REFORESTATION RESEARCH AT AMAX’S KITSAULT MINE

Paper Presented by

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A lot of information pertaining to reforestation research at the Kitsault minesite has been collected (Price, 1982) and in this paper I will not be able to discuss it all. What I will try to do is to show how this information has been used to develop our present ideas about the optimum strategy for reforesting the wasterock dumps.

ENVIRONMENTAL SETTING

The Kitsault mine exists to mine molybdenum. It is an open pit, truck and shovel operation (Figure 1). The main terrestrial disturbances of the minesite are a relatively small open pit and the wasterock dumps. Because of the steep topography the wasterock is placed in terraced dumps.

Figure 1. SCHEMATIC DIAGRAM ILLUSTRATING THE PROCESS OF MINING AT THE KITSAULT MOLYBDENUM MINE.
Figure 2.

In the present mine plan the terraced slopes will be regraded to a gentler angle by combining two slopes and one bench into one slope.

Diagram showing a soil profile with labeled sections indicating different elevations and distances.
Figure 3. MAP OF BRITISH COLUMBIA COAST SHOWING THE STUDY AREA.
The present mine plan proposes to regrade the terraced slopes to a gentler angle by combining 2 slopes and 1 bench, by cutting and filling, into 1 slope (Figure 2).

The minesite is in north coastal British Columbia, just south of the Alaska panhandle and north east of Prince Rupert (Figure 3). Kitsault is at the head of Alice Arm. The townsite is at sea level, and the minesite is 7 km south at an elevation of 600 to 800 meters.

The topography is steep and rugged with glaciated mountains rising from sea level to 1800 m in less than 10 km.

Figure 4 THE RELATIONSHIP BETWEEN THE TOPOGRAPHY, VEGETATION, AND SOILS (Gill, 1978).
At the minesite the climate is cool and wet, with heavy snowfalls in the winter. However, in the summer it is not uncommon to have 3 or 4 weeks without rain.

The kinds of vegetation and soils are closely linked to the type of terrain (Figure 4). Well drained soils and Western Hemlock (Tsuga heterophylla) are found on the predominant steep slopes and waterlogged organic soils supporting a Mountain Hemlock (Tsuga mertensiana) parkland have developed where the topography is relatively flat. The minesite is about 100 m below the lower limits of the subalpine vegetation.

Unconsolidated surficial mineral deposits can be glacial, fluvial or colluvial in origin. However, as a result of the steepness of the landscape, erosion dominates over deposition and the mineral overburden cover is rarely very deep. The deep deposits of overburden are mainly organic. Plant debris decomposes very slowly in this cool, wet climate and peat accumulates in waterlogged hollows and on gentle slopes.

REFORESTATION RESEARCH

Background

In 1967 the mine, owned by B.C. Molybdenum Ltd., opened. In 1970, when requesting an extension of their mining permit, B.C. Molybdenum proposed to turn the pit into a lake and allow the wasterock dumps to revegetate naturally. The assurance for the latter was said to be (1) the humid climate and lush natural vegetation, and (2) the natural reforestation that had already occurred at Anyox. Anyox, located at the mouth of Alice Arm, was in the 1920's said to be the largest smelter in the British Commonwealth. In case natural plant invasion failed, B.C. Molybdenum also agreed to set up some field trials to test artificial revegetation methods. In 1972 low molybdenum prices coupled with an inefficient extraction technique, caused the mine the close.

In 1973 AMAX bought the property. On the basis that the pre-mining environment was an overmatured forest with no "productive" soils, lacked "useful" wildlife and had no access for recreation, AMAX proposed that after mining the end land use for the disturbed areas would be a "wilderness forest" with "protected watershed values" (AMAX, 1980). The exception being that the pit would be turned into a lake. The term "wilderness forest" describes a forest grown for no specific used group, but one of similar quality to that present before mining. To help reforestation AMAX proposed to strip, store and reapply soil-like overburden wherever possible. These proposals were accepted by the provincial government and the mine re-opened in 1980.
Even before the mine re-opened, work was started to find an acceptable manner of meeting the proposals. Conceptually, information needed to accomplish the proposal has and will be provided by field trials, literature reviews, biological, chemical and physical analyses, and laboratory and greenhouse experiments. The backbone of the program is a series of field trials, each of a pragmatic nature, testing how theoretically sound ideas actually will perform in terms of plant and soil development. The other three techniques will hopefully provide ideas for new trials, resolve problems that occurred in old trials, and improve the present ones.

