LONG TERM RECLAMATION MONITORING OF VEGETATIVE COVERS AT THE ISLAND COPPER MINE, PORT HARDY, BC

David Polster

Polster Environmental Services Ltd.
5953 Deuchars Drive
Duncan, BC
V9L 1L5
d.polster@telus.net

Repeat vegetation sampling along transects established in 1997 at the Island Copper Mine provides a unique picture of the development of vegetation on the reclamation sites. Reclamation at the mine has consisted of resloping waste rock dumps to a stable angle and shape, creating a reclamation cap by placing glacial till over the waste rock, seeding with agronomic grasses and legumes and planting woody species, primarily red alder (*Alnus rubra* Bong.). Five transects have been established in representative areas at the mine. Ten plots were established at 30 m intervals along each transect. Each plot consists of a circular plot with a radius of 5.64 m giving a plot area of 100 m^2 or 1/10th of a hectare. In each plot a listing of the vascular plant species present was compiled along with an estimate of their combined cover and abundance. A count of the number of woody species present and an estimate of their cover was made. This data has been used to document the progress of the vegetation cover and to project the future of the vegetation on the mine site. Results to date confirm the visually obvious excellent growth of the vegetation on most sites. In addition, the data illustrate the detrimental effects of the grass and legume seeding on the growth of forest species. In the past few years more forest species have been showing up in the dense alder stands where competition from the seeded grasses and legumes has been reduced. This paper compliments the field tour to the mine.

Key Words: Repeat sampling; successional processes; trajectories; filters; novel ecosystems; dynamics.

INTRODUCTION

Reclamation assessments have been conducted on an annual basis since mining at the Island Copper Mine was completed in 1995. Reclamation work at the mine however was initiated with the advent of mine production in 1971. Reclamation treatments that have been applied over the years at the mine have had various effects on the progress of ecological recovery. The information that has been collected through the assessment process over the years provides an excellent resource for the determination of the progress of the recovery as well as the effectiveness of the treatments that have been applied in assisting that process. Reclamation treatments at the Island Copper Mine have been designed to mimic the natural successional processes (Polster 1989) that operate in the region. A seeded cover of grasses and legumes was used to replace the initial cover of herbaceous species that was noted on many recently disturbed sites. Seeded grasses and legumes have been widely used in mine reclamation throughout British Columbia. Red alder and other trees were planted to provide the structure for subsequent succession development. On the North Dump, lodgepole pine was planted as a pioneering conifer with the seeded grasses and legumes. Natural successional processes have been gaining acceptance as a model for restoration of drastically disturbed sites (Walker et al 2007).

Problems with the establishment woody species within a cover of seeded agronomic grasses and legumes were recognized relatively early in the development of reclamation science (Green 1982). Unfortunately, seeding grasses and legumes has become such an integral part of mine reclamation that it is difficult to find a mine in British Columbia where seeding grasses and legumes has not been used as part of the reclamation program. Studies at the Island Copper Mine and elsewhere are showing that this treatment is not appropriate where natural successional advancement towards a woody species forest is desired. New solutions for performing the functions of the seeded grasses and legumes (erosion control, organic matter and nitrogen enrichment and forage for wildlife) are needed. This paper presents the results of repeat sampling that has been undertaken at the Island Copper Mine since 1997.

METHODS

Reclamation assessments have been conducted annually at the Island Copper Mine. The same assessment methodology has been used since 1997. By using the same methods for the assessments, the data that is gathered can be compared to determine trends. Initially four transects were established at selected locations at the Island Copper Mine. Sampling methods at all transects is the same. Ten plots have been established at 30 m intervals along each transect. Plots are circular with a radius of 5.64 m giving a plot area of 100 m^2 or $1/10^{th}$ of a hectare. At each plot a listing of the vascular plants present has been collected along with an estimate of their cover and abundance using a modified Braun-Blanquet scale (Mueller-Dombois and Ellenberg 1974; Luttmerding et al 1990). This scale allows species that only occur rarely in the plots to be recorded as an R (one or two individuals) or + (several to many individuals) where their cover is less than 1 percent. Where species are more common, their cover was recorded as a percent cover (aerial view). Initially only 4 transects were established and only information on the numbers of surviving woody species was collected, but an additional transect was added on the Beach Dump in 2004 and data on percent cover along all transects was included. The reclamation assessments have also included inspections of most sites at the Island Copper Mine with photographic documentation of the vegetation conditions, including indications of successional patterns at these sites. Understanding the way recovery takes place naturally can provide ideas about how these natural processes can be enhanced at reclamation sites such as the Island Copper Mine (Temperton et al 2004).

