High Elevation Regeneration Strategies for Subalpine and Montane Forests of Coastal British Columbia
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by

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ABSTRACT

An assessment of artificial and natural regeneration was carried out in 12 different locations in the montane Coastal Western Hemlock and subalpine Mountain Hemlock forests of southwestern British Columbia. The survival, growth, and stem form of eight different species, three stock types, and two planting seasons were compared to the growth, stocking, and stem form of naturally regenerated species. With the exception of western white pine, survival in both zones was generally excellent; the poorest-growing species was amabilis fir. Although Douglas-fir and western hemlock had very rapid growth rates in the montane CWH, they also displayed increasingly variable height growth and stem form defects, particularly at the upper elevational limits of the montane CWH. Noble fir performed well in both zones and had excellent stem form. By comparison, natural regeneration did not grow as rapidly as planted stock. Recruitment of most natural regeneration occurred within the first 6 years following harvesting, with patchy stocking and poor site occupancy due to clumpy stem distribution. The results are summarized with a cost analysis, by species, of the different planting options, and with a quantification of their silvicultural productivity, reliability, and feasibility. It is concluded that a mixed regeneration strategy is appropriate for these montane and subalpine forests, with natural regeneration of amabilis fir and western hemlock providing the basic silviculture resource, and planted species, such as noble fir and yellow-cedar, being used to increase the stand value and crop reliability.
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1 INTRODUCTION

As a result of the depletion of easily accessible, mature coastal lowland forests, there has been an increasing reliance placed on montane and subalpine forests for timber resources. On Vancouver Island, these montane and subalpine forests account for about 30% of the forest land base (Smith 1992) and are expected to provide a significant proportion of the Vancouver Forest Region’s timber supply in the coming years. In spite of the economic value of these forests, few data are available on their establishment and juvenile performance for either artificial or natural regeneration. Current regeneration strategies are modeled on those used at lower elevations.

These forests range between 600 and 1200 m in elevation, and fall within the montane Coastal Western Hemlock (CWH) and subalpine Mountain Hemlock (MH) forests of Vancouver Island and the adjacent coastal mainland (Klinka et al. 1984). Detailed ecological descriptions of these forests are provided by Klinka et al. 1979. They are characterized by high levels of annual precipitation, short growing seasons, and high snow accumulations. In the montane CWH the forests are dominated by amabilis fir (Abies amabilis [Dougl. ex Forbes]) and western hemlock (Tsuga heterophylla [Raf.] Sarg.). The subalpine MH forests are dominated by amabilis fir and mountain hemlock (Tsuga mertensiana [Bong.] Carr.) with a characteristic but variable component of yellow-cedar (Chamaecyparis nootkatensis [D. Don] Spach). Associated species present include western redcedar (Thuja plicata [Donn ex D. Donl]), Douglas-fir (Pseudotsuga menziesii [Mirb.] Franco), Sitka spruce (Picea sitchensis [Bong.] Carr.), western white pine (Pinus monticola Doug. ex D. Donn), and subalpine fir (Abies lasiocarpa [Hook.] Nutt.). In neighbouring Washington State there may also be a component of noble fir (Abies procera Rehd).


1.1 History of Regeneration Strategies

Concerns were raised in the mid-1970s about the poor survival and growth of plantations within the montane CWH and subalpine MH forests of southwestern British Columbia (Klinka and Pendl 1976). Well into the 1960s and early 1970s bareroot Douglas-fir was almost the only species and stock type planted in these forests (Klinka and Feller 1984; Scagel et al. 1989; Scagel et al. 1993). The majority of these plantations exhibited high mortality, stem and form defects, and decreased growth. Poor regeneration success was attributed to inappropriate slashburning and tree species selection (Klinka and Pendl 1976). As a result, site-specific tree species selection and slashburning guidelines were published (Klinka 1977). Tree species selection principles were also subsequently developed (Nuszdorfer and Klinka 1982; Klinka and Feller 1984).

It was against this background of significant regeneration problems and a lack of data on the performance of species other than Douglas-fir that these research trials, and those of others (Scagel et al. 1989), were initiated.

1.2 Current Regeneration Practices

The silvicultural practices used in these stands are still based on clearcut harvesting, although the size of clearcut has decreased since this trial was established in 1978. Due partly to the slashburning guidelines introduced in the mid-1980s (Klinka et al. 1984), and partly to public concern with smoke, there is very little slashburning now (von der

The three current regeneration practices used in these montane and subalpine forests are:

- **Artificial**: Plant only.
- **Mixed**: Rely on natural regeneration and then fill-plant to achieve site occupancy and species composition goals.
- **Natural**: Rely entirely on natural regeneration.

### 1.3 Evaluating Regeneration Performance

It is frequently assumed in studies of stock type performance that plantation forestry is the preferred regeneration strategy. Stock type performance is described only in relation to other stock types, even when the regeneration alternative may be natural regeneration. In the subalpine and montane forests of coastal British Columbia, natural and advanced regeneration is relied on as the dominant method of forest regeneration (Koppenaal and Mitchell 1993). Continuing public concern about clearcutting suggests that the reliance on natural regeneration for these stands will continue. For the subalpine MH, Klinka et al. (1992) concluded that "relatively few cutovers were considered not satisfactorily restocked (NSR) and without potential for natural regeneration." Although these montane and high-elevation forests are not as productive as lower-elevation forests, their species composition, particularly the yellow-cedar component, make them valuable resources. To achieve the desired species composition and uniform stocking, natural regeneration is supplemented with planted stock.

To date, there have been no published comparisons of plantations with naturally regenerated stands for the montane forests of southwestern British Columbia. If natural regeneration is to be prescribed with confidence, stocking, distribution, composition, and growth of natural regeneration must be evaluated to determine realistic expectations. The artificial regeneration species/stock type/time-of-planting trials, established jointly by the Canadian Forest Service and the B.C. Ministry of Forests (Arnott and Pendl 1994), afford an important source of information against which the stocking, performance, and form of natural regeneration can be compared. An examination of natural regeneration also allows comparisons with the only other published trials of artificial regeneration in these montane forests (Scagel et al. 1989; Murray et al. 1991; Pendl and D'Anjou 1991).

