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# An examination of 27-year stand- and tree-level responses to a range of post-harvest basal area densities in moist sub-boreal multi-aged spruce-*Abies* stands of central British Columbia

*(working title only)*

**Introduction and Study Rationale**

In British Columbia, naturally-occurring mixed forests of Interior spruce (*Picea glauca* x *engelmannii*) and subalpine fir (*Abies lasiocarpa* Hook. Nutt.) are extensively distributed across the moist cool montane plateaus and windward mountain ranges of Interior British Columbia. These natural spruce-fir stands are frequently multi-aged in character and multi-sized in structure, due to both the shade tolerance of these tree species, the age of stands, and the prevalence of small-scale natural disturbances including factors such as wind, ice and snow damage, bark beetles, and stem rots as and resulting gap mortality and regeneration with increasing stand age. Interior spruce as referred to in this paper is a well-documented naturally-occurring hybrid of Engelmann spruce (P. engelmannii) and white spruce (Picea glauca) which ranges across the Cordilleran mountain ranges, valleys, and plateaus of central and northern Interior British Columbia (references, \_\_\_\_).

This complex character and structure of many spruce-fir stands is common in these continental regions in British Columbia where wet and snowy climates tend to result in relatively low to very low frequency of catastrophic disturbances. These spruce-Abies stand types are most frequent and productive on lower topographic positions (mesic to hygric sites) with moist soil conditions and favorable soil nutrient availability.

Many SBS and ESSF spruce-balsam stands have silvical and structural characteristics that can be adapted for various types of partial-cut silvicultural systems, including selection management. These characteristics include moderate- to high shade-tolerance of both tree species, demonstrated ability to establish and grow in smaller canopy gaps; variable, and often multistoried stand structures which contain a wide range of intermingled diameter and height classes and tree species, and relatively open, multilayered canopies. On appropriate sites and soils, these characteristics provide opportunities for the retention of windfirm secondary structure, understory regeneration, and individual leave-trees, after moderate partial harvest of selected trees.

There has been a long history (up to a century) of use of partial-cut timber-harvesting methods and of its related reliance on natural regeneration in multi-aged hybrid white spruce and subalpine fir (or “balsam”) stands (Weetman and Vyse, 1990). Such practices were in frequent use historically in Interior British Columbia from the 1910’s to the late 1960’s and early 1970’s. However operational use of these systems became more limited after the late 1960’s, when the rise of the pulp-milling industry in Interior British Columbia led to increased utilization of smaller and previously unmerchantable trees and to use of certain types of mechanized logging methods that were not conductive to protection of understory trees. From the 1970’s to the present, clearcut harvesting and regeneration via planting became the primary silvicultural system of choice for the forest sector in this region.

Factors that also contributed to the mid-20th century demise of partial-cutting practices in British Columbia spruce-fir forest types were the often-significant deficiencies in harvest policy, planning, and implementation for these forest types, with a focus on extraction of the best trees, and lack of attention to the condition of the residual post-harvest stand. Such “high-grading” practices included the common practice of loggers “selectively” removing larger merchantable spruce from stands while retaining only whatever non-merchantable advance and natural regeneration remained in these multi-layered stands. The resultant stands were often highly irregular in stocking and conditions, varying widely in density, species composition, and the age and quality of advance regeneration (reference, 19\_\_).

Replicated long-term research trials like EP 1162 described in this paper (with its associated 27-year results) provide opportunities for more systematic assessment and comparisons of the outcomes of different stand management options and a range of uneven-aged stand conditions in sub-boreal spruce-*Abies* stands. Such trials and resultant data provide the basis for better understanding and quantification of tree and stand response to a range of treatment options, leave-tree basal area densities, and target stand structures. These trials and treatment response data provide the basis for forest managers to develop more detailed evidence-based guidelines for the improved silvicultural management of unevenaged spruce-fir stands.

Increasingly, forest land managers are also interested in wider use of partial-cut silvicultural systems in spruce-Abies forest types to maintain complex stand structures that meet a greater range of stand and landscape conditions than is possible with clearcut methods alone (Bankowski, 2018, Jull, 2018; BC Ministry of Forests, Range, Nat. Res. Operations, and Rural Development, 2020). This is especially true as the range of forest and landscape values for which we are managing becomes more challenging and complex. For example, silvicultural research and specialized operational application of partial cut silvicultural systems in spruce-fir types has continued over the last few decades in British Columbia in areas such as mountain caribou habitat (Stevenson et al, 1999; Waterhouse et al, 2011) and visually-sensitive areas, demonstrating the success and efficacy of these methods to meet both regeneration and integrated-resource-management goals.