Natural Invasion Trial

On the basis of their evaluation of the climate and vegetation the previous mine owners proposed that natural plant invasion would quickly reforest the minesite. To prove this they established a natural invasion trial. The trial area was an untreated portion of wasterock dump backing onto the forest. Plants grew on bear faeces and beside a tree which fell on the plot, but after 9 years the plot was almost totally bare.

At the same time (1970) the other scenario investigated was that the wasterock was too infertile to support rapid natural plant invasion. This, coupled with a literature review to find species and amendments that would be compatible with the climate, led to the simultaneous establishment of both a grass/legume/amendment trial and a conifer trial. Later an alder trial was included.

Grass/Legume/Amendment Trial

The grass/legume/amendment trial has a preponderous design that was not statistically sound (Figure 5). Four amendments and seven seed mixes were tested. However, only three seed mixes were tested with all four amendments. The soil treatments were untreated wasterock, fertilizer, peat and peat plus fertilizer. The last two strips were sown with an annual grass. One was fertilized.

Initial growth was good on the fertilized and on the peat-treated plots. For the first 6 years there was very strong grass growth. By the fourth year the legume birdsfoot trefoil (Lotus corniculatus) had become a dominant species. After 12 years the trials had the following percent herbaceous cover (see Figure 6). Plant cover on the rock plots alone was never more than 15% and is now less than 5%. The fertilized plots are better, particularly the strip of plots seeded with seed mix 5,
Figure 6. % HERBACEOUS COVER IN 1981 ON SPECIES/AMENDMENT FIELD TRIAL SOWN IN 1970.
the only one containing birdsfoot trefoil. The peat amendment has stimulated the best growth of all, whereas the peat plus fertilizer treatment was worse than either peat or fertilizer individually.

Trefoil is a major component of both fertilized and peat-treated plots (Figure 6). For example, on the peat-treated plots trefoil contributes 46% out of the overall 73% cover. Also significant is the large contribution of red fescue (Festuca rubra), a thrifty acid tolerant species, to strip 1.

As expected the % N in the 0-5 cm deep soil samples reflect the contribution of nitrogen fixation by the legume birdsfoot trefoil (Figure 7).

Figure 7 % N IN 0-5 cm DEEP SOIL SAMPLE FROM 11 YEAR OLD SPECIES/AMENDMENT FIELD TRIAL.
The relatively strong growth of red fescue is an indication that the pH of the peat is acid. Less expected is the low pH found on plots amended with just fertilizer and seed (Figure 8). Even on the unfertilized but seeded plots the pH is much lower than on the nearby undisturbed areas of wasterock. The decrease in surface pH which varies with wasterock geology, topography and plant growth, is apparently caused by the addition of organic acids, the leaching of bases, the oxidation of fertilizer ammonium and possibly the oxidation of pyritic sulphur. Changes in pH will certainly have an effect on the mobility and availability of elements in the wasterock. However, the low pH is similar to that of the surrounding soils and does not appear to reduce the growth of acid tolerant vegetation.
Acidification may have caused the negative interaction between peat and fertilizer in stimulating plant growth in KM-70.K In this trial the fertilizer application included 62.44 kg/ha of urea-N. As both seed and fertilizer were applied by broadcasting, the high fertilizer rate may have resulted in close contact between seed and fertilizer. This will have been more likely on the peat treated plots where, relative to the stony wasterock, broadcast amendments are retained on the surface. Ammonification of fertilizer urea will create ammonia, which in high concentrations is toxic for plants. Ammonia may then be converted to ammonium and then by nitrification to nitrates. The nitrification process creates acidity, which may be toxic for the germinating seedling.

The hypothesis that ammonia or nitrification caused the negative interaction is supported by the fact that the peat will already have a large microbial population that is capable of carrying out N transformations, while the wasterock will be relatively sterile.

Although no tests have been carried out to prove either of these theories, a solution based on their validity has been tested in field trials built in 1981. In these field trials, on the peat plots the rate of N fertilizer applied was reduced to 20 kg/ha and limestone was applied at a rate equivalent to the acid producing potential of the fertilizer. The resulting growth of grasses and legumes in 1981 and 1982 was far better on the peat plus fertilizer plots than where either amendment was applied separately.

Conifer Trial

At the same time, and on the same site as the 1970 grass/legume amendment trial was established, conifers were planted in the walkways between rows. The species tested were lodgepole pine (Pinus contorta var. contorta), amabilis fir (Abies amabilis), sitka spruce (Picea sitchensis) and western hemlock (Tsuga heterophylla). Each individual was planted as bare root stock and fertilized. The conifers grew slowly. The best growth was by lodgepole pine. However, as its twisted stems attest, the pine has suffered from the weight of snow. Overall the growth of the conifers has not been satisfactory. Even the best of the lodgepole pine have only grown 1.5 m in 12 years.