In 2006 an assessment of the metals uptake by the vegetation at the Island Copper Mine was conducted. Samples were collected at the centre plot of each transect (Plot 5 of 10). At each site 400 to 500 grams of the above ground portion of the vegetation was collected. Collections were made of grasses and legumes separately and care was taken to avoid collection of soil materials with the samples. The samples were analysed by a commercial laboratory using Inductively Coupled Plasma Mass Spectrometry following standard laboratory methods.

Reclamation methods have varied considerably over the years at the Island Copper Mine. However, the treatments have generally entailed seeding with an agronomic grass and legume mix and planting woody species. The unbalanced mix that was used prior to 1995 was dominated by sod forming small seeded species was replaced with a balanced seed mix that increased the percentage of larger seeded species, including alfalfa. This has had an impact on results that have been achieved at the sites where these mixes were used. These differences are discussed below. Woody species have been planted on most sites throughout the mine area. A variety of different species, stock types and planting timings have been used although container grown alder seedlings (1+0) are the most common plants to have been planted at the mine (Table 1).

Table 1
Woody Vegetation Planting Programs at Island Copper Mine

Date	Number	Site	Species	Stock Type
April 1978	150 150 150	North Dump, Plantsite & Beach Dump North Dump, Plantsite & Beach Dump North Dump, Plantsite & Beach Dump	Lodgepole Pine Douglas Fir Hemlock	Bare root Mud pack Container
February 1978	800	North Dump	Red Alder	Transplants
March 1980	750	Beach Dump & Emergency Tailings Pond and Dike	Red Alder	Transplants
June 1980	6,000	S. face of North Dump	Lodgepole Pine	Mud pack & Bare root
February 1981	10,000	North Dump	Red Alder	Transplants
March 1982	3,500 750	Easternmost slopes of North Dump Beach Dump	Red Alder Red Alder	Transplants Transplants
April/May 1983	25 75 50 200 25 485 100 200	Beach Dump Beach Dump Beach Dump Beach Dump North Dump North Dump North Dump North Dump	Sitka Spruce Douglas Fir Hemlock Red Cedar Sitka Spruce Douglas Fir Hemlock Red Cedar	1+0 plugs [1] 1+0 plugs [1] 1+0 plugs [1] 1+0 plugs [1] 1+0 plugs [1] 1+0 plugs [1] 1+0 plugs [1] 1+0 plugs [1]
February 1985	3,200 1,200 5,000	North Dump West & Beach Dumps Northwest, North & Beach Dumps	Red Alder Red Alder Douglas Fir	Transplants Transplants 1+0 plugs
February 1987	4,150 3,000 750	Easternmost slopes of North Dump North Dump Northwest Dump	Red Alder Red Alder Red Alder	Transplants Transplants Transplants
October 1994	6,000	North Dump	Lodgepole Pine	1+0 plugs
February 1995	3,500	North & Beach Dumps	Red Alder	Transplants
October 1995	28,000	North Dump	Red Alder	1+0 plugs
April 1996	50,000	North Dump	Lodgepole Pine	1+0 plugs
October 1996	390,000	Beach, West, former NW & North Dump	Red Alder	1+0 plugs
April 1997	4,000 2,000 1,326	North Dump Roadside East of “A” Pond Rear of Cat Shop	Hemlock White Pine Lodgepole Pine	1+0 plugs 1+0 plugs 1+0 plugs
October 1997	7,000	Crusher Roadside & Con Shed	Red Alder	1+0 plugs
October 1998	15,300 4,590	Tripper Gallery Beach Till stockpile (Beach) & Roadways	Red Alder Sitka Alder	1+0 plugs 1+0 plugs
October 1999	10,080	North Dump and Lagoon	Red Alder	1+0 plugs
June/November 2000	3,400	Mill Building area	Red Alder	1+0 plugs
October 2003	14,510 5,740	Beach Dump (log dump area) NW Dump Seepage Collection System	Red Alder Red Alder	1+0 plugs 1+0 plugs
December 2006	830	Twin Lakes Compensation Channel & waste dumps	Willow	Live stakes
TOTALS WOODY SPECIES PLANTED	**586,986**			

[1] The stock type is unknown in these 1983 plantings but has been assumed to be 1+0 plugs as these are the most common. 505,630 Red Alder plants have been planted over the years.