Klinka and Feller (1984) proposed three qualitative criteria for species selection that can also be adapted for silviculture systems (Klinka and Carter 1992) and regeneration systems:

- **Productivity**
- **Reliability**
- **Feasibility**

These criteria have been adopted by the Silviculture Interpretations Working Group (SIWG) (1993). They are explicitly quantified in this report.

### 2 OBJECTIVES

There were three objectives to this study:

- to examine the relative productivity, reliability, and feasibility of several tree species;
- to compare natural and artificial regeneration after clearcutting; and,
- to provide establishment and juvenile height-growth expectations for several tree species.

Although data are available for individual sites, this report focuses at the zonal rather than site level.
3 MATERIALS AND METHODS

3.1 Plantation Establishment and Measurement

Full details on the experimental methodology and results of this planting trial are described by Arnott and Pendl (1994). The planting trial was initiated in fall 1978 and, over a 2-year period, three stock types of eight species were planted each fall and spring at 12 locations in the montane CWH and subalpine MH forests.

3.1.1 Species, stock types, and nursery culture

Most container-grown stock was grown at the Pacific Forestry Centre, Victoria. Most of the field-grown stock was raised at Mesachie Lake. Due to plant quarantine regulations (Sutherland et al. 1989), all Abies species were grown at Campbell River. Cultural regimes followed standard guidelines developed during the late-1960s and early-1970s (van den Driessche 1969; Van Eerden 1974; Arnott and Matthews 1981). The seed source for each species was matched to location wherever possible. Details of the seedlots are provided in Arnott and Pendl (1994). The species are listed in Table 1.

The species were grown as three stock types (Table 2). The morphological sizes of the different species/stock type combinations used (Arnott and Pendl 1994) are similar to those used currently by the B.C. Ministry of Forests trading and adjudication.

<table>
<thead>
<tr>
<th>Stock type</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Container grown (PSB 211 1+0)</td>
<td>Plug (P)</td>
</tr>
<tr>
<td>Container, transplant (PSB</td>
<td>Plug+1 (PT)</td>
</tr>
<tr>
<td>211+1)</td>
<td></td>
</tr>
<tr>
<td>Field grown (Bareroot 1+1)</td>
<td>Bareroot (BR)</td>
</tr>
</tbody>
</table>

All planting took place between fall 1978 and spring 1980. For fall planting, all stock was planted within 2–4 days of lifting. Fall planting started in mid-September, after the fall rains had begun, and was finished by late-October. For spring planting, all stock was lifted in mid-January and cold stored (2°C) until the planting sites were free of snow—usually mid- to late-May.

3.1.2 Test areas

Six test areas were selected within each of the montane CWH and subalpine MH forests of southwestern British Columbia. There were four test areas at Guyline Road, two each in the subalpine MH (G1 and G2) and montane CWH (G3 and G4). The sites were distributed over a wide range of ecological conditions, and over a 1.5° latitude and 4° longitude spread (Figure 1). Both burned and unburned clearcuts were included in the sample. Clearcut sizes also varied. Each test area was classified by subzone and variant on the basis of adjacent forest stand and indicator plant species (Klinka 1977). An abbreviated ecological description of each area is given in Table 3 together with a logging history. A more complete description is available in Arnott and Pendl (1994). A randomized complete-block design was used with four
replicate blocks at each test area. Within the blocks, each treatment combination of tree species, stock type, and planting season was randomly assigned to a row of 25 trees. At some test areas (Guyline Rd. and Meade Ck.), individual plots were transitional between montane CWH and subalpine MH.


<table>
<thead>
<tr>
<th>Location</th>
<th>Variant</th>
<th>Longitude</th>
<th>Latitude</th>
<th>Elevation (m)</th>
<th>Moisture†</th>
<th>Nutrient</th>
<th>History</th>
</tr>
</thead>
<tbody>
<tr>
<td>Montane CWH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cypress Ck.</td>
<td>CWHvm2</td>
<td>126°08'40&quot;</td>
<td>49°50'25&quot;</td>
<td>485</td>
<td>F</td>
<td>Med.-Rich</td>
<td>L78</td>
</tr>
<tr>
<td>Garbage Ck.</td>
<td>CWHvm2</td>
<td>124°06'40&quot;</td>
<td>48°34'40&quot;</td>
<td>830</td>
<td>F</td>
<td>Med.-Rich</td>
<td>L76</td>
</tr>
<tr>
<td>Guyline Rd.</td>
<td>CWHvm2</td>
<td>122°02'00&quot;</td>
<td>49°22'00&quot;</td>
<td>950</td>
<td>F</td>
<td>Med.-Rich</td>
<td>L74/ B75</td>
</tr>
<tr>
<td>Labour Day Lk.</td>
<td>CWHmm2</td>
<td>124°28'00&quot;</td>
<td>49°08'00&quot;</td>
<td>875</td>
<td>F</td>
<td>Med.-Rich</td>
<td>L68/ B69</td>
</tr>
<tr>
<td>Quatchka Ck.</td>
<td>CWHvm2</td>
<td>125°39'10&quot;</td>
<td>49°40'00&quot;</td>
<td>500</td>
<td>F</td>
<td>Med.-Rich</td>
<td>L77</td>
</tr>
<tr>
<td>Subalpine MH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mt. Arrowsmith</td>
<td>MHmm1</td>
<td>124°36'40&quot;</td>
<td>49°14'50&quot;</td>
<td>1075</td>
<td>F</td>
<td>Med.</td>
<td>L76</td>
</tr>
<tr>
<td>Mt. Cain</td>
<td>MHmm1</td>
<td>126°20'00&quot;</td>
<td>50°13'30&quot;</td>
<td>1100</td>
<td>F</td>
<td>Poor-Med.</td>
<td>L66/ B67</td>
</tr>
<tr>
<td>Guyline Rd.</td>
<td>MHmm1</td>
<td>122°02'00&quot;</td>
<td>49°22'00&quot;</td>
<td>1050</td>
<td>F</td>
<td>Poor-Med.</td>
<td>L74/ B75</td>
</tr>
<tr>
<td>Iron R.</td>
<td>MHmm1</td>
<td>125°28'00&quot;</td>
<td>49°49'30&quot;</td>
<td>1070</td>
<td>F</td>
<td>Poor-Med.</td>
<td>L73</td>
</tr>
<tr>
<td>Meade Ck.</td>
<td>MHmm1</td>
<td>124°09'30&quot;</td>
<td>48°54'20&quot;</td>
<td>1000</td>
<td>M</td>
<td>Med.-Rich</td>
<td>L77</td>
</tr>
</tbody>
</table>

