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The mine that almost closed – a review of fifteen years of reclamation at the Kitsault Mine, Alice Arm, Canada

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Abstract

The Kitsault Mine, a molybdenum mine located on the northwest British Columbia coast at the end of Alice Arm, operated intermittently from 1968 until 1982 when low molybdenum prices and market conditions forced its shutdown. The mine operation was under a care and maintenance programme until 1996 when mine reclamation began with the development of a reclamation plan, implementation of mine facilities decommissioning and site preparation for revegetation. Revegetation and water quality goals were also addressed in the plan. The mine was on target to apply for a closure certificate, until redevelopment of the mine was announced in late 2008. This paper presents information on the successful implementation of the reclamation plan, particularly site revegetation, addresses how reclamation planning was used, and reports some of the lessons learned in revegetation efforts in mining.

1 Introduction

The Kitsault molybdenum mine is located on the northwestern British Columbia (BC) coast at the end of Alice Arm ~100 km northeast of Prince Rupert, BC. The mine is ~5 km inland by road and 600 m higher in elevation than the town of Kitsault, which is located at sea level at the end of Alice Arm. The area around Kitsault Mine consists of rugged, mountainous terrain accessible by logging road from Terrace, BC. The Kitsault deposit was first staked in 1911. Kennco Explorations commenced exploration in 1959 and in 1964 announced the presence of a molybdenum ore body. In 1968, BC Molybdenum Ltd. (a Kennco subsidiary) began operating the mine at a production rate of 5,450 tpd. They operated for four years, producing 10.4 M kg of molybdenum from 9.3 Mt of ore. The ore was mined from an open pit at a stripping ratio of 1.5:1. The mining operation was terminated in 1972 due to low molybdenum prices and escalating costs.

In 1973 the property was purchased by Climax Molybdenum Corporation of BC and transferred to Amax of Canada, an affiliated company, in 1979. Mining operations recommenced under Amax in April 1981 following construction of the Kitsault town site and mine facility improvements. Mining continued until November 1982 when low prices and market conditions forced another closure. The town site was closed in 1983. Amax then adopted a care and maintenance programme for both the mine and town site. In 1996, a decommissioning and reclamation programme was developed and initiated. The care and maintenance programme for the Kitsault town site continued until 2005 when the town was sold to a private individual.

From 1996 to present, ownership of the mine property changed several times: Cypress Amax Mineral Co. (Climax Canada Ltd.) (1996 to 2000); Phelps Dodge (2001 to 2005); ALCOA (2005 to 2007); and Avanti Mining Inc. (2008 to present). Throughout this time period all of the owners have continued the reclamation programme as per their requirements under BC Ministry of Energy and Mines (MEM) Reclamation Permit M-10.

2 Reclamation planning

In 1996, under Climax Canada Ltd. and Cyprus Amax Minerals Co., a decommissioning and reclamation programme for the Kitsault mine site was initiated. Steffen Robertson and Kirsten Canada Inc. (SRK) were commissioned to prepare an environmental management plan, develop and implement a reclamation plan and arrange for removal of hazardous wastes. Stantec (formerly CE Jones & Assoc. Ltd.) was contracted to design and implement a revegetation programme for the reclamation plan when areas were available for reclamation.

The reclamation plan, developed by SRK and Stantec, focused on re-contouring and revegetation of the mine site in addition to controlling water quality. The ultimate objectives of the reclamation plan included (SRK, 1997):

- Ensure long-term physical stability of water courses, waste dumps and pit walls.
- Return the site to a wilderness forest environment while retaining access for future mineral resource exploitation.
- Establish a long-term monitoring programme for water quality and vegetation establishment and growth.
- Control chemical instability issues related to water quality where evident.
- Monitor and provide contingency measures for chemical instability should it occur.

The reclamation plan provided details on general site conditions and biophysical environment; various mine site facilities and disturbances; and recommended reclamation, rehabilitation and revegetation measures for various mine site areas.

