stocking and density levels tended to be higher in older stands than in younger stands. This may be related to the amount of time needed for abundant layerings to develop. Also, layerings and seedlings may become established in openings that develop in overmature stands with canopy break-up. This latter relationship is likely to be highly variable due to temporal variability in mortality occurring in such stands (e.g., blowdown related to wind storms).

Site conditions related to the abundance and distribution of black spruce advance growth included:

- *The abundance of tall woody shrubs in the understory.* Shading may cause black spruce trees to lose their lower branches and thereby reduce the opportunity for layering. On peatlands, speckled alder is the most common tall shrub species. Leaf litter accumulations from woody shrubs may also reduce the receptivity of the forest floor for layering.
- *The abundance of* Sphagnum *mosses. Sphagnum* provides the best substrate for layering since it remains continuously moist and grows quickly, covering lower branches that are located at the ground surface. *Sphagnum* mosses are most abundant on nutrient-poor, wet peatlands, and are associated with herb-poor, black spruce-dominated uplands and moist depressions in bedrock sites. *Sphagnum* mosses also provide excellent seedbeds for the germination of black spruce seeds.
- *The abundance of materials on the forest floor that inhibit or reduce layering.* Black spruce advance growth was less abundant on sites with leaf litter, debris, logs, and water-filled depressions on the forest floor. Feathermosses provide a less suitable substrate for layering since they grow more slowly than *Sphagnum* mosses and dry out quickly when exposed. However, some layering was observed on moist feathermoss substrates on herb-poor, fresh to moist, black spruce-dominated upland sites and on shallow soil sites.
- *Plant species that were associated with nutrient-poor, black spruce-dominated sites.* Poor black spruce stands are often associated with ericaceous shrubs, including Labrador-tea, sheep laurel (*Kalmia angustifolia* L.), blueberries (*Vaccinium* spp.), and leatherleaf. These species (and others) often occur in association with advance growth, but are probably not related to its development.

Stand and site conditions related to the abundance of balsam fir advance growth included:

- *Stand productivity.* Stocking and density levels of balsam fir advance growth were highest in medium to rich, conifer-dominated mixedwoods. They were lowest in poor, black spruce-dominated stands.
- *Stand age.* Stocking and density levels of balsam fir advance growth tended to be higher in older stands.
- *Species composition.* High stocking and density levels of balsam fir advance growth were frequently associated with stands containing white spruce and/or hardwood components.
- *Soil moisture regime.* Stocking and density levels of balsam fir advance growth were highest on fresh to moist soils having thin organic layers. They were lowest on wet peatland sites.

- *The nature of materials on the forest floor.* Balsam fir advance growth was associated with stands that had a mixture of materials, including mosses, debris, decomposed logs, needle litter, leaf litter, and exposed mineral soil, on the forest floor. These materials provide suitable seedbeds for the germination of balsam fir. Unlike black spruce, balsam fir advance growth was not related to the abundance of *Sphagnum* mosses. It is possible that *Sphagnum* substrates occurring on acidic, nutrient-poor, peatland sites do not supply sufficient nutrients for balsam fir seedlings to survive.

FEC site types integrate information about a number of these stand and site features, including soil moisture regime, organic matter depth, the abundance of *Sphagnum* mosses and other materials on the forest floor, understory vegetation, and stand species composition. Hence, the FEC site types provide a useful framework for understanding the distribution of black spruce and balsam fir advance growth in forested ecosystems in northeastern Ontario.

- Nutrient-poor, black spruce-dominated peatlands, including Site Types 11, 12, and 14, generally had high stocking and density levels to black spruce advance growth.
- Nutrient-poor, black spruce-dominated upland sites, including Site Types 4, 5a, 5b, and 8, generally had intermediate stocking and density levels.
- Nutrient-poor, dry shallow soils, and jack pine-dominated stands, including Site Types 1, 2a, and 2b, sometimes had high levels of black spruce advance growth, but advance growth abundance levels were generally quite variable in these site types.
- Rich, moist to wet, coniferous mixedwoods, including Site Types 9 and 13, generally had intermediate to low stocking and density levels.
- Fresh to moist, upland hardwood–mixedwoods and hardwood sites, including Site Types 3a, 3b, 6a, 6b, 6c, 7a, 7b, and 10, generally had low stocking and density levels.
- Mesic, mixed coniferous upland spruce–fir sites, including Site Types 6a, 6b, and 6c, generally had high stocking and density levels to balsam fir advance growth.
- Mesic to rich hardwood–mixedwoods on uplands, rich, moist mixedwoods, and moist hardwood sites, as well as sites on shallow soils, including Site Types 1, 3a, 3b, 7a, 7b, 9, and 10, generally had intermediate stocking and density levels to balsam fir advance growth.
- Poor, dry, jack pine-dominated stands, including Site Types 2a and 2b, generally had low stocking and density levels.
- Nutrient-poor, black spruce-dominated stands on dry to wet conditions, including Site Types 4, 5, 8, 11, 12, 13, and 14, also had low stocking and density levels. Balsam fir advance growth was least abundant on peatland sites occurring on organic soils.