† vm2 = Montane Very Wet Maritime CWH; mm2 = Montane Moist Maritime CWH; mm1 = Windward Moist Maritime MH

‡ Actual Soil Moisture Regimes: F=Fresh; M=Moist

**FIGURE 1.** Locations of different planting sites (● = subalpine MH; ▲ = montane CWH).
TABLE 4. Natural regeneration assessment sample size and survey area

<table>
<thead>
<tr>
<th>Location</th>
<th>Varianta</th>
<th>No. Plots</th>
<th>No. Trees</th>
<th>Total survey area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Montane CWH</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cypress Ck.</td>
<td>CWHvm2</td>
<td>21</td>
<td>103</td>
<td>0.11</td>
</tr>
<tr>
<td>Garbage Ck.</td>
<td>CWHvm2</td>
<td>20</td>
<td>100</td>
<td>0.22</td>
</tr>
<tr>
<td>Guyline Rd.</td>
<td>CWHvm2</td>
<td>12</td>
<td>60</td>
<td>0.18</td>
</tr>
<tr>
<td>Labour Day Lk.</td>
<td>CWHmm2</td>
<td>20</td>
<td>100</td>
<td>0.18</td>
</tr>
<tr>
<td>Meade Ck.</td>
<td>CWHmm2</td>
<td>36</td>
<td>180</td>
<td>0.61</td>
</tr>
<tr>
<td>Quatchka Ck.</td>
<td>CWHvm2</td>
<td>12</td>
<td>60</td>
<td>0.10</td>
</tr>
<tr>
<td>Subalpine MH</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mt. Arrowsmith</td>
<td>MHmm1</td>
<td>13</td>
<td>65</td>
<td>0.17</td>
</tr>
<tr>
<td>Mt. Cain</td>
<td>MHmm1</td>
<td>24</td>
<td>108</td>
<td>0.18</td>
</tr>
<tr>
<td>Guyline Rd.</td>
<td>MHmm1</td>
<td>12</td>
<td>60</td>
<td>0.14</td>
</tr>
<tr>
<td>Iron R.</td>
<td>MHmm1</td>
<td>20</td>
<td>100</td>
<td>0.12</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>190</td>
<td>936</td>
<td>2.01</td>
</tr>
</tbody>
</table>

a vm2 = Montane Very Wet Maritime CWH; mm2 = Montane Moist Maritime CWH; mm1 = Windward Moist Maritime MH

3.1.3 Seedling measurements

Seedling survival and height were measured at the end of each growing season in years 1, 2, 3, 5, 7, 9, 11, and 13. Causes of mortality and injuries on surviving trees were noted at each assessment.

For the last assessment at year 13, tree form was also classified into two general defect classes:

- **Stem defect**: Multiple-topped, forked, or crooked stems.
- **Bush form**: Seedling with multiple stems, no clearly expressed dominance, and torn and broken branches.

Illustrated examples of these stem form defects can be found in Scagel et al. 1988.

Tree survival is usually determined within the first 3 years after planting; thereafter, mortality can occur, but usually at a significantly lower frequency and rate. The factors causing tree mortality during the establishment are often different from those in later years. The three most frequent types of injuries causing seedling mortality were summarized for establishment (1–3 years) and juvenile growth (4–13 years) stages.

3.2 Natural Regeneration Measurement

Since there is no published information comparing the performance of plantations to natural regeneration in the montane forests of southwestern British Columbia, natural regeneration adjacent to the planting trials was measured. Surveys were stratified according to site series (Scagel 1989)3 and planting history. Sites were selected that represented the same site series and history as the adjacent trial. At most locations the area available for sampling was extremely limited. At least 0.1 ha was surveyed at each location (Table 4). Where sites were ecologically heterogeneous, surveys were conducted in each ecological stratum.

---

At each location seedlings taller than 30 cm were classified as natural regeneration (i.e., those seedlings that had germinated on site after logging). To remove ambiguity from this classification (Herring and Etheridge 1976), ages were estimated from height increment counts and supported by stem cross-sections. Where stem age was in question, the stem was cut at the root collar and the rings were counted. Naturals were at least 4 years old. An additional complication due to fill-planting was encountered at some locations. To distinguish natural regeneration from fill-planted seedlings, the distribution of stems, species, and excavation of the upper part of the root system was necessary.

Total density of natural regeneration was assessed using a tree-centred quarter technique (Batcheler 1971), a modification of the point-centre quarter technique (Mueller-Dombois and Ellenberg 1974), because of the small areas available for surveying natural regeneration. A comparison of this technique with fixed-radius count-plot and other survey techniques is provided by Evans and Scagel (1993).

3.3 Data Analysis

Within each of the montane CWH and subalpine MH forests, statistical analyses were conducted for 13th year survival, height, height increment, and stem diameter (Arnott and Pendil 1994). No attempt was made to examine the differences between the two forest types statistically, since they are recognized to be ecologically and silviculturally distinct. Differences among treatments and among their interactions were only declared statistically significant if the probability level was less than 1%.

For natural regeneration, the variable species composition and stem age did not permit statistical examination of growth differences on individual sites. All species were not equally represented at all sites.

