Designing Mixedwood Experiments
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Stand Reconstruction

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ABSTRACT

Stand reconstruction is used to reconstruct the historical development of forest stands. This retrospective technique can provide useful information on stand dynamics and on the outcome of interactions between different species when grown in mixture. Some sampling issues associated with the use of these techniques are discussed in this paper.

STAND RECONSTRUCTION

“Stand reconstruction” describes the past development of an existing forest stand through retrospective examination of vegetative structure, growth, and mortality. Living and non-living evidence within the stand and historical records are used to make inferences about the past sequence of disturbance events. In order to accomplish this, the following information is first collected from the stand:

- a map of plot contours, living and dead standing stems, boulders, stones, logs, stumps, other tree remnants, and features of interest
- species, diameter (dbh), canopy position, crown projection, stem abnormalities, direction of lean, physiological condition, stem origin, and location of root collar for all standing trees
- measurements of total height, age, and annual diameter growth at the root collar and at any number of successive intervals along the bole, crown length, branch lengths and diameters, branch extensions, and foliage mass from felled and bucked stems
- identification and age of all stumps, woody debris, and windthrow mounds
- timing and configuration of sprout growth
- identification and age of fire scars and charcoal layers

Subsequent analyses of the data can determine the relative height and diameter growth of individual trees and species over time, spatial relationships among individuals and among species, and approximate dates of
disturbance events and regeneration. As a “retrospective” technique, it requires not only meticulous examination of the data but also considerable deductive reasoning to arrive at plausible conclusions.

Earl P. Stephens is likely the first to describe this “historical-development dissection” approach in the North American literature (Stephens 1955). Lorimer (1985) provides a good overview, with emphasis on non-destructive methods for determining disturbance patterns on regional scales.

Ian Cameron (MOF Research Branch, Kamloops Region), Phil LePage (MOF Prince Rupert Region), and I have recently experimented with stand reconstruction techniques to determine the structure and development of even-aged mixed species stands near Woss (Vancouver Island, CWH), Hazelton (“Date Creek,” ICH), and Clearwater (ICH), British Columbia. Many of the observations that follow are from these studies.

When planning a stand reconstruction project, a number of sampling issues arise:

**Plot location within the stand:** the number and location of sample plots depend on the objectives of the study. Cases of subjective (Stephens 1955; Henry and Swan 1974; Oliver 1978) and systematic (Stubblefield 1978; Cobb 1988) plot location are described in the literature. At Woss and Date Creek, stands representing a chronosequence of ages within the same species mix were located within the subzone. Attempts were made to “link up” the backdated plots to trace the developmental history. The stand structure variation was greatest at the Clearwater sites, so efforts were focused on 60-year-old stands. In all cases, a systematic grid of “structure plots” was first established to cover the area and to estimate stand-level parameters. Destructive sampling plots were chosen from among these, usually to represent the range of structures encountered.

**Destructive sampling intensity:** in light of the project objectives, the researcher must determine the investigation parameters. Some parameters to be considered are:

1. Reconstruction of several smaller plots that cover the range of structures and sites present in the stand, or fewer large plots, which provide more detailed information about selected areas.
2. Sample all trees within a plot or take subsamples. Stem analysis of all trees in the plot allows study of the growth of each individual and its neighbours, but it is expensive; subsampling reduces time and labour costs but with a subsequent loss of information.
3. The amount of information to collect from each tree. This includes deciding the frequency of crosscuts up the bole to sample volume and height growth, and the intensity of crown, branch, and foliage sampling.

In our work, we destructively sampled plots of several sizes: a few small plots to estimate site variation (e.g., across a moisture gradient), and a few large plots to capture the spatial arrangement. All stems were dissected within a subplot located at the centre of the larger plot; trees surrounding this subplot were subsampled based on species and height. In some cases,
a subplot was established in which to map and dissect smaller trees. Crosscuts were taken at the root collar, 0.30 m height, 0.70 m height, 1.3 m (breast) height, 2.0 m height, and every 2.0 m thereafter. Limited branch sampling was done at the Clearwater site.

We encountered difficulties determining the correct point of germination and therefore total age; counting and measuring densely packed rings; correcting age counts at each crosscut when annual growth did not produce a detectable increment over the wholebole; and dating mortality. These sources of error can critically affect the interpretations of canopy and gap dynamics. Other drawbacks to this technique are the destructiveness to the trees and site; the costs of obtaining thorough information on a full range of site types and stand ages; and the difficulties of using plot information to make generalizations with respect to stand-level dynamics.