Quantitative data-driven silvicultural guidelines would provide the basis for improved stand management and evidence-based silvicultural planning for partial-cutting prescriptions in multi-aged spruce-fir stands. Such guidelines would better inform ecologically-appropriate post-harvest stand stocking goals and structural objectives for complex uneven-aged stands, as well as silvicultural expectations for the growth and stand development of these partial-cut stands in response to different intensities of partial-cutting and basal area removal.

**Spruce-Abies forest types in the global and North American context**

Globally and continentally, these spruce-fir forest types discussed in this paper are part of the *Cool Temperate Forest and Woodland Formation* (USNVC ver 2.03, 2019). In the northern hemisphere, this forest biome occurs in west and central Europe, eastern Asia including Korea and Japan, northeastern North America, and western North America. Eastern North American analogues include Acadian temperate spruce-fir forests, while comparable western North American vegetation zones include Interior Cordilleran subalpine and sub-boreal spruce-fir forest types.

In British Columbia, *Picea-Abies* forests occur mainly within two main vegetation zones under British Columbia’s biogeoclimatic ecological classification system (reference, date), including the lower- to mid-elevation *Sub-boreal Spruce* (SBS) zone, and the mid- to higher-elevation *Engelmann Spruce-Subalpine Fir* (ESSF) zone. These forest types are most predominant in the moist to wet SBS and ESSF biogeoclimatic subzones in the located east of the Coast Range and west of the Continental Divide in the Rocky Mountains (references, years) where stand-destroying disturbances such as fire are rare and small gap-phase disturbances are common (reference, \_\_\_\_).

Early Canadian classifications of this forest type classified these British Columbian forests as *Montane* and *Subalpine* (Rowe, 1972), and later, as the *Interior Cordilleran Ecoclimatic Province* (Ecoregions Working Group, 1979). However, in the current Canadian Forest Ecosystem Classification (reference, 2019), these forest types are now subdivided and renamed as *Cordilleran Sub-boreal Forest* and *Montane Cordilleran Forests*.

In the US National Vegetation Classification (which also extends conceptually to other regions of North America), these British Columbian forest types are described as *Rocky Mountain Intermontane Subboreal Forests*. These are similar or regionally analogous to the *Rocky Mountain Dry-Mesic and Mesic Wet Spruce-fir Forest* types in southern BC and moist cool upper-elevation continental forests of the Cordilleran mountain ranges in the western United States (NatureServe, 2009; Alexander, 19\_\_).

**EP 1162 Experimental Purpose and Design**

Experimental Project (EP) 1162 was established in 1992 as a long-term silvicultural field experiment that tests and examines the effects of a range of residual basal area (stand density) management options for complex uneven-aged subalpine fir-hybrid white spruce stand types of Interior British Columbia. This long-term field experiment is also referred to as the Summit Lake Basal Area Density Trial.

The overall goal of EP 1162 is to provide scientific data that will improve our understanding of short- to long-term trends in uneven-aged stand development and growth patterns, over a wide range of possible residual basal area densities in sub-boreal spruce-subalpine fir forest types. Trial findings will aid and inform forest managers and practitioners in the prescription and application of partial-cut silvicultural systems, for a variety of forest resource values including timber production, habitat characteristics related to stand structure, and forest carbon.

The study and experimental design, treatments, and monitoring protocol are described in and guided by the EP 1162 Working Plan (Jull, 1992). A detailed review and documentation of trial history, establishment, and methodology is described in the EP 1162 Progress and Status Report (Jull and Gonzalez, 2020).

**Description of Study Area and Site Characteristics**

The EP 1162 trial site is located between 710 and 740 metres elevation above sea level on gently to moderately rolling terrain, in the Crooked River valley north of Summit Lake area about 50 km north of Prince George.

The landform within the trial area is drumlinized glacial till, (Dawson, 1989). Slopes range from 5 to 25%. Dawson classifies these soils within the Dominion soil association, describing them as being medium to moderately fine textured with variations to moderately coarse textures at the surface; stoniness is variable, ranging from slightly to very stony.