The relationships between black spruce and balsam fir advance growth and the stand and site factors can be related to forest inventory. FRI attributes such as species composition, stand age, stocking, and site class (the latter two attributes are related to stand basal area) are all related to the abundance and distribution of advance growth.

If FEC inventory, or FEC information collected during a preharvest inspection, is available to the forest manager, the relationships of advance growth abundance to the FEC site types will be useful in identifying stands with the capability to support different levels of abundance of advance growth. Since there is considerable variability in stocking and density levels to advance growth within FEC site types, FEC information used in conjunction with stand data may provide more accurate predictions of advance growth potential.

Stand and site features visible on aerial photographs can be used to identify stands that have ecological characteristics associated with high levels of advance growth. Aerial photo interpretation could also be used to double-check or to refine predictions of advance growth potential that were determined using FRI and/or FEC information.

Tools were provided to assist forest managers in recognizing stands with the capability to support abundant black spruce advance growth. These tools included a key for interpreting FEC and stand information, and a key for interpreting aerial photographs. The keys are intended for use mainly as forest-level planning aids. The keys may also allow managers to optimize limited resources for field work by helping to select areas for field inspection.

Since temporal variation in advance growth abundance and distribution cannot be predicted using these tools, they can only be used to identify areas with the potential (or capability) for supporting high levels of advance growth. Hence, it is recommended that predictions of advance growth levels for individual stands should be confirmed with visual inspections. Large-scale photography may also offer the potential to confirm advance growth levels in inaccessible areas.

Once stands having high levels of advance growth have been identified, silvicultural prescriptions to protect the advance growth during harvesting can be planned and implemented. Preservation of advance growth offers a number of advantages. Harvesting and regeneration operations can be better integrated. Since preserving advance growth takes advantage of existing stock in the stands, the burden on seed and tree production programs is reduced. Layer origin black spruce trees will grow equal to or greater than planted or seeded trees following harvesting. The initial height advantage of advance growth over planted or seeded trees enables it to compete better for site resources. Potential benefits include an increased long-term harvest volume and growing stock and a shortened rotation period (Archibald and Arnup 1993).

Careful logging is also beneficial to the forest environment. Machine travel on the site during harvesting is restricted to specified travel corridors so that large portions of the area remain undisturbed. Careful logging is conducted either on frozen ground, or in the frost-free period using high-flotation equipment. This reduces ground disturbance, preserves seedbeds, and reduces rutting and compaction. This reduced ground disturbance can also result in less proliferation of competing vegetation which, in turn, may reduce the need for future vegetation management treatments. Preserving larger advance growth stems in significant numbers increases shading and results in the protection of seedbeds and the moderation of microclimates.

Preserving the advance growth component of a stand during harvest meets the criteria commonly associated with gene conservation. Careful logging to preserve advance growth will also provide wildlife habitat forms that will be more complex than the structurally simpler habitats created by traditional clear-cutting. This can result in protecting or creating more potential niches. In addition, minimizing damage to advance growth during harvest will ensure that the incidence of disease and insect pests remains relatively low (Archibald and Arnup 1993).

The Ontario Ministry of Natural Resources has been exploring the feasibility of regenerating black spruce ecosystems in northeastern Ontario by protecting the advance growth component during harvesting operations. As a result, several forest industry companies have implemented programs to preserve the advance growth in black spruce ecosystems. This has been accomplished through combinations of preharvest planning, careful logging, the use of high-flotation technology, winter logging, modified felling methods and forwarding patterns, and intensive operator training. Readers are encouraged to refer to Archibald and Arnup (1993) for further details on careful harvesting methods that protect advance growth.

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APPENDIX 1. Locational information and FRI stand listings for surveyed stands.