Although lacking the rigour associated with traditional experiments, this research has assisted us in comparing the relative growth trajectories and emergence of different species over time.

LITERATURE CITED


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Planting Designs for Neighbourhood-Level Analysis of Species Interaction

MATTHEW J. KELTY AND IAN R. CAMERON

ABSTRACT

Mixed-species stands are becoming increasingly important in forest management. It is necessary to understand the interactions among the species that make up a mixture in order to develop appropriate management strategies. Two basic kinds of interaction effects have been identified that can cause yields in mixtures to exceed those in monocultures of the component species: 1) complementarity and 2) facilitation. Two hypotheses define the extremes of competitive interactions between two species: Hypothesis A: interspecific competition equals intraspecific competition (the species occupy the same niches); Hypothesis B: interspecific competition is entirely absent (the species have no niche overlap). Agronomy- and plant ecology-based substitutive (replacement series) and additive experimental designs have been used to study these interactions. The replacement series design can directly test Hypothesis A, but cannot directly test Hypothesis B for all stand densities; the converse is true of the additive design. Another type of experimental design, referred to as addition series, multiple replacement series, and bivariate factorial, share the characteristic of including both additive and substitutive comparisons. When these designs are used in forestry studies, they require large land areas, which must be maintained for long periods. Alternative planting designs are presented here that allow the efficient analysis of individual tree/neighbourhood interactions within the context of a replacement series. These designs are a modification that gives a constant neighbourhood composition for every tree of a species in each plot; it therefore may be useful to incorporate into a study design to allow efficient stand-level and neighbourhood-level analysis from the same planting trial.

PLANTING DESIGNS FOR STUDIES OF SPECIES INTERACTION

Mixed-species stands, compared to monocultures, are becoming increasingly important in forest management because of their greater
biological and structural diversity, their potentially higher stability in response to the effects of pests, diseases, and changing climate, and in some cases for their greater long-term productivity. It is necessary to understand the interactions among the species that make up a mixture in order to develop appropriate management strategies and to predict yields and stand structural changes in response to treatments.

Two basic kinds of interaction effects have been identified that can cause yields in mixtures to exceed those in monocultures of the component species: 1) "complementarity," in which species differences in height, crown form, rooting depth, and phenology result in reduced competition and a more complete use of a site's resources (most evidence for this interaction comes from mixed stands with stratified canopies); and 2) "facilitation," in which the presence of one species directly benefits another (most forest studies of facilitation have focused upon mixtures of nitrogen-fixing species with non-nitrogen-fixing species). Many researchers discuss species interactions as being entirely competitive in nature (in which the question is whether or not complementarity exists); however, in some cases, interactions are the net result of both competitive and facilitation effects.

Studies by agronomists and plant population ecologists using herbaceous crop species have employed two kinds of experimental designs to study interactions between two species: the "substitutive" design (or replacement series), in which density is held constant across a series of plots and species proportions are varied; and the "additive" design, in which one species density is held constant and the density of the second species is varied across the series of plots. The interaction effects are measured in terms of the biomass yield of each species in stands of different densities and proportions. There has been disagreement in recent literature as to the usefulness and validity of the two designs (Snaydon 1991, 1994; Sackville Hamilton 1994). While there is no resolution of many of these points, I suggest that Sackville Hamilton (1994) has made an important contribution in describing the way that each design can be used to test a specific hypothesis about competitive interactions. Two hypotheses define the extremes of competitive interactions between two species:

Hypothesis A: interspecific competition equals intraspecific competition (the species occupy the same niches); Hypothesis B: interspecific competition is entirely absent (the species have no niche overlap). The replacement series design can directly test Hypothesis A, but cannot directly test Hypothesis B for all stand densities; the converse is true of the additive design. In order to assess productivity in relation to both hypotheses for any mixture of a given density and species proportion, it would be necessary to have four monocultures: two monocultures at the total given density and two monocultures at each species respective proportions. This would provide both the additive and substitutive comparisons. However, interaction effects between species may vary with overall density, so it would be necessary to repeat this kind of design at different densities, which would lead to a rather complex experimental design.

Another way of defining the objective of such studies in an applied management context is with the following question: what is the yield/density relationship for each monoculture and each mixture of given species proportions? For either statement of objectives, complex designs are called
for in order to completely analyze the effects of interactions on yield. These designs have been referred to as addition series, multiple replacement series, and bivariate factorial designs (Firbank and Watkinson 1985). All share the characteristic of including both additive and substitutive comparisons.