3.4 Quantification of Productivity, Reliability, and Feasibility

Although Klinka and Feller (1984) have provided a useful concept for evaluating regeneration systems over a rotation, they provide no example of quantification of the concept, nor of application to plantation establishment. To summarize the relative productivity, reliability, and feasibility of these planting trials as they approached the free-growing state, species means and standard deviations were used. The procedure for determining productivity and reliability was based on a doubly standardized ranking of each species. All species were ranked for height, survival, and form, and the ranking for each attribute was standardized to a scale of 0–10, with 10 being the best. For each species, all the rankings were averaged and then standardized again to a scale of 0–10. All ranked attributes (height, survival, form) were weighted equally in the analysis. The largest species, with the best survival and form, was assigned the highest value for overall productivity of 10. The species with the least variability in height, survival, and form was assigned the highest value for overall reliability of 10.

Evaluation of productivity was based on species means, calculated for each test location, and by pooling across all stock type combinations and planting seasons. Reliability was evaluated based on the between-site variability of the data. Feasibility was determined based on cost analysis for each treatment combination over all areas.

The height-growth example provided in Figure 2 clarifies this procedure for ranking an individual attribute. On the basis of height growth alone, Fd is clearly the most productive species in the montane CWH. It is assigned a height-growth rank of 10.0 (Appendix 3), but because of a high standard deviation, it is assigned a low height-growth reliability of 2.7 (Appendix 3). Similarly, Hw has a height-growth rank of 7.1 but has the lowest reliability.
FIGURE 2. Example of relative species productivity and reliability for the montane CWH. The dashed, diagonal line indicates the point at which an increase in height is matched by an increase in variability of height.

rank of 0. By contrast, Pw and Cw grow more slowly, and rate a low height-growth productivity (3.1 and 3.5 respectively), but their equally low standard deviations give them high reliability rankings, 10.0 and 8.8 respectively. The overall rankings for productivity and reliability in Appendix 3 are based on the same procedure for ranking a combination of height, survival, and form.

This graph also demonstrates the departure from an arbitrary 1:1 relation between mean and standard deviation. Along the diagonal line, increases in productivity are matched by decreases in reliability. Above the diagonal, increases in productivity exceed decreases in reliability. Below the diagonal, increases in productivity are exceeded by decreases in reliability. In the example in Figure 2, all species exceed the 1:1 line, but Ba clearly departs the least from the 1:1 line. The diagram can also be divided into four quarters as indicated in Table 5, with the most productive and most reliable species occupying the upper left corner of the diagram, and the low-productivity, low-reliability species occupying the lower right corner. In this study, the 1:1 ratio between productivity and reliability is arbitrary. Where other management strategies apply, this ratio can be adjusted to reflect the cost advantages of maintaining higher productivity at low variability—perhaps by as much as 2:1.
TABLE 5. Classification of productivity and reliability graph into four quarters

<table>
<thead>
<tr>
<th>Productivity</th>
<th>High</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>The best species –</td>
<td>Might be worth the risk –</td>
</tr>
<tr>
<td></td>
<td>large and reliable.</td>
<td>large but unreliable.</td>
</tr>
<tr>
<td>Low</td>
<td>Might not be worth</td>
<td>The worst species –</td>
</tr>
<tr>
<td></td>
<td>the risk – small but</td>
<td>small and unreliable.</td>
</tr>
<tr>
<td></td>
<td>reliable</td>
<td></td>
</tr>
</tbody>
</table>

In summary, productivity was quantified as average performance, represented by the mean value for tree height, survival, and form. Species with better survival, larger size and fewer form defects were more productive than species with poorer survival, smaller size, and more stem defects. Reliability was quantified as variability, represented by the standard deviation of the mean. Species with high variability are less reliable than species with low variability. Feasibility was not investigated as thoroughly as productivity and reliability. Instead, the cost and height cost of surviving seedlings were computed for CSS and HCSS, respectively. The cheapest species was the most feasible.

3.5 Cost Analysis

A cost analysis of the different species/stock type/planting seasons was prepared according to Scagel et al. 1990. This analysis uses the 13-year survival and height growth, and has a target stocking of 900 well-spaced stems per hectare (wsph). The cost analysis for the planted seedlings considers only the cost of purchasing and planting seedlings; there is no provision for fill-planting or additional brushing, thinning, or spacing. It does not consider the cost of any Pw treatment because of the high incidence of mortality from white pine blister rust (Cronartium ribicola J.C.

TABLE 6. Stock type related costs in ¢ per seedling (See Table 2 for stock type abbreviations)

<table>
<thead>
<tr>
<th>Stock type</th>
<th>Season</th>
<th>Storage</th>
<th>Transport</th>
<th>Planting</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>Fall</td>
<td>0.00</td>
<td>0.37</td>
<td>40.0</td>
<td>40.37</td>
</tr>
<tr>
<td>BR</td>
<td>Fall</td>
<td>0.00</td>
<td>0.45</td>
<td>53.0</td>
<td>53.45</td>
</tr>
<tr>
<td>PT</td>
<td>Fall</td>
<td>0.00</td>
<td>0.93</td>
<td>58.0</td>
<td>58.93</td>
</tr>
<tr>
<td>P</td>
<td>Spring</td>
<td>0.91</td>
<td>0.37</td>
<td>40.0</td>
<td>41.28</td>
</tr>
<tr>
<td>BR</td>
<td>Spring</td>
<td>1.13</td>
<td>0.45</td>
<td>53.0</td>
<td>54.58</td>
</tr>
<tr>
<td>PT</td>
<td>Spring</td>
<td>2.30</td>
<td>0.93</td>
<td>58.0</td>
<td>61.23</td>
</tr>
</tbody>
</table>
TABLE 7. Species related costs in $ per seedling for growing the different stock types (See Table 2 for stock type abbreviations)

<table>
<thead>
<tr>
<th>Species</th>
<th>Stock type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Seed</td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Amabilis fir (Ba)</td>
<td>3.5</td>
</tr>
<tr>
<td>Noble fir (Bp)</td>
<td>2.0</td>
</tr>
<tr>
<td>Yellow-cedar (Yc)</td>
<td>6.6</td>
</tr>
<tr>
<td>Mountain hemlock (Hm)</td>
<td>1.4</td>
</tr>
<tr>
<td>Western redcedar (Cw)</td>
<td>0.5</td>
</tr>
<tr>
<td>Coastal Douglas-fir (Fd)</td>
<td>2.0</td>
</tr>
<tr>
<td>Western hemlock (Hw)</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Fisch. ex Rab.). Species and stock type related costs are shown in Table 6 and Table 7. The costs are taken from the 1993 B.C. Ministry of Forests Stock Trading Procedures, and assume a progress-payment schedule to nurseries that includes packaging. The fixed costs to purchase and plant ranged from 57.6¢ per fall-planted Hw plug to 98.8¢ per fall-planted Yc transplant.