Plot No.	MNR district	Township	Grid	Easting	Northing	FRI stand	Species composition	Age (y)	Height (m)	Stocking	Site class	Area (ha)
01	TIMMINS	FALLON	17U	495580	5345600	14	SB10	60	11	0.5	2	37
02	TIMMINS	FALLON	17U	497020	5344410	34	SB8BW2	80	14	0.6	1	29
03	TIMMINS	BEEMER	17U	473870	5325520	49	SB7B2CE1	90	14	0.7	2	53
04	TIMMINS	BEEMER	17U	474275	5319135	117	SB10	90	9	0.8	3	10
05	TIMMINS	MCNEIL	17U	505115	5336050	30	SB10	120	15	0.7	2	24
06	GOGAMA	STLOUIS	17T	439360	5278680	36	SB10	90	21	0.5	x	5
07	GOGAMA	CHESTER	17T	434583	5268188	71	B5SB2BW2PO1	40	12	0.8	x	66
08	GOGAMA	CARTER	17T	441474	5293027	131	BW4SB3PO2BY1	70	16	0.5	3	42
09	GOGAMA	GARABALDI	17T	465577	5256386	134	SB9PJ1	75	12	0.5	2	15
10	GOGAMA	JACK	17T	444700	5284200	118	SB8PO1BW1	55	14	0.4	x	124
11	GOGAMA	STLOUIS	17T	439360	5279100	40	SB9BW1	100	19	0.6	x	49
12	GOGAMA	STLOUIS	17T	439360	5278680	36	SB10	90	20	0.5	x	13
13	GOGAMA	STLOUIS	17T	439500	5278200	35	SB8BW2	80	17	0.4	1	23
14	GOGAMA	STLOUIS	17T	439100	5277800	32	SB9BW1	79	20	0.3	1	23
15	GOGAMA	STLOUIS	17T	438700	5277100	11	SB6BW2PO2	50	13	0.8	x	19
16	GOGAMA	STLOUIS	17T	438680	5276900	182	SB8BW1PO1	75	18	0.4	x	33
17	GOGAMA	STLOUIS	17T	437600	5274200	191	SB7BW3	60	17	0.5	x	28
18	GOGAMA	NEVILLE	17T	436100	5273700	252	SB7CE2B1	80	10	0.4	3	35
19	GOGAMA	NEVILLE	17T	436000	5272000	257	SB9B1	77	11	0.3	2	19
20	GOGAMA	HAZEN	17T	454600	5299200	243	SB6BW2PO2	40	9	0.6	1	25
21	GOGAMA	HAZEN	17T	454400	5304500	252	SB8PO1BW1	105	15	0.7	2	14
22	CHAPLEAU	SANDY	17T	358200	5317000	67	SB8PJ1SW1	70	14	0.5	1	55
23	CHAPLEAU	SANDY	17T	357400	5317500	58	SB8SW1PJ1	110	17	0.7	1	27
24	CHAPLEAU	SANDY	17T	356200	5316800	60	SB9PJ1	77	17	0.4	x	36
25	CHAPLEAU	SANDY	17T	355600	5316300	164	SB8L2	79	13	0.7	2	44
26	CHAPLEAU	DAOUST	17T	324180	5288540	276	SB10	120	13	0.6	3	30
27	HORNEPAYNE	BEATON	16U	674325	5436128	82	SB9L1	100	9	0.3	3	21
28	HORNEPAYNE	LIPTON	16U	678683	5422909	579	PJ6SB3PO1	70	15	1.0	3	49
29	HORNEPAYNE	HORNEPAYNE	16U	661490	5452260	461	SB10	90	14	1.0	2	31
30	HORNEPAYNE	HORNEPAYNE	16U	662030	5460270	143	SB9PJ1	76	13	0.5	1	20
31	HORNEPAYNE	HORNEPAYNE	16U	662498	5464476	23	CE6SB4	67	8	0.6	3	27
32	HORNEPAYNE	ELGIE	16U	665320	5471600	294	SB6PO3BW1	80	14	0.7	1	21
33	HORNEPAYNE	HORNEPAYNE	16U	662005	5561730	148	SB9L1	74	13	0.9	2	20
34	HORNEPAYNE	ELGIE	16U	665500	5471950	306	SB8PJ2	90	14	0.8	2	18
35	HORNEPAYNE	ELGIE	16U	666240	5479240	121	SB9L1	145	11	0.6	4	30
36	TIMMINS	BRISTOL	17U	464034	5364773	78	SB10	68	12	0.4	2	26
37	TIMMINS	BRISTOL	17U	463249	5365552	74	SB10	73	12	1.0	2	14
38	TIMMINS	GODFREY	17U	460413	5366372	276	SB6PO2PJ1B1	95	14	0.6	2	28
39	TIMMINS	DENTON	17U	452603	5356114	77	SB6B4	58	9	0.6	2	42
40	TIMMINS	BRISTOL	17U	463900	5362644	105	SB8B1BW1	98	1	0.5	3	68
41	TIMMINS	BRISTOL	17U	452429	5366244	22	SB10	8	6	0.6	2	26
42	TIMMINS	THORNLOE	17U	456955	5354335	106	SB9PJ1	63	0	0.4	2	46
43	TIMMINS	BRISTOL	17U	459427	5359478	297	SB10	73	10	0.4	2	55
44	TIMMINS	THORNLOE	17U	457067	5353654	0		0	0	0.0	2	0
45	TIMMINS	THORNLOE	17U	465432	5353365	56	Sb7B2CE1	78	11	0.4	2	15
46	TIMMINS	PRICE	17U	465570	5353371	137	PJ5SB5	85	21	0.7	1	16
47	TIMMINS	THORNLOE	17U	457288	5355549	11	SB9L1	76	16	0.4	1	35
48	CHAPLEAU	FOLEYET	17U	384503	5339611	582	SB10	76	17	0.8	X	24
49	CHAPLEAU	FOLEYET	17U	383736	5340853	565	SB9 BW1	157	18	0.5	1	15
50	CHAPLEAU	FOLEYET	17U	383183	5340897	561	SB6PO2CE1BW1	72	18	0.6	X	16
51	CHAPLEAU	EVANS	17U	362650	5320263	374	SB10	79	15	0.7	1	20
52	CHAPLEAU	EVANS	17U	362937	5321085	380	SB8CE1L1	100	15	0.5	2	32
53	CHAPLEAU	EVANS	17U	363165	5323009	242	SB7SW2PO1	100	17	0.6	X	14
54	CHAPLEAU	EVANS	17U	363378	5323865	196	SB10	100	15	0.8	2	19
55	CHAPLEAU	EVANS	17U	363735	5325189			100	23	0.7	1	90
56	CHAPLEAU	EVANS	17U	363173	5322972	342	SB6 PJ2 PO1 SW1	100	17	0.6	1	28
57	CHAPLEAU	FOLEYET	17U	394782	5348798	169	SB9BW1	50	11	0.6	1	17
58	CHAPLEAU	FOLEYET	17U	394903	5347574	188	SB7PJ3	50	9	0.4	2	11
59	CHAPLEAU	CARTY	17U	380889	5333681	275	SB6 CE3 L1	120	14	0.5	2	27
60	CHAPLEAU	MURDOCK	17U	358072	5321141	209	SB9L1	120	14	0.8	2	51