When these designs are used in forestry studies, they require large land areas that must be maintained for long periods. It is unlikely that they will be established in many situations. This problem alone indicates the need to use individual-tree modelling techniques to study interactions based upon data from smaller, less costly experimental designs. Forestry studies also differ from agricultural studies in that there is direct interest in stand structure when objectives such as wildlife habitat and aesthetics are important, and harvests may occur at intervals (as commercial thinning) leading to a final harvest. Thus, there is considerable interest in the

![Diagram of four-plot replacement series using hexagonal spacing](image)

**Figure 1** Diagram of four-plot replacement series using hexagonal spacing; this series provides for efficient analysis at both stand level and individual-tree level. Within each plot, each tree of a given species has the same neighbourhood composition, as indicated by solid lines for one tree of each species.
process of how yield and structure develop over time, not just in the final outcome. These questions also lend themselves to individual-tree modelling approaches.

Planting designs are presented here (Figure 1) that allow the efficient analysis of individual tree/neighborhood interactions within the context of a replacement series. These use triangular (also called hexagonal) spacing in which each tree is equidistant from six neighbors. From the viewpoint of neighborhood composition, a four-plot series (two monocultures and two mixtures with 67:33 and 33:67 species proportions) gives three important conditions for each tree: 1) surrounded by six of the same species; 2) surrounded by six of the opposite species; 3) surrounded by three of each species. This planting design does not overcome the need for repeating plot series at different densities, nor does it solve the question of how large the functional neighborhood actually is. However, it is a modification that gives a constant neighborhood composition for every tree of a species in each plot; it therefore may be useful to incorporate into a study design to allow efficient stand-level and neighborhood-level analysis from the same planting trial.

**LITERATURE CITED**


Mixedwood Monitoring and Modelling: Mystery or Madness?

KERRY DESCHAMPS

ABSTRACT

A new era of mixedwood management is dawning in northeastern British Columbia. In the Prince George Forest Region, much interest has been expressed in mixedwood management and its impact on stand development. A growth and yield strategy is needed in mixedwoods. The strategy should include a combination of experimentally designed trials and operational monitoring plots. The information generated from experimental trials and monitoring plots will provide guidance and feedback to foresters who prescribe various mixedwood management treatments. This paper is intended to generate discussion on obtaining useful information and on the use of adaptive management for improving the management of mixedwood forest types.

INTRODUCTION

In northeastern British Columbia, a large portion of the landscape is dominated by mixedwood forests composed mostly of a trembling aspen overstorey with a white spruce understorey. The presence of white spruce as an understorey component poses significant operational problems, especially where spruce is greater than 20% by volume or greater than 800 stems/ha. It has been particularly challenging to find harvesting methods that permit removal of merchantable aspen while protecting the vulnerable spruce understorey. Alberta and Ontario have conducted research and harvesting operations of mixedwoods that demonstrated efficient removal of the hardwood overstorey and preservation of the immature spruce understorey, thereby promoting healthy future stand development.

MOMENTUM

Prior to 1986, there was very little utilization of trembling aspen in northeastern British Columbia. Often the management prescription on aspen
sites was to knock the aspen down and plant more valuable conifers. The signing of Pulpwood Agreement #10 with Louisiana Pacific in 1986 marked the beginning of a new era of hardwood utilization. The momentum for hardwood and mixedwood management has steadily increased, as has the need for information to guide prescriptions.

Below is a list of recent activities relating to mixedwood management:

- **Fort St. John**
  - various mixedwood workshops and field tours
- **Dawson Creek**
  - various mixedwood workshops and field tours
  - **MOT**—small business 1993 mixedwood cut near Kelly Lake
- **Fort Nelson**
  - mixedwood demonstration area and field tours
  - **CCMC**—mixedwood cuts CP11 and CP23 in 1994
  - proposed mixedwood cut 1995 along Sierra Yoyo, CP24
  - Slocan OSB Mill
  - proposed 1996 mixedwood cut

Mixedwood management has created many new hardwood and mixedwood forest management issues for northeastern British Columbia. Robinson (1993) recently completed a report summarizing significant hardwood and mixedwood issues in the Prince George Forest Region. The report covered four broad categories of issues: 1) timber and economic; 2) land use; 3) planning and inventory; and 4) silviculture. Forty-three issues were identified with recommended actions. Three issues related to growth and yield:

- no provincial strategy for growth and yield in hardwood and mixedwood stands
- growth and yield equations may not reflect succession of mixedwood stands, and
- no representation in the Forest Productivity Council from the Prince George Region.

