Poster Summaries

Utilizing Municipal Wastewater in the Short-rotation Intensive Culture of Hybrid Poplars near Vernon, British Columbia

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The City of Vernon is located in the semi-arid Okanagan Valley 175 km north of the international border. Annual precipitation averages 35 cm, daily temperature averages in July and January are 20°C and -5°C, respectively, and the area has an accumulated heat sum of about 2000 degree days on a 5°C base. Vernon's frost-free growing season is about 170 days.

Vernon has irrigated nearby managed and wild grasslands with treated municipal effluents for the past 16 years with little or no discharge to nearby waterways. Vernon's relatively warm, dry climate coupled with a well developed effluent irrigation system, available lands, and a need to experiment with other uses for the nutrient rich wastewater led to the establishment of a 13.6 ha demonstration and research plantation complex in 1988.

Site preparation began in fall 1987 with a glyphosate spraying, followed by plowing. In spring 1988 the site was thoroughly disked and a solid set aboveground irrigation system was installed. Forty thousand cuttings of selected hybrid clones were planted in pure clonal and mixed clonal blocks at two initial spacings. Western conifer and eastern broadleaf species were also outplanted in small plots near the poplar plantings.

A UBC forestry graduate student (George Nercessian) has used a portion of the poplar plantings to satisfy the following objectives: 1) to determine ground water quality characteristics under tree stands versus pasture, 2) to quantify nutrient cycling dynamics in an irrigated hybrid poplar stand, 3) to measure clonal and clonal mix growth responses to varying irrigated levels, and 4) to estimate individual tree and stand growth parameters at varying plant densities. A thesis addressing these objectives is now available.

Additional objectives of the Forest Service research staff and the City of Vernon include examining the postulated advantages of fast-growing tree stands compared with pasture grass culture for the utilization of municipal effluent: 1) trees can be managed on ground topographically and edaphically ill suited for forage management; 2) the deeper root system penetration of trees should improve percolation and reduce surface runoff probability; 3) a high leaf area index coupled with a large aboveground surface area (stems, branches, and foliage) should result in greater evaporation and transpiration rates and thus greater wastewater disposal/utilization rates; 4) the longer growing season of some of the fast growing hybrid cottonwoods should result in longer irrigation seasons; and 5) irrigation system operation and maintenance costs should be less with tree plantations due to heavier but less frequent applications and thus less sprinkler movement and maintenance.

After six seasons of plantation irrigation, observations and measurements are beginning to answer the above questions.

Modelling Interactions Between Red Alder and Douglas-fir

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Introduction

Red alder (Alnus rubra Bong.) occurs on a variety of low- to mid-elevation forest sites in the Pacific Northwest region of North America. Its range extends along the coast from southeastern Alaska to southern California. Red alder has commercial timber value, it can contribute to short-term and long-term site productivity through symbiotic nitrogen fixation, and it can contribute to the structural diversity of forests, as well as to non-timber resource values.

Juvenile height growth of red alder is more rapid than that of most conifers, it can rapidly overtop conifers, and it can maintain height dominance in a stand for up to 30 or 40 years. Depending on its density in the stand and site factors, red alder can compete with conifers for light and water, and can cause physical damage to conifers.

This poster describes results obtained using the FORCYTE-11 ecosystem simulation model to explore the potential effects of different amounts of red alder on stemwood biomass yields of pure and mixed stands. FORCYTE-11 is a hybrid empirical/process stand level model. The model uses empirical data on tree and plant biomass accumulation over time, together with data on key processes such as photosynthesis, detrital decomposition, and nutrient cycling as a basis for simulations.

Model Calibration

FORCYTE-11 requires information on biomass accumulation and distribution for each species to be simulated, on the turnover of detrital materials, and on nutrient cycling for each site class simulated. For the purposes of these simulations, existing data sets for Douglas-fir and red alder provided by Forestry Canada were supplemented with unpublished data from sample plots and yield tables characterizing coastal B.C. sites.

Simulations

Three sets of simulations were completed to examine:

1. effects of initial alder density on stemwood yield over a single 80-year rotation;
2. effects of delaying planting of red alder until year 5 on stand yield; and
3. effects of five management strategies on total yield over a 240-year period.

For these simulations, 1000 Douglas-fir were planted in year 1 for all but pure red alder simulations. Red alder regenerated naturally at the various densities in year 1 for all but the second set of simulations. Red alder were harvested in years 40 and 80 and Douglas-fir were harvested in year 80 of the simulation. At the time of harvest, 85% of total stemwood and 80% of stembark was removed from the site. Branches, leaves, and roots were left on site.

Effect of Initial Density of Red Alder

Maximum yield of Douglas-fir stemwood biomass at 80 years was predicted in mixed stands with red alder densities of 100 to 200 trees/ha (for a site with Douglas-fir SI_{50}=30 m (site index at 50 years) and red alder SI_{50}=17 m) (Figure 1). In these mixed stands, Douglas-fir yield was 13% higher than that of Douglas-fir grown without alder. Total (Douglas-fir + red alder)stemwood biomass yield was 30% higher in stands with 200 alder than in pure Douglas-fir stands. At 300 and 400 alder/ha total stemwood biomass yield exceeded that of Douglas-fir grown alone; however, Douglas-fir yield was reduced compared to that of Douglas-fir grown without alder.

On a better quality site (Douglas-fir SI_{50}=40 m and red alder SI_{50}=25 m) simulations suggest that maximum stemwood biomass yield of Douglas-fir would be achieved when red alder densities are below 100 trees/ha (Figure 2). Because of the greater availability of nitrogen on this better quality site, the presence of red alder did not provide any increase in Douglas-fir stemwood biomass yield. For this better site, total (Douglas-fir + red alder) stemwood biomass yield was greatest in mixed stands with an initial density of 200 red alder and 1000 Douglas-fir.

Effects of Underplanting Red Alder

Delaying the establishment of red alder (for a site with Douglas-fir SI_{50}=30 m and red alder SI_{50}=17 m) until 5 years after planting of Douglas-fir gave a small improvement in Douglas-fir biomass yield (6.5%) and total yield (3%) over that obtained by planting alder and Douglas-fir at the same time (Figure 3).

Effects of Five Management Strategies on Long-term Yield

Mixedwood management regimes utilizing 200 red alder/HA appear to be the most appropriate of five management strategies (for a site with Douglas-fir SI_{50}=30 m and red

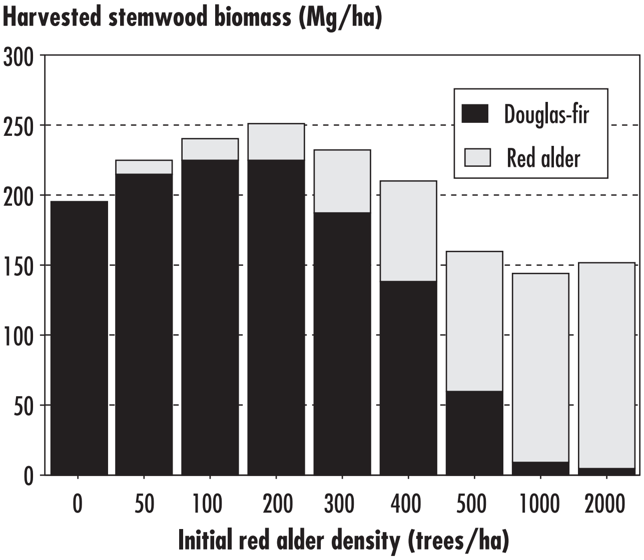

Figure 1. Effects of initial red alder density on cumulative stemwood biomass yield of Douglas-fir and red alder for a site with a Douglas-fir site index (SI) of 30 m at 50 years and red alder SI of 17 m at 50 years. Results are based on simulations using FORCYTE–11.

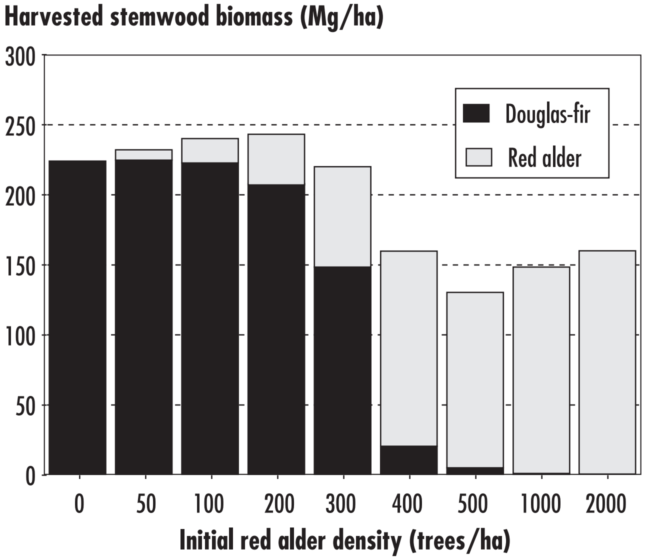

Figure 2. Effects of initial red alder density on cumulative stemwood biomass yield of Douglas-fir and red alder for a site with a Douglas-fir site index (SI) of 40 m at 50 years and red alder SI of 25 m at 50 years. Results are based on simulations using FORCYTE–11.

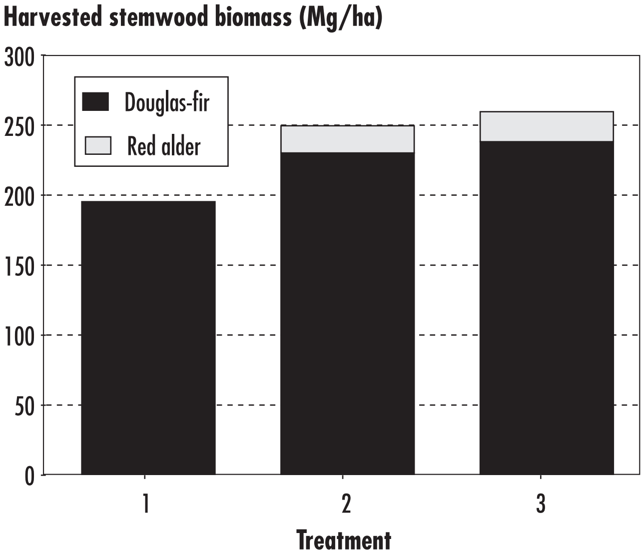

Figure 3. Simulated effects of time of establishment of red alder on cumulative stemwood biomass yield over an 80-year period (Treatment 1 = no red alder; Treatment 2 = 200 red alder at year 1; Treatment 3 = 200 red alder planted in year 5. For all treatments 1000 Douglas-fir were planted in year 1).

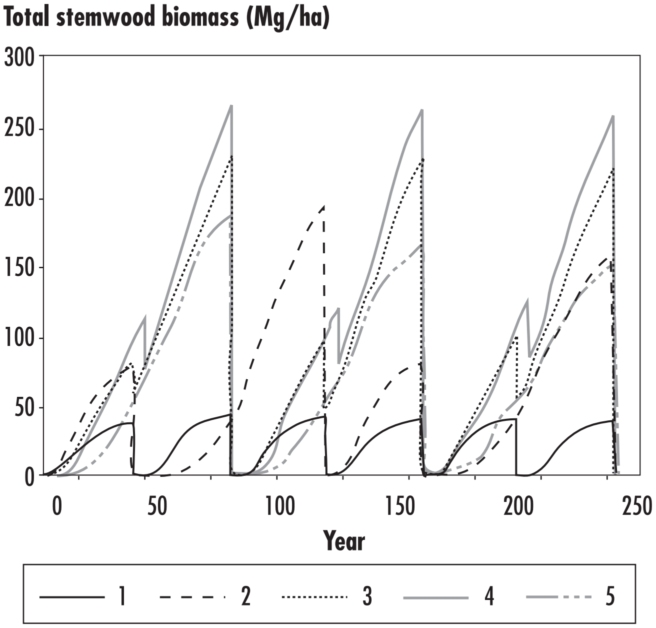

Figure 4. Predicted accumulation of stemwood biomass over time for five management strategies for a site with a Douglas-fir site index (SI) of 30 m at 50 years and red alder SI of 17 m at 50 years. The five strategies are: 1) six 40-year rotations of red alder; 2) two cycles of alternating rotations of red alder and Douglas-fir; 3) three 80-year mixedwood cycles; 4) three 80-year mixedwood cycles with red alder planted in year 5; and 5) three 80-year rotations of Douglas-fir.

alder SI_{50}=17 m) for maintaining sustainable stemwood production over a 240 year simulation (Figure 4). The five management strategies simulated were:

1. Six 40-year rotations of red alder, red alder naturally regenerating at 2000 trees/ha;
2. Two cycles of alternating rotations of red alder (2000 trees/ha, 40 years) and Douglas-fir (1000 trees/ha, 80 years);
3. Three 80-year mixedwood cycles, red alder regenerating at 200 trees/ha and Douglas-fir planted at 1000 trees/ha in year 1, red alder harvested year 40 and year 80 (if present), Douglas-fir harvested year 80;
4. Three 80-year mixedwood cycles, Douglas-fir planted at 1000 trees/ha in year 1 and red alder planted at 200 trees/ha in year 5, red alder harvested year 45, Douglas-fir harvested year 80; and
5. Three 80-year rotations of Douglas fir, 1000 trees/ha.

Little or no decline in yield was predicted after three cycles of mixedwood management regimes (3 and 4) or after six cycles of red alder (regime 1). However, alternating rotations of red alder and Douglas-fir (management regime 2) and management for pure Douglas-fir (regime 5) resulted in declines in stemwood biomass yield with each successive rotation.

