Sustainable Forest Management Network Conference
"Advances in Forest Management: From Knowledge to Practice"
13-15 November 2002
Shaw Conference Centre, Edmonton, Alberta

SPATIAL ASPECTS OF BOREAL MIXEDWOOD SUCCESSION AND STAND DYNAMICS

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ABSTRACT

Aspen and white spruce mixedwood forests cover a significant portion of the western Canadian boreal forest region. While both species often establish right after a fire disturbance, the faster-growing aspen soon overtops the young spruce. It may take white spruce 60-80 years to grow up through the aspen canopy. As white spruce grows into the aspen canopy, it is subjected to physical abrasion by aspen swaying on windy days. This, along with the reduced light levels can significantly reduce the growth rates and survival of the spruce.

The issue of boreal mixedwood management has risen in prominence, with increased use of both aspen for paper fibre and white spruce for lumber, as well as recognition of the ecological benefits of having both species growing together on the same sites. However, viewpoints concerning how to manage these stands often differ between forestry companies that use deciduous versus coniferous trees, and substantial resources are put into manipulating species mixtures early in stand development, without a full understanding of future implications. While previous research on mixedwood forests has helped us understand the general sequence of stand development, we know very little about the spatial dynamics of spruce and aspen as natural and managed stands develop, given specific initial densities and distributions of both species. Attempts to model the development of both species growing together have been hampered by a lack of understanding of how these species mixtures change over time.

This study examines spatial changes between white spruce and aspen during the development of mixedwood stands, both at a fine-scale (how individual stems are arranged in relation to one another) and coarse-scale (how patches of aspen and spruce are arranged throughout a stand). The relative influence of competition for sunlight and the effect of physical abrasion of aspen branches on spruce growth are being examined as possible underlying causes of spatial relations in aspen and white spruce and development of mixedwood stands.

Results will contribute to refinements in models that simulate the growth of these two species as closely spaced "intimate mixtures". An improved understanding of mixedwood stand dynamics will contribute to development of management practices that are ecologically as well as economically sound.

INTRODUCTION

Aspen and white spruce mixedwood forests cover a significant portion of the western Canadian boreal forest region. Mixedwood management is of great interest to the forestry community, and is becoming increasingly important as utilization of aspen and poplar increases and as companies strive to more fully integrate their operations.

There has been some progress made in understanding the physical stand conditions and the physiological requirements of both white spruce and aspen (e.g., Lieffers et al. 1999). This has included the development of models such as MIXLIGHT to predict light levels in mixed stands (Stadt and Lieffers 2000) and the application of models such as SORTIE in evaluating successional dynamics of mixedwood stands (Pacala et al. 1993). We are, however, just beginning to understand the complex ecological relationships between spruce and aspen throughout stand development. Traditional thinking is that mixedwood succession proceeds in a systematic sequence of phases from deciduous to conifer-dominated seres, as the stands age, although recent research disputes this rather simplistic representation of successional dynamics (e.g., Cumming et al. 2000). While previous research on mixedwood forests has given us some general understanding of the sequence of stand development, our understanding of the spatial dynamics of spruce and aspen as natural and managed stands develop is poor. Attempts to model the development of both species growing together have been hampered by a lack of understanding of how these species mixtures change over time.

The issue of boreal mixedwood management has risen in prominence recently, with increased use of both aspen for paper fibre and white spruce for lumber, as well as recognition of the ecological benefits of having both species growing together on the same sites. However, viewpoints concerning how to manage these stands often differ between forestry companies that use deciduous versus coniferous trees, and substantial resources are put into manipulating species mixtures early in stand development, without a full understanding of future implications. Current emphasis in mixedwood management is on retaining "intimate mixtures" of spruce and aspen to meet a variety of ecological and management objectives. These have been instrumental in developing new approaches to mixedwood management, including patch retention (Coates and Burton 1997), and white spruce understory protection (MacIsaac et al. 1999). A better understanding of the appropriate spatial mixing of species from both an ecological and economic perspective is required as a basis for examining the implications of these approaches.