**MONITORING**

Monitoring is simply the repeated measurement of conditions over time. Operational monitoring is done primarily for the purposes of setting standards and for quality control (Moss 1993). As Moss (1993) points out, operational monitoring is designed to answer questions such as:

> To what degree do treatment regimens, as applied to different site and stand (ecological) conditions, succeed in producing stands with desired species composition, survival, stocking and growth?

> What minimum and desired targets should be set as a means toward improving the success?
How can we ensure that the treatment regimen we have applied will indeed produce free growing plantations that will not incur further liabilities?

Even if free growing establishment standards are met, how can we ensure that the long term productivity of these new conditions will satisfy demands for future wood supply, habitat, recreation, water quality and biodiversity?

A statistically sound system of monitoring could provide answers to the above questions, without which, mixedwood and hardwood management would be left to personal biases and intuition.

Scientifically designed experiments have a very important role in improving mixedwood management practices. However, scientifically designed experiments are often too detailed and too site specific, require conditions that are not normally observed in practice, and are difficult to implement.

The statistical design of the monitoring system for the previous list of mixedwood cuts in northeastern B.C. was somewhat of an afterthought, as outlined below:

• MOF—Kelly Lake Study
  - first thought was a visual walk-through
  - final thought was two 17.84 m radius PSPs
  - added a research site prep/planting component

• CCMC—Sierra Road CP11
  - final thought was a visual walk-through

• CCMC—Sierra Road CP33
  - first thought was four photo points
  - second thought was four 3.99 m radius plots
  - final thought was 42 5.64 m radius plots/PSPs

There is a need for both better-designed experiments and operational monitoring systems of mixedwood forest types. Some issues to address in an operational monitoring system include: sampling design; location number, and size of plots; what to measure and how often; and data storage and sharing, analysis, and reporting.

MODELLING

Information from experiments and monitoring plots can be used to calibrate or develop growth and yield models. Models allow us to try out (simulate) different management practices and observe the outcomes.

Presently there are only two growth and yield models for our northern boreal mixedwood forest types. They are 1) IFS—Mixedwood Model (Moss 1992) and 2) Mixedwood Growth Model (MGM) (Titus 1993). Also, a third model is being developed by the Canadian Forest Service (CFS) in Victoria (Bonnor 1993).
The IFS-Mixedwood Model is a stand-level model developed for use with only trembling aspen and white spruce, either individually or in combination. The model was developed from various component data and parts, including local data and Petawawa white spruce yield curves. The growth components include diameter, height, mortality, and competition index. The model is written in Fortran and runs on a VAX.

MGM is an individual-tree, distance-dependent model that is applicable to the boreal forests of Alberta. The main species in the model are trembling aspen and white spruce, although 14 other species are included. Most of the component relationships are based on data from Alberta PSPs. Stand dynamic relationships include: diameter increment, height increment, mortality, and ingrowth. Recently the model has been implemented in Microsoft Excel 5.0 for Windows (Titus 1993).

The mixedwood model being developed by the CFS is called STIM (Stand and Tree Integrated Model). STIM is designed for inventory update, management planning, and AAC calculations. STIM includes both a tree and stand growth model component and has been implemented for western hemlock. Plans include using STIM as a framework for modelling trembling aspen-white spruce.

CONCLUSION

Mixedwood management in northeastern British Columbia is gathering momentum, and a growth and yield strategy is needed to keep it on the right track. The strategy should include both designed experiments and an operational monitoring system. The information generated from experimental trials and plot monitoring will provide guidance and feedback to foresters who prescribe various mixedwood management treatments.

Mixedwood monitoring and modelling is a bit of both: mystery and madness.

LITERATURE CITED


Assessing the Feasibility of a Triple Rotation System in Mixed Trembling Aspen—Conifer Stands: Its Effects on the Regeneration, Growth, and Survival of Aspen, Balsam Fir, White Spruce, and Other Competing Species

CHRISTIAN MESSIER

ABSTRACT

In the summer of 1995, a study will be initiated to examine the effects of different partial cutting regimes on the short-term and medium-term dynamics of understorey vegetation in an aspen-dominated stand. The experiment will be conducted in the experimental forest of Lake Duparquet in Abitibi (southwestern Québec), and will include three types of stands: 1) 50-year-old pure trembling aspen stands originating from fire, 2) 72-year-old aspen stands originating from fire, and 3) 50-year-old trembling aspen stands originating from the clearcutting of conifer-dominated old-growth stands. The treatments will be three levels of overstorey removal: 1) 20–30%, 2) 40–50%, and 3) a total cut with protection of the advanced regeneration. Micro-environmental and soil conditions will be monitored to determine the effects of the different cutting regimes. The aspen is expected to re-sprout vigorously under all three cutting regimes. Conifer growth will be strongly influenced by their ability to respond quickly to the increased light availability, which will be related to the degree of overstorey removal and the re-growth of aspen and minor vegetation.