2.1 Site description

The Kitsault area is located in rugged mountainous terrain and steep narrow valleys on north coastal BC with mid-mountain elevations up to 1,500 m above sea level (masl). The mine site is situated on the south side of Widdzech Mountain adjacent to Patsy and Lime Creek drainages from 558–745 m elevation. The climate of the area is dictated by maritime influences with high precipitation and moderate temperatures. The majority of the annual precipitation occurs in the fall as rain and during the winter as snow.

Soils in the Kitsault Mine vicinity have been influenced by glaciation, fluvial erosion and colluviation of bedrock material. Colluvial material is the predominant surficial material. Soil surveys on undisturbed areas of the mine site documented Humo-Feric, Ferro-Humic and Orthic Humo-Ferric Podzols and Folisols on well-drained forest sites and Mesisol organic soils at saturated topographic depression sites (Canada Soil Survey Committee, Subcommittee on Soil Classifications, 1978). Soil sampling of disturbed sites identified soil textures as primarily sandy loam, with very low total nitrogen and phosphorus levels; pH levels ranged from 5.4 to 8.1 and elemental concentrations were within normal ranges for natural soils except for zinc, copper and molybdenum.

Vegetation types in adjacent undisturbed areas consist of mature coniferous forests. Most of the mine site is within the Coastal Western hemlock Wet Submaritime Subzone, Montane Variant. Site series present include Hemlock-Balsam-Bramble; Balsam-Cedar-Oakfern, and Hemlock-Balsam-Queen's Cup. In general, these site series consist of forests dominated by western hemlock and balsam fir; and shrub and herb layers consisting of blueberries, bunchberry, devil's club, foam flower, skunk cabbage and pipecleaner, step and lanky mosses (MOF, 1993).

2.2 Reclamation research

Vegetation establishment and growth on severely disturbed ground material was studied in various reclamation research trials established on Kitsault Mine disturbance sites from 1970–1989 (Price, 1982, 1989). The principal objectives of the programmes conducted during this time period were to:

- Evaluate the potential for natural revegetation by encroachment and invasion of species from forested areas adjacent to disturbed sites.
- Identify appropriate seed mixes.
- Evaluate seed mix performance on sloping and flat waste rock sites.
- Evaluate the influence of surface amendments, including peat and fertiliser additions, to waste rock prior to seeding and planting sites.
- Evaluate the performance of selected deciduous and conifer species for reclamation of selected waste rock sites.

Results of the research trials are summarised as follows:

Table 1 Reclamation research results and implications for reclamation planning

Reclamation Research Results	Reclamation Planning Implication
Unseeded and unfertilised trial areas for natural revegetation of disturbed areas exhibited slow recolonisation during a seven year monitoring period and were abandoned. In contrast, seeded and fertilised trials encouraged natural recovery of native species including mosses, forbs, shrubs (blueberry) and western hemlock.	Seeding and fertilising of reclamation sites a preferable treatment in order to encourage vegetation growth and ecosystem development.
Seeding trials on waste rock demonstrated that vegetation could be established directly on waste rock material with the most positive results obtained on waste rock sites amended with peat, and waste rock sites amended with fertiliser.	Vegetation establishment on waste rock material is possible. Important consideration if topsoil capping material not available.
Assessments of per cent cover by various ground-cover seed mixes were conducted until 1983 with legume seed mixtures containing birds foot trefoil and sainfoin exceeding 50% total cover on waste rock sites amended with peat, and waste rock sites amended with fertiliser.	Reclamation seed mixes should contain a legume component as they are able to establish on waste rock material.
Seed and fertiliser applied to waste rock slopes at angle of repose (36°) resulted in poor vegetation cover limited to the upper portion of the steep slope.	In order to revegetate dump slopes; they must be resloped to a much lower gradient.
Lodgepole pine (Pinus contorta) demonstrated the best growth and survival compared to amabilis fir (Abies amabilis), Sitka spruce (Picea sitchensis) and western hemlock (Tsuga heterophylla) also planted on trial areas.	Consider lodgepole pine as a candidate reclamation species.
Natural establishment of black cottonwood (Populus balsamifera), Sitka willow (Salix sitchensis) and western hemlock was noted on vegetated trial areas with annual growth of black cottonwood and Sitka willow generally greater than the conifer species.	Black cottonwood, Sitka willow, and Sitka alder are strong candidates for reclamation species due to good results in trials and natural colonisation observed on study sites.
Transplanted Sitka alder exhibited high survival and good growth on waste rock at an elevation of 660 masl.	
Sitka alder was the most productive species evaluated in the field trials with survival and growth rates considerably greater than lodgepole pine.	