Cumulative stemwood biomass yield over the 240-year period was highest with management of mixedwood stands with 200 red alder planted at year 5 (Figure 5). This regime maximized both Douglas-fir and total (Douglas-fir + red alder) stemwood biomass yield. Three rotations of Douglas-fir provided lower total yields as well as lower yield of Douglas-fir than those achieved in mixedwood stands. Growing either alternating crops of red alder and Douglas-fir or rotations of red alder alone provided the lowest yields of stemwood biomass.

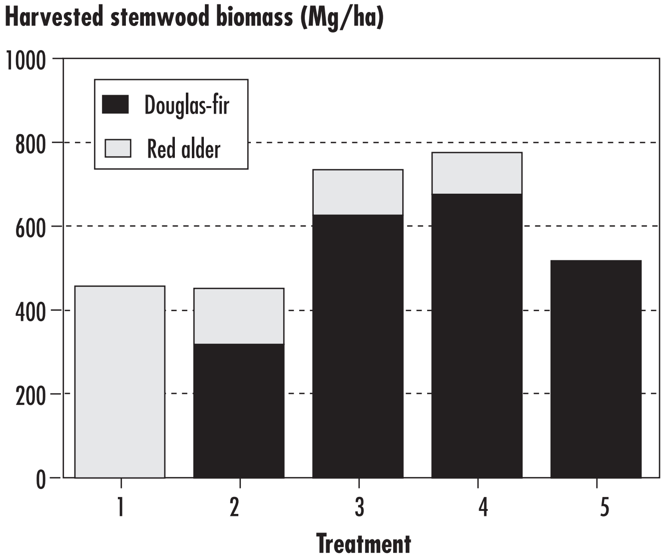

Figure 5. Predicted stemwood biomass yield over 240 years for five management strategies. The five strategies are: 1) six 40-year rotations of red alder; 2) two cycles of alternating rotations of red alder and Douglas-fir; 3) three 80-year mixedwood cycles; 4) three 80-year mixedwood cycles with red alder planted in year 5; and 5) three 80-year rotations of Douglas-fir.

Conclusions

Results of these simulations indicate that, on sites where nitrogen deficiencies occur, retaining or establishing a small amount of red alder (less than 200 trees/ha) could be beneficial to both short-term and long-term productivity of Douglas-fir stands.

Simulations completed using FORCYTE-11 provide results consistent with published information and observations on the performance of pure and mixed stands of red alder and Douglas-fir. This model shows potential for exploring the consequences of a variety of mixedwood management strategies. However, further verification of model behaviour and validation of model predictions is required before using model predictions as a basis for operational decisions. A variety of field studies in pure and mixed stands are required to acquire the data necessary for improvements in model calibration and for model verification and validation.

Acknowledgements

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Reference

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Genetic Variations in Ecophysiological Variables in Red Alder (*Alnus rubra*)

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Red alder (*Alnus rubra* Bong.) is the most abundant hardwood tree species in the Pacific Northwest and coastal Alaska. It occurs naturally over a wide geographic range, from southern California (34°N latitude) to southeastern Alaska (60°N) within 200 km of the ocean, and at elevations up to 1200 m. Within this range, climatic and edaphic conditions vary considerably; annual precipitation ranges from 400 to 5600 mm, extreme temperature ranges from -30°C to 46°C, and soils vary from well drained gravels or sands to water-logged clays or organic soils (Harrington 1991). Such a diversity of environmental conditions has led to adaptive differentiation among red alder populations in growth, morphology, and phenology (Briggs et al. 1978; Ager 1987; Lester and DeBell 1989). Ecophysiological differentiation in red alder, however, has not received much attention. We examined the genetic variations and geographic patterns of ecophysiological variables in 40 red alder provenances representing the entire range of the species in British Columbia. Intercorrelations among ecophysiological variables were examined in the context of adaptation mechanisms of red alder.

The 40 provenances were selected from a common garden installation (containing 67 provenances) at the Surrey Forest Nursery (described separately by Xie and Ying in these workshop proceedings). All seedlings were 2 years old. Two families per provenance and two individuals per family were used. The experiment was replicated in two blocks.

The experiment was conducted August 18 to September 4, 1993. Mid-day xylem water potential (γ) was measured between 12:30 pm and 3 pm when it was low and stable, using a Scholander pressure chamber. Gas exchange was measured between 9:00 am and 11:40 am using an ADC LCA-3 open system and a PLC B broadleaf cuvette. Photosynthetically active photon flux density of 1000 mmol/m^2/s was provided by a halogen cool-spot lamp. CO_2 concentration inside the cuvette was controlled at 335 ± 10 mL/L. To determine the sensitivity of stomata to changes in vapour pressure deficit (VPD), two measurements were taken on each sample at different relative humidities (low, 30–45%, and high, 70–85%). The humidities were later converted to VPD. Diurnal changes in other environmental factors and ecophysiological variables were taken into account by using covariates in data analysis.

Differences in γ among provenances were tested using ANOVA, and Analysis of Covariance was used for net photosynthesis (A), stomatal resistance to H_2O (r_s), transpiration (E), mesophyll conductance ($g_m = A/C_i$), photosynthetic water-use efficiency (WUE = A/E), and stomatal sensitivity to VPD ($SENS_{VPD}$ = r_s/VPD). Covariates were air temperature and VPD for WUE and r_s, and time of day and temperature for all other variables. Stepwise Multiple Regression Analysis and Canonical Correlation Analysis were conducted to examine the geographic patterns of ecophysiological variables.

Significant genetic differentiation ($P < 0.001$) was found among different provenances of red alder in A, g_m, E, r_s, $SENS_{VPD}$, and γ. Positive correlations were found between A, g_m, WUE, and γ, and these variables were also negatively correlated with r_s and $SENS_{VPD}$, indicating that there was genetic differentiation in drought resistance. It was postulated that the different drought resistances may have been achieved through variation in root-to-shoot ratios (not measured).

A general geographic trend was found for ecophysiological variables: γ, A, g_m, and E increased, and $SENS_{VPD}$ and WUE decreased, from southeast to northwest. However, although the provenances covered a wide geographic range, particularly latitude (42–54°N), only 18% of the total between-provenance variation in ecophysiological variables could be attributed to geographic location. The geography within the species range was extremely complex. Therefore, we speculate that micro-environmental conditions are likely to be more important in defining ecophysiological characteristics in red alder. If so, local environmental and site conditions should be given serious consideration in managing red alder and in the utilization of seed resources from different regions.

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Effect of Aspen Competition on Survival and Growth of Lodgepole Pine and White Spruce

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Introduction

Trembling aspen (*Populus tremuloides*) is one of the most frequent competitors with lodgepole pine and white spruce in plantations in the Prince George Forest Region. More than one million dollars (rehabilitation and current) is spent annually to control aspen in the region. It seems appropriate to establish if these treatments are an efficient use of limited resources.

Forest vegetation management has been viewed as the practice of efficiently channelling limited site resources into useable forest products rather than into non-commercial plant species. This raises an important concern about aspen control. With aspen utilization increasing rapidly in British Columbia, aspen can no longer be considered non-commercial. This, coupled with increased public concern over the main aspen control tool, herbicide, means that the need for aspen control to meet our conifer production goals must be clearly demonstrable. Forest managers must ultimately decide the ratio of conifer and aspen volume they are willing to accept at rotation, but research and development must provide them with the tools to predict and achieve these ratios.

Objectives

1. To compare the impact of different levels of aspen competition on young conifer growth and site factors.
2. To study the regrowth or invasion of clearcut sites by aspen, after different forest management treatments.
3. To investigate the relationship between various measures of aspen competition and crop tree survival and growth.
4. To study the effects of different amounts of aspen on soil moisture, soil temperature, and below canopy light regime.
5. To study the effect of different densities of aspen on the foliar nutrient concentrations of conifers after 5–30 years.

Methods

A site in the SBSmk1, located approximately 60 km northwest of Prince George (CP 324 cc # 16) was selected for the study. Four plots (20 × 20 m) were established in each of three aspen control treatments (control, pre-logging hack and squirt and post-logging hack and squirt) prior to logging in areas that contained mature aspen. Two plots each were located in areas of low and high aspen densities respectively. The sub-units were clearcut and received the following treatments: control (piled or drag scarified); pre-treatment (aspen treated by hack and squirt method with glyphosate 1 year prior to logging and then piled or drag scarified); and post-treatment (treatment of standing aspen immediately after harvesting with glyphosate, by hack and squirt method, and then piled or drag scarified). The plots were planted to lodgepole pine and white spruce seedlings in the spring of 1987.

A summary of the data collected over the past 7 years is included in Table 1.

Results and Conclusions

Environmental monitoring indicated that high densities of aspen reduced light and soil moisture to levels that would be limiting for a portion of the growing season. Microsites with the best light, soil moisture, and soil temperature regime were areas of bare mineral soil where trees had been uprooted and piled. However, these microsites also showed the poorest growth of pine and spruce, probably due to the lack of nutrients in this bare mineral soil.

For the whole data set, the discrete variable most significantly correlated with both lodgepole pine and spruce tree growth was soil type. Among the continuous variables, it was vegetation cover (measured in the year of planting) that was strongly correlated with both lodgepole pine and spruce growth. This relationship was positive, indicating that total vegetation cover was a good indicator of the relative quality of the microsite for crop tree growth. Combinations of soil type, total vegetation cover, and moisture regime provided the best multiple regression models. Once the data set had been separated by soil type, some of the data sets showed a strong correlation for combinations of humus depth/soil displacement (negative response) and total vegetation cover (positive response) for lodgepole pine and humus depth and the light interception index (LII) for spruce. LII, a relative measure of non-crop competition with the crop tree, was only significant in the plots with the highest level of competition (e.g., >10 000 aspen stems/ha).

This experiment indicates the importance of minimizing site disturbance (e.g., minimizing mineral soil exposure) during forest operations. It indicates that aspen competition is important in controlling growth of conifer crop trees but only at high levels (e.g., >10 000 stems/ha for spruce). This may change as the forest matures but this needs to be examined in greater detail before large amounts of money are spent on aspen control. This study suggests that the role of factors such as soil type and humus displacement deserve further investigation.

Table 1. A summary of the data collected over the past 7 years

	Non-crop		Vegetation		Crop tree		Site				Environmental		
Year	Co	Ht	Pr	Ad	Ht	Di	Hd	Ss	St	Ex	Ul	Sm	T
1986	x			x				x	x	x			
1987	x			x									
1988	x	x	x	x	x	x							
1989	x	x	x	x	x	x	x		x		x	x	x
1990				x	x	x						x	x
1991				x	x	x							
1992				x	x	x							

Co – % cover, Ht – height (cm), Pr – distance from crop tree to inner edge of foliage of vegetation, Ad – average distance from crop tree to inner edge of foliage of vegetation, Di – basal diameter (mm), Hd – humus depth or soil displacement (cm), Ss – BEC site series, St – soil type, Ex – exposure, Ul – understory light (PPFD), Sm – soil moisture (bars), T – soil temperature (°C).

Underplanting Aspen Stands with White Spruce to Mimic Natural Mixedwoods in the BWBSmw1

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Introduction

Underplanting aspen stands with white spruce is the third phase of research directed at mimicking natural mixedwoods in the boreal forest. This research has been driven by the need to produce coniferous and deciduous volume from the land base of northeastern British Columbia while minimizing the impact on other resources such as agriculture, range, recreation, and wildlife. It is believed that mixedwood management may be advantageous, especially if it can be demonstrated that total volume yields are greater than when managed for pure coniferous or pure deciduous. Phase 1 of this project summarized existing underplanting trials and attempted to determine reasons for success or failure. Phase 2 examined the microenvironment under aspen canopies and identified the stand characteristics most amenable to underplanting. Phase 3 of this project, begun in 1992, intends to develop nursery regimes that adapt seedlings to underplant environments and then monitor outplanted seedlings in clearcuts and under canopies that offer the most favourable microenvironment.

Objectives

The primary objective of this project is to examine the survival and growth of white spruce planted under an aspen canopy and compare it to survival and growth in a clearcut environment. The specific objectives are as follows:

1. To compare the survival and growth of two stock types, 1+0 research and 1+0 operational white spruce stock, within and between aspen understory and clearcut environments.
2. To compare the survival, growth and seedling physiological differences of 1+0 stock grown under shade cloth versus that grown in full sun, and planted under an aspen canopy.
3. To compare the survival and growth of shade-adapted stock planted on brushed microsites to stock planted on brushed and screefed microsites under an aspen canopy.
4. To compare the seedling microenvironment under an aspen canopy to that in a clearcut.

5. To measure net photosynthesis, water use, and carbon allocation of seedlings planted in a clearcut and under an aspen canopy and relate this to microclimate data in order to help explain gross morphological and survival observations.

Methods

Six sites (three clearcuts and three aspen stands) were located in the BWBSmw1 within one hour driving distance south of Dawson Creek, B.C. Aspen stands were 40–60 years old and had basal areas between 20 and 40 m^2/ha. All sites were circum-mesic in moisture regime and each site was relatively uniform with respect to slope, aspect, and soil texture. The clearcut sites were as closely matched ecologically to the aspen sites as was feasible. The overall design of the experiment is a randomized block, split-plot design. A summary of treatments is included in Table 1.

Site preparation on the clearcut was disk-trenching or no treatment. In the aspen understory, site preparation consisted of removing all shrub/herb vegetation within a 1 m radius around each seedling location with a brush saw, or this brushing treatment plus screefing with a Hawk scarifier a 50 × 50 cm patch centred on the seedling. At each site, 70 seedlings of each stock type or stock type/site preparation combination were planted in May 1993. A climate station was set up in one underplant and one clearcut site to measure relative humidity, soil moisture, air and soil temperature, and light availability (photosynthetic photon flux density).