(cont'd)

APPENDIX 1. Locational information and FRI stand listings for surveyed stands. (concl.)

Plot No.	MNR district	Township	Grid	Easting	Northing	FRI stand	Species composition	Age (y)	Height (m)	Stocking	Site class	Area (ha)
61	CHAPLEAU	MURDOCK	17U	358621	5320745	226	SB9PJ1	110	18	0.9	1	35
62	CHAPLEAU	SANDY	17U	358533	5319569	71	SB6 PJ2 CE2	112	16	0.7	2	40
63	CHAPLEAU	SANDY	17U	358666	5319290	73	SB9L1	97	13	0.6	2	30
64	CHAPLEAU	SANDY	17U	358757	5318864	80	SB6 PJ4	110	17	0.8	1	19
65	COCHRANE	STIMSON	17U	529372	5425486	168	SB10	80	11	0.7	2	43
66	COCHRANE	STIMSON	17U	530017	5427419	94	SB10	120	12	0.8	3	30
67	COCHRANE	STIMSON	17U	530458	5428495	98	SB9 PJ1	110	14	0.7	2	32
68	COCHRANE	SWARTMAN	17U	514976	5481300	4709	SB8 L1 CE1	150	14	0.7	3	71
69	COCHRANE	POTTER	17U	517504	5465360	7255	SB10	110	10	0.4	3	13
70	COCHRANE	51549	17U	517170	5496302	7064	SB10	110	12	0.6	3	87
71	COCHRANE	51549	17U	517189	5494315	6835	SB9 PO1	110	15	0.8	2	116
72	COCHRANE	51549	17U	519090	5494913	9252	SB10	140	16	0.8	2	53
73	COCHRANE	POTTER	17U	516223	5465030	5647	SB8 L2	110	11	0.5	3	36
74	COCHRANE	POTTER	17U	517264	5465077	6856	SB10	130	18	0.8	1	111
75	COCHRANE	STIMSON	17U	527219	5433600	22	SB9 BW1	70	9	0.9	2	22
76	COCHRANE	STIMSON	17U	526777	5433524	16	SB10	65	7	0.8	2	39
77	KAPUSKASING	FLECK	17U	357962	5517096	157	SB10	110	15	0.6	2	318
78	KAPUSKASING	FLECK	17U	357952	5514422	277	SB9 L1	110	13	0.8	2	39
79	KAPUSKASING	FLECK	17U	357925	5513535	280	SB10	120	13	0.7	3	43
80	KAPUSKASING	SWANSON	17U	400109	5455317	354	SB10	98	16	0.9	1	33
81	KAPUSKASING	SWANSON	17U	400168	5457924	677	SB7 PO3	98	17	0.8	1	19
82	KAPUSKASING	SWANSON	17U	400479	5458776	388	SB8 PO2	98	17	0.8	1	12
83	KAPUSKASING	CASSELMAN	17U	396565	5443153	5833	SB10	98	18	1.0	1	50
84	KAPUSKASING	CASSELMAN	17U	396565	5443153	7323	SB10	98	19	1.0	X	53
85	KAPUSKASING	CASSELMAN	17U	395355	5439555	5703	SB8 PO2	98	18	0.9	1	29

APPENDIX 2. Step-wise multiple regressions for black spruce advance growth.