The cost analysis for the natural regeneration assumes only a single spacing and thinning in the 13th year. Although thinning is typically scheduled where there is 5–6 m of dominant height, this criterion is applicable only for submontane forests. The thinning costs assume that the stand densities were in excess of 5000 sph, which results in a cost of $1.10 per residual stem.

The results of the cost analysis are presented as:

- Cost of a surviving seedling
  (CSS; Scagel et al. 1990)
- Height cost of a surviving seedling
  (HCSS; Scagel et al. 1990)

Like other analyses, the results of the cost analyses have been presented as mean costs and their standard deviations pooled within a species, over all combinations of stock type and planting seasons. The cost analyses have been prepared separately for each subzone over all locations within each subzone.

4 RESULTS AND DISCUSSION

The largest sources of variation in the data were the test locations and the tree species. Although there were many statistically significant interactions, the largest within each forest type were the species/area interactions (Arnott and Pendl 1994). While stock type and planting season effects were significant, the actual differences among these treatments were much smaller than among the tree species (Arnott and Pendl 1994). For this reason, plantation results in this report are only summarized and presented by zone and tree species. Site effects and site preparation effects were evident at several of the test locations. Although important, they are beyond the scope of this summary report.

4.1 Plantation Performance

4.1.1 Survival

The overall survival of planted trees in the subalpine MH was about 85%—higher and less variable than the 82% survival in the montane CWH (Figure 3). Detailed cumulative survival
results for each species in each zone is given in Appendix 1. Three patterns of mortality were observed:

- Immediate mortality
- Progressive mortality
- Delayed mortality

**Montane CWH**

**Subalpine MH**

FIGURE 3. Cumulative survival among planted species at 3 and 13 years after planting.

With the exceptions of Pw in the montane CWH and Hm in the subalpine MH, most species displayed immediate mortality in the first 3 years after planting. This immediate mortality was attributed to small stock (Ba), poorly conditioned stock (Cw), girdling by root collar weevils (Ba), and drought (all species) (Table 8). Subsequently, all species had a progressive mortality of 2–5% per decade. This progressive mortality was usually caused by vegetation smothering of small-stemmed seedlings (Table 8). At some sites the progressive mortality was due to continual smothering of slow-growing species by fireweed. Pw displayed severe delayed mortality after the 5th year due to blister rust (*Cronartium ribicola*)—on some sites the Pw has been eradicated. In the 13th year, at some sites, Hm has started to display a delayed mortality due to *Armillaria ostoyae* and *Phellinus weirii* root diseases.

Western hemlock (Hw) and Cw were more variable than the other species (Pw excepted) in the montane CWH (Figure 4). Part of the increased variability in survival of the Hw and Cw in this zone was due to the lack of frost-hardy stock for the fall planting. Noble fir (Bp) and Ba had very similar survivals and variability of survival in both zones. The relative variability of the survival indicated that Hm was less variable than the other planted species in the subalpine MH. Noble fir survived as well as other species in the montane CWH, but was equal to Ba in the subalpine MH. Noble fir also had the least variability of survival of all species tested in the montane CWH.
TABLE 8. Principal causes of mortality during establishment and juvenile growth stages of planted species in the montane CWH and subalpine MH

<table>
<thead>
<tr>
<th>Species</th>
<th>Mortality Causes</th>
<th>Mortality Causes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Establishment (years 1–3)</td>
<td>Juvenile Growth (years 4–13)</td>
</tr>
<tr>
<td>Montane CWH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ba</td>
<td>Drought, root collar weevils, vegetation smothering</td>
<td>Vegetation smothering, root rots</td>
</tr>
<tr>
<td>Bp</td>
<td>Drought, root collar weevils, frost damage</td>
<td>Vegetation smothering</td>
</tr>
<tr>
<td>Cw</td>
<td>Winter desiccation, drought</td>
<td>Vegetation smothering</td>
</tr>
<tr>
<td>Fd</td>
<td>Frost damage, winter desiccation</td>
<td>Vegetation smothering, root rots</td>
</tr>
<tr>
<td>Hw</td>
<td>Drought, frost damage, winter desiccation</td>
<td>Vegetation smothering, root rots</td>
</tr>
<tr>
<td>Pw</td>
<td>(Little mortality)</td>
<td>Blister rust</td>
</tr>
<tr>
<td>Subalpine MH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ba</td>
<td>Drought, root collar weevils</td>
<td>Vegetation smothering</td>
</tr>
<tr>
<td>Bp</td>
<td>Drought, frost damage, winter desiccation</td>
<td>Vegetation smothering</td>
</tr>
<tr>
<td>Hm</td>
<td>Minor amount of drought</td>
<td>Root rots</td>
</tr>
<tr>
<td>Yc</td>
<td>Drought, winter desiccation</td>
<td>Vegetation smothering</td>
</tr>
</tbody>
</table>

FIGURE 4. Mean 13-year survival and variability of planted species. The dashed diagonal line indicates the point at which an increase in survival is matched by increased variability of survival.
4.1.2 Growth

Considering the overall mean height of all species, planted stock in the montane CWH had almost twice the productivity of that in the subalpine MH. However, for species such as Ba and Bp, that were planted in both zones, the between-zone growth differences were not as large. In both zones Ba was the least productive species (Figure 5). The height growth of Ba in these trials was not unusual, and is very similar to that reported by Scagel et al. (1989) and Pendl and D'Anjou (1991). The relatively high productivity of Fd was manifested by the 4th year and exceeded all other species by the 8th year. The relative ranking of the different species had stabilized between the 4th and 5th years. Although the height growth of Fd and Hw in the montane CWH was larger than for any other species, the variability was also dramatically larger (Figure 6). This increased variability was due to the poor performance of these species at the upper elevational limits of the montane CWH.