Results and Conclusions

Continuous light measurements across 18 stands varying in basal area and stand densities indicated an excellent relationship between basal area and density and percentage of maximum potential photosynthesis. These data demonstrate that basal area and density information can be used as predictors of stand suitability for potential underplanting. Frost damage, which has been known to damage up to 60% of seedlings in clearcuts in the BWBSmw1, was negligible in underplanted environments and ranged from 25–55% damage in the different clearcuts. Observed frost damage corresponds with minimum air temperatures recorded on the two sites. Air temperatures of -4 to -5°C occurred on the clearcut site in each month during the growing season, whereas air temperatures in the underplanted site never fell below -1°C. Vegetation competition was also found to be non-vigorous: hence, site preparation and brushing and weeding required for establishing white spruce in clearcuts would not be necessary. Since only first year data have been collected, differences in tree growth and physiology have not yet been demonstrated. Microenvironmental data collection, however, does indicate differences in frost incidence between these two sites.

This method of managing mixedwoods offers additional non-timber benefits. Large-diameter aspen snags can be maintained for cavity-nesting birds, and aspen woodlands provide important habitat for many passerine birds. Public concern for aesthetics would be alleviated by the continual maintenance of tree cover. The 40–60 year period during which spruce would be absent from the site would allow for inoculum of tomentosus root rot to disappear. Boreal hardwood species contain substantially higher concentrations of N and P in their current year foliage than does white spruce. Increased nutrient availability may substantially benefit spruce growth response after release.

Table 1. A summary of treatments

Main plot treatments	Split plot treatments
Clearcut (plot dimension = 25 × 50 m)	1 - 1+0 psb 313 research (full sunlight) 2 - 1+0 psb 415 operationally grown
Aspen underplant (plot dimension = 50 × 50 m)	1 - 1+0 psb 313 research (full sunlight) 2 - 1+0 psb 415 operationally grown 3 - 1+0 psb 313 research (66% full sunlight) 4 - 1+0 psb 313 research (66% full sunlight + screefing)

Hardwood Silviculture Cooperative

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Interest in managing hardwood species to ensure future supplies of hardwood lumber, for species diversity, and as an alternative to conifers in disease pockets, is increasing in the Pacific Northwest. In 1991, the hardwood industry in Washington and Oregon employed more than 7000 people, providing an annual income of just under $200 million US.

The Hardwood Silviculture Cooperative (HSC), based at the Oregon State University College of Forestry, conducts high priority research on hardwood species and mixed hardwood/conifer stands in the Pacific Northwest. The goals of the cooperative are to:

- develop guidelines for stand establishment and management,
- synthesize and disseminate information on hardwood resources,
- encourage and cooperate in fundamental research on the biology of hardwood species as a component of forest systems, and
- facilitate integration and cooperation among Pacific Northwest organizations concerned with the hardwood resource and its management.

Participants in the cooperative include members of industry, public agencies, and educational institutions. Priorities for cooperative activities are set by members and are carried out by cooperators and Oregon State University staff. General activities of the cooperative include:

1. silvicultural research on hardwood species,
2. publications, and
3. information and technology transfer, through written materials, workshops, and field tours.

Some specific examples include working with forest nurseries to develop quality alder growing stock, helping land owners and managers identify appropriate sites and treatments for managing hardwoods, and the publication of guides for the management of hardwood species.

The two main research priorities at the present time are the Red Alder Stand Management Study and the Alder Wood Quality Study.

The Red Alder Stand Management Study was initiated in 1988. Its goal is to develop an information base with which to model growth and yield in red alder in managed stands, and to monitor the effects of various planting and thinning regimes on growth, yield, and wood quality. This will be accomplished through manipulation of a series of natural stands (Type 1 installations) and plantations (Type 2 installations) over a range of physiographic regions and site qualities. In addition, mixtures of red alder and Douglas-fir will be planted (Type 3 installations—nine are planned) to examine the interaction of these two species growing together.

The Alder Wood Quality Study is being conducted in two parts. The Lumber Recovery Study was completed in 1992. This was a cooperative study with the Pacific Northwest Timber Quality Project in which the HSC supplemented their log-to-lumber and grade recovery project with tree and stand data. This study found that the dollar value from alder trees was from high-grade lumber, primarily in the butt log (the first 3 m).

The second part of the study, tree growth and self-pruning as a function of spacing and thinning, has begun this year. Three objectives for the current effort are to:

- Develop equations that describe branch growth, branch mortality, and crown lift as a function of spacing,
- Quantify the effects of spacing on stem taper, and
- Examine the effects of thinning on branch, height, and bole diameter (taper) development.

Data are being collected from research plots with a well-known history of controlled spacing.

Where Have All the Big Pores Gone? Impacts of Concentrated Heavy Equipment Traffic on Aeration Porosity and Bulk Density in an Aspen Ecosystem

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Introduction

Impacts of concentrated heavy equipment traffic on forest soils and aspen regeneration were evaluated by quantifying changes following logging on a site in the Dawson Creek Forest District. The site was a BWBSmw1/$01 site series. The majority of the study are was cut during the winter of 1987/88. Portions of the block were logged in the summer of 1988 using rubber-tired skidders.

Aerial and ground observations of the block clearly showed that skid trails were identifiable as open paths through dense aspen sucker stands. Soils were a sandy loam veneer (10–20 cm thick) over clay-loam till deposits. Soils with no obvious harvesting disturbance had granular or fine platey structure in the upper mineral soil. Soils in skid trails had coarse platey structure, and increased mottling.

The objectives of the study were to: 1) quantify observed differences in aspen regeneration between skid trials and undisturbed soils, and 2) assess if significant differences in aeration porosity and bulk density occurred between skid trails and undisturbed soils.

Methods

In September of 1993, poorly regenerated skid trails were selected in a well stocked portion of the cut-over area. Ten randomly selected points were located in the wheel tracks of the skid trail. These were paired with a sampling point 4 m away in the sucker stands with no obvious soil disturbance.

Soil compaction was assessed by measuring bulk density (500 cm^3 cores) at the 8–15 cm depth, and aeration porosity (@10J/kg, 55 cm^3 cores) at 8 and 12 cm depths. Outside of the skid trails, dense networks of aspen lateral roots prevented soil compaction assessment in the 0-8 cm profile. The total numbers of aspen regeneration, plus the height and basal diameter of the five largest dominants, were assessed in seven paired plots, with a 1.5 m radius. Results were analyzed using a paired "t"-test (alpha = 0.05).

Results

Aspen density, height, and basal diameter were significantly lower in the skid trails (Table 1). The differences in ages of aspen dominants between the undisturbed areas and the skid trails were 2 years or less. Age differences alone are unlikely to account for the differences observed. Aspen stumps and dead lateral roots in the skid trails indicate that original stand conditions would have been very similar.

Table 1. Means and standard deviations (in parentheses) of aspen regeneration density, height, and basal diameters for skid trails and undisturbed soils

Property	Skid trail	Undisturbed soil
Regeneration (st/ha)	9 093 (12 136)	48 696 (16 068)
Total height (cm)	86.8 (27.0)	375.7 (29.6)
Basal diameter (cm)	0.97 (0.30)	3.30 (0.34)

Skid trails had significantly lower aeration porosity and greater bulk density than the undisturbed soils at the sampled depths (Table 2). Mean aeration porosity was consistently reduced in the skid trails at both sampling depths. Aeration porosity of the undisturbed soils at the 8 cm depth ranged from 4.7% to 25.3%, with an average of 13.3%. In the skid trails, aeration porosity ranged from 0.06% to 6.3%, with an average of 3.0% at 8 cm (Table 2). The relative decrease in aeration porosity was greater at the 8 cm depth (72.9%) than at the 12 cm depth (47.4%).

Table 2. Means and standard deviations (in parentheses) of bulk density and aeration porosity for skid trails and undisturbed soils

Property	Skid trail	Undisturbed soil
Bulk density (kg/m^3)	1607 (85)	1296 (213)
Aeration porosity, 8 cm (%)	3.0	13.3
Aeration porosity, 12 cm (%)	5.5	10.7

Changes in bulk density, though significant, were not as great as changes in aeration porosity. Bulk densities in the skid trails averaged 1635 kg/m^3 at 8 cm, compared to 1296 kg/m^3 for undisturbed soil (Table 2). At the 8 cm depth, relative bulk density changes were 34.2%, compared to relative aeration porosity changes of 72.9%. At the 12 cm depth, the relative bulk density changes averaged 16.6%, compared to relative aeration porosity changes of 47.4%.

Conclusions

Concentrated heavy equipment traffic during summer harvesting had negative impacts on aspen regeneration, productivity, and soil properties. Maintaining the long-term productivity of aspen ecosystems will require careful management of the soil resource.

The observed changes in soil structure of skid trails were reflected in significant decreases in aeration porosity and increases in soil bulk density. Aeration porosity would appear to be a more sensitive indicator of changes in soil properties than bulk density.

Comparison of Modelling Approaches for Managed Red Alder Stands

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Introduction

Red alder (*Alnus rubra* Bong) is a widely distributed hardwood species in the Pacific Northwest that has proliferated as a result of harvesting in the Douglas-fir region. Interest in red alder as a timber resource has increased in recent years. The potential for nitrogen fixation in mixed stands with Douglas-fir (*Pseudotsuga menziesii*) may be an incentive to manage red alder. Much of the growth and yield research in red alder has been conducted in natural stands and has focused on size-density relationships, thinning effects, and height-age curves. Despite the need, very little is known about growth and development of managed red alder stands. Detailed quantitative information regarding the silvicultural and economic consequences of different planting densities is needed.

The purpose of this study was to develop and compare three approaches to modeling the structure and dynamics of red alder plantations. The modeling approaches include: a diameter distribution prediction method that uses only stand-level information; a stand table projection method that uses both stand- and tree-level information; and an individual-tree growth model.

Diameter distributions obtained for each modeling method were compared to the observed diameter distributions for a range of planting densities. A red alder spacing study was established in 1974 near Apiary, Oregon, and included six planting densities: 976 (3.2 × 3.2 m), 1600 (2.5 × 2.5 m), 3086 (1.8 × 1.8 m), 4630 (1.2 × 1.8 m), 6944 (1.2 × 1.2 m), and 13 889 (0.6 × 1.2 m) trees/ha. Each planting density was represented by one or two plots. Diameter of the surviving trees on each plot was measured annually between plantation ages 7 and 12, 14, and 16 years. Tree and stand data were arranged in non-overlapping growth series of 1 or 2 years.

Survival Function

A survival function (Clutter and Jones 1980) was selected for use in all three modeling approaches. This function is based on the assumption that stand mortality is proportional to age and density, and is age- and path-invariant.

Diameter Distribution Prediction Approach

This approach is most useful for comparing the effects of planting density when a tree list is not available. Only stand-level information is needed to generate a diameter distribution at any age. Components of this approach include the survival function, a basal area prediction function that is asymptotic with respect to dominant height and density, prediction functions for the 0th, 25th, 50th, and 95th diameter distribution percentiles, and a parameter recovery procedure for the three-parameter Weibull distribution function (Knowe et al. 1992). The quadratic mean diameter in the predicted distributions is the same as implied by prediction equations for stand basal area and survival.

Stand Table Projection Approach

This approach produces a future stand table that is consistent with stand- and tree-level functions (Pienaar and Harrison 1988). A tree list and stand information are needed. Components of the stand table projection approach include the survival function, a basal area projection function that is functionally compatible with the basal area prediction function and is both age- and path-invariant, and a diameter projection function for individual trees based on relative tree size, defined as the ratio of individual-tree basal area to average basal area per tree in the stand. Any growth interval may be used. The future diameter of individual trees can be estimated from the product of projected relative tree size and projected mean size obtained from the stand-level survival and basal area functions. The relative size projection function for individual trees can be constrained to ensure consistency of the future stand table with stand-level basal area and survival functions. Stand mortality is allocated to dbh classes assuming that smaller trees in a stand have a greater probability of dying than larger trees.

Individual-tree Diameter Growth

The diameter growth function for individual trees is similar to the functions developed by Hann and Larsen (1991). A tree list is required to make growth predictions for fixed growth intervals. The function is applicable to even- or uneven-aged stands that have been thinned or stands with multiple canopies. The potential annual diameter growth of individual trees is predicted as a function of current diameter. Smaller trees have a greater potential for growth than larger trees. The potential growth is modified by basal area of larger dbh trees (BAL) and stand basal area. Thus, smaller trees in a stand have less growth than the larger trees, and trees in stands with low basal area exhibit greater growth than trees in stands with higher basal area. Stand mortality is allocated to dbh classes assuming that smaller trees in a stand have a greater probability of dying than the larger trees.

Results

The two-sample Kolmogorov-Smirnoff test was used to determine whether the observed and predicted or projected diameter distributions are samples from the same population. For the diameter distribution prediction approach, the predicted and observed diameter distributions were significantly different for two plots (2.9% of total) corresponding to 1399 trees/ha planting density (ages 14 and 16). For the stand table projection approach, the observed and projected diameter distributions were significantly different for two plots (2.9% of the total) corresponding to 13 899 trees/ha planting density (age 16 only). For the individual-tree growth approach, the observed and projected diameter distributions were significantly different for one plot (1.5% of the total) corresponding to 1600 trees/ha planting density (age 16 only). Visual inspections of diameter distributions revealed the diameter distribution prediction approach tends to over-predict dbh for larger trees in stands planted at high density. The stand table projection approach tends to under-predict dbh for smaller trees in stands planted at low density and to over-predict dbh for smaller trees in stands planted at high density. The individual-tree growth approach provides the best representation of observed diameter distributions at all planting densities.