Ecologically, this trial is situated in the Mossvale Moist Cool SBSmk1 biogeoclimatic subzone (DeLong et al, 1993). SBSmk1 biogeoclimatic site series relevant to EP 1162 trial sites and permanent plots include 01 or mesic (Spruce-Huckleberry-Highbush Cranberry), 07 (Spruce-Oak Fern), and 08 (Spruce-Devils Club). Minor inclusions of slightly drier and wetter site series occur occasionally within the trial area.

Tree species within the trial area primarily include subalpine fir, Interior spruce, paper birch (*Betula papyrifera*), and occasional Douglas-fir (*Pseudotsuga menziesii* var *glauca*). At time of trial planning establishment, scattered old stumps within the study area as well as old timber sale records were evidence of past low-volume diameter-limit removal of some mature spruce in the area in the mid-1950’s; the year of this prior selective harvest was approximately 1955.

1991 pre-harvest basal area across all treatment units averaged 33.6 m2/ha. Pre-harvest average stand basal areas as of 1991 had a moderate range of variation, from a low of 30.1 to a high of 37.1 m2/ha, with standard deviations of 4.3 to 5.7 m2/ha within each treatment class (Jull, 1992; Jull and Gonzalez, 2020).

**Treatments and Field Monitoring Methods**

The processes and stages of trial layout and design, and implementation of prescribed basal area removals are described in detail in Jull (1992) and Jull and Gonzalez (2020), and summarized here.

Three target residual basal area density levels (10 m2/ha, 20 m2/ha, and a 30 m2/ha “control”) were randomly allocated and replicated to the available treatment units across the trial area, on a systematic grid. Stand basal areas within each treatment unit were reduced to the target densities as prescribed by a combination of selection harvesting for timber, and post-harvest sanitation felling of selected non-merchantable trees. These processes are described below in this section. To monitor stand growth and development, a permanent sample plot (PSP) was located and monitored in the centre of each treatment unit.

For each treatment unit, marking crews adjusted the intensity of tree harvest and leave-tree retention in each treatment unit to meet the approximate prescribed (and randomly selected) basal area retention level identified in the experimental design.

The stages in the stand assessment and treatment process included: (1) pre-harvest stand inventory and marking-to-cut of harvested trees within randomized treatment units in 1991, (2) commercial winter harvesting of selected marked trees in Winter 1991/92, (3) post-logging stand assessment and adjustments for treatment impacts in Summer 1992, (4) sanitation cutting of logging-damaged trees in 1992/93, and (5) final resolution and quantification of initial basal area densities and stand structure in each treatment unit.

During Winter 1991/92 selection harvesting throughout the trial area, marked-to-cut trees were manually felled by chain-saw equipped fallers, and felled trees were ground-skidded on snowpack to designated landings for log sorting. Logging crews were instructed to selectively remove only marked trees within each treatment unit and to minimize damage or incidental harvest of other, unmarked trees.

In the 1992 summer field season following timber harvesting, research crews assessed the condition and post-harvest basal area of each treatment unit. A complete post-harvest live-tree inventory was conducted, and PSP’s established, to quantify the actual level of basal area retention achieved in each treatment unit. Damaged non-merchantable trees were marked for post-harvest sanitation felling without skidding or extraction. Where necessary to more closely approximate the prescribed basal area density for each treatment unit, minor additional poorer-quality coniferous trees were marked-to-cut and felled.

General operational fill-planting of the prescription area was conducted with container-grown PSB 415 1+0 hybrid white spruce planting stock (BC Ministry of Forests Seedlot # 6585), in order to restock perceived ‘voids’ created by logging, including skid trails and other unstocked gaps based on the spatial distribution of good-quality residual trees and advance regeneration, and to mitigate the heavier (85-90%) subalpine fir composition of the residual stand. The average density of planted trees within the experimental area ranged from about 300 to 600 stems-per-hectare.

Mean post-treatment percent basal area retention level and basal area density statistics by prescribed treatment classes are described in Table 1 and Figure 1 below, based on comparisons of Fall 1994 PSP data for each of the basal area density treatment classes.

**Permanent Sample Plot Layout and Measurements**

One 0.05-hectare (12.6 m-radius) circular growth-and-yield permanent sample plot (PSP) was established at the center of each 0.25-hectare experimental treatment unit, as per Jull (1992). The original 1990 Ministry standards for PSP maintenance and measurement cited in the working plan were also updated as per Forest Analysis and Inventory Branch (2016) standards.