Studies show how well spruce and aspen are co-adapted to occur as mixtures (e.g., temporal light resource partitioning (Constabel and Lieffers 1986)). However, there are phases during mixedwood stand development where moderate to high aspen cover negatively influences spruce survival and growth. To investigate this relationship, a study was initiated in 1951 to assess growth of juvenile white spruce following release from dominating aspen competition at various stand ages on a range of sites in the Boreal Mixedwood zone of Alberta. Forty-eight year results show periodic volume increases between released and control (not released) trees ranged from 55 to 93%, depending on the age when the spruce trees were released (unpublished data) (Fig. 1).

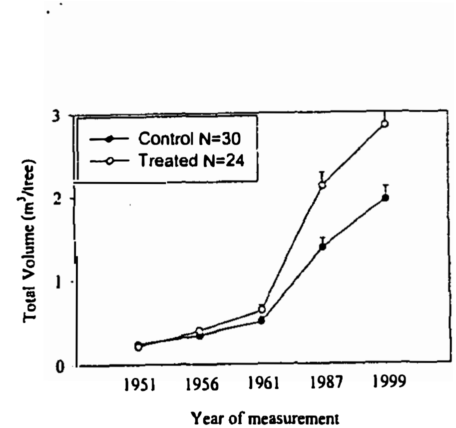

Figure 1. White spruce stem volume growth for trees released at spruce age class of 46-65 on a good site quality (MacIsaac et al. 2000).

Mechanisms of growth response were not studied, although they are probably related to increases in light and reductions in physical abrasion, as moisture is not a major limiting factor on these sites. White spruce shows incredible plasticity in long term growth, under a range of stand conditions, such that modeling even simple aspen-spruce mixtures is difficult.

OBJECTIVES

The purpose of the study presented in this paper is to examine changes in spatial arrangements of white spruce and aspen during the development of mixedwood stands. For this purpose we have examined how individual stems are arranged in relation to one another, the influence of spatial arrangement on interactions, and the influence of interactions on future spatial arrangement. The relative influence of competition for sunlight and the effect of physical abrasion of aspen branches on spruce growth are being examined as probable underlying causes of spatial relations between aspen and white spruce and development of mixedwood stands.

METHODS

Research Strategy

The approach is to compare current spatial stand characteristics with initial spatial conditions in plots in Manitoba and Saskatchewan first measured 50 years ago as part of a Canadian Forest Service research study established to determine the growth response of white spruce to release from trembling aspen (Yang 1989). In this original research, eight fire-origin aspen-spruce mixedwood stands (approximately 40 years in age) were selected, in which six to eight 0.04 ha plots (20m x 20m) were established. Complete aspen removal (by hand cutting) was randomly conducted on half of the plots in each site, with the other half of the plots left as uncut controls. The plots were stem mapped, white spruce trees were tagged and growth (DBH, ht) was recorded for all species, and leader condition and canopy position of all spruce was recorded in all control and treated plots. Measurements were taken in 1953-54, 1958-59, 1964-65 and 1985.

Current Measurements

At each site, up to three treated and three control plots are being used for this research. A 0.04 ha (20m x 20m) plot was established coincident with each of the original 20m x 20m plots. In one-third of the plots, a larger 0.36 ha (60m x 60m) plot, centred on the original plot center, was mapped to provide information on stand structure and spatial distribution of aspen and spruce around the original core plot. The remainder of the plots just had the original core plot area measured.

For all trees taller than 1.3 m, stem location (x,y), tag number, tree condition, crown class, height, DBH, height to live crown and crown radius was collected. Spatial interactions between spruce and aspen crowns were described using variables that quantify the proximity of the spruce crowns to aspen crowns (both vertically and horizontally) and intermingling with the surrounding aspen. In addition, the severity and type of current and previous white spruce leader damage was recorded. Data was collected in 31 plots from seven sites, on a total of nearly 8,000 trees.