STUDIES OF TRIPLE ROTATION SYSTEM IN MIXED TREMBLING ASPEN—CONIFER STANDS

This year we will be initiating a study to examine the effects of different partial cutting regimes on the short-term (first three years) and medium-term (until the remaining overstorey is removed) dynamics of understorey vegetation. We want to determine the optimal understorey conditions for conifer growth, and the suppression of the aspen and other non-crop...
vegetation. We want basic ecological information on the feasibility of a triple rotation system in which almost pure aspen stands will alternate with mixed aspen-conifer and mainly conifer stands. This silvicultural system will simulate the natural stand dynamics in this area, where, following fire, aspen (Populus tremuloides) is slowly being replaced by balsam fir (Abies balsamea) and white spruce (Picea glauca). Other ongoing experiments indicate that the maintenance of a broadleaved component is important for maintaining long-term site productivity.

The experiment will be conducted in the experimental forest of Lake Duparquet in Abitibi (southwestern Québec), and will include three types of stands: 1) 50-year-old pure trembling aspen stands originating from fire, 2) 72-year-old aspen stands originating from fire, and 3) 50-year-old trembling aspen stands originating from the clearcutting of conifer-dominated old-growth stands. For each type of stand, four plots (60 m × 60 m) will be installed, one plot for each of the three silvicultural treatments and one control. The treatments will be three levels of overstorey removal: 1) 20–30%, 2) 40–50%, and 3) a total cut with protection of the advanced regeneration. All of the vegetation will be inventoried and mapped prior to the cut. Also, the physiological (photosynthesis, respiration, stomatal conductance, and hydraulic conductivity) and morphological (crown shape, height growth, lateral growth, and number of nodal and internodal branches) conditions of the advanced regeneration (spruce, fir, birch, and aspen if present) will be studied along a natural gradient of light and sapling size. Prior to the cut, micro-environmental (light availability and quality, air and soil temperature) and soil conditions (NH₄⁺, NO₃⁻, PO₄⁻, and water tension) will be characterized using a 3 m grid located within the 60 m × 60 m plots.

Following cutting, the micro-environmental and soil conditions will be recorded at each grid location to determine the effects of the different cutting regimes on these factors. We will also monitor the growth and dieback of the vegetation present before cutting. The changes in the growth, physiology, and morphology of the tagged advanced regeneration will be followed for 5 years. Their ability to respond to the opening will be related to their physiological and morphological state prior to cutting and the micro-environmental conditions in which they grew. The sprouting of aspen will be followed in 2 m × 2 m plots centred on the points of the grid where the micro-environmental conditions are monitored. Overstorey canopy closure will be followed to document the changes in the understorey light environment under the different cutting regimes.

We expect the aspen to sprout vigorously under all three cutting regimes, but its vigour will decline where a certain percent of the canopy is left. The ability of the shade-tolerant conifers to respond quickly to the opening will be related to their vigour prior to cutting. Following cutting, the rapid growth of aspen and other competing shrubs, and the gradually declining light availability due to crown closure, will affect conifer growth. It is hoped that the conifers' greater morphological plasticity will enable them to survive these stresses until the aspen and other competing vegetation begin to thin and die back. The number of years for this to occur will determine the timing of the second and final cut.

We hope that by the time of the final cut, the conifers will be big enough to be free to grow. We also expect that at the end of the first
rotation the overstorey will contain at least 40% aspen, the rest being conifers. It will then take another rotation (a partial cut, followed by the removal of the remaining trees) to produce a stand dominated by conifers. We expect that some aspen will be present, but they will form only a minor component of the overstorey stand. At maturity, this stand will be clearcut, and we expect enough dominant aspen trees to be left per hectare to ensure that the regeneration will be strongly dominated by aspen sprouts. Then we will start another triple rotation cycle with an aspen-dominated stand.

This system has the obvious advantage of maintaining the natural stand dynamics found in this region, where pure aspen, mixed broadleaf-conifer, and pure conifer stands alternatively dominate the sites. Also, such a system will reduce the use of herbicides and the need for re-planting. In the next few years, we want to experiment with the feasibility of increasing the spruce component of our stands by planting white spruce in the understory. The plots will be selected and site conditions characterized in the summer of 1995. The cut will be done during the winter of 1995/96.

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