Findings from the research trails were used to develop revegetation prescriptions for the reclamation plan and are discussed in detail in the following sections.

2.3 Mine site components

A detailed inspection of mine site facilities and disturbed areas was conducted in June 1996 to evaluate physical and chemical site conditions and identify site specific reclamation objectives. The following disturbances were documented on the Kitsault Mine.

Table 2 Mine site components reclaimed

Mine Site Components	Reclamation Treatment
Patsy and Clary waste rock dumps	Resloping, scarification, seeding, tree/shrub planting
Low grade ore stockpiles	Recontouring, scarification, seeding, tree/shrub planting
Overburden stockpiles	Recontouring, scarification, seeding, tree/shrub planting
Crush rock stockpiles	Recontouring, scarification, seeding, tree/shrub planting
Open pit area	Topsoil capping, seeding, tree/shrub planting
Plant / mill site	Overburden capping, seeding, tree/shrub planting
Pit shop	Overburden capping, seeding, tree/shrub planting
Tailings line	Seeding

2.4 Reclamation programme

The reclamation plan recommended reclamation, rehabilitation and revegetation prescriptions of the principal mine site areas. The principal areas included the Pit Area, Patsy and Clary Waste Rock Dumps, Mill Site and Pit Shop. Prescriptions included surface preparation and revegetation.

2.4.1 Surface preparation

Surface preparation was recommended in the plan in order to facilitate tree and shrub seedling planting and establishment and growth of vegetation on reclamation sites. Techniques proposed included:

- Re-sloping of most waste dump slopes to 2:1 (H:V) to reduce slope angles and distribute fine materials in waste rock material. Re-sloping was not to be done on portions of the Patsy Dump alongside Patsy Creek as material would be pushed down and encroach on the creek and have an adverse impact.
- Scarification or ripping of level surfaces such as waste dump platforms, pit shop and mill site platforms and roads to de-compact the ground surface material and release fine materials into the waste rock material.
- Capping pit floor, benches and Central Core areas with 40 cm of overburden material from adjacent stockpiles to provide a suitable growth medium for vegetation. Ripping prior to capping was not required since ground material in these sites was too compacted and lacked fine materials that would support vegetation establishment.

2.4.2 Revegetation

Reclamation research conducted from 1970–1989 at the Kitsault Mine provided valuable information to develop revegetation prescriptions at this site. Trials demonstrated that a productive vegetation cover can be established directly on waste rock accompanied by an initial application of fertiliser at the time of seeding or planting. Furthermore, agronomic species of grasses and legumes could provide erosion control and supplement the build up of organic material and nutrients in the soil while a shrub and tree cover developed on a reclaimed site. Deciduous native tree and shrub species, including Sitka alder, Sitka willow, and black cottonwood, demonstrated long-term productivity on sites without maintenance fertiliser applications. Natural establishment of Sitka willow, black cottonwood and hemlock was also documented. Monitoring of reclamation trials from 1970 to1989 documented natural recolonisation of native species, including native conifers on trial areas. This indicated that once vegetation is established on reclaimed sites, natural revegetation will enhance site productivity at this mine site.

Findings of the research trials were used to develop appropriate seeding and planting mixes. One tree/shrub planting mix was developed for use on mine disturbed areas. Two other seeding mixes were developed: one mix was formulated to provide a non-competitive ground cover on tree/shrub planted areas; the second mix was formulated to provide erosion control on specific sites. Formulation of each of the mixes is detailed in Tables 3 and 4. Fertiliser, a 18:18:18 N:P:K formulation applied at a rate of 200 kg/ha, was to be applied to each area at the time of revegetation.