To quantify spatial variation in understory light conditions and crown architecture, canopy images were taken with a hemispherical ("fish-eye") lens during both leaf-on and leaf-off conditions. These images, taken at a height of 1 m, were spaced over a 4 m grid to detect effects of tree distribution on light levels. Light sensors (calibrated photo-diodes) were placed in two control and two released plots at two sites, to measure light levels over a two month period, in order to calibrate the light levels developed through the light simulation models.

In each plot, composition and cover for all vascular and dominant non-vascular flora were recorded in a 5m x 5m vegetation sub-plot, in order to determine successional trajectories. Soils were also described and samples taken for nutrient and texture analysis.

Analysis

Analysis is proceeding using several statistical and modeling approaches to determine the spatial dynamics over five time periods, based on the previous and current measurements, comparing spruce growth in mixtures and in situations where aspen is removed. Circumcircle analysis (Dale and Powell 2001) is the spatial statistical approach being used to test spatial patterns of aspen and spruce. This new method, which is derived from the commonly-used Ripley's K statistic, is being used to determine the spatial association of aspen and spruce seedlings and trees.

Determination of light levels includes modeling approaches, using the LITE (Light Interception and Transmission Estimator) model (Comeau 2002). The LITE model incorporates the spatial stem-mapped data and hemispherical images, to give a simulated estimate of light levels in the proximity of each tree. The model output is being combined with tree data through regression analysis to determine the effect of understory light levels on survival and growth of white spruce. The relative importance of competition for light vs physical damage on spruce growth is then tested by stratifying the population of trees into similar light condition classes and testing the effect of different levels of physical damage on spruce growth.

SOME INITIAL RESULTS

Density of spruce declined over the first 30 years of plot measurements, but has started to increase in the past two decades (range 825-1600 stems ha^{-1}) due to an increase in spruce regeneration as aspen canopies have started to open up due to mortality of individual aspen trees. Combined aspen and spruce volume is approximately around 300 m^3 ha^{-1}, for both control and released plots. Leaf area index calculated with the LITE model using stem maps and hemispherical data ranges from 5.8 to 7.3.

For the stands examined in this study, mature aspen exhibits uniform crown depth (5-6 m) across a range of densities. However, crown width is highly variable as a reflection of density and lean of trees. Open grown white spruce have very symmetric crown depth and width. Adjacent to aspen, spruce crown depth is extremely variable, whereas crown width is somewhat variable. Released white spruce trees show strong branchiness over the full length of the stem.

Circumcircle analysis has been conducted on a variety of univariate data groups (e.g., spatial pattern of conifers shorter than 6 m) and bivariate species groups (e.g., spatial association of deciduous trees taller than 10 m vs conifers of all sizes). One interesting result is that circumcircle analysis shows that there are fewer spruce trees growing at a distance of 3 m from aspen stems, whereas more spruce trees are found closer and farther from that distance (Fig. 2). The fewer number of spruce at the 3 m distance may be associated with the influence of maximum aspen tree abrasian at this distance. As well, there is some evidence that spatial patterns in light levels may contribute to this observed pattern. Analysis is ongoing to answer this question by determining the relative influence of light levels vs physical interactions on spruce survival and growth.

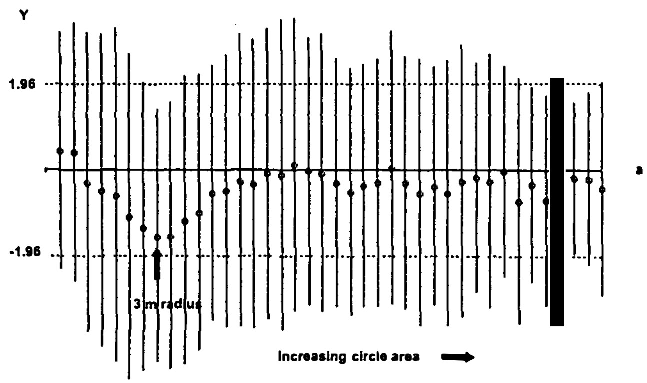

Figure 2. Bivariate circumcircle analysis of spatial association between white spruce (all sizes) vs aspen (> 10 m tall), for Plot 12 at Big River, SK. The graph shows means (with standard deviations) of standardized residuals of white spruce counts, y_i as a function of circle area a_i, where the circles are circumcircles of different sizes, based on the position of aspen trees (a circumcircle is a circle drawn through the positions of three aspen trees). Values below the centre line indicate fewer spruce trees associated with aspen than expected for a specific circumcircle area, given the overall spruce density in the plot.