RESULTS AND DISCUSSION

Plot data details from the reclamation assessments are provided in Table 2. The number of woody species (alder and pine) as well as the cover of woody species (since 1996) is presented. Figure 1 presents a graph of the total vegetation cover found along four of the transects. Figure 2 shows the average number of alder trees counted on these transects. Although the overall trend since 2000 when the alfalfa became fully established was for the number of alder trees to decline, 2009 saw an increase in the numbers of alders as the many of the alder at the mine are reaching maturity and producing seed. This has allowed new alder plants to establish in any bare areas. While the ability of alder to displace established grass and alfalfa stands remains in question, the new alder plants that are starting to show up suggest that this may be a possibility. In addition, the percent cover of legumes is provided in Table 2. Although legumes have been shown to be important in providing nitrogen on mine reclamation sites (SEAM 1978); they can also be severe competitors where woody species are being established as has been found in the current study. Increases in legume content over the initial years of vegetation establishment since closure have been associated with a decrease in the number of alder trees that have survived, although in more recent years, as the canopy of alder has closed and the planted trees have matured to the point where they are producing seed, the number of alder trees has increased.

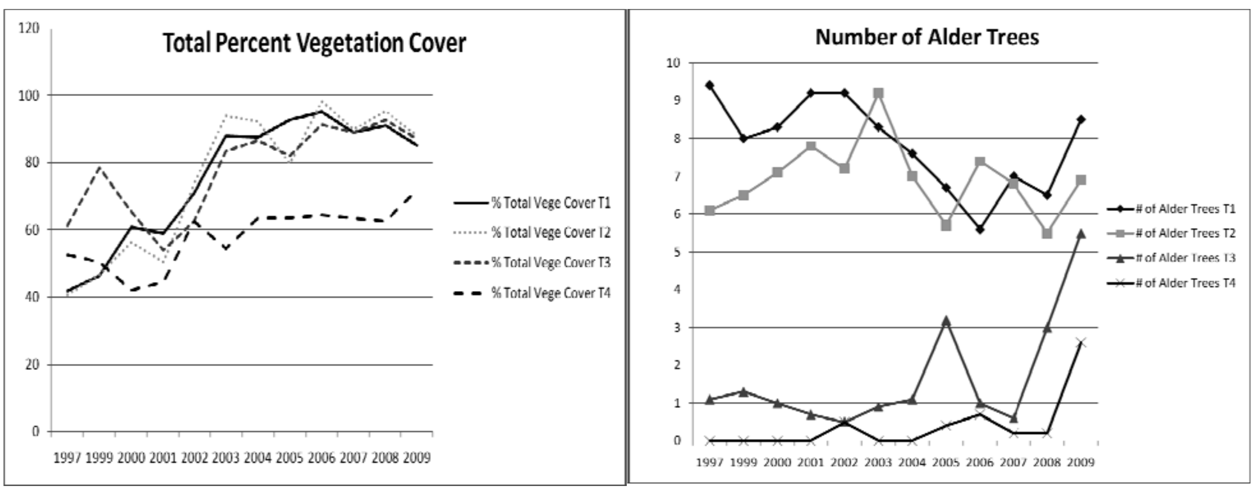

Figure 1 (left) and 2 (right). Changes in the number of alder trees (right) has tended to go down while the average total vegetation cover (left) has gone up (1997 to 2009).

Table 3 provides a summary of the basal area data that was collected during the 2009 assessment. Basal area is a measure of the volume of solid wood on a site and is used to calculate the value of the stand. Basal area comparisons over the years can also be used to demonstrate the productivity of a site. A general increase in basal area over time is predicted up to some limit based on the qualities of the site and the species being measured. However, if competition with the seeded grasses and legumes creates significant patches in the stand being sampled, then the average basal area may not increase uniformly. For this reason, it is of interest to look at the standard deviation, a measure of the uniformity of the sample data in comparison to the mean. In this case, only on Transect 5 was the standard deviation of the basal area a reasonable proportion of the mean (20.1 %), indicating a patchy vegetation cover over most of the areas sampled.