![Montane CWH](image1)

![Subalpine MH](image2)

**FIGURE 5.** Height-growth curves for planted species.

Although species differences in the subalpine MH were not as pronounced as in the montane CWH, Bp exceeded all other species by the 9th year. There was considerably less variability in height growth in the subalpine MH than in the montane CWH (Figure 6). Noble fir (Bp) was the most variable species in the subalpine MH, suggesting that it might not be as well suited as the native species in this zone.
FIGURE 6. Mean 13-year height and variability of planted species. The dashed diagonal line indicates the point at which an increase in height is matched by increased variability of height.

FIGURE 7. Stem form defects of planted species. Form defects are described in the methods section.
4.1.3 Form

There were pronounced differences in form defects between the two zones (Figure 7). Although species in the montane CWH were less severely damaged than those in the subalpine MH, the frequency of damage was approximately the same as in the subalpine MH (Arnott and Pendr 1994).

There was much greater variability of stem form defects in the subalpine MH than in the montane CWH (Figure 8), due to the effects of a deeper snowpack and a longer winter. In the montane CWH, Fd and Hw had a frequency of stem defects comparable to that of Cw, but Fd and Hw were far less variable. Similarly, in the subalpine MH, Ba had the least variability of form defects compared to the other species. Noble fir (Bp) had a better stem defect incidence than most native species. It was the least variable species in the montane CWH, and was intermediate in the subalpine MH.

![Montane CWH](image1)

![Subalpine MH](image2)

**FIGURE 8.** Mean form defects and variability of planted species. The dashed diagonal line indicates the point at which a decrease in form defects is matched by increased variability of form defects.

4.2 Natural Regeneration

4.2.1 Growth

Height-growth curves for natural regeneration in the montane CWH and subalpine MH are presented in Figure 9. The overall mean height of all species in the montane CWH shows about 30% more productivity than in the subalpine MH. *Amabilis fir* (Ba) naturals were the least productive species (Figure 10). Productivity of the natural regeneration was slightly less than that of planted stock. However, it should also be noted that there were large differences in the age of individuals within the naturally regenerated stands; i.e., there were relatively few 13-year-old individual
stems owing to the lapse time between time of harvest and the establishment of the naturally regenerated seedlings. There was considerably less variability in height growth in the subalpine MH than in the montane CWH (Figure 10), but the variability was comparable to that seen in planted stock (Figure 6).

**FIGURE 9.** Height-growth curves for natural regeneration.

**FIGURE 10.** Mean 13-year height and variability of naturally regenerated species. The dashed diagonal line indicates the point at which an increase in height is matched by increased variability of height.
4.2.2 Form

In comparison to planted stock, the natural regeneration experienced less frequent and less severe form defects where the same species were planted. This was due to the slower overall growth of the natural regeneration, and to the naturally selected microsites in which the natural regeneration were found. Where naturally regenerated Fd and Cw were found in the subalpine MH, a much higher incidence of form defects (due to the climatic intolerance of such species within the climatic intolerance of such species within the subalpine MH) were observed (Figure 11).

![Form defects comparison](image)

FIGURE 11. Stem form defects of naturally regenerated species. Form defects are described in the methods section.

4.2.3 Species composition

Depending on the area, there was substantial variation in the species composition of natural regeneration (Scagel and Evans 1993). Over the two zones, Hw was the predominant species of natural regeneration in the montane CWH. Amabilis fir (Ba) was equally dominant in both the montane CWH and subalpine MH (Figure 12).

Western hemlock (Hw) and Ba will always be a part of the natural regeneration (Figure 13). However, the abundance of Hw and Ba varies more in the montane CWH than in subalpine MH. Consequently, predictions of abundances of Hw and Ba are less reliable in the montane CWH.

---

FIGURE 12. Species composition of natural regeneration.

FIGURE 13. Mean species composition and variability of species composition of natural regeneration. The dashed diagonal line indicates the point at which an increase in species composition is matched by increased variability in species composition.
4.2.4 Density and recruitment patterns

On average, there were 5600 stems/ha in the subalpine MH and 2900/ha in the montane CWH. For all sites, natural regeneration was patchy and grossly overstocked. More than 50% of the natural regeneration was recruited within the first 6 years after harvesting in both the montane CWH and subalpine MH (Figure 14). For most sites, this speed of recruitment resulted in the site becoming overstocked.

Depending on the site and the species there were substantial differences in the recruitment patterns, but within 6 years of harvest the species composition was determined. The most rapid recruitment was Ba in the montane CWH (Appendix 2). Western hemlock (Hw) and Yc had nearly identical recruitment patterns in both zones. The delay in recruitment of Hm in the subalpine MH was particularly noticeable compared to recruitment in the montane CWH (Appendix 2; Scagel and Evans 1993).

4.3 Costs

Offsetting seedling mortality by increasing the planting density is one strategy for avoiding the need to fill-plant. This strategy is only appropriate where there are enough plantable spots to allow for increased planting density. If the anticipated mortality is too high (Pw, for example) there may not be enough plantable spots. The range of planting densities required to achieve the target stocking of 900 wsph is presented in Figure 15. Considering the variety of combinations of species, stock type, and planting season, the majority of sites would require a planting density of about 1100 wsph to offset the expected mortality. The high variability of densities in the montane CWH was due to many losses of fall-planted Cw on some sites, and the unacceptable survival rates for Pw on many sites.