Table 3 Proposed native tree/shrub planting mix (planting rate: 1,200 stems/ha)

Species	Per Cent of Mix
Sitka alder (*Alnus sinuata*)	60
Sitka willow (*Salix sitchensis*)	20
Black cottonwood/balsam poplar (*Populus balsamifera*)	20
Total	**100**

Table 4 Proposed erosion control and ground cover seed mixes

Species	Erosion Control Mix Application Rate: 45 kg/ha Per Cent of Mix	Ground Cover Mix Application Rate: 6 kg/ha Per Cent of Mix
Perennial ryegrass (*Lolium perenne*)	25	
Orchardgrass (*Dactylis glomerata*)	25	
Timothy (*Phleum pratense*)	10	
Meadow foxtail (*Alopecurus arundinaceus*)	10	
Creeping red fescue (*Festuca rubra*)	10	
Canada bluegrass (*Poa compressa*)	10	
Birdsfoot trefoil (*Lotus corniculatus*)	5	60
Alsike clover (*Trifolium hybridum*)	5	25
White clover (*Trifolium repens*)		15
Alder seed	0.2 kg/ha	
Total	**100**	**100**

3 Reclamation implementation

Decommissioning of the mine facilities, infrastructure and equipment was carried out from 1996–1999. Activities included dismantling the mill and pit shop buildings and the tailings pipeline; as well as removal of concrete drop boxes and pipe; removal of equipment from the mine property; collection and removal of hazardous wastes; and on-site burial of garbage and concrete foundations. During this same period surface preparation of mine site disturbances was conducted as areas became available except the Pit Area which was remediated in 2006. Sites underwent surface preparation techniques as prescribed in the reclamation plan. Activities carried out included installation of drainage diversion ditches around the Pit Floor and Central Core areas; draining and treating water in ponded areas adjacent to the Central Core; scaling the west face of the Central Core, blending the material with limestone and placement of a soil buttress on the site; regrading and capping the Central Core with a low permeability compacted bentonite layer; and capping the Pit Floor and Central Core areas with a growth medium material (topsoil/overburden).

The Kitsault town site, sold to a third party, did not fall under the mine reclamation plan and no reclamation was carried out. The Kitsault access road and power transmission line were left in place and remain active and in use.

The revegetation programme at the Kitsault Mine happened during four separate years within a 10 year time frame. Planting of native shrubs and trees occurred in 1997, 1998, and 1999 at the Mill Site Area, Pit Shop Area, Clary Dump and Patsy Dump (1997–1999 planting sites). Following completion of the pit remediation work, planting in the Pit and Central Core Areas and associated disturbance sites was carried out in 2006 (2006 planting sites). In addition to planting of native trees and shrubs, reclamation sites were seeded during the same periods with the erosion control mix or the ground cover mix depending on the site. The erosion control mix was applied to sites without trees or shrubs planted and required a vegetation cover for erosion control (e.g. Patsy Waste Rock Dump Slope); the ground cover mix was applied to tree and shrub planted areas to provide a light vegetation cover to limit erosion and invasive plant establishment. All reclamation sites received an initial application of granular fertiliser at the time of seeding (18:18:18 N:P:K; applied at 200 kg/ha).

Native tree and shrub seedling stock planted on the reclamation sites was propagated at commercial nurseries from seed and cuttings harvested from the Kitsault Mine area. Collection of local seed and cuttings material ensured that stock would be adapted to local environmental and soil conditions. Seed and cutting material was collected during the fall of the previous year, prepared and grown over the following growing season and then planted the following fall. Seedling stock was packaged and shipped to the mine site via transport truck and planted by professional, experienced tree planters. Planting quality inspections were conducted during the planting operations to ensure seedlings were planted properly.