Table 2 Results of 1997 to 2009 Reclamation Assessments

Transect No.	Year	Alder # (%)	Pine # (%)	Legumes (%)	Total Cover of Vegetation (%)
1	1997	9.4	-	29.1	41.7
	1998 [1]	9.8	-	NS	NS
	1999	8.0	-	27.7	46.3
	2000	8.3	-	44.5	61.0
	2001	9.2	-	34.5	59.0
	2002	9.2	-	46.0	71.0
	2003	8.3	-	55.0	88.0
	2004	7.6	-	47.8	87.4
	2005	6.7	-	25.6	92.8
	2006	5.6 (24.5)	-	27.7	95.1
	2007	7.0 (38.0)	-	24.1	88.9
	2008	6.5 (30.0)		24.1	91.2
	2009	8.5 (41.5)		21.5	85.0
2	1997	6.1	-	27.8	40.5
	1999	6.5	-	32.1	46.7
	2000	7.1	-	35.5	56.5
	2001	7.8	-	30.0	50.5
	2002	7.2	-	40.5	73.5
	2003	9.2	-	57.0	94.0
	2004	7.0	-	42.8	92.2
	2005	5.7	-	18.8	79.5
	2006	7.4 (30.0)	-	15.7	98.2
	2007	6.8 (34.1)	-	15.6	90.0
	2008	5.5 (42.0		20.0	95.5
	2009	6.9 (43.0)		18.5	88.0
3	1997	1.1	11.1	27.5	61.5
	1999	1.3	6.5	34.0	78.5
	2000	1.0	9.4	31.0	65.5
	2001	0.7	11.5	12.5	54.0
	2002	0.5	9.9	12.9	62.5
	2003	0.9	11.4	25.5	83.5
	2004	1.1	10.3	30.6	86.5
	2005	3.2	12.1	7.6	82.0
	2006	1.0 (2.6)	9.3 (28.0)	16.7	91.4
	2007	0.6 (7.5)	7.9 (33.5)	11.7	88.9
	2008	3.0 (10.0)	10.2 (30.5)	10.2	92.8
	2009	5.5 (10.5)	9.1 (32.5)	15.6	87.0
4	1997	-	9.0	23.5	52.5
	1999	-	7.8	10.1	50.5
	2000	-	7.9	13.5	42.0
	2001	-	7.5	6.4	44.5
	2002	0.5	9.9	12.9	62.5
	2003	-	7.4	5.4	54.5
	2004	-	8.0	5.2	63.5
	2005	0.4	7.5	6.1	63.5
	2006	0.7 (0.18)	11.8 (21.5)	5.3	64.5
	2007	0.2 (0.02	10.8 (25.6)	7.0	63.5
	2008	0.2 (0.4)	11.4 (24.0)	7.0	62.5
	2009	2.6 (3.2)	16.0 (26.5)	6.0	72.0
5	2004	12.1	-	24.0	91.5
	2005	13.8	-	1.0	94.4
	2006	10.8 (54.5)	-	9.6	97.8
	2007	11.3 (64.0)	-	1.8	96.6
	2008	10.8 (69.1)		1.3	96.7
	2009	11.2 (76.5)		1.6	97.0

[1] The 1998 assessment was conducted on the Beach Dump only and seeded vegetation was not sampled (marked as NS).

Table 3
Basal Area of Woody Species in 2009

Transect Number	Basal Area (m^2/ha)			
	Lodgepole Pine		Red Alder	
	Average	SD	Average	SD
T1			14.48	12.89
T2			17.74	17.81
T3	16.59	9.64	2.30	3.64
T4	19.37	16.97	0.23	0.45
T5			25.70	5.17

The number of alder trees found on the top of the North Dump (Transects 3 and 4, Figure 2) has increased over the past several years as alder establish within the pine stand with the decrease in cover of the seeded vegetation. The cover of legumes has decreased on Transect 3 from 27.5% in 1997 to 15.6% in 2009 while on Transect 4 the legume cover has decreased from 23.5% to 6.0% over the same period. This has decreased the vigour of the seeded grasses and allowed space for alder seedlings to establish. The increase in alder in these pine stands may reflect a shift towards a successional trajectory that is more congruent with the trajectories operating in the surrounding areas. Alder is the dominant pioneering species found on disturbed mineral soils on northern Vancouver Island. As the cover of alder and pine increases, understory species composition is expected to change. On the Beach Dump (Transects 1, 2 and 5) alder was planted into the seeded grasses and legumes and a dynamic was established where the growth of alfalfa suppresses the growth of the alder while the growth of the alder suppresses the growth of alfalfa. Following this dynamic allows projections of the progress of the successional trajectory to be made.