Conclusions

The diameter distribution prediction approach gives a reasonable representation of the smoothed diameter distribution, and may be useful for comparing planting densities when a tree list is not available. The stand table projection approach provides for consistency between stand- and tree-level growth projections, and should be useful for comparing planting densities when a tree list is available. The individual-tree growth approach may be best suited for stands that have been thinned, stands with mixtures of species, or stands with various size classes.

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Garry Oak (*Quercus garryana*) Recruitment on Vancouver Island

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Introduction

Less than 1% remains of the Coastal Douglas-fir ecosystem, and within that, the Garry oak savannah is even more imperilled. The Garry oak savannah is unique in B.C. and Canada, and contains many rare and endangered plant species. Because protected areas are generally quite small, natural ecosystem processes would be disrupted and management of some kind is therefore required for perpetuation of the "natural" ecosystem. Garry oak communities at the Department of National Defense properties: at Rocky Point, Mary Hill, and Nanoose Hill are large and relatively undisturbed and therefore provide an opportunity to determine some of the "natural" characteristics of the ecosystem. This past summer, more than 2800 seedling/juveniles were labelled and measured to study possible factors associated with establishment. What is presented here, in a very preliminary form, is a summary of the labelled seedlings/juveniles. Statistical tests are still needed on the differences found. Survival and growth of the seedlings/juveniles will be followed throughout the coming years. Hypotheses with respect to factors important to survival will be tested in experiments to be set up in fall 1994 or 1995.

Sites

Nanoose Hill

Near Nanaimo, this site is approximately 60 ha in area, half of which is on private property. It is a southwest-west facing slope, with sparse vegetation, shallow soil, and many exposed rocks and boulders.

Mary Hill

Near Metchosin, this site consists of a rocky, south-west facing section ("outcrop") of 4.9 ha in size. At the base of the hill, there is a flat section ("meadow") of deeper soils and larger trees. It covers 6.2 ha in area, and is not directly on the shore.

Rocky Point

Near Metchosin, the "closed canopy" site is on level ground, with deeper soils. Douglas-fir are encroaching upon the 4.5 ha site, with adults on the periphery, and saplings in the understory of the oaks. Surrounding this site, along the coast, is the "coastal" strip, a highly variable site with pockets of soil and small, wind-swept oaks interspersed amongst rocky shelves and boulders.

Methods

Seedlings/juveniles were sampled in 2.5 m wide transects until several hundred were found per site: Nanoose Hill—747 individuals in 1.94 km, Rocky Point (closed canopy)—597 individuals in 259 m, Rocky Point (coastal)—319 individuals in 457 m, Mary Hill (meadow)—528 individuals in 145 m, Mary Hill (outcrop)—547 individuals in 302 m. We measured basal diameter and total branch length to provide an estimate of size, which was calculated as the volume of a cone of those dimensions. Age was determined from bud scale scars. Presence of a decaying acorn indicated seedlings in their first year of growth. The following variables were recorded for each seedling/juvenile: none, slight, moderate, or severe damage by jumping gall wasp, leaf miners, leaf curlers, herbivory and "brown spots"; presence or absence of tarspot (fungal), mechanical damage, browse damage, creeping form; the number of canopy layers above each seedling, and the "productivity" of the location, as crudely estimated by the height and vigour of surrounding herbaceous vegetation.

Results

There were site differences in seedling/juvenile age distributions, size of seedlings of the same age, and prevalence of different factors possibly involved in seedling growth and survival.

Nanoose Hill had few juveniles over the age of 3 years (less than 10% of all seedlings/juveniles sampled), and 3-year-olds were not bigger (median = 0.06 cm^3) than seedlings germinated in the same year (median = 0.07 cm^3). Jumping gall wasp (*Neuroterus saltarius*) was not present and the other insect pests were not in abundance (up to 3% of those sampled). However, herbivory was an important factor (70% showed some level of herbivory); grasshoppers were predominant at the site, but we cannot link them directly to the herbivory observed.

At Mary Hill, in the meadow, there were many large juveniles (up to 50 cm^3). The ages of 25% of the seedlings/juveniles sampled at this site could not be determined because they had suffered dieback or browsing; they were on average larger than those with known ages (median sizes = 0.91 versus 0.20 cm^3). Three-year-old juveniles were much larger (median = 0.16 cm^3) than seedlings germinated in the same year (median = 0.04 cm^3). Damage from browsing was the most significant in this site (37% of those sampled), but may be simply attributable to the preponderance of older individuals. At this site, many individuals (10.8%) exhibited a creeping form, because a thick mat of dead grass covered the soil. Herbivory was experienced by almost 40% of those sampled, and jumping gall wasp infested over 20%. Other insect pests were not abundant (up to 7%).

On the rocky outcrop, at Mary Hill, the results were not unlike those found at the meadow. Differences: 1) not as many older juveniles and most individuals could be aged, 2) slightly smaller 3-year-old juveniles (median = 0.14 cm^3), 3) fewer jumping gall wasp infestations (only 8.2% of those sampled), and 4) leaf miners were more abundant (15%).

Rocky Point, at both the coast and under the closed canopy, was intermediate between Nanoose Hill and Mary Hill in terms of age and size distributions. This was the only site at which "tarspot" was present (3% of those sampled) whereas herbivory was less prevalent at this site (just over 20%). Leaf miners were present on about 10% of the individuals sampled and jumping gall wasp was present on about 15%.

Discussion and Conclusions

These results suggest that conditions at Nanoose Hill are not conducive to seedling survival and growth as compared to those found at Mary Hill. Next summer, along with remeasuring the individuals marked this year, we will more precisely describe the physical characteristics of the sites to better define the parameters with which we are concerned. For example, is Nanoose Hill nutrient limited, drier, hotter, etc.? The results from this past summer suggest that competition from other angiosperms (grasses, shrubs), as found at Mary Hill, does not affect Garry oak seedling growth and survival. Competition from conifers, such as Douglas-fir, was not present at Mary Hill. With data on physical parameters, and on survival and growth of individuals marked this year, we will be able to better refine possible factors important to the survival and growth of Garry oak seedlings. Controlled experiments will distinguish between alternative hypotheses. Only then will we be able to suggest, with confidence, management practices that would be effective for perpetuating Garry oak communities.

Scott Paper Limited Hardwood Tree Farm License

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Scott Paper's management system for growing and utilizing poplars on the B.C. coast is illustrated with photographs, flow charts, tables, and background information.

Scott Paper's mill in New Westminster has been operating continuously since 1929 and is the city's largest employer and taxpayer. The company's success has been largely due to the use of low-cost local cottonwood fibre and to the integrated nature of the business, with value-added conversions turning raw materials into shelf-ready packaged product for delivery to Canadian stores.

Poplars are grown on a 25–30 year rotation on inaccessible or medium growing sites, or on a 15 year rotation on productive, accessible sites close to the mill. All of Scott's operations are reforested promptly, usually with tested hybrid poplars grown in Scott Paper's nurseries.

Intensively managed plantations produce roughly 33 m^3/ha per year, well over ten times the average growth rate of forest crops in B.C.

Vine Maple Clone Growth and Reproduction in Managed and Unmanaged Coastal Oregon Douglas-fir Forests

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Introduction

Vine maple (*Acer circinatum* Pursh.) regenerates from seed, basal sprouting, and layering. It layers when its stems contact the forest floor, root, and produce new ramets. Prior to this study the potential for vine maple clonal development and expansion via layering, and its importance versus seedling establishment in different stages of forest succession, had not been determined. The objectives of this study were: 1) to quantify clonal development and regeneration in relation to coastal Douglas-fir (*Pseudotsuga mensiezii* (Mirb) Franco) stand development, 2) to examine the effects of layering on clone development and expansion, and 3) to asses the impact of commercial thinning and prescribed fire following a regeneration harvest on clonal development and regeneration.

Methods

Twenty-five Douglas-fir stands in the Oregon Coast Range were selected and grouped into four broad categories to generally represent the stages of forest stand development: 5–20 years old—stem initiation; 21–70 years old—stem exclusion; 71–120 years old—understory reinitiation, and 140–240 years old—old stands with a well developed understory. Half of the 5–20-year-old stands had been burned for site preparation and planted with Douglas-fir, and half only planted. In age classes 21–70 years old and 71–120 years old, half the stands had been commercially thinned from below at least 5 year previously. No thinning had been done in stands 140–240 years old.

Within each stand we located three 0.05 ha plots under a uniform overstory canopy that contained at least 10 vine maple clones. We excavated and measured all vine maple clones within the plots; a total of 1083 clones. Also, clone seed production was noted and seedlings were measured.

In addition, in three 21–70-year-old stands we conducted a study to determine the time and pattern of layering, whether forest floor conditions affected layering, and whether stems severed from the clone would layer. Within each stand, 20 pairs of live, similar stems and 12 severed pairs of stems were pinned to the forest floor, half covered with forest floor litter. After 1 year the stems were lifted and examined for layering.

Clonal Development in Unmanaged Stands

Vine maple growth, vegetative reproduction, and seedling establishment are closely related to stand development and its related disturbances. It appears that vine maple clone development follows a fairly predictable pattern for the first 50–60 years following disturbance and stand regeneration. After about 70 years, however, clone development is much more stochastic—being influenced largely by the amount of fallen debris, and clone form is much more variable. Relationships of number of stems per clone, upright-stem length and diameter, and crown area to stand age were nonlinear and significant ($p \leq 0.01$). The strongest relationship was between age and average number of stems per clone ($R^2 = 0.85$), while the relationships of the other variables to stand age were weaker ($R^2 = 0.18$ to 0.41).

Artificial Layering Study

Ninety-five percent of the live, pinned stems layered after 1 year. Roots were evenly distributed along the stem, not clustered at nodes. Covered stems averaged 25–30 roots/m and 11–25 roots/m on uncovered stems. There was no relationship between stem diameter and root density. Stems from less than 1.0 cm to 9.0 cm in diameter rooted. In addition, all stems severed from the clones died, and none produced roots.

Clonal Development in Managed Stands

Commercial Thinning

There was a significant increase in clone expansion and reproduction in thinned stands compared to unthinned stands. Thinned stands had significantly ($p \leq 0.003$) more layered stems/clone (4.0), and independent ramets/clone (1.6) than unthinned stands (1.2 and 1.1, respectively), as well as significantly ($p \leq 0.05$) greater matted stem density and area. In addition, seedling number was significantly ($p = 0.003$) greater in thinned stands compared to unthinned. Interesting to note was that no seed or seedlings were found in unthinned 21–70 year-old stands, while 10% of the clones produced seed and 76 seedlings/ha were present in thinned stands. Vegetative expansion appears to be more important than seedling establishment and growth in vine maple's ability to rapidly establish a dense understory.

Prescribed Fire in Stands 5–20 Years Old

Layering in unburned plantations was substantially greater than in burned plantations, due in most part to the size of crown areas, the presence of residual stems, and the physical pinning of stems to the forest floor during stand harvest and regeneration practices. In unburned plantations there was an average of 2.4 independent ramets/clone and 0.8 layers/clone, significantly ($p < 0.05$) greater than in burned stands (0.7 ramets and 0.03 layers). Mat number (70/ha) and area (1293 m^2/ha) were also significantly greater than in burned stands (30/ha and 525 m^2/ha, respectively). Moreover, seed production and seedling stocking (143/ha) in unburned plantations were significantly higher ($p \leq 0.01$) than in burned plantations, or other age classes (19/ha).

Management Implications

The results of this study suggest ways to manage the regeneration and density of vine maple in forest stands. While it provides structure, cover, and fall colour, dense vine maple cover decreases light levels and may have allelopathic effects (Del Moral and Cates 1971). Therefore, vine maple plays an important role in regulating the microenvironment for the regeneration and growth of plants in the understory of Douglas-fir stands.

- Thinning and regeneration harvest have the potential to increase vine maple density by increasing layering, mat formation, stem growth and seedling establishment.
- Any physical pinning of live stems (e.g., slash piling) encourages layering.
- Cutting, burning, or treating aerial stems with herbicides reduces layering and seed production. Cutting does not remove vine maple from the stand since a new cohort of basal sprouts will be produced.

Literature Cited

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Aspen Managers' Handbook for British Columbia

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A key incentive for this project was to help narrow the gap that often exists between forest management questions and scientific solutions. Current literature on how to integrate science and management emphasizes that today's forest managers must ask scientific questions, or at least seek scientific justification for policy decisions. The purpose of this handbook, prepared on behalf of the Hardwood and Vegetation Management Technical Advisory Committee, B.C. Ministry of Forests, is to bring together information on questions likely to be faced by foresters involved with aspen management in British Columbia. It is intended to be applicable to all of the area in British Columbia where aspen occurs naturally—essentially all of the province east of the Coast Mountains.

The handbook addresses practical questions such as: What are the interim and long-term objectives for aspen in stands where it is managed? How should aspen be viewed in relation to pre-harvest silvicultural prescriptions? What is an acceptable regeneration delay for aspen? What is a free-growing aspen? What steps are necessary to achieve the desired range of aspen densities? What is a healthy aspen? The list of questions could go on, and that is what this handbook is about. A handbook of manageable size cannot address all silvical and silvicultural questions about a wide-ranging species such as aspen. Therefore, it focuses on those questions most important for foresters whose work involves aspen. The handbook begins with the biogeoclimatic setting and site associations in which aspen is a significant component in British Columbia. The key aspen management tools available today are discussed at the beginning, before the sections on silvics and silviculture, to emphasize that this is intended to be a handbook of practical application. This report was published in 1995.