Far more encouraging is the growth of naturally invading species like black cottonwood (Populus trichocarpa) and sitka willow (Salix sitchensis). In Figure 9 we show which amendments in the grass/legume trial native deciduous tree species have been most successful in colonizing. Two trends are evident. The first is the inverse relationship between % cover of herbaceous species and the invading tree species. For example,
Figure 9. THE NUMBER OF DECIDUOUS TREES, >10 cm, INVADING KM-70.3 IN 1982.
Figure 10. 1982 HEIGHT OF WOODY SPECIES ON PLOTS AND BETWEEN PLOTS SOWN IN 1970 WITH ANNUAL GRASSES AND FERTILIZER.
invasion on the peat plus fertilizer plots is greater than where only peat was applied. However, this relationship is modified towards the treatments with better fertility as the fertilized plots have had a greater invasion than the unfertilized plots.

Also noteworthy is the invasion of native conifers, for example on the annual grass plus fertilizer strip (Figure 10). One would expect a lot of hemlock germinants because the surrounding forest is dominated by hemlock. However, on the fertilized annual grass strip the invading hemlock is disproportionately in the smallest size range. It has established itself but it isn't growing. In comparison there are less cottonwood, but they are growing quite quickly and have passed the planted sitka spruce in height and are now exceeding the lodgepole pine.

The relative growth of these different species is shown in Table 1. The 12 year old introduced sitka spruce and western hemlock are growing slowly,

<table>
<thead>
<tr>
<th>SPECIES</th>
<th>NO.</th>
<th>( \bar{H}_t ) in'81 (cm)</th>
<th>( \Delta H_t \pm S_D ) (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INTRODUCED</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SITKA SPRUCE</td>
<td>11</td>
<td>26</td>
<td>6.55± 7.15</td>
</tr>
<tr>
<td>WESTERN HEML.</td>
<td>10</td>
<td>30</td>
<td>5.50± 4.66</td>
</tr>
<tr>
<td>LODGEPOLE PINE</td>
<td>9</td>
<td>78</td>
<td>12.22± 5.56</td>
</tr>
<tr>
<td><strong>NATIVE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SITKA WILLOW</td>
<td>16</td>
<td>46</td>
<td>15.25±16.91</td>
</tr>
<tr>
<td>COTTONWOOD</td>
<td>43</td>
<td>54</td>
<td>13.86±10.65</td>
</tr>
<tr>
<td>&quot; (&gt;50 cm)</td>
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<td>84</td>
<td>19.65±11.90</td>
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<tr>
<td>&quot; (10-20 cm)</td>
<td>8</td>
<td>16</td>
<td>6.88± 5.87</td>
</tr>
<tr>
<td>WESTERN HEML. (10-20 cm)</td>
<td>26</td>
<td>13</td>
<td>2.73± 1.67</td>
</tr>
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</table>
only 5 cm per year. The lodgepole pine is growing faster at 12 cm per year. The average for the cottonwood and for the willow is 14 and 15 cm per year respectively. This is better, but not by that much when compared with the lodgepole pine. However, it must be remembered that the cottonwood and willow growth data includes struggling germinants, while that for the lodgepole pine includes only well established larger individuals. For the larger individuals the cottonwood and willows are growing at an average rate of 20 cm a year.

The average growth of individuals in the 10 to 20 cm high category confirms that invading cottonwood are growing much faster than hemlock. The hemlock is growing an average of 3 cm a year while the cottonwood is growing 6.5 cm. On this field trial only a few alders have been able to establish themselves.

Alder

Off the minesite, alder is the dominant natural colonizer of disturbed land. A spectacular example of this is the growth of red alder (Alnus rubra) at sea level at the townsite. Unfortunately, red alder will not grow above 200 m in elevation.

Above 200 m the alder family is represented by sitka alder (Alnus sinuata). This species grows much slower than red alder and unlike it has a low shrubby form with many branches emanating from the base. This form is very effective in trapping litter. Very few alder have established themselves on the wasterock dumps, so in 1977 a field trial was established where bare root stock alder was transplanted onto an untreated portion of wasterock beside the 1970 trials.

Initially alder growth was slow, but in the last two years it has accelerated and a litter layer has developed underneath half of them. The five year old alder, which average 68 cm high, have averaged 24 cm height growth over the last two years (12 cm per year).