RESEARCH BENEFITS AND SIGNIFICANCE TO FOREST MANAGEMENT

Research benefits include the following: 1. A better understanding of the importance of spatial aspects of light competition and physical leader abrasion in stand development, for use in designing mixedwood silviculture systems. 2. Increased knowledge of long-term stand dynamics (recruitment, survival, mortality) and growth trajectories in mixed stands. 3. Calibration of LITE and SORTIE models for range of mature stands across the boreal region. 4. Development of algorithms in SORTIE model to simulate effect of physical abrasion of aspen on spruce growth. 5. Determination of 50 year understory vegetation successional trajectories in stands with aspen removal and aspen retention

This SFM-funded research is unique in that it directly compares the relative influence of light competition and physical interactions between aspen and spruce on stand development, through detailed measurements of research stands that have a 50-year history of data collection. This research will hopefully provide valuable information on how these two species fit with one another. The results will help to improve models that simulate the growth of these two species as closely spaced "intimate mixtures". This may provide guidance as to what are the most appropriate spatial arrangements and species mixes (from both an ecological and economic perspective), which can then be applied to serve the needs of industry and government as they develop strategies for mixedwood management.

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13-15 November 2002
Shaw Conference Centre, Edmonton, Alberta

NUTRITIONAL INDICATORS OF FUTURE PRODUCTIVITY: CHALLENGES AND INSIGHTS

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ABSTRACT

The 'Nutritional Indicators of Future Productivity' research program involves ten researchers from nine institutions and five research areas across the Canadian boreal forest. The overall objective of the project is to develop a set of indicators that can be used operationally to determine whether the effects of forest management on nutrient availability and nutrient cycling could influence future forest productivity. The research has recently finished it first full field season and thus all results are preliminary. Nevertheless a literature review to compile known nutritional information about the boreal forest in the framework of a forest ecosystem classification is nearing completion. The conceptual basis for considering indicators has been explored and approaches to definition of a 'reference condition' and an 'indicator hierarchy' developed. Current and previous research suggests that new indicators relating to the presence of species that may degrade site quality and to ecotype and humus form classification show potential as nutritional indicators.

WHAT IS FOREST NUTRITION?

Forest nutrition, broadly defined, deals with any aspect of the forest ecosystem that involves nutrients. This would include the more traditional areas of tree nutrition and soil fertility as well as the processes that influence nutrient inputs to and losses from forests and the factors controlling nutrient transformations and storage in soils. Because nutrient dynamics is often closely linked to the dynamics of organic matter, the processes of plant material and soil organic matter production and turnover are considered within this area.

WHY IS FOREST NUTRITION WORTH THINKING ABOUT?

Forest nutrition and its role in determining productivity are, at the same time, well known and poorly understood. The roles of various nutrients in plant physiological processes and the importance of good nutrition for optimum plant growth have been known for many years. That forest productivity can be enhanced by addition of nutrients has also been well documented, at least on some sites and under certain conditions. It is well known that nutrients are removed from forest sites during harvesting and that removals are higher when foliage and small branches are removed along with the wood. It is being increasingly recognized that the inherent fertility of forest soils can be altered by site preparation treatments and changes in vegetation composition.

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EDMONTON, ALBERTA, CANADA
13-15 NOVEMBER, 2002

PUBLISHED BY:
SUSTAINABLE FOREST MANAGEMENT NETWORK
G-208 BIOLOGICAL SCIENCES BUILDING
UNIVERSITY OF ALBERTA
EDMONTON, AB CANADA T6G 2E9
WEB SITE: http://www.ualberta.ca/sfm
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