1. Black spruce advance growth stocking, all stands (n=85).

Equation for the model:

Stocking = + .581021 + .000936* organic depth - .040352* moisture regime + .000093* stand density - .012258* total basal area - 1.242062* % debris - .270053* feathermoss cover + .741333* total moss cover

DEP VAR: Stocking	N: 85	MULTIPLE R: 0.804	SQUARED MULTIPLE R: 0.647
ADJUSTED SQUARED MULTIPLE R: .615		STANDARD ERROR OF ESTIMATE: .151290	

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	0.581021	0.125072	0.000000	.	4.64551	0.00001
DOM	0.000936	0.000460	0.255360	0.2903858	2.03225	0.04558
MR	-0.040352	0.013578	-0.358208	0.3155948	-2.97192	0.00395
TDENS	0.000093	0.000049	0.191978	0.4491904	1.90021	0.06115
TOTBA	-0.012258	0.002520	-0.494299	0.4438746	-4.86358	0.00001
DEBRIS	-1.242062	0.697700	-0.129285	0.8693271	-1.78022	0.07898
FMOSS	-0.270053	0.121182	-0.228113	0.4375733	-2.22850	0.02876
TOTMOSS	0.741333	0.175852	0.485333	0.3459221	4.21566	0.00007

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	3.229795	7	0.461399	20.158329	0.000000
RESIDUAL	1.762435	77	0.022889		

2. Stocking, lowland site types 11, 12, 13, 14 (n=39).

Equation for the model:

Stocking = + .380747 - .008929* total basal area + .506382* percent black spruce - 2.303242* hardwood litter cover + .285627* total Sphagnum moss cover

DEP VAR: SBSTK2	N: 39	MULTIPLE R: 0.838	SQUARED MULTIPLE R: 0.703
ADJUSTED SQUARED MULTIPLE R: .668		STANDARD ERROR OF ESTIMATE: 0.134259	

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	0.380747	0.203960	0.000000	.	1.86677	0.07058
TOTBA	-0.008929	0.002638	-0.396385	0.6375541	-3.38496	0.00181
SBBAPCT	0.506382	0.174764	0.328260	0.6811807	2.89752	0.00654
HDWDLIT	-2.303242	0.988799	-0.236752	0.8462882	-2.32933	0.02592
TOTSPHAG	0.285627	0.124778	0.247432	0.7482646	2.28909	0.02841

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	1.448922	4	0.362231	20.095434	0.000000
RESIDUAL	0.612868	34	0.018026		

3. Stocking, black spruce-dominated upland site types 5,8,9 (n=20).

Equation for the model:

Stocking = - .301509 + .001816* maximum age + .004014* hardwood density
+ .453449* percent black spruce + .601770* total Sphagnum moss cover

DEP VAR: Stocking N: 20 MULTIPLE R: 0.879 SQUARED MULTIPLE R: 0.772
ADJUSTED SQUARED MULTIPLE R: .711 STANDARD ERROR OF ESTIMATE: 0.104579

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	-0.301509	0.182123	0.000000	.	-1.65552	0.11858
MAXAGE	0.001816	0.000939	0.250920	0.9033585	1.93463	0.07213
HDWDDENS	0.004014	0.000940	0.566740	0.8622164	4.26898	0.00067
SBBAPCT	0.453449	0.175564	0.333957	0.9089516	2.58281	0.02080
TOTSPHAG	0.601770	0.124969	0.638464	0.8644170	4.81537	0.00023

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	0.555649	4	0.138912	12.701430	0.000104
RESIDUAL	0.164051	15	0.010937		

4. Stocking, upland mixedwoods, jack pine/black spruce and shallow soil site types 1, 2, 3, 4, 6, 7, 10 (n=26).

Equation for the model:

Stocking = + .611353 - 0.069264* moisture regime - 0.004599* average age - 0.003768* total basal area
+ 1.945678* willow cover - 0.422567* feathermoss cover + 1.354451* total moss cover

DEP VAR: Stocking N: 6 MULTIPLE R: 0.947 SQUARED MULTIPLE R: 0.897
ADJUSTED SQUARED MULTIPLE R: .864 STANDARD ERROR OF ESTIMATE: 0.096411

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	0.611353	0.180207	0.000000	.	3.39251	0.00306
MR	-0.069264	0.014954	-0.400321	0.7292196	-4.63191	0.00018
AVGAGE	-0.004599	0.001151	-0.316363	0.8693206	-3.99666	0.00077
TOTBA	-0.003768	0.002451	-0.142695	0.6322242	-1.53733	0.14070
OSHRUB	1.945678	0.839025	0.243096	0.4956708	2.31897	0.03169
FMOSS	-0.422567	0.195101	-0.350876	0.2075477	-2.16588	0.04325
TOTMOSS	1.354451	0.218747	1.117437	0.1672442	6.19185	0.00001

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	1.529855	6	0.254976	27.431325	0.000000
RESIDUAL	0.176606	19	0.009295		

5. Black spruce advance growth density, all stands (n=85).

Equation for the model:

Density = - 2671.8 + 115.3* average age + 6.3* total density - 456.9* total basal area + 12035.0* total moss cover - 815.0* total basal area* tall woody shrub cover

DEP VAR: SBD N: 85 MULTIPLE R: 0.656 SQUARED MULTIPLE R: 0.431
ADJUSTED SQUARED MULTIPLE R: .395 STANDARD ERROR OF ESTIMATE: 7175.628572