Natural Plant and Soil Development

The field trials have provided several candidate species for revegetation and some information about how they are likely to react to each other and to amendments.

To further illustrate how these species could be combined in a reforestation strategy, information was obtained from the research that has been done on plant and soil development in S,E. Alaska, particularly
that done at Glacier Bay by Crocker and Major (1955) and Ugolini (1968).
Despite geographic differences, Glacier Bay and Kitsault have similar climates, the available floras are almost identical and both have a coarse, barren, rocky, rooting media.

Soon after the glacier recedes, plant propagules start to arrive (Figure 11). The first species to successfully colonize the site is mountain avens (Dryas drummondii), which creates a low matting ground

Figure 11 FEATURES OF SUCCESSION AT GLACIER BAY, ALASKA (Ugolini, 1968).
cover that prevents soil erosion, begins to develop a humus layer, increases soil N and protects and stimulates the growth of other seedlings. From within the Dryas matts a shrub cover of sitka alder develops and eventually becomes dominant. As one can see in Figure 11, with a complete alder shrub cover the levels of soil organic matter and nitrogen rapidly increase. These in turn stimulate the growth of sitka spruce which out-grows and eventually shades out the alder, creating a "wilderness forest".

An important difference between Kitsault wasterock and Glacier Bay glacial moraine is that the latter is calcareous. According to various authors, Dryas only grows well on calcareous substrates.

From the pH data I've presented, the Kitsault wasterock and Dryas do not seem compatible. However, Dryas is important. In comparing plant development with and without it, Lawrence et al. (1967) stated that Dryas speeded up the rate of succession to a fully developed forest by a period of perhaps 20 to 30 years.

So if the Kitsault reclamation plan intends to mimic nature, there is going to be an empty niche. This could be filled by the legume birds-foot trefoil, or perhaps by an application of peat and fertilizer. Maybe alder won't be compatible with either trefoil or fertilizer and one should use cottonwood and willow in its place.

Also, it would be nice to accelerate the development of the forest. For example, to develop a complete shrub cover in 10 years. Artificial amendments may make this possible.

1982 Field Trials

From these ideas about how to establish a forest cover it is possible to develop a new hypothesis about how to develop a forest, and from this a new set of research trials.

In general terms the objective of the trials is the end land use objective for the minesite, to develop a wilderness forest with protected watershed values.

To do this it is proposed to establish a complete erosion controlling cover of self-sustaining trees and shrubs. Based on numerous natural reforestation studies done in similar climatic conditions, further forest development will be already occurring naturally. If not, it will be easy to stimulate.
From a review of the literature and of the previous field trials, it has been proposed that the following series of operations will create conditions favourable for the rapid development of a woody cover on the waste-rock dumps:

1. an initial treatment of overburden as a topsoil to improve the rooting media,
2. fertilizing and liming before seeding and planting,
3. the establishment of a herbaceous ground cover to quickly stabilize and ameliorate the site,
4. planting seedlings of several species of shrubs and trees to develop the complete canopy cover and to accelerate the formation of a surface organic layer.

The research trial initiated in 1982 will test the combination of these actions (Figure 12).

There will also be an attempt to compare the effectiveness of different types of each component (for example, 4 different seed mixes). However, a lack of space has limited the number of variables that can be tested. So for factors such as the fertilizer rates and date of seeding the trial design will use the information already available.

The reforestation trial initiated is extensive, combining five overburden treatments, four seed mixes and four tree species. As they will be used together they must be tested together.

Each overburden treatment is applied to four of the 20 plots. Each 8.0 m x 8.0 m plot is divided into four 4.0 m x 4.0 m sections. One seed mix was broadcast on each section. Then each 4.0 m x 4.0 m section is further divided into four 2.0 m x 2.0 m sections, each with space for planting four of one of the seedling species with a 1.0 m row spacing between them.

Overall, this is a complete block design with overburden treatments applied to entire plots, seed mixes applied to split plots and woody seedlings applied to the split split plots.
FUTURE RESEARCH

This brings us to the present (Figure 13). What about things to come? A good herbaceous cover has developed on the plots that were built last summer. Tree seedlings will be planted this spring. This trial will be monitored but it will take at least five years before one can conclude how successful the ideas tested have been.

More immediately, research will look at the rates and products of the weathering of different wasterock types. As some of the wasterock is very incompetent and quickly weathers to soil-sized particles it could provide a supplement to the limited overburden supplies.
Figure 13. THE PROGRESSION OF REFORESTATION RESEARCH AT THE KITSAULT MINE, 1970-1983.
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