![Figure 14](image)

**FIGURE 14.** Cumulative recruitment of natural regeneration.
FIGURE 15. Range of planting densities required to achieve target stocking of 900 wspf on sites in the montane CWH and subalpine MH. The dashed diagonal line indicates the point at which an increase in stem density is matched by increased variability of density.

FIGURE 16. Cost of a surviving planted seedling (CSS) by species. The dashed horizontal line is set at $1.10 per residual stem from spacing and thinning of naturally regenerated stands. The dashed diagonal line indicates the point at which an increase in CSS is matched by increased variability of CSS.
For both zones, the median cost per surviving planted seedling (CSS) was about 85¢, or about $900/ha (Figure 16). The slightly inflated costs and increased cost variability in the montane CWH were due to site-specific higher mortality of Cw, unacceptable survival rates of Pw, and slightly poorer overall survival due to brush competition. These costs are slightly less than the anticipated cost of $1.10 per residual stem for a single spacing and thinning of natural regeneration in the same zones (Pw excepted).

The median height-growth costs of surviving planted seedlings (HCSS) were very different in the two zones (Figure 17). In the subalpine MH, the median HCSS was about 42¢/m and in the montane CWH, the median was only 28¢/m. By species, the height growth of Ba was significantly more expensive and variable than all other species. Of the species in the subalpine MH, Bp was very cost effective but slightly more variable than Hm or Yc. Western white pine (Pw), Ba and Cw were highly variable in the montane CWH. The relative variability of the different species indicates the need to carefully consider site conditions and planting season when prescribing these species, particularly for Cw.

**FIGURE 17.** Height cost of a surviving planted seedling (HCSS) by species. The dashed diagonal line indicates the point at which an increase in HCSS is matched by increased variability of HCSS.
4.4 Productivity, Reliability, and Feasibility

A detailed presentation of the ranking procedure is given in Appendix 3. The overall ranking of the individual species is shown in Table 9. In the montane CWH, the species with the best productivity (measured by a combination of species survival and growth over the 13-year study period) were Fd and Bp (Table 9). The species with the lowest productivity was Pw, closely followed by Cw. Although Pw was ecologically suitable for planting throughout this zone, its high risk of infection from the white pine blister rust placed it in a low-productivity category. Until seed sources of western white pine that are resistant to blister rust become available, this species should not be selected for planting within the montane CWH. If Pw is planted within this zone, then pruning to 1.5 m as soon as possible is the only remedial action that can be taken to minimize the risk of infection from the blister rust (Hunt 1991). Western redcedar did not survive and grow consistently well throughout the montane CWH. It was particularly prone to overwinter injury if planted in the fall, and was at risk at the higher elevations within the zone. Amabilis fir had only moderate productivity in this zone. In the subalpine MH, Bp had the highest productivity, closely followed by Hm. While Yc survived well, it was placed in an intermediate productivity class since repeated stem breakage from deep winter snow depressed its height growth. The species with the lowest productivity in the subalpine MH was Ba. The low productivity in montane forests of Ba compared to Fd, Yc and Bp has been noted in other planting trials in coastal British Columbia (Arnott and Pendle 1984).

TABLE 9. Overall ranking of species' productivity, reliability, and feasibility in the montane CWH and subalpine MH. Species have been ranked 0–10, with 10 being the most productive, reliable, and feasible for the zone, and 0 being the least productive, reliable, and feasible for the zone.

<table>
<thead>
<tr>
<th>Location</th>
<th>Species</th>
<th>Productivity</th>
<th>Reliability</th>
<th>Feasibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Montane CWH</td>
<td>Ba</td>
<td>5.4</td>
<td>9.8</td>
<td>6.4</td>
</tr>
<tr>
<td></td>
<td>Bp</td>
<td>10.0</td>
<td>10.0</td>
<td>8.9</td>
</tr>
<tr>
<td></td>
<td>Cw</td>
<td>1.0</td>
<td>0.0</td>
<td>7.6</td>
</tr>
<tr>
<td></td>
<td>Pw</td>
<td>0.0</td>
<td>4.4</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Fd</td>
<td>9.5</td>
<td>4.1</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>Hw</td>
<td>5.9</td>
<td>0.7</td>
<td>9.0</td>
</tr>
<tr>
<td>Subalpine MH</td>
<td>Ba</td>
<td>0.0</td>
<td>5.2</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Bp</td>
<td>10.0</td>
<td>0.0</td>
<td>6.9</td>
</tr>
<tr>
<td></td>
<td>Hm</td>
<td>8.5</td>
<td>10.0</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>Yc</td>
<td>5.8</td>
<td>1.9</td>
<td>7.2</td>
</tr>
</tbody>
</table>

While productivity is one measure of the performance potential of the various species available for outplanting in montane forests, other criteria influence this choice, such as reliability. Estimates of reliability based on a combination of survival, growth, and form of the individual tree have been prepared. The latter variable is important because, although a tree may grow quickly, such growth may predispose it to stem damage from ice and snow. As Scagel et al. (1988) states, "big may not be beautiful." The relative reliabilities of the planted species are shown in Table 9. True firs, Bp, and Ba had the highest overall reliability rankings in the montane CWH because these species survived well and had
crowns that shed snow easily, which resulted in low incidences of form defects. However, as shown in Table 9, they are not the fastest growing species within this zone. The low reliability indices for Fd and Hw derive from the fact that these trials covered the entire elevational range of the montane CWH and, as a result, these two species were prone to higher incidences of form defects on sites at the higher elevational limits. Because of the higher incidences of form defects, Fd, Hw and Cw should be restricted to the lower- and middle-elevational variants of the zone, where less snow and frost occur, or on sites where these hazards are known not to occur. As previously noted, western white pine should be avoided until blister rust resistant seed sources become available. In the subalpine MH, species with the highest reliability rankings were Hm and Ba, while Bp had the lowest. This means that Bp will require careful selection of planting locations to capitalize on its productivity. Although the reliability of Yc has been ranked low because of the severity and extent of stem breakage from snow, it was found to have accumulated a large biomass of multiple leaders; in fact, many of these trees looked like bushes. It is believed that once these trees emerge above the average depth of winter snow, rapid height growth will make Yc one of the more productive and reliable species choices for the subalpine MH.