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	-2671.762130	5448.636798	0.000000	.	-0.49035	0.62524
AVGAGE	115.303417	36.638779	0.290430	0.8460595	3.14703	0.00233
TDENS	6.260678	2.370661	0.342642	0.4280593	2.64090	0.00996
TOTBA	-456.938770	119.847568	-0.487030	0.4415974	-3.81267	0.00027
TOTMOSS	.120350E+05	6231.754253	0.208256	0.6196579	1.93123	0.05704
BAXSHRUB	-815.013217	371.243702	-0.196766	0.8969987	-2.19536	0.03107

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	.307793E+10	5	.615586E+09	11.955533	0.000000
RESIDUAL	.406768E+10	79	.514896E+08		

6. Black spruce density, lowland stands (n=39).

Equation for the model:

Density = + 6983.0 + 163.6* average age + 6.5* total density - 587.8* total basal area - 41881.9* tall woody shrub cover

DEP VAR: SBD N: 39 MULTIPLE R: 0.798 SQUARED MULTIPLE R: 0.636
ADJUSTED SQUARED MULTIPLE R: .593 STANDARD ERROR OF ESTIMATE: 6169.468808

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	6983.013812	6018.869733	0.000000	.	1.16019	0.25405
AVGAGE	163.585699	40.841443	0.419666	0.9747598	4.00538	0.00032
TDENS	6.506895	2.877635	0.286756	0.6653757	2.26120	0.03026
TOTBA	-587.747391	126.268527	-0.628175	0.5875511	-4.65474	0.00005
TSHRUB	-.418819E+05	.158461E+05	-0.304271	0.8074246	-2.64304	0.01234

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	.226284E+10	4	.565711E+09	14.862738	0.000000
RESIDUAL	.129412E+10	34	.380623E+08		

7. Density, black spruce-dominated uplands 5,8,9 (n=20).

Equation for the model:

Density = - 2568.6 + 105.1* white birch density + 12151.0* percent black spruce - 87604.0* debris cover
- 20570.1* tall woody shrub cover + 18382.3* total Sphagnum moss cover

DEP VAR: SBD N: 20 MULTIPLE R: 0.849 SQUARED MULTIPLE R: 0.721
ADJUSTED SQUARED MULTIPLE R: .621 STANDARD ERROR OF ESTIMATE: 3585.114845

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	-2568.636305	5518.025934	0.000000	.	-0.46550	0.64873
BWDENS	105.134565	31.114000	0.495790	0.9256179	3.37901	0.00450
SBBAPCT	.121510E+05	6119.603491	0.298930	0.8791929	1.98558	0.06702
DEBRIS	-.876040E+05	.374261E+05	-0.359795	0.8434065	-2.34072	0.03457
TSHRUB	-.205701E+05	.107515E+05	-0.335798	0.6468800	-1.91323	0.07639
TOTSPHAG	.183823E+05	5196.076122	0.651481	0.5876149	3.53772	0.00328

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	.465055E+09	5	.930109E+08	7.236489	0.001540
RESIDUAL	.179943E+09	14	.128530E+08		

8. Density, upland mixedwoods, jack pine and shallow soils (n=26).

Equation for the model:

Density = - 1157.8 - 2783.3* moisture regime + 98089.5* willow cover + 30161.5* total moss cover

DEP VAR: SBD N: 26 MULTIPLE R: 0.722 SQUARED MULTIPLE R: 0.521
ADJUSTED SQUARED MULTIPLE R: .456 STANDARD ERROR OF ESTIMATE: 7298.988975

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	-1157.787585	6030.282122	0.000000	.	-0.19200	0.84951
MR	-2783.259180	1023.473541	-0.424734	0.8922345	-2.71942	0.01252
OSHRUB	.980895E+05	.530631E+05	0.323589	0.7102836	1.84855	0.07801
TOTMOSS	.301615E+05	7711.308422	0.657018	0.7713531	3.91133	0.00075

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	.127569E+10	3	.425231E+09	7.981771	0.000879
RESIDUAL	.117206E+10	22	.532752E+08		

Step-wise multiple regressions for balsam fir advance growth.

1. Balsam fir advance growth stocking, all stands (n=85).

Equation for the model:

Stocking = + .851522 - .001440* organic depth - .000254* total density - .000601* balsam fir density + 1.366248* conifer litter cover + 1.384844* cover of logs - .551210* ericaceous shrub cover

DEP VAR: BFSTK2 N: 85 MULTIPLE R: 0.767 SQUARED MULTIPLE R: 0.588
ADJUSTED SQUARED MULTIPLE R: .556 STANDARD ERROR OF ESTIMATE: 0.203746

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	0.851522	0.106553	0.000000	.	7.99156	0.00000
DOM	-0.001440	0.000414	-0.313165	0.6514701	-3.47743	0.00083
TDENS	-0.000254	0.000054	-0.419661	0.6683846	-4.72007	0.00001
BFDENS	-0.000601	0.000249	-0.190705	0.8456601	-2.41267	0.01818
CNFRLIT	1.366248	0.527900	0.211713	0.7895596	2.58808	0.01151
LOGS	1.384844	0.935148	0.133236	0.6527110	1.48088	0.14267
ERIC	-0.551210	0.179470	-0.288386	0.5992796	-3.07133	0.00293