The tentative table of contents for the aspen managers' handbook is as follows:

1. Introduction (scope and purpose of handbook).
2. Locations in British Columbia where aspen is a lead species.
3. Biogeoclimatic setting and site associations in which aspen management will occur.
4. Key aspen management tools available today.
5. Biological features of aspen that distinguish its silvicultural responses from conifers.
6. Why clone recognition is significant to the forest manager.
7. Soil compaction and root-system protection in aspen silviculture.
8. Stand conditions of diagnostic importance to the manager.
9. Maturity ages, rotation lengths, and dealing with deteriorating aspen.
10. Controlling or removing aspen where it is not wanted.
11. Biological aspects of aspen regeneration silviculture.

12. Achieving the desired range of densities to meet stocking standards.
13. Management to reduce effects of damaging agents and to maintain forest health.
14. Aspen management to enhance nutrient cycling and site productivity.
15. Management to enhance aspen stem production.
16. Role of short rotations in aspen management.
17. Use of aspen to create specific microclimatic conditions.
18. Managing aspen to enhance wildlife habitat and forest biodiversity.
19. Aspen-livestock relationships.
20. Managing aspen to meet the goals of integrated resource management.
21. Aspen management on small private woodlots.
22. Special situation management problems with aspen.
23. Managing aspen to protect spruce understory.
24. Adapting pure-stand aspen silviculture to mixedwood management.

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Simulation of the Growth of Mixed Stands of Douglas-fir and Paper Birch Using the FORECAST Model

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Introduction

The growth of mixed stands of Douglas-fir (*Pseudotsuga menziesii*) and paper birch (*Betula papyrifera*) in the Interior Cedar-Hemlock (ICH) zone of British Columbia was simulated using the FORECAST model. FORECAST is an ecosystem model that explicitly simulates the effects of nutrient availability and light competition on the growth of trees, shrubs, herbs, and mosses. It is the latest in the FORCYTE series of ecosystem models (Kimmins et al. 1990). For this simulation, calibration data for tree stemwood and height growth were based on predictions from the B.C. Ministry of Forests VDYP and TIPSY growth and yield models. Data on the biomass and nutrient content of a chronosequence of birch stands was taken from a study by Wang et al. (1996). Data on early height growth of birch and Douglas-fir came from Simard and Vyse (1992). Additional model calibration data came from the literature.

Initial State and Model Testing

To run FORECAST an initial state file describing the forest floor detrital materials and soil nutrient capital must be created. This was done by running the model with nutrient limitation to growth disabled for a 400-year simulation consisting of two rotations. The initial rotation started with a mixture of Douglas-fir and birch that was grown for 250 years, and then destroyed by a fire. This was followed by another mixed stand that was clearcut harvested after 150 years. The resulting forest floor was used as the starting point for all subsequent simulations.

Initial test simulations indicated that birch was much more sensitive to site nitrogen availability than was Douglas-fir. This is not surprising, since the nitrogen content of birch tissue is significantly higher than that of Douglas-fir. Simulated pure stands of birch demanded as much as 70 $kgNha^{-1}yr^{-1}$ whereas Douglas-fir demand rarely exceeded 50 $kgNha^{-1}yr^{-1}$. Birch needed an annual N input of at least 5 kg/ha to maintain productivity in the simulations. As an initial test, the model was used to simulate a mixed stand containing 1200 Douglas-fir and 400 birch seedlings/ha at planting with an annual N input of 5 kg/ha from non-symbiotic N fixation (Figure 1a). However, this level of N input far exceeded the demands of a pure Douglas-fir stand, and site productivity for Douglas-fir quickly increased to the highest level in the model, resulting in Douglas-fir out-competing birch in later rotations. In order to lower the annual N input when birch was not present, the constant annual N input due to non-symbiotic N fixation was lowered to a more reasonable

1.5 kg/ha. In addition, symbiotic N fixation of approximately 5 kgNha^{-1}yr^{-1} was simulated for birch, based on initial laboratory data from Simard, Lee, and Perry (in progress). In FORECAST, symbiotic N fixation is dependent on the total leaf biomass of the N-fixing species. Thus stands of Douglas-fir do not receive excessive N inputs when birch is present at low levels or absent entirely. As the amount of birch in a stand increases, the annual input of N increases. As a result, the simulated mixture grows more consistently in later rotations (Figure 1b). This N input scenario was used in the subsequent management simulations.

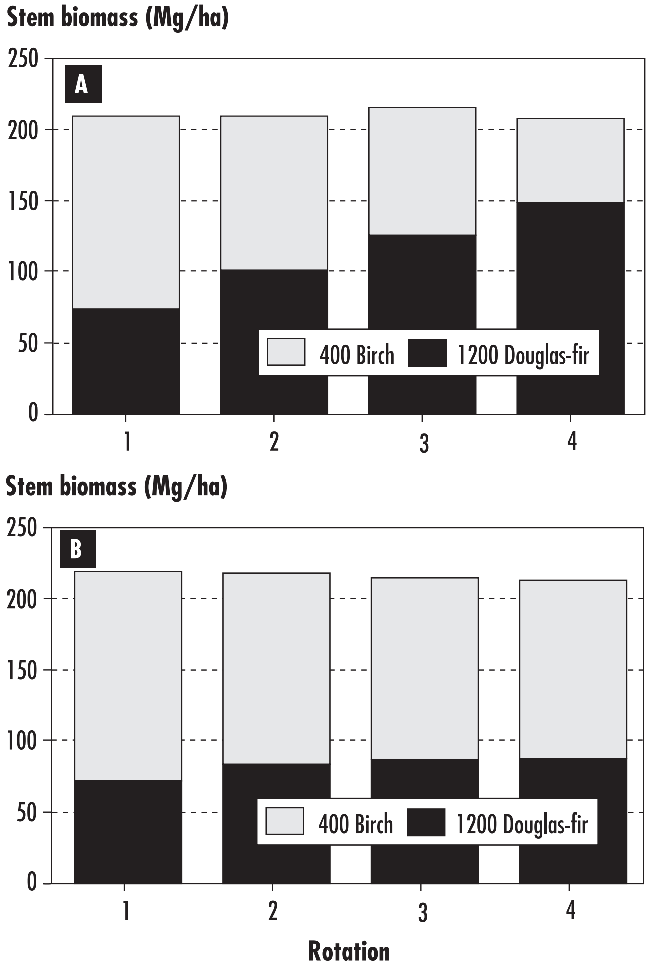

Figure 1. The same mixture simulation under two assumptions concerning nitrogen fixation: a) constant nitrogen input of 5 kgha^{-1}yr^{-1} due to non-symbiotic fixation; and b) nitrogen inputs of 1.5 kgha^{-1}yr^{-1} from non-symbiotic fixation + approximately 5 kgha^{-1}yr^{-1} from symbiotic fixation associated with birch roots.

Management Simulations

A series of management simulations of pure stands and mixtures of different initial planting densities of Douglas-fir and birch was simulated. Each simulation consisted of four consecutive 100-year rotations. Each rotation ended with a clearcut harvest and replanting of the mixture. The first two scenarios simulated pure stands of birch and Douglas-fir (Figure 2). Birch showed a very slight decline in predicted yield in the last two rotations. Douglas-fir showed a greater decline in yield over four rotations. Birch dominated the mixed stands in all but the 200 birch:1400 Douglas-fir simulation (Figure 3). Total cumulative yield for the four rotations was approximately equal for all combinations containing birch (Figure 4). The pure Douglas-fir stands had the lowest predicted yield (Figure 4). The 400 birch:1200 Douglas-fir mixture was

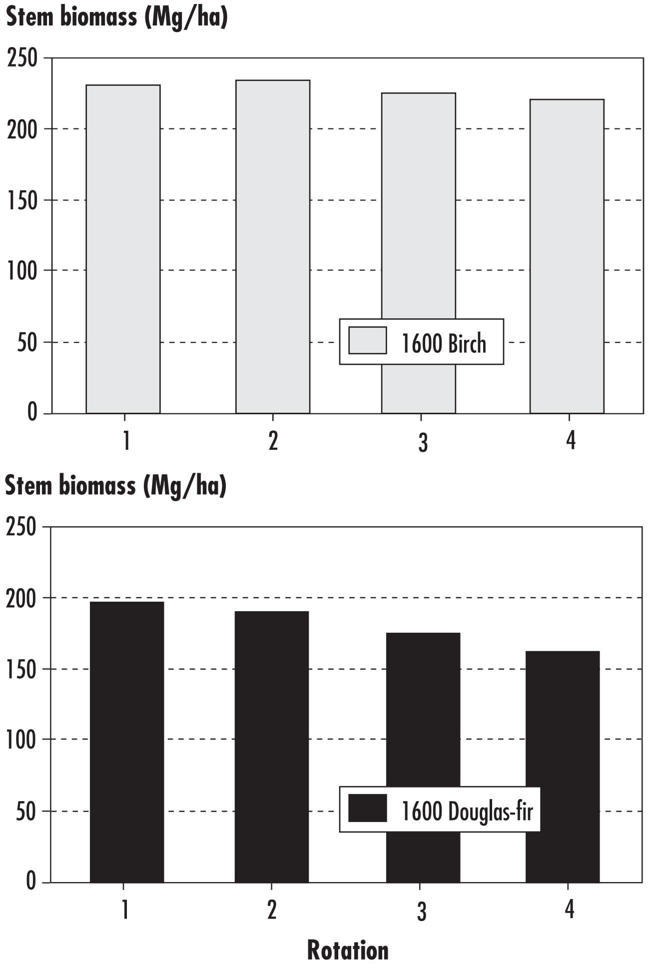

Figure 2. Predicted stemwood biomass produced growing each species separately.

extended for an additional 400 years to examine extreme long-term trends (Figure 5). Douglas-fir yields increased slightly each rotation and appeared to plateau in rotations 7 and 8. Total yield remained stable for 800 years.

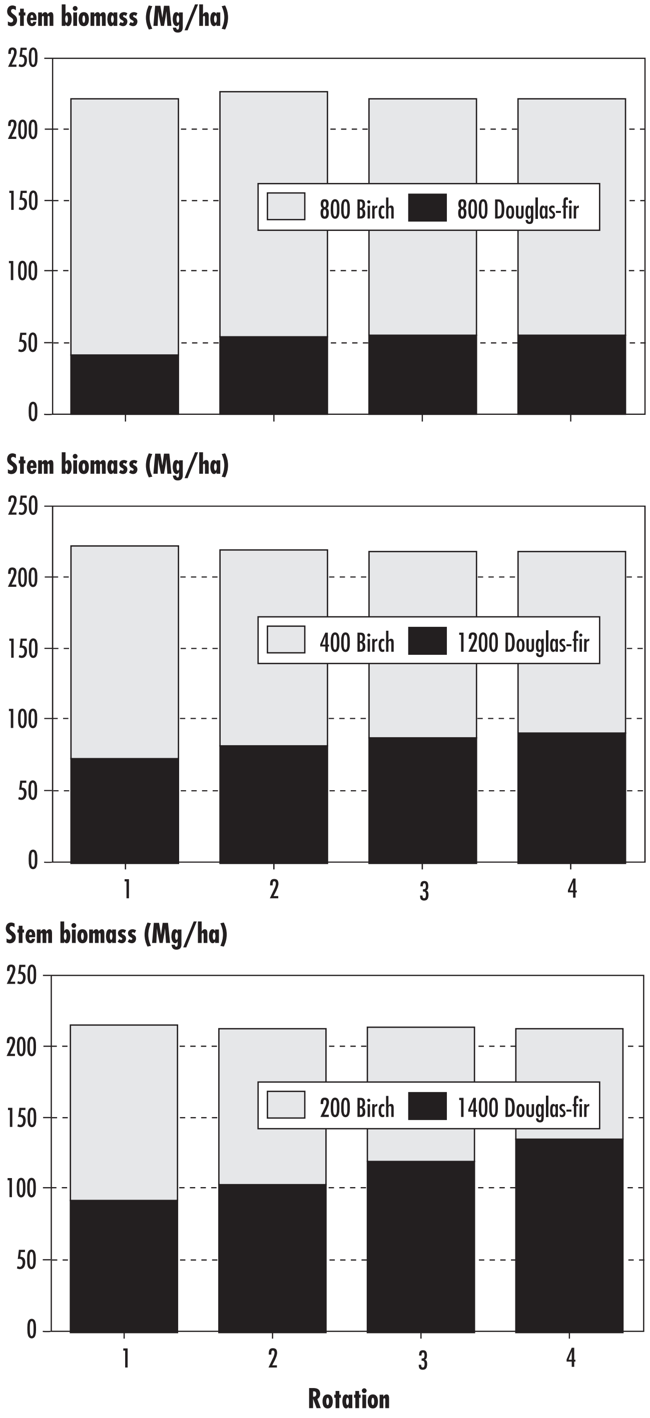

Figure 3. Stemwood biomass produced growing species in combination.