With the exception of Cw and Pw, the CSS of the other species in the montane CWH were comparable (Figure 16). Thus, the silvicultural feasibility was determined largely by the HCSS, which was identified as being sensitive to the elevation of the planting location—higher elevations in the montane CWH experienced slower growth than lower elevations (Arnott and Pendl 1994). On the basis of HCSS, the species with the best overall silvicultural feasibility were Fd and Hw (Figure 17, Table 9). As with the montane CWH, the overall feasibility depends on the HCSS—Ba had the slowest growth and thus the most costly increment. The species with the best silvicultural feasibility in the subalpine MH was Hm.

5 CONCLUSIONS

5.1 Feasibility of Regeneration in Montane and Subalpine Forests

Regeneration by either natural, artificial, or mixed strategies is feasible in these forests. Although regeneration by completely artificial means appears to be the most cost effective, it could become the more expensive strategy if these plantations require extra brushing and spacing of regeneration ingress. These costs may not be justified, considering the generally low site productivity of the sites (Green and Klinka 1994), unless stand value can be increased by incorporating a mix of more valuable species.

Natural regeneration can always be relied on to provide a basic silviculture resource. However, the exact species composition and distribution (hence value) following clearcutting is difficult to predict with confidence. The mixed species regeneration strategy is likely to be the best option because it can capitalize on the introduction of higher-value species, and on the control of spatial distribution.

5.2 Productivity and Reliability: Biological Risks and New Opportunities

Klinka and Feller (1984) concluded that the choice of species was a complex optimization problem, particularly over the full rotation in a stand. While this degree of prediction has not been attempted in this study, estimates of species' productivity, reliability, and feasibility at, or near, the time of free growth give some indication of the type and degree of differentiation in performance that can occur among
all of the species that can be planted in the montane CWH and subalpine MH forests of coastal British Columbia. Based on the results to date—that is, to the free-growing stage—estimates of the relative ranking among the eight tree species studied can be provided.

Summarizing the separate productivity, reliability, and feasibility estimates presented above results in the following overall rankings. In the montane CWH, the species with the overall highest productivities were Fd and Bp (Table 9). The poorest overall productivity was Cw. In the subalpine MH the highest overall productivity was Bp and the poorest was Ba.

The relative reliability of the different planted species is given in Table 9. The overall highest reliability in the montane CWH were the true firs, Bp and Ba. In the subalpine MH, species with the highest reliability were Hm and Ba, and that with the lowest reliability was Bp.

The overall feasibility of different planted species is based on ranked CSS and HCSS. In the montane CWH, Fd and Hw were the most feasible species. In the subalpine MH, Hm was the most feasible species.

For natural regeneration the issue of productivity and reliability focuses around the presence of particular species and their respective growth rates. Western hemlock had the best overall productivity in the montane CWH. In the subalpine MH, all species were equally productive. The overall reliability of natural regeneration presents a rather different pattern to the species’ productivity. Yellowcedar was the most reliable species in the montane CWH and Ba was the most reliable species in the subalpine MH.

5.4 Why is Regeneration in the Montane CWH So Variable?

The variability of growth, survival, and form of the different species was higher in the montane CWH than in the subalpine MH because of the large climatic variability in the zone, and because of the ecological tolerance of species. The variability of growth and survival and the frequency of form defects also appeared to increase with elevation, suggesting that decreasing length of growing season, increasing snow depths, and frost-related events were the causative agents (with several species, such as Cw and Fd, reaching the limits of climatic tolerance). Scagel et al. (1989) demonstrate how poorly these lower-elevation species grow when planted at even higher elevations within the subalpine MH. In the montane CWH there is a wider selection of available species to choose from, but they are also less ecologically robust at the uppermost elevational limits. Hence, the high degree of variability found among the species that were planted in this trial.

The choices of species for the subalpine MH are much more limited than in the montane CWH. This helped to reduce the impression of overall variability of planted stock, except for Bp. The variability of Bp appeared to increase with elevation in the subalpine MH, suggesting that it might be approaching the upper limits of its climatic tolerance. Perhaps its use in the subalpine MH should be confined to the lower elevations, and/or sites with warmer aspects.

5.5 Counting on Natural Regeneration to Satisfy Regeneration Needs

Most natural regeneration, in both zones, occurred within 6 years of harvest, and 80% of the regeneration had been recruited within 8 years of logging. However, not all species followed this pattern. To best utilize a natural
regeneration option in these forests, an early survey to examine stocking, distribution, and species composition is necessary. This will provide information on which species to fill-plant, and will increase the value of the regenerated stand by improving both the species mix and stem distribution.
REFERENCES


von der Gonna, M.A. 1992. Site preparation: where we are, how we got here, and where we’re going. Forest Nursery Assoc. Annual Meet., Penticton, B.C.
APPENDIX 1. Plantation survival curves.

Data are pooled over all sites, stock types, and planting seasons for each species.
APPENDIX 2. Natural regeneration recruitment patterns of several species within the montane CWH and subalpine MH.
APPENDIX 3. Productivity, reliability, and feasibility of planted species in the montane CWH and subalpine MH.

Plantation productivity is based on average height, survival, and form. Plantation reliability is based on standard deviation of height, survival, and form. Plantation feasibility is based on cost of surviving seedling (CSS) and height cost of a surviving seedling (HCS).

### Plantation Productivity

<table>
<thead>
<tr>
<th>Location</th>
<th>Species</th>
<th>Height</th>
<th>Rank</th>
<th>Survival</th>
<th>Rank</th>
<th>Form</th>
<th>Rank</th>
<th>Average Standardized</th>
</tr>
</thead>
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<tr>
<td>Montane CWH</td>
<td>Ba</td>
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<td>8.6</td>
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<th>Rank</th>
<th>Form</th>
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<th>Average Standardized</th>
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29
## Plantation Feasibility

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