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	4.618951	6	0.769825	18.544425	0.000000
RESIDUAL	3.237974	78	0.041512		

2. Balsam fir stocking, all uplands (n=46).

Equation for the model:

Stocking = +.656608 - .000291* total density + 2.495722* debris cover + 1.697715* conifer litter cover

DEP VAR: BFSTK2 N: 46 MULTIPLE R: 0.685 SQUARED MULTIPLE R: 0.470
ADJUSTED SQUARED MULTIPLE R: .432 STANDARD ERROR OF ESTIMATE: 0.226172

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	0.656608	0.124550	0.000000	.	5.27183	0.00000
TDENS	-0.000291	0.000060	-0.546797	0.9784413	-4.81326	0.00002
DEBRIS	2.495722	1.178690	0.240569	0.9781928	2.11737	0.04019
CNFRLIT	1.697715	0.690943	0.276143	0.9997398	2.45710	0.01822

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	1.903	3	0.634	12.398	0.000
RESIDUAL	2.148	42	0.051		

3. Bf stocking, upland mixedwoods, jack pine, and shallow soils (n=26).

Equation for the model:

Stocking = + 1.021470 - .006429* organic depth - .000404* total density + 1.304501* conifer litter cover

DEP VAR: BFSTK2 N: 26 MULTIPLE R: 0.689 SQUARED MULTIPLE R: 0.475
ADJUSTED SQUARED MULTIPLE R: .403 STANDARD ERROR OF ESTIMATE: 0.221919

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	1.021470	0.160252	0.000000	.	6.37417	0.00000
DOM	-0.006429	0.003585	-0.282005	0.9655459	-1.79321	0.08670
TDENS	-0.000404	0.000099	-0.642521	0.9650570	-4.08462	0.00049
CNFRLIT	1.304501	0.831222	0.245718	0.9741085	1.56938	0.13083

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	0.979	3	0.326	6.626	0.002
RESIDUAL	1.083	22	0.049		

4. Balsam fir advance growth density, all stands (n=85).

Equation for the model:

Density = + 9459.3 - 25.3* organic depth + 25.0* maximum age - 3.5* black spruce density
- 12.8* balsam fir density - 7073.1* ericaceous shrub cover

DEP VAR: BFD N: 85 MULTIPLE R: 0.612 SQUARED MULTIPLE R: 0.374
ADJUSTED SQUARED MULTIPLE R: .335 STANDARD ERROR OF ESTIMATE: 4134.953075

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	9459.295974	2304.072679	0.000000	.	4.10547	0.00010
DOM	-25.342613	8.180315	-0.332557	0.6871841	-3.09800	0.00270
MAXAGE	25.023819	14.157758	0.171233	0.8436954	1.76750	0.08101
SBDENS	-3.452442	0.965161	-0.347607	0.8385334	-3.57706	0.00060
BFDENS	-12.813857	4.882457	-0.245431	0.9054545	-2.62447	0.01041
ERIC	-7073.133426	3164.159035	-0.223227	0.7940664	-2.23539	0.02821

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	.808499E+09	5	161700E+09	9.457319	0.000000
RESIDUAL	.135073E+10	79	.170978E+08		

5. Balsam fir density, all upland stands (n=46).

Equation for the model:

Density = + 11985.2 - 5.2* total density + 38189.2* debris cover - 11363.6* ericaceous shrub cover + 6863.6* total Sphagnum moss cover - 320636.1* exposed mineral soil cover

DEP VAR: BFD N: 46 MULTIPLE R: 0.670 SQUARED MULTIPLE R: 0.449
ADJUSTED SQUARED MULTIPLE R: .380 STANDARD ERROR OF ESTIMATE: 3684.864

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	11985.244	2287.104	0.000	.	5.240	0.000
TDENS	-5.234	1.091	-0.631	0.7960772	-4.796	0.000
DEBRIS	38189.249	19833.264	0.236	0.9170664	1.926	0.061
ERIC	-11363.575	4776.784	-0.328	0.7231062	-2.379	0.022
TOTSPHAG	6863.584	3594.801	0.248	0.8134433	1.909	0.063
MINSOIL	-320636.056	215105.115	-0.179	0.9552538	-1.491	0.144

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	.442886E+09	5	.885772E+08	6.523	0.000
RESIDUAL	.543129E+09	40	.135782E+08		

6. Balsam fir density, upland mixedwoods, jack pine, and shallow soils (n=26).

Equation for the model:

Density = + 177.6 - 175.5* organic depth + 1297.6* moisture regime - 8.1* total density + 23.5* hardwood density + 98190.3* debris cover - 555064.0* exposed bedrock cover - 770414.0* exposed mineral soil cover + 15897.6* total moss cover

DEP VAR: BFD N: 26 MULTIPLE R: 0.897 SQUARED MULTIPLE R: 0.804
ADJUSTED SQUARED MULTIPLE R: .712 STANDARD ERROR OF ESTIMATE: 2507.072907