Discussion

The model indicates that birch stands require an average annual N input of at least 6–7 kg/ha to maintain productivity. This is not unreasonable given preliminary laboratory evidence that the rhizospheres of birch seedlings support a high level of associative N-fixing bacteria. FORECAST appears to overpredict birch yield in mixed stands. This probably occurs because the model does not simulate

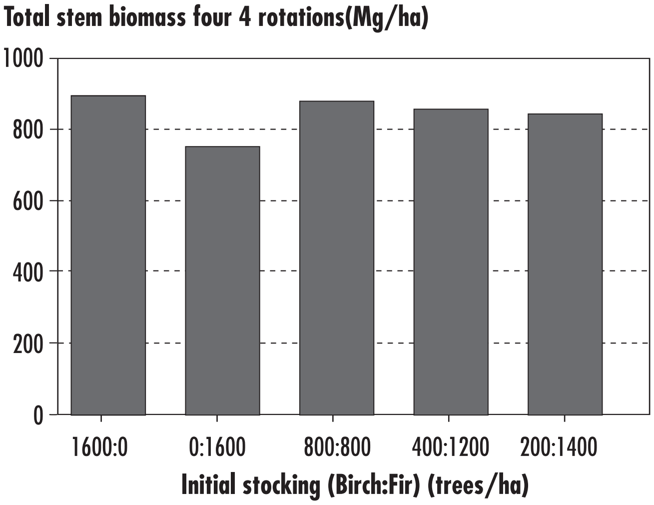

Figure 4. Predicted cumulative yield for four consecutive 100-year rotations of pure and mixed stands of birch and Douglas-fir.

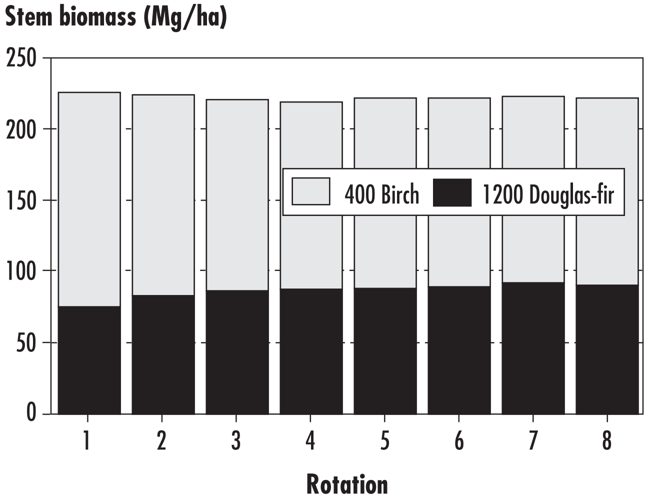

Figure 5. Predicted stemwood biomass produced growing species in combination for eight rotations.

individual tree canopies. Instead, all foliage of a species is simulated as an opaque blanket covering a unit area. The opaque blankets of each tree species interact to compete for light. In reality, trees grow in patches. This is especially true in the ICH where root disease is common. In order to more accurately simulate the growth of these mixed stands there must be some spatial representation of individual tree canopies or at least patches of trees. Aside from the simulation of light competition, the other main problem with this version of FORECAST is that nitrogen is considered to be the only other factor limiting tree growth. In reality, soil moisture is important, with birch being a much stronger competitor on the moist ICH sites (Simard and Vyse 1992). Other nutrients may also be limiting, as evidenced by the high cation levels in birch foliage. However, despite these shortcomings, the model does indicate that mixed stands could be feasible and may offer higher long-term yields of fibre than do pure stands of Douglas-fir.

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Site Preparation and Hardwood Regeneration

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Introduction

The optimal seedbed conditions for regeneration of many hardwood species are not well known. It is likely that regeneration of hardwoods on logged areas differs according to the form of site preparation used. Three broadly similar areas exist in the forest, which were all cut at the same time; one was slash burned, one scarified, and the last planted with no treatment. Research into the species, density, and vigour of hardwoods that have regenerated on all these sites will have significant management implications.

The three sites are quite uniform as regards aspect, elevation, slope, and seed source. Two were planted in 1986, one in 1987. The approximate sizes are: burned block 1 ha; scarified block 2 ha; untreated block 0.5 ha. All have road edges, so access is straightforward. The sites have not been cleaned or thinned post planting.

Other Ideas

Two compatible and accessible areas exist that can be used for studies comparing hardwood colonization on burned and unburned sites. Due to their topography and size, a number of ecosystem units are represented. Harvesting in both areas was done in 1982 and 1984, with burning done the next year, followed by planting with Douglas-fir. The burned sites cover a total of 22 ha, while the unburned sites are 12 ha in total.

Hardwoods for Site Enhancement

Research into the effects of hardwoods on site quality, and their influence on other species are possible here. Many suitable areas are well established.

Many areas of cutbanks on forest roads and other degraded sites are initially colonized by alder. Soils are stabilized and enriched, thus enabling conifers to regenerate with time. The mechanisms of this process are not fully understood; research is required for example into rooting patterns, soil changes, and the microclimates created by the hardwoods as they ‘reclaim’ a site.

Little is known about above- and below-ground interactions, effects on volume production through competition at different percentage mixtures, and hardwood potential as nurse species.

Other areas of interest might include:

- Changes in vigour over time (due to site enhancement by hardwoods)
- Successional processes from pure hardwood to hardwood conifer mixtures.
- Comparative studies between natural processes due to the presence of hardwoods versus application of fertilizers and other soil enhancers.
- Investigation of the nutrient balance during ‘reclamation’.

Chemically Controlling Growth

Through the use of stem injection techniques, it is possible to partially kill trees; either killing selected branches, or from a certain height upwards.

These methods may be useful in the management of water courses, by increasing leaf fall and resulting water nutrient levels, while keeping the trees alive to stabilize banks and produce new growth for future treatment. Improvement of air circulation and sunlight through this type of thinning may increase the productivity of streams or soils that were previously subjected to heavy shading and cool temperatures. Slow thinning of nurse crops could also be studied.

Many kilometres of creeks, most Class B with resident trout populations, are found in the research forest. Streamside vegetation includes alder of varying ages and densities, as well as areas dominated by willow, cottonwood, bigleaf maple or conifers. Many are accessible year round and near roads. Stands of natural and planted hardwoods, some with understory conifers, are available for further studies. The main areas on which little is known are:

- assessment of detritus input to streamwater under varying levels of 'top kill' due to chemical treatment;
- the effect on water flora and fauna of increased water temperature and nutrient levels; and
- residual levels of herbicide in detritus input as a result of chemically controlled growth.

Pure Hardwood Stands

Research is needed on important management issues, such as the harvesting of hardwood stands and the resulting timber characteristics under different growing conditions. There are many sites, some of which are described below. Also, there is room for the establishment of provenance trials, and investigation of the cultivation of hardwoods—which presently is not well understood. Thinned and pruned hardwood areas have been established, particularly in red alder, and more sites and species trials are planned in the near future.

Site 1

Provenance trials of red alder

These trials were established in 1976. Provenances were established in a randomized Latin square plot arrangement. They were thinned in recent years and remeasured in 1987 and 1992.

Site 2

Pure birch plots

Transplanted white birch (*Betula papyrifera*) were established at a regular spacing on a 0.25 ha plot in 1977. This plot is located on a high site (Foamflower-Swordfern-western redcedar association) in the Coastal Western Hemlock, Drier Maritime subzone.

Site 3

Nelder plots

Two Nelder plots (circular design spacing trails) were established with red alder on a high site in 1977. Growth patterns and yield at various spacings and rectangularities are of particular interest here. The trials were measured in 1983 and 1992.

Hardwood-conifer Mixes

A number of sites with potential for research on mixed stands exist in the forest, some of which are outlined below. These sites could be used for spacing trials, growth and yield investigation, soil nutrient studies, and wildlife interaction research.

Site 1

Douglas-fir-birch mixture

This 25-ha area was harvested in 1982, broadcast slashburned in 1983 and planted with Douglas-fir in 1984. Over a 3- to 5-year period, white birch regenerated naturally throughout the site. The entire site is now fully stocked with both species. In the near future it is planned to thin the area in blocks of varying proportions of the two species, followed by the establishment of permanent sample plots for further study.

Site 2

Sludge application

Digested sewage sludge from GVRD treatment plants has been applied in several plots in the Malcolm Knapp Research Forest. Two plots are established in red alder/Sitka spruce mixtures, one a 13-year-old and the other a 4-year-old stand.

Other Sites

- Western redcedar/cottonwood, interplanted in 1986 on an intensively prepared, high-site plot.
- Douglas-fir/alder established in 1986 in alternating rows on 2 ha of totally cleared, high-site land.
- Alder with western redcedar understory, both thinned and unthinned.

Hardwood Management in Riparian Zones

Hardwoods, either pure or in mixtures, may have numerous beneficial effects in riparian zones. Nutrient cycling, groundwater purification, streambank stability, and fish habitat are all related to the riparian vegetation. Management techniques to enhance or retain these values are not fully understood at present, and are lacking in scientific basis. Numerous alternative management regimes need to be compared in controlled studies.

Site 1

East Creek

Stream flow and chemistry data have been collected here since 1979, providing an unsurpassed data base from which to launch further research. This class B stream has also been subjected to various site treatments, including harvest, total site clearing, and establishment of a predominantly hardwood riparian vegetation. A 500 m section has been thinned and underplanted in varying blocks. Fish populations were assessed at various times throughout the 1970s and 1980s. Stream morphology has also been documented in this and other creeks.

Site 2

Road A10

A shorter, upstream section of East Creek was subjected to a different set of treatments in the late 1950s, and provides an older riparian vegetation with a higher proportion of conifers.

Site 3

Donegani Creek

A 200 m section of this Class B creek was harvested, along one side only, in early 1993. Studies of natural or cultivated riparian vegetation are possible, including comparison with untreated sections.

Hardwood Suppression

Many of the areas that are clearcut and replanted with coniferous crop trees on the Gavin Lake block of the forest are vigorously recolonized with hardwood tree species such as aspen and cottonwood. These competing deciduous species typically occur in clumps that are dispersed throughout a treatment area and are controlled by manual brushing methods. Research about alternative methods of suppressing clumps of competing deciduous tree vegetation would be useful.

Research efforts could be directed towards comparisons between the cost and efficiency of different methods of growth suppression (e.g., manual, chemical). Interests might also include the effects of various methods and intensities of suppression on surrounding vegetation species composition and crop tree growth response. Several sites are available for research into different methods of hardwood vegetation suppression, two of which are listed below.

1. Opening 351

Approximately 70 ha of a 10-year-old mixed coniferous plantation near Fire Lake on the Gavin Lake block of the forest is currently not considered free growing due to patches of competing aspen. This site is located beside a road that has easy two-wheel-drive access during the snow-free months of the year.

2. Opening 367

Another potential research site, also on the Gavin Lake block, is a 7 ha block between Choate and Timothy lakes that was logged in 1993. Vigorous patches of aspen recolonization are expected on this block. This site is located alongside a road that would require four wheel drive access during wet and winter months.

Cultivation

Nurse Crop Tree Densities

Hardwoods are currently being used and established on some sites in the forest as nurse crop species. Information is lacking about optimum nurse tree densities required to provide adequate cover for shade-requiring species without inhibiting crop tree growth through light competition.

1. Opening 343

On the slopes of Beaver Valley, in the SBS dw1/01 BGC zone, 3.3 ha of a 30–35-year-old aspen stand was underplanted in 1992 with Douglas-fir. Due to a heavy layer of underbrush, the block was screefed prior to planting. Roughly 100 ha of similar unplanted aspen forest is available for researching optimum nurse tree densities. Overstory densities could be manipulated and the resulting light levels and crop-tree growth monitored.

Stand Tending

Stand-tending guidelines for the production of hardwoods in either pure or mixed stands are lacking. Several sites with a main component of hardwood species are available for research in this area. Areas of interest could include developing stocking standards and a suitable free-growing definition for hardwoods or coniferous species planted under hardwoods.

1. Opening 22

On the Knife Creek block, 150 ha of a layered Douglas-fir stand was manually brushed in 1991. Prior to that, 60% of the total stems were aspen, ranging from 5 to 30 years old. Three 1 ha controls were left untreated and could now be spaced to different densities. The effect of not suppressing hardwood growth on coniferous crop tree growth could also be assessed. A four-wheel-drive vehicle is required to access this block in spring and winter.

2. Opening 20

There is a 2.3 ha area in this opening, also on the Knife Creek block of the forest, which is part of an old burn. It is satisfactorily stocked with layered Douglas-fir and lodgepole pine, and is scheduled for juvenile spacing. 70% of the stems on this site are aspen, which will also be spaced. Opportunities exist for research into mixed stand tending here.

Site Productivity

Many opportunities for research into the effect of deciduous tree cover on soil nutrient cycling and subsequent site productivity exist in the research forest. A gradient of sites from pure hardwood, through a variety of percentage mixes, to pure coniferous can be made available to investigate and compare some of the following areas:

- soil nutrient cycling, capital and availability;
- site productivity—tree growth and volume; and
- cost analysis of mixedwood versus coniferous wood products.

Site productivity could be assessed in comparative trails of different cultivation and stand-tending regimes. These could be established in young stands at the juvenile spacing stage or through planting. Long-term benefits of such trials could include models for predicting mixedwood and pure stand growth and yield. In combination with individual tree growth data, product yields can be determined and costs of various regimes can be analyzed.

Biodiversity

As with site productivity, sites can be made available to study stand-level biodiversity in pure and mixedwood forests. Some areas of interest might include:

- flora and fauna inventories
- soil biodiversity
- types and distribution of wildlife habitat and use

- comparative genetic studies in different provenances/gene pods.

1. Openings 320, 321, 322

Three sites are available in the ICHmk3/01 biogeoclimatic zone, where cottonwood has been planted as a nurse crop for interior spruce. The intent is that the cottonwood will provide side shade to the spruce trees to lower the incidence of attack by spruce terminal weevil. At each of these sites, pure spruce and mixed spruce/pine plantation controls exist.