Measuring the changes in vegetation over the years since the initial treatments can help to define the successional trajectory the vegetation is on. Species such as sword ferns and salmonberry can be used to document the gradual shift in understory vegetation from the seeded agronomic grasses and legumes to native species. Sword ferns were first found in one of the 50 monitoring plots (T1P5) in 2007. By 2008 four plots (T1P5, T5P2, T5P6 and T5P10) had swordferns while in 2009, sword ferns occurred in 12 plots (T1P5, T1P6, T2P3, T2P4, T2P10, T5P1, T5P2, T5P3, T5P4, T5P5, T5P7 and T5P9). Salmonberry was first found in 2009 in plot T5P10. Both salmonberry and sword ferns are only found on sites where the canopy of alder has reached a level of closure to allow the spores of the ferns to be trapped on the branches of the alder and washed down to the ground with the winter rains. Similarly, salmonberry establishment requires that the alder reach a size where birds moving from established salmonberry patches into the alder forest pause to sit on a branch for a while. This can be seen in the older alder stands (approximately 25 years old) on the slopes of the North Dump where salmonberry and sword ferns have closed the understory and where conifers are moving in. The shift from the seeded grasses and legumes to sword ferns and salmonberry appears to occur in the years between age 11 and 25 of the alder stands. Swordferns and salmonberry might be appropriate indicators of successional change. The number of plots in which these species are found out of the 50 sample plots is graphed in Figure 3. A rapid rise in the number of swordfern occurrences is evident over the three years since this plant was first found in the sample plots. It will be interesting to see if the salmonberry follows this same pattern.

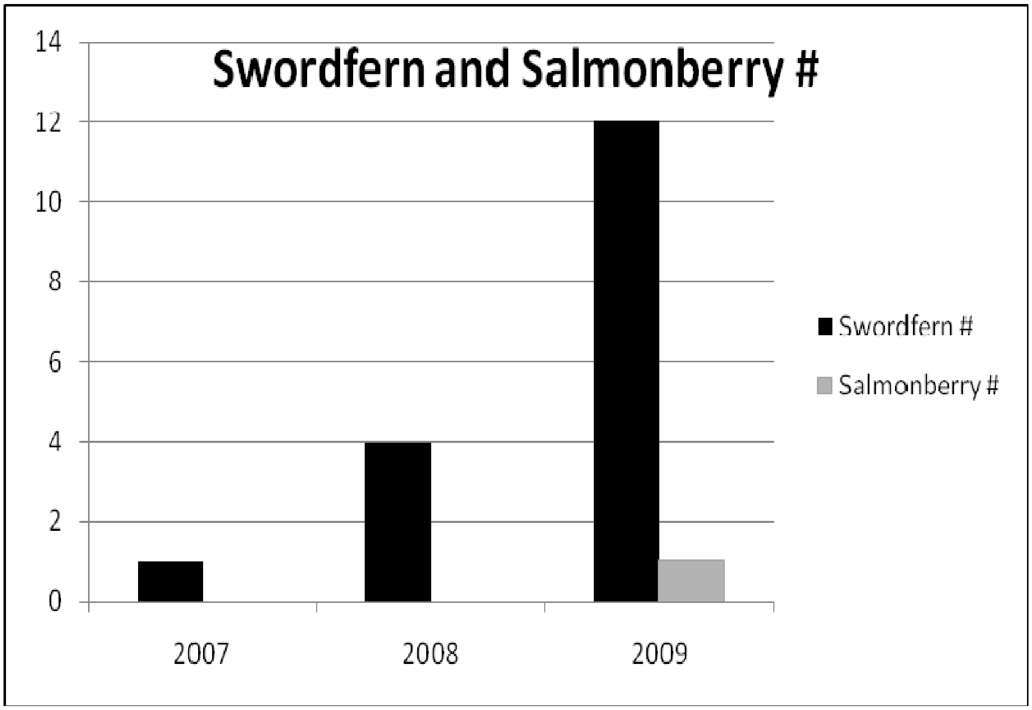

Figure 3. Numbers of swordfern and salmonberry plants found in transect plots.