The PSP’s were established in 1992, with the exception of two PSP’s (# 4 and 15) established in 1994. The 15 PSP’s were remeasured in Fall 1994, October 1997, May 2009 (prior to onset of growing season), and October 2019.

For the 2009 remeasurement and onwards, the small-tree minimum-diameter measurement limit was raised from 4.0 cm dbh to 7.5 cm dbh. This change was spurred by both logistical and sampling considerations. From a logistical perspective, we found through experience that smaller conifer saplings < 7.5 cm dbh could not be effectively tagged (i.e. – via nailing a number tag at breast height) without significant damage to the small tree stem. And from a sampling perspective, we streamlined our PSP sampling regime by focusing on monitoring trees > 7.5 cm dbh that contributed more significantly to stand growing space occupancy, volume growth, and forest carbon accumulation than trees less than this size. As smaller trees grew to or above the 7.5 cm dbh threshold, they were tagged, measured, and incorporated into PSP statistics.

The tree population within each PSP was systematically subsampled at each measurement period to measure tree heights (except for 2009 when no heights were measured). In 2019, tree heights were measured with Vertex® ultrasonic hypsometers. At each PSP, height sampling started at the North end of the plot and worked clockwise through the plot. For measuring 2019 tree heights at the Summit lake EP 1162 site, field crews followed 3 guidelines: (1) first, heights were measured on all trees that had height measurements in the previous remeasurement intervals (1992 through 2009), unless the trees were dead in 2019 or had major top damage at the current remeasurement; (2) second, heights were measured on all trees with undamaged tops, greater than 20 cm dbh; and (3) third, within the ≥ 7.5 to ≤ 20 cm dbh diameter class, heights were measured on every 3rd tree in a tag number sequence (i.e. approx. 33% of the trees in this diameter class), with the exception of trees with broken tops and poor vigour. If the latter type of defective or damaged tree was encountered, the tree was skipped, and the next non-defective tree in the tree-tag number sequence was measured for height.

**Field Data Management**

Permanent sample plot data for EP 1162 have historically (and to date) been collected on water-resistant field data collection “hard copy” forms customized this trial, and updated for each remeasurement period. EP data entry and storage has been managed in MS Excel or equivalent “flat file” spreadsheets. This digital format provides an easily extractable / retrievable, stable, and durable file format for EP 1162 data management over 3 decades of research trial management. Data files are stored on large institutional computer servers (UNBC, provincial government) for legacy digital data archiving.

In additional, full printed data sets and original field sheets (or photo copies of originals) are stored in EP 1162 paper files for an additional measure of data backup and security. Original hard copies of field data sheets for each measurement period are retained and stored in Ministry EP records, for archival purposes, and for future cross-checking and validation of data, when required.

Table 1: Mean 1992-1994 initial post-harvest basal areas and range of variation within the 3 basal area treatment classes in EP 1162. Percent basal area retention statistics are relative to measured pre-harvest data.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Basal Area Treatment Class**  **(Prescribed)** | **Percent of Basal Area Retention** | **Mean Post-harvest Basal Area** | **Basal Area Range (Min. to Max.)** | **Standard Deviation** |
|  | % | (m2/ha) | (m2/ha) | (m2/ha) |
|  |  |  |  |  |
| “Low”  (target of 10 m2/ha) | 29.8 % | 9.05 | 3.0 - 14.7 | 4.3 |
| “Medium”  (target of 20 m2/ha) | 43.1 % | 16.0 | 8.2 – 18.6 | 4.4 |
| “High”  (target of 30 m2/ha) | 82.5 % | 27.3 | 24.1 – 31.3 | 3.7 |

Figure 1: Mean post-harvest residual basal areas (green bars) and actual basal

**Literature Review**

Ecological and economic importance of this forest types

* Past management – various techniques
* Current management – dominant and alternative techniques
* Desired nature of future management – rationale for change

Review past experience, but look beyond traditional experiences and generalizations

Past experience from other spruce-abies types elsewhere.

Past learnings, limitations of experience; limitations of existing data, here or elsewhere.

Constraints to innovation due to lack of scientific knowledge.

Bases for Silvicultural and Stocking Goals for Complex / Uneven-aged Temperate to Boreal Coniferous Stands

Historical traditions and Operational Conventions

Theoretical and practical basis for basal area management of complex and uneven-aged stands

Static vs Dynamic Interpretations of Stand Structure and Development

Previous Experience and Stand Response Data from comparable forest types

Stand management assumptions in need of further testing