2. Wildlife diversity

A study of the effects of brushing and weeding (manual and herbicide) and juvenile spacing on small mammals and birds was conducted on the Gavin Lake block of the forest and in surrounding areas in 1988. The study sites are plantations of Douglas-fir between 15 and 25 years old. Brush species at the time of treatment included willow and paper birch. A comprehensive database on species abundance and diversity is available for these sites. Further study could occur 5 years post-treatment to assess how diversity has changed over time.

Cultivation

Little information is available about artificial regeneration of hardwoods. Sites can be made available in the forest for study in this area. Research could provide information about the following:

- seed collection, stratification, and germination;
- methods of establishment and cultivation—vegetative production; strategies, direct seeding, planting (seedlings and whips);
- stock type comparison trials for various hardwood species; and
- growth rates and biomass production.

Re-invasion

Understanding the types of recruitment (seed, root suckers, layering, etc.) that lead to hardwood regeneration is helpful in planning activities in both the suppression and cultivation of hardwoods. Monitoring the re-invasion of hardwood species into blocks where these species have been eradicated, prior to coniferous plantation establishment, can provide us with some of this information.

1. Openings 361 and 358

These two sites are on the Gavin Lake block and are 6.3 and 4.6 ha, respectively, that were rehabilitated in 1992 with a cat and brushblade. All deciduous species (mainly aspen, alder, and cottonwood) were removed and piled on site. They were planted with interior spruce and lodgepole pine in the spring of 1993. The two replicates are within 5 km of each other and require four-wheel-drive vehicle access during the winter and wet months.

Mixedwood Free Growing Guidelines

The B.C. Ministry of Forests is currently updating and modifying existing free-growing guidelines. New guidelines need to be flexible enough to allow the implementation of forest management objectives such as mixedwood stand cultivation. For example, in situations where coniferous trees are underplanted in deciduous stands, the existing free-growing guidelines will need to be modified.

Sites can be made available in mixed stands for study in areas such as:

- Stocking densities.
- Light/growth relationships.
- Photosynthetically active radiation (PAR) under different species canopies.
- Regeneration performance assessments (RPAs).
- Acceptable crop tree characteristics for hardwoods not currently defined,for silviculture surveys.

Vine Maple Gaps in Conifer Forests: Implications for Forest and Wildlife Management

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Unmanaged forests are characteristically heterogeneous. Forest management practices frequently reduce structural and spatial heterogeneity by eliminating hardwoods and creating stands of relatively uniform tree size and spacing. Vine maple (*Acer circinatum*) is a common hardwood of southwestern British Columbia and the American Pacific Northwest. This species can be found in forests of all ages and frequently occupies canopy openings ("gaps") where it may exclude conifers. Such canopy gaps have been shown to be areas of diverse, concentrated resources for a wide variety of plants and animals in many forest types. The demography of vine maple in canopy openings of mature, second-growth Douglas-fir/western hemlock is being studied to assess its role in forest vegetation dynamics and biodiversity.

It is hypothesized that some vine maple gaps originate at the time of stand establishment and persist throughout forest succession. Vine maples would thus maintain "priority gaps" of heterogeneous, deciduous vegetation within the conifer forest, as a result of early establishment after stand disturbance and rapid growth of the vine maples relative to that of adjacent conifers. If this were true, we would expect that 1) stems within a vine maple clone exhibit a range of ages, 2) a gap size threshold exists below which vine maples are not viable, and 3) vine maples exclude growth of conifer seedlings in gaps.

The demography of vine maples was studied along transects in second-growth forests of the Seymour Watershed, Greater Vancouver Water District. Diameter, growth rate, growth form, and leaf geometry were measured for all stems in a clone. A subset of clones within the stand was selected for core analysis. The vegetation and light characteristics of the vine maple plots and paired closed canopy plots were measured to determine which aspects of the forest environment are most divergent between vine maple nodes and the adjacent conifer forest environment.

Preliminary analyses indicate that new vine maple clones, and stems within a clone, are recruited throughout time as second-growth forests develop to maturity. Individual clones exhibit three characteristic stem size distributions. Stem age is significantly, linearly related to diameter in this population ($r^2=0.60$, $n=136$, $F=291.79$, $p<0.001$), suggesting that age distributions within clones follow these patterns. Viability of vine maple clones appears to be weakly related to simple measures of gap size ($r^2=0.12$, $n=24$, $F=4.05$, $p=0.056$). One hundred and eighty degree canopy photographs are being analyzed to study canopy structure, and to determine the influence of more complex measures of gap size, such as percentage open sky and available photosynthetic photon flux density (PPFD), on persistence of vine maple clones. The number of conifer seedlings did not differ between vine maple and closed canopy vegetation plots (Mann-Whitney U test, $p>0.1$). However, a minority of saplings in vine maple plots occur under the vine maple foliage (mean percentage under vine maple=11.6, sd=21.2). The saplings are primarily restricted to edges of vine maple gaps. The canopy photos are being used to further investigate light environments for conifer seedling growth under vine maple and coniferous canopies. Thus, initial results suggest an important role of vine maple in contributing to heterogeneity of vegetation structure and the dynamics of Douglas-fir/western hemlock stands.

The consequences of this vine maple induced heterogeneity for forest bird communities was examined. Birds were counted using 10-minute, fixed-radius point counts during the summers of 1992 and 1993, in the UBC Research Forest and Seymour Watershed. Mean number of individuals, mean number of species, maximum number of individuals, and maximum number of species were higher in vine maple plots than in closed canopy plots, excepting Seymour 1993. Of 24 bird species observed in censuses of vine maple gaps and closed canopy plots, 12 species showed an overall preference for vine maple gaps and five species preferred closed canopy areas, based on numbers of individuals seen in each plot type. The mean of the proportion of sightings that occurred in vine maple plots was 0.53. A proportion of 0.50 indicates no preference between plot types. The extremes of this preference distribution are biased towards those species for which we have relatively small sample sizes, and we are unable to determine whether these results are true indications of preference for one plot type over another or simply artifacts of limited sample size. Vine maple gaps exhibited different vegetation profiles and a greater vertical diversity of foliage than the closed canopy plots (Mann-Whitney U test, $p=0.002$). The vine maple plots had greater percentage cover at lower levels of the canopy, and more species of vegetation at these heights (Mann-Whitney U tests, $p<0.05$). Preferential use of gap habitat by a subset of the avifauna may be due to higher productivity within gaps or the greater diversity of resources, such as insects or seeds, available in these areas. Pacific-slope Flycatchers (*Empidonax difficilis*, PSFl) and Winter Wrens (*Troglodytes troglodytes,* WiWr) showed the strongest association with vine maple plots, preferring this plot type in all four site/year combinations. These species may frequent areas with good aerial foraging opportunities (PSFl) and heavier vegetation for defensive cover at lower levels in the canopy (WiWr).

Recent management initiatives, such as the proposed Coastal and Interior Biodiversity Guidelines, stress the importance of maintaining ecological complexity in forests. Our initial results indicate that vine maples are persistent components of unmanaged forests and thus may represent an alternative stable state to the surrounding coniferous matrix. This study also emphasizes the significance of vine maples in particular, and potentially hardwoods in general, for maintaining diverse structure within conifer forests. The environments maintained by persistent patches of vine maple and associated vegetation are vital for supporting a diverse avian community in these second growth forests. Thus, it is necessary to design silvicultural practices that will create and maintain this heterogeneous foliage structure if we want to retain the entire complement of forest bird species. In the future, we hope to expand this study to investigate the importance of other hardwoods, such as cascara (*Rhamnus purshiana*) and broadleaf maple (*Acer macrophyllum*), for structure and biodiversity in second-growth stands.

A Greenhouse Method for Clonal Propagation of Aspen (*Populus tremuloides*)

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Introduction

Trembling aspen (*Populus tremuloides* Michaux) is an abundant species in the boreal forest (Russell and Honkala 1990) and is of increasing importance to the forest industry. As part of studies assessing genetic variation and plasticity in aspen, a technique was developed to propagate large numbers of aspen stecklings to look at both within- and among-clone variation. This poster was prompted by the interest expressed by silviculturalists working for a variety of forest companies in both Alberta and northeastern British Columbia. Many of these individuals were faced with mandates within their companies to produce many replicates of selected superior clones, but unfortunately had little or no success. This work was done at the University of Alberta in Edmonton in the spring and summer of 1992.

Trembling aspen is a clonal species that reproduces largely by vegetative means (Schier 1973, 1981), but, unlike balsam poplar (*Populus balsamifera* L.), it cannot be regenerated from dormant hardwood, softwood, or greenwood stem cuttings. However, the ability to artificially stimulate and exploit the sucker production after "disturbance" of the parent stem provides an ideal means to mass produce large numbers of individual clones. In addition, shoots that arise from adventitious buds on the roots of the main tree(s) often remain connected for 25 years or more (Cook 1983), making it easy to identify the clonal origin of material when collecting roots for propagation.

Methods

Aspen, like balsam poplar, is a dioecious species and therefore a particular clone will have either male or female flowers. Flowers emerge prior to bud burst when the sex of the clone can be determined by examining the individual flowers of a catkin. In Alberta, males appear to predominate in approximately a 4:1 or 5:1 ratio to females, (personal observation, 1992). The sex of the clone may only be of importance if a breeding program is planned for the future.

After the desired clones have been selected, roots must be collected. If collections are made in early spring before bud burst, damage to the roots will be minimized and propagation can commence immediately. If this is not possible, they can also be collected in the fall and kept frozen (-2°C) and dark over-winter. Roots can be held for several weeks at 1-2°C in the dark but may begin to mold after this time. The best roots for collection are 1–4 cm in diameter and can be clipped at the time of collection to the length of the propagation tray. Assuming that five roots will be planted per tray (50 cm lengths) and that five shoots will be produced per root section, then a minimum of 25 cuttings per tray can be expected. Although there is a fair amount of clonal variation in suckering, 51 of the 53 clones collected throughout Alberta produced significantly more than 25 shoots per tray. Always collect more clones than the final number desired for any planting scheme.

Prior to planting, wash roots and re-cut the ends. Use several sections lengthwise if they are too short to fill the length of the tray. Half-fill trays with horticultural vermiculite, place washed roots on top, and fill in the remainder of the tray with additional vermiculite. Drench the trays with a fungicide to prevent damping off of the new suckers and place in a 22°C greenhouse for best results. Shoots should begin to appear after a couple of weeks and continue to be produced for approximately 6 weeks. Fertilize with a one-half strength solution of 20-20-20 NPK fertilizer every 2 weeks.

When suckers have reached about 5 cm in height, begin taking cuttings. Using a sterilized scalpel (dip in a 10% bleach solution and rinse), cut the sucker from the root, remove the larger basal leaves, dip the end in a commercial rooting hormone, and place into pre-filled Spencer-Lemaire or styro-block containers. Metromix 190 or another propagation mixture can be used. Place a thin layer of 1 mm sand on the surface to reduce moisture loss and weed growth. Prior to planting, treat the mix with a fungicide drench.

To promote rooting of the cuttings, place them under high humidity and reduced light conditions to minimize water stress in the remaining leaves. A misting bench is ideal but an adequate set-up can be achieved with PVC piping, a roll of both polyethylene plastic and construction paper, and a misting nozzle on the end of a watering wand. The piping provides a frame around the new cuttings, the plastic provides a high humidity environment and the paper keeps the material from becoming too hot. Cuttings should be misted twice daily and a foliar fertilizer once per week should be used, being washed off after 1 hour. A minimum of 2 weeks is required from the time of the last cutting being placed into a tray before moving the rooted cuttings (stecklings) outside. They may need a few days of shading in order to adjust to the new conditions. Stecklings should be ready for planting by mid-August, having been outside for a minimum of 10 days. By mid-September, roots were being air pruned at the base of the plugs.

This material can also be successfully stored over-winter. In this case, stecklings were maintained at 2°C with a three-hour photoperiod and watering once per week, with only a couple of plants out of 5000 not flushing the following spring.

Conclusions

This method of propagation requires regular attention but is not necessarily a full-time job, depending on the number of stecklings being propagated. During sprouting, 2–3 hours a day may be needed to check for shoots large enough to cut and a few minutes each day is needed to mist newly cut sprouts. The final product is an extremely uniform set of stecklings for any given clone. This type of propagation appears to minimize "C" effects, which are of greater concern with hedgerow-type cuttings of, for example, western hemlock or yellow cypress.

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Physiological Responses to Thinning in Paper Birch Stands in the ICH Zone of British Columbia

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Introduction

The study was conducted in the Kamloops Forest Region, British Columbia, Canada. Four trials were established in paper birch (*Betula papyrifera* Marsh.) stands within ICHmw subzone in the Salmon Arm, Vernon, and Clearwater districts. On each of the four sites, Barnes Creek (BC), Clearwater (CW), Eagle Bay (EB), and Lee Creek (LC), pure paper birch stands aged at 15 years were selected.

This study was aimed mainly at examining the physiological responses of residual trees to thinning in terms of changes in specific leaf area (SLA), leaf area index (LAI), photosynthetic rate (A), nitrogen use efficiency (NUE), and water use efficiency (WUE) of paper birch, and change in photosynthetically active radiation (PAR) under canopy in order to improve our understanding of how thinning increases growth. Secondly, the study aimed at determining the suitable thinning density for paper birch stand management in the ICH zone.