Seed and fertiliser were applied aerially by helicopter using a broadcast spreader bucket slung underneath the aircraft. Seed and fertiliser applications were carried out in spring or late fall depending on revegetation programme schedules.

Minor variations in the revegetation programme occurred between 1996 and 2006. The following tables detail the actual sites, mixes and rates applied: Table 5 summarises the sites and years they were revegetated, Table 6 details the native tree/ shrub species actually planted in the revegetation programme, Table 7 details the species in the erosion control and ground cover seed mixes.

Table 5 Kitsault mine revegetation sites

Site	Area (ha)	Year Planted
Patsy dump	19.0	1997
Patsy dump	9.6	1998
Clary dump	9.0	1998
Pit area	2.8	1998
Mill site area	5.4	1999
Pit shop area	13.5	1999
Pit area	1.8	1999
Pit floor area	15.2	2006
Central core area	4.5	2006
Borrow area 1	1.0	2006
Borrow area 2	0.5	2006
625 bench	2.5	2006
Soil stockpile area	1.0	2006
Total area planted and seeded with ground cover mix	85.8	
Total native tree/shrub seedlings planted:	110,000	
Remaining area seeded only with erosion control mix	35.2	
Total area reclaimed	**121**	

Table 6 Actual native tree/shrub planting mixes utilised in revegetation programme

Species	Per Cent of Mix
1997–1999 planting sites (1,400 stems/ha)	
Sitka alder (*Alnus sinuata*)	60
Sitka willow (*Salix sitchensis*)	20
Black cottonwood/balsam poplar (*Populus balsamifera*)	20
Total	**100**
2006 planting sites (1,200 stems/ha)	
Sitka alder (*Alnus sinuata*)	82
Black cottonwood/balsam poplar (*Populus balsamifera*)	7
Red-osier dogwood (*Cornus stolonifera*)	8
Sitka mountain ash (*Sorbus sitchensis*)	3
Total	**100**

Table 7 Actual erosion control and ground cover seed mixes utilised in revegetation programme

Species	Erosion Control Mix Application Rate: 45 kg/ha Per Cent of Mix	Ground Cover Mix Application Rate: 25 kg/ha Per Cent of Mix
Perennial ryegrass (*Lolium perenne*)	25	15
Orchardgrass (*Dactylis glomerata*)	25	15
Timothy (*Phleum pratense*)	10	10
Creeping foxtail (*Alopecurus arundinaceus*)	10	10
Creeping red fescue (*Festuca rubra*)	10	
Canada bluegrass (*Poa compressa*)	10	
Birdsfoot trefoil (*Lotus corniculatus*)	5	20
Alsike clover (*Trifolium hybridum*)	5	8
Red clover (*Trifolium pratense*)		7
White clover (*Trifolium repens*)		15
Total	**100**	**100**

4 Reclamation monitoring/results

A vegetation monitoring programme has been ongoing since the 1997–1999 planting was completed and is a requirement under Reclamation Permit M-10.

A component of the monitoring programme is to measure growth, survival and densities of trees and shrubs on reclamation sites. Some of the key findings from the monitoring programme include the following (Stantec Consulting Ltd, 2010):

- Tree and shrub heights at the 1997–1999 planting sites are steadily increasing with heights of the planted stock and older naturals exceeding the cover of seeded grass/legume vegetation (Table 7).
- Plant heights at the 2006 planting sites are increasing; and heights of the planted stock are at a level that they are becoming a substantial presence on the reclaimed sites (Table 5).
- Tree/shrub densities in the older 1997–1999 planting sites are high overall relative to target densities detailed in Ministry of Forests and Range (MOFR) deciduous species management handbooks and MOFR Prince Rupert Forest Region Establishment to Free Growing Guidebooks. Supplemental plantings will not be required since a considerable amount of willow and hemlock, and to a lesser degree Sitka alder, balsam poplar and spruce, are naturally establishing on the sites (Figure 1).
- Overall plant densities and survival of planted stock in the 2006 planting sites for the Pit Floor, Borrow Areas, Central Core and 625 bench have decreased by 20–60% since initial planting, but plants that have survived are growing well (Figure 2).
- The decrease in densities of the 2006 planted stock is alleviated by the considerable amount of willow seedlings that have naturally established on the sites since planting in 2006 (Figure 3).