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	177.558546	3763.136434	0.000000	.	0.04718	0.96292
DOM	-175.454786	47.662458	-0.472848	0.6973050	-3.68119	0.00185
MR	1297.574004	352.911324	0.419137	0.8853389	3.67677	0.00187
TDENS	-8.078966	1.377045	-0.788830	0.6364084	-5.86688	0.00002
HDWDDENS	23.499846	12.672646	0.323731	0.3774968	1.85438	0.08112
DEBRIS	.981903E+05	.225099E+05	0.686752	0.4641728	4.36210	0.00042
BEDROCK	-.555064E+06	.335093E+06	-0.248631	0.5106613	-1.65645	0.11597
MINSOIL	-.770414E+06	.196865E+06	-0.483736	0.7529776	-3.91341	0.00112
TOTMOSS	.158976E+05	4389.219483	0.733022	0.2808945	3.62197	0.00211

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	.439467E+09	8	.549334E+08	8.739820	0.000102
RESIDUAL	.106852E+09	17	.628541E+07		

Explanation of stand and site variables used in regression equations.

Acronym	Description	Measurement units
AVGAGE	Mean stand age	years
BAXSHRUB	Basal area times shrub cover	na
BFDENS	Balsam fir density	stems/ha
BWDENS	White birch density	stems/ha
CNFRLIT	conifer litter on forest floor	percent
DEBRIS	debris on forest floor (twigs and branches)	percent
DOM	depth of organic matter	cm
ERIC	ericaceous shrub cover	percent
FMOSS	feathermoss cover	percent
HDWDDENS	hardwood density	stems/ha
HDWDLIT	hardwood litter on forest floor	percent
LOGS	logs on forest floor	percent
MAXAGE	age of oldest tree in stand	years
MINSOIL	amount of exposed mineral soil	percent
MR	soil moisture regime	integer, 0 to 8
OSHRUB	tall woody shrub cover	percent
SBBAPCT	amount of Sb in stand	percent of total BA
SBDENS	density of Sb	stems/ha
TDENS	total stand density	stems/ha
TOTBA	total stand basal area	m^2/ha
TOTMOSS	total moss cover	percent
TOTSPHAG	total Sphagnum moss cover	percent
TSHRUB	total shrub cover	percent

APPENDIX 3. Descriptions of aerial photo interpretation attributes for 1:20 000 scale, black and white imagery.

Gray tone

1 White
2 Very light gray
3 Light gray
4 Medium gray
5 Dark gray

Stand Pattern

1	Uniform	stand with trees uniformly spaced, generally not clumped, open or closed canopy
2	Stippled	small, dark or medium gray flecks on a light gray background, open stands with scattered trees or patches of shrubs
3	Mottled	medium-sized, light gray spots against a medium or dark gray background, stands with many small canopy openings, trees clumped
4	Patchy	medium-sized to large patches of different gray tones, stands with mixed species composition and/or large canopy openings
5	Banded	stand with internal linear drainageways, often open, giving stand a banded appearance

Percentage canopy openings

1 10 percent or less
2 11 to 20 percent
3 21 to 30 percent
4 more than 30 percent

Number of linear drainageways

1	None	
2	Few	1 to 3 internal linear drainageways, usually narrow in width and oriented parallel to the slope
3	Medium	more than 3 internal linear drainageways, narrow to medium in width, usually oriented in a single dominant direction
4	Many	stand with many internal linear drainageways, of different sizes, with at least one drainageway wide and open, oriented in many different directions

Position on slope

1 Upland plateau (flat)
2 Crest
3 Upper slope
4 Middle slope
5 Lower slope
6 Toe slope
7 Depression
8 Flat peatland

Slope complexity

1	None	level or very gently sloping terrain
2	Simple	a regular slope gradient oriented in a single dominant direction
3	Complex	hummocky, undulating, or rolling terrain, with slopes oriented in different directions, often with numerous hummocks and concavities

Slope grade

1	Level	less than 1 percent slope
2	Gentle	a noticeable gradient, 1–10 percent slope
3	Medium	11–25 percent slope
4	Steep	more than 25 percent slope

Species composition

1	Mainly coniferous	less than 10 percent hardwood species
2	Mixed coniferous	50–90 percent coniferous species
3	Mixed hardwood	50–90 percent hardwood species
4	Mainly hardwood	less than 10 percent coniferous species

Percent black spruce

1	90–100 percent spruce
2	80–90 percent spruce
3	less than 80 percent spruce

Appearance of understory

0	None	not visible due to closed stand
1	Sphagnum moss and low shrubs	stippled appearance, dark flecks against light gray background
2	Alder and/or tall shrubs	uniform, medium gray, fuzzy appearance in canopy openings, often in open linear drainageways
3	Feathermoss and/or lichen	light or very light gray tones in canopy openings with uniform appearance
4	Grasses and sedges	very light gray or white tones in canopy openings (usually in uplands)
5	Exposed bedrock	appear as white, irregular patches in canopy openings