Methods

A randomized complete-block design was used to lay out the experimental blocks. Four levels of thinning treatments (control, 400, 1000 and 3000 stems/ha), hereafter referred to as Control, T400, T1000 and T3000, were replicated three times on each site. An installation was composed of 12 treatment plots. Measurement plots were 35 × 35 m (0.1225 ha). Each measurement plot was surrounded by a 10–20 m buffer zone. Remaining trees were marked and tagged before thinning. Thinning was done in June 1991. The amount of photosynthetically active radiation (PAR, 400–700 nm) was measured in August 1992 and 1993, in cloudless light conditions, avoiding days of changing cloud cover, to minimize variability in incident light intensity. Canopy transmittance was used to determine LAI. A "Sunfleck Ceptometer" (Model SF-40, Decagon Devices, Inc.) was used to measure PAR at 50 randomly selected points within each plot. At each sampling point, four measurements were taken in four directions.

Ten sample trees were randomly selected from each treatment for physiological measurements. Five attached leaves were randomly sampled from each tree. Net photosynthetic rate and stomatal conductance were measured using a portable closed CO_2 gas analyzer (Li-Cor 6200, Lincoln, Nebraska). All physiological measurements were made between 1100 and 1400 hours. Light intensity, air temperature, relative humidity, and CO_2 concentration were monitored during all measurements. Specific leaf area (cm^2/g) was calculated as the ratio of leaf area to corresponding leaf weight. Leaf samples were ground and analyzed for total nitrogen.

WUE was calculated as the ratio of A to g, because it represents a more consistent estimate of the relative WUE than does the ratio of A to E (transpiration). NUE was calculated as the ratio of A to leaf nitrogen content per unit leaf area. The data were analyzed separately by sites and years after thinning. Analysis of variance was used to test for differences among thinning treatments. When there were significant differences ($p<0.05$), multiple comparison using Tukey's test was made among treatment means. Differences among means were considered to be significant if $p<0.05$. Simple linear regression was used to examine relationships between selected variables.

Results

Analysis of variance indicated that thinning treatments significantly affected all the measured physiological variables of residual birch trees ($p<0.001$) on all sites in both the first and second growing seasons. Tukey's test showed that all the variables from control and T3000 stands were significantly different from those of T1000 and T400 stands. All variables from T1000 and T400 stands were not significantly different in the first growing season except for NUE. During the second growing season, only T400 stand was significantly different from the others except for PAR and SLA. Photosynthetic rate of thinned paper birch increased significantly compared with that of unthinned trees. Photosynthetic rates were 2.2, 7.9, 10.6, and 16.4 mmol $CO_2\ m^{-2}\ s^{-1}$ for control, T3000, T1000, and T400 respectively in the second growing season. This increase was attributed to increases in PAR and foliage nitrogen concentration, and a decrease in SLA. Among the three thinning densities, the 400 stems/ha treatment had the best physiological responses to thinning. However, in terms of management, 1000 stem/ha appears to be the optimal density for thinning these stands in ICH zone.

There was a clear trend that thinning increased leaf net photosynthesis significantly ($p=0.001$). Ranking of leaf photosynthetic rate among treatments for all sites was identical. The treatment with 400 stem/ha had the highest A in the first and second growing seasons. No significant difference in photosynthetic rate between T1000 and T400 treatment was found in the 1992 growing season, but there was a significant difference between the two treatments in 1993. In the first growing season, photosynthetic rates were 2.3, 9.6, 19.9, and 21.5 mmol $CO_2m^{-2}s$-1 for Control, T3000, T1000 and T400 respectively. And, in the second growing season photosynthetic rates decreased to 2.2, 7.9, 10.6, and 16.4 mmol $CO_2m^{-2}s$-1, respectively. WUE ranked 5.6, 8.8, 10.9, and 13.8 mmol CO_2/mol H_2O in 1992, and 3.6, 4.9, 8.4, and 11.1 mmol CO_2/mol H_2O in 1993 for control, T3000, T1000, and T400. No significant difference was found between T1000 and T400 in 1992, nor between T3000 and T1000 in 1993. WUE decreased in all treatments in the second growing season. This might be related to soil moisture.

In this study, physiological performance of individual trees in thinned stands was found to be better than that of trees in unthinned stands. "Thinning shock" (a decrease in relative growth rate and net assimilation rate of paper birch) was not observed during the second summer following treatment. The remaining trees in thinned stands may have acclimated to the increased light conditions because the thinning was done during June 1991. On the other hand, all remaining trees were among the better ones present before thinning.

Net photosynthesis was positively correlated ($r=0.843$ $P<0.001$) with stomatal conductance (g) for trees of all treatments. There were no differences detected in this relationship among treatments ($p<0.05$). However, in the controls, trees tended to have low stomatal conductance and photosynthesis. Decreases of photosynthetic rate, NUE, and WUE in the second growing season indicate a gradual reduction of thinning effect.

The study found that there was no significant difference in all physiological characteristics of paper birch between 400 and 1000 stems/ha. This indicates that if we want to thin these kinds of birch stands, the density of 1000 stems/ha will be a good density at this age.

Aboveground Biomass and Nutrient Accumulation in Age Sequences of Paper Birch (*Betula papyrifera*) in the Interior Cedar-hemlock Zone, British Columbia

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Introduction

This study was conducted in the Thompson Moist Warm ICH variant (ICHmw3) in the southern interior of British Columbia. The study sites were located in the valley bottom and lower slopes of the north Adams River drainage, just north of Kamloops, British Columbia. The primary objective of the study was to describe the temporal patterns of biomass and nutrient accumulation in chronosequence of paper birch stands on good, medium, and poor sites in the ICH zone of British Columbia. The study was mainly focused on variation of biomass and nutrient with stand age and site.

Specific objectives were: 1) to develop biomass regression equations of paper birch that are applicable to the wide range of ages and sizes typically encountered in the ICH zone; 2) to use these equations to estimate biomass of stem, branches, and foliage in age series of paper birch stands on good, medium, and poor sites in the ICH zone; 3) to determine the nutrient concentrations and nutrient content of birch tree components; 4) to determine the nutrient capital of mineral soil and organic matter in these chronosequences of paper birch stands. A secondary objective was to use these data in the calibration of an ecosystem management model FORCAST.

Methods

Seventy-four dominant and codominant trees, proportionally distributed between the different ages and site qualities to cover the range of stem sizes measured in the study, were harvested for destructive biomass and nutrient analyses sampling. The aboveground biomass of shrubs and herbs was clipped from five 1 m^2 frames, randomly located in each replicate of each site-age combination. On each replicate plot, five 25 × 25 cm samples of forest floor were taken. All surface organic material was removed and separated into L, F, and H layers in the field, and fresh weighed. In some cases, L and F layers could not be separated. The line intersect method was used to estimate the mass of dead wood on the forest floor. Regression equations of the form $\ln y = a + b \times \ln$ dbh were derived for the tree component biomass (y) of the 74 sample trees. Data were fitted to the model using the general linear model (MGLH) procedures of SYSTAT. The equations were solved for all trees surveyed in the sample plots, giving estimates of average plot biomass for the four tree components: foliage, branch, stemwood, and stembark.

Results

The aboveground biomass of paper birch increased with stand age from 1.41 t/ha at 2 years to 202 t/ha at 75 years. Biomass varied among site qualities from 0.5 on poor sites to 2.1 t/ha on good sites at age 2, from 9.9 on poor sites to 13.7 t/ha on good sites at age 8, from 101.5 on poor sites to 191.8 t/ha on good sites at age 60, from 155.8 on poor sites to 233.5 t/ha on good sites at age 75. Aboveground biomass was allocated as follows: stemwood > foliage > branch > stembark for stands aged 2 years, stemwood > branch > stembark > foliage for stands aged 8 and 15 years, and stemwood > stembark > branch > foliage for stands aged 45, 60, and 75 years on all sites. Stemwood biomass comprised between 45 and 78% of the total aboveground biomass for all ages and sites. Foliage biomass was proportionally the greatest in the 2-year-old stand, where it exceeded branch biomass, declined with increasing stand age, and stabilized at about 3% of total aboveground biomass after 45 years.

The aboveground biomass of shrubs and herbs ranged from 0.2 to 1.0 t/ha and from 0.2 to 0.4 t/ha, respectively. No relationship was found between aboveground understory biomass and stand age. The mass of woody detritus varied between 17.7 t/ha and 62.7 t/ha. The maximum mass of woody detritus was found in an 8-year-old stand and was related to the harvesting operation and the abundance of birch trees in the stand prior to clearcutting. Forest floor mass decreased from 122.3 t/ha in the 8-year-old stand to 57.9 t/ha in the 60-year-old stand, but reached 84.2 t/ha in the 75-year-old stand.

Nutrient content of aboveground tree biomass increased with stand age and was generally in the order of N > Ca > K > Mg > P. Average rates of nutrient accumulation in biomass were greatest in the early stages of stand development, and less marked as stands aged. The concentrations of nutrients in tissues decreased in the following order: leaf > branch > stembark > stemwood. Understory minor vegetation contributed little to the nutrient pool of these birch ecosystems. Mineral soil contained greater quantity of nutrients than the other ecosystem components.

The concentrations of N, P, and K were highest in the 2-year-old stand. The concentration of P tended to decrease with stand age. Generally, foliage accumulated the greatest percentage on a weight basis of all the nutrients. Although foliage biomass usually represented <9% of the total aboveground biomass (except in the 2-year-old stand in which foliage biomass accounted for 24%), this component accounted for 34% of the N, 29% of the P, 34% of the K, 20% of the Ca, and 32% of the Mg accumulated by paper birch trees. The stemwood, which generally accounted for more than 70% of the aboveground biomass, accumulated only 48% of the N, 51% of the P, 47% of the K, 60% of the Ca, and 43% of the Mg in the aboveground biomass.

Aspen Management Information System

Richard Yang
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The Canadian Forest Service has developed an *Aspen Management Information System (MIS).*[1] In response to the growing interest and utilization of Trembling Aspen throughout Canada, there is a need to supply the forest manager, educator, mill operator, and people interested in the forest ecosystem with an easily accessed and comprehensive guide to the challenges of managing and using one of Canada's most valuable forest resources—*trembling aspen.*

The aspen MIS is a compilation of textual and graphical information concerning various aspects of trembling aspen (*Populus tremuloides* Michx.) management and utilization that are most important to forestry professionals in North America. This personal computer (PC) based system is derived from more than 7000 sources of published literature and has been synthesized, condensed, restructured, organized, and linked to achieve a user-friendly computer tool.

The Aspen MIS is composed of two main parts:

- the information base
- published literature bibliography.

The Aspen MIS program is laid out in a five-part Table of Contents. Accessing information is also available through "key-words" and author searching. The result is an extremely user-friendly Microsoft Windows 3.0 or 3.1 environment (4 mb of RAM + Hard Drive—386 PC or laptop).

For more information on the Aspen MIS and how you can purchase a copy ($100.00), contact:

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Canada/Alberta Partnership
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[1] Developed by Richard Yang, CFS, Edmonton, Alta.

Optimum Nutrition of *Populus* Hybrids in SRIC Plantations in British Columbia

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Populus hybrids in short-rotation intensive-culture (SRIC) plantations have the potential to produce large amounts of biomass for veneer, pulp and paper, energy, and forage using a fraction of the landbase and time required by other species. Poplars in SRIC plantations are very nutrient-demanding and require supplementary fertilization to maximize production. The conventional method of a single fertilizer application at the start of the growing season can lead to leaching losses, low nutrient uptake efficiency, and reduced cost-effectiveness.

Ingestad (1974) proposed that optimum nutrition can be achieved by matching fertilizer application to plant demand. This idea has been examined using solution and soil-less culture, but has not been adequately tested in the field.

The project objectives are to examine the theories that nutrient uptake efficiency can be improved through fertilization regimes that closely follow plant demand over time and that application of a balance of nutrients provides a growth advantage over applying a single nutrient, and to investigate the growth potential of hybrid poplar clones in response to these fertilization practices, in order to develop cost-effective management practices for SRIC hybrid poplar plantations in British Columbia.

The hybrids used in pot and field trials are numbered clones of *Populus trichocarpa* (Black cottonwood) x *P. deltoides* (eastern cottonwood). A field trial will be conducted in an SRIC plantation on northern Vancouver Island at Sayward, B.C. Growth response to six fertilization regimes with respect to an untreated control will be assessed for 2 years. The regimes are as follows:

N – one application @ 225 kg/ha in April.

N – three equal applications (6-week intervals) @ 75, 75, and 75 kg/ha.

N – three incremental applications (6-week intervals) @ 50, 75, and 100 kg/ha.

NPK – one application @ 225 kgN/ha, 75 kg P/ha, and 75 kgK/ha, in April.

NPK – three equal applications (6-week intervals) @ 75, 75, 75 kgN/ha, @ 25, 25, and 25 kgP/ha, and @ 25, 25, and 25 kgK/ha.

NPK – three incremental applications (6-week intervals) @ 50, 75, and 100 kgN/ha, @ 15, 25, and 35 kgP/ha, and @ 15, 25, and 35 kgK/ha.

A pot trial at the University of British Columbia campus will test the theories of optimum nutrition in a more controlled environment, assessing effects of nutrient combinations, loading rates, and fertilization timing.

The outcome of the trials will be two-fold.

1. Fertilization recommendations will be developed to maximize fibre production while minimizing fertilizer waste and negative effects of over-fertilization.
2. This system of trials will provide insight into the applicability of Ingestad's principles to soil culture and field conditions.

The co-operation of MacMillan Bloedel Limited, Woodlands Services Division, 65 Front St., Nanaimo, B.C. is gratefully acknowledged.

Reference

Ingestad, T. 1974. Towards optimum fertilization. Ambio. pp. 49–54.