A diversity of reclamation treatments have been applied at the Island Copper Mine over the years since reclamation started in the late 1970's. This has resulted in a diversity of reclamation responses. The general pattern for reclamation at the mine has been to seed in a cover of grasses and legumes and then plant woody species. Following the recovery dynamics at the different areas of the mine can provide an understanding of how future reclamation programs at this mine or at other mines might be improved. Specific treatments such as the creation of shallow beach areas and bays on the Beach Dump have created very natural looking intertidal areas. The coarse angular rocks from which the beach areas were constructed are starting to smooth with the edges becoming rounded. The grass and legume seeding on the South Dump has created a dense thatch of seeded species. Although no specific woody species planting program has been conducted on the South Dump, some woody species are slowly moving in from the margins. Wildlife makes extensive use of the South Dump and both deer and bears can often be seen grazing on the seeded grasses and legumes. The old plantsite area was revegetated in 2000 with the planting of 3,400 one year old red alder plugs. These have managed to establish well and to suppress the seeded grasses and legumes.

There is a potential for high metal concentrations in vegetation growing on the mine waste dump areas, although the dumps may contain two or more times the concentration of metals than are taken up by the plants (Sobolewski, A. 1996). A program to test the metals in plants growing on the waste materials at the Island Copper Mine was established in 2006. None of the metals levels found in the plants growing on the mine site exceeded those reported in the literature for natural conditions (Kabata-Pendias and Pendias. 2001).

Invasive species can adversely impact reclamation treatments. There are a variety of non-native species that have established on the reclaimed lands. Eastern Eyebright (*Euphrasia nemorosa* (Pers.) Wallr.) has been found on the reclaimed lands for many years. This small species does not appear to create a problem for the reclamation. Bull Thistle (*Cirsium vulgare* (Savi) Tenore) has also established on the reclaimed areas. These species will disappear once a successionally advanced forest cover is established (Polster 2009). However, they may persist for many years in the successionally delayed alfalfa dominated stands of grasses and legumes. These stands may be considered to be successionally stagnant (Kimmins 1987).

CONCLUSIONS

Reclamation work at the Island Copper Mine has been a continuous process since the start of mining in 1971. Some of the earliest reclamation sites now show a maturing forest cover and illustrate the potential for establishing self-sustaining, productive vegetation covers on sites disturbed by mining. With the closure of the mine in 1995, many of the sites that could not be reclaimed prior to closure such as the plantsite and the Beach Dump were treated. Reclamation at the mine generally entailed seeding with a agronomic grass and legume cover and planting with native trees. In 1995 a shift was made and although the reclamation work continued to consist of seeding and tree planting, the grass and legume seed mix was balanced so that the dominance of sod forming species and the limited legume content was changed. Tree planting in later years used mainly red alder with lodgepole pine established on the top of the North Dump. The reclamation design was modelled on the natural successional patterns that operate in the region with red alder providing the main cover on fresh mineral soils.

Detailed assessments of the progress of the reclamation at the Island Copper Mine have been undertaken on an annual basis since 1997. Repeat sampling on transects established in representative reclaimed areas have provided a wealth of data that is used to document the reclamation progress and to identify recovery patterns and processes. Analysis of the data from this sampling has indicated that seeding with grasses and legumes was a well-intentioned mistake as the seeded cover competes successfully with planted woody species. The grass and legume cover has, however, provided excellent habitat for a wide variety of wildlife species and the diversity of open and closed areas currently found on the mine site is ideal for most species. Testing the metal content was conducted to ensure that wildlife using minesite vegetation would not be exposed to high metals levels. None of the metals present in either the grasses or the legumes were found to exceed natural background levels (Kabata-Pendias and Pendias. 2001). Although conditions may change as the soils weather and organic surface horizons are added, metals levels in the vegetation are not expected to become a problem in the future.

Red alder acts in a facilitative way (Temperton et al 2004) to expedite the recovery of the forest ecosystems common to this part of Vancouver Island while the seeded grasses and legumes serve as a filter (Clewell and Aronson 2007) preventing recovery of the natural forests. Alder will add nitrogen and organic matter to the mineral soils while the shade and increased relative humidity under the canopy will improve the growth of conifers that establish under the alder. By serving as a facilitator, alder provides conditions that benefit other species. The vegetation patterns that have been established on the Island Copper Mine sites represent a novel ecosystem complex (Hobbs and Suding 2009) that may merge with the locally operating successional trajectories at some point in the future as the soils and vegetation patterns mature in the centuries ahead. At present these ecosystems are providing effective habitat for local wildlife and re-integrating the mined lands with the surrounding landscape. Monitoring the changes in vegetation confirms the self-sustaining nature of the vegetation while the abundance of wildlife at the mine illustrates the productive nature of this vegetation.

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