Tables 8 and 9 and Figures 1, 2 and 3 outline data from the monitoring programme.

Table 8 Tree/shrub heights at 1997–1999 planting sites

Species	Overall Mean Heights (cm)* at 11–13 Years Old	Individual Species Measured Height Ranges (cm)**	Target Heights (cm)***
Sitka alder	154.9	10–500	180 (at 5 years)
Balsam poplar	81.1	10–600	130 (at 8 years)
Sitka willow	44.4	10–500	n/a
Hemlock	32.1	10–150	130 (at 11–14 years)
Spruce	53.3	40–70	100 (at 11–14 years)

* Mean height of species (>10 cm tall) measured at all of the 1997–1999 monitoring sites including planted stock and naturals.

** Minimum and maximum heights measured at all of the 1997–1999 monitoring sites.

*** Target heights based on the Prince Rupert Forest Region Free Growing Guidebook (MOFR, 2000); Black Cottonwood and Balsam Poplar Managers' Handbook (Petersen et al., 1996a); Alder Managers' Handbook (Petersen et al., 1996b).

Table 9 Mean tree/shrub heights and height increases: 2006 planting sites

Species	Mean Heights (cm)*	Height Increase Four Years After Planting (cm)**
Sitka alder	100–115	85–100
Balsam poplar	90–108	75–93
Sitka willow	70–71	55–56
Red osier dogwood	85	70
Sitka mountain ash	70–83	55–68

* Range of mean heights measured at all of the 2006 planting sites where species were planted.

** Seedling height at time of planting: 15 cm.

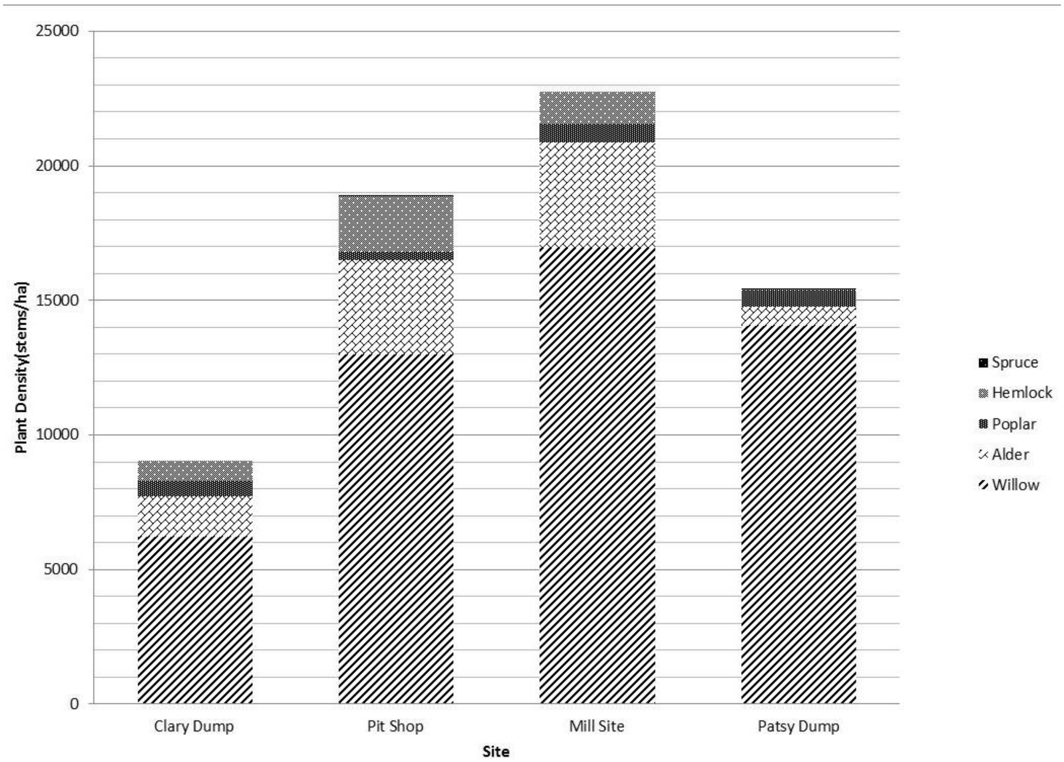

Figure 1 2010 mean plant densities at 1997–1999 planting sites (plants >10 cm height)

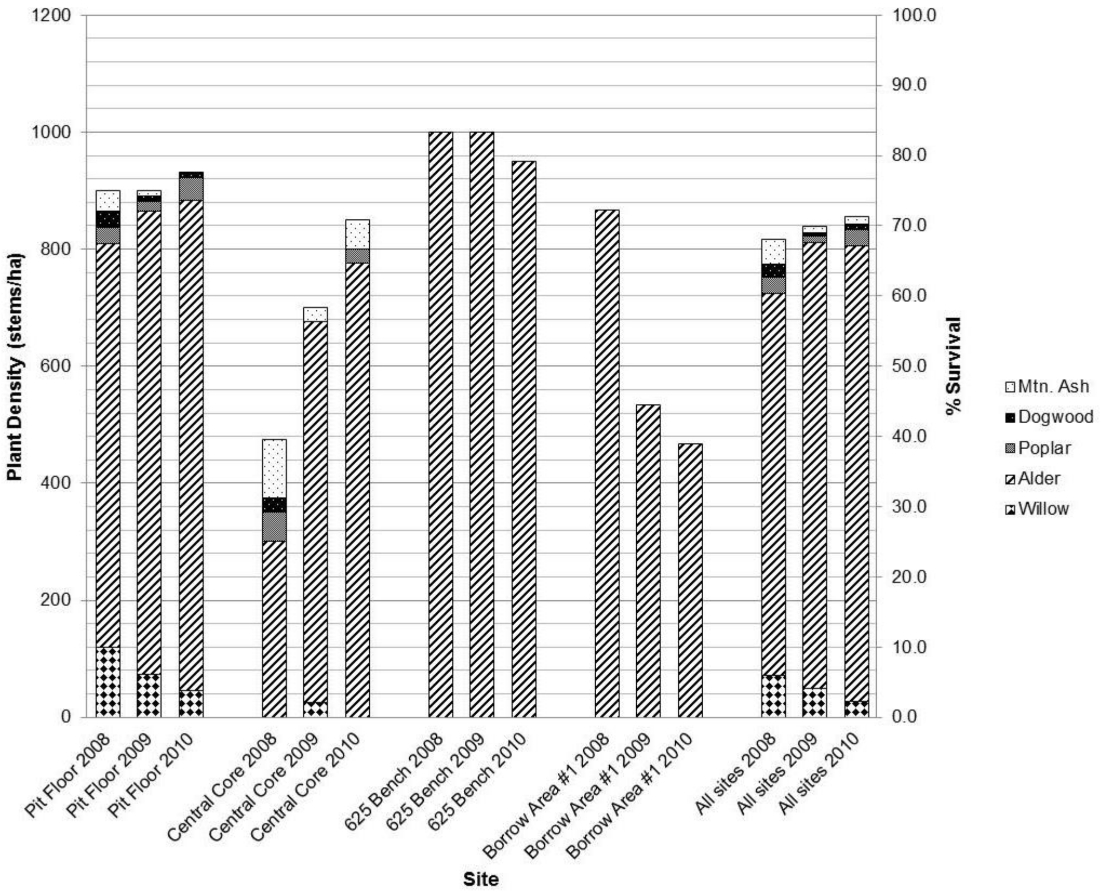

Figure 2 2008, 2009 and 2010 mean plant densities and survival rates at 2006 planting sites – planted stock

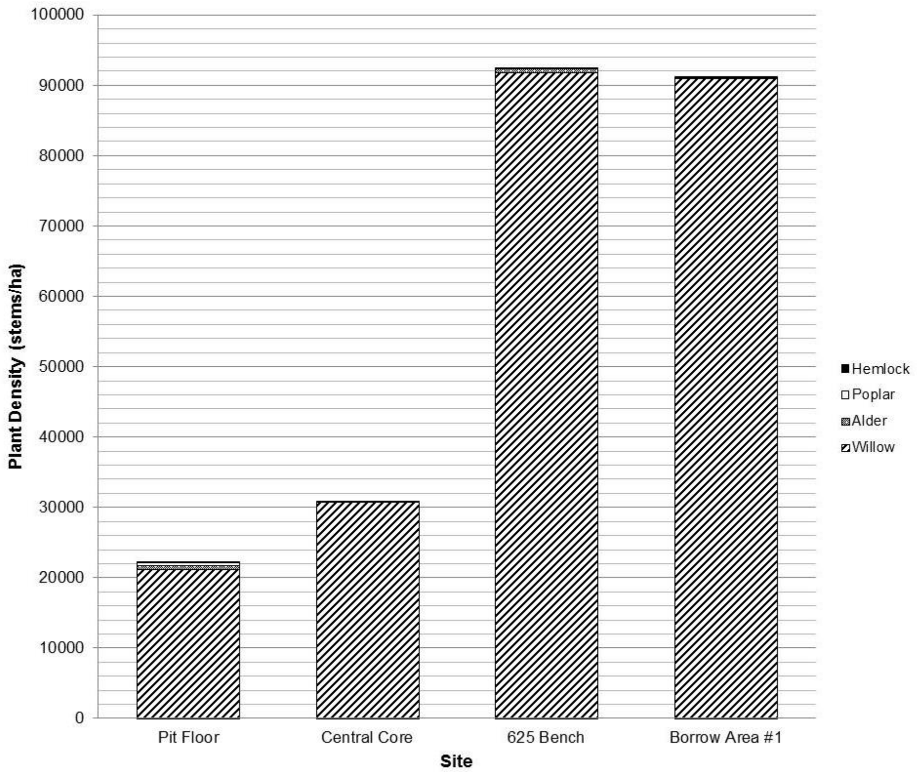

Figure 3 2010 plant recruitment density (2006 planting sites) (plants <10 cm height)

5 Summary

Reclamation of the Kitsault Mine was conducted in a progressive manner once reclamation planning was completed. Mine infrastructure and facilities were decommissioned followed by surface preparation and revegetation of a majority of the disturbance areas. Vegetation establishment and growth on reclamation sites has been quite successful and is becoming self sustaining. Without seeding or fertilising, natural revegetation was not successful relative to prepared, seeded and planted sites. Fertiliser treatments at the time of seeding were critical for survival of both planted and natural species. Seeded grass/legume cover for most areas did not inhibit planted tree/shrub seedlings except at the Central core due to better quality capping cover which resulted in a denser cover. Planted deciduous trees were the most successful vegetation cover. Conifers naturally colonised reclaimed areas, with slower growth, but will become dominant over time. Natural recolonisation of native species supplemented 30–40% losses from planted stock such that replanting is not required.

5.1 Lessons learned

Success of reclamation at the Kitsault Mine is linked to the extensive reclamation research that was conducted prior to the final decommissioning, recontouring and revegetation of the site. The reclamation research provided the information required to make sound planning decisions on methods of ground preparation, and selection of plant species for site revegetation. For successful final reclamation and re-establishment of ecosystems at any mining operation, a programme of research trials must be carried out on the disturbance sites prior to and during operations in order to determine appropriate methods of preparation and revegetation.

Due to market conditions, the mine may become operational once again which will result in the re-disturbing and loss of most of the successfully reclaimed areas. However, the lessons learned and the information derived from the reclamation research trials and the 1996–2006 reclamation programme will be useful for future mine decommissioning and reclamation.

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