AQAUTIC PLANT ESTABLISHMENT ON NICKEL TAILINGS FIVE YEARS AFTER FLOODING [1]

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Abstract. Nickel tailings were deposited between 1978 and 1988 in Falconbridge's New Tailings Area located northeast of Sudbury, Ontario, Canada. In 1996, construction of a new dam and dredging split the site into an Upper Terrace (56 ha) and a Lower Terrace (30 ha) to facilitate flooding. Water covers minimize the oxidation of acid generating tailings but some oxidation and release of metals may still occur. The effectiveness of a water cover could be improved with aquatic plant establishment to control tailings resuspension, remove metals from the water column and develop an organic layer to consume oxygen and support sulphate-reducing bacteria.

In the New Tailings area the natural development and changes in the aquatic plant community over the five years since flooding was monitored. In 1999 and 2001 aquatic plant distribution was assessed at 121 plots along 5 transects across the Lower Terrace. Every 10 m along each transect a 0.25 m^2 quadrat was established from which aboveground biomass was harvested and samples were analyzed for nutrients.

In the Lower Terrace, *Potamogeton pusillus* and *Chara* were the dominant aquatic species. In 1999, 88 plots contained aquatic plants, which increased to 113 by 2001. Over the same period, mean biomass increased from 40.2 to 103.0 g DW/m^2. Biomass decreased, however, at 22 sites from 166.3 g DW/m^2 in 1999 to 74.6 2 g DW/m^2 in 2001. *Potamogeton pusillus* tissue nitrogen and phosphorus concentrations decreased from 2.18 % and 0.20 % to 1.43 % and 0.12 % with 1.3 % and 0.13% being the critical concentrations that indicate potential deficiencies. The nitrogen phosphorus ratio is typically 7 but in the Lower Terrace is 12.9 indicating that phosphorus is more limiting than nitrogen.

Additional Key Words: plant colonization, acid mine drainage, wetlands, reclamation

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Introduction

In mining, when waste rock and tailings containing sulphide minerals (principally pyrite and pyrrhotite) are exposed to air and water a series of chemical and biological oxidation reactions occur. Acidic drainage occurs when the sulphide mineral oxidation products are flushed from the tailings or waste rock by water. Typically acid drainage has a low pH and high concentrations of sulphate, dissolved iron and other metals. If not controlled or treated, acidic drainage can have a significant environmental impact on surface and ground water quality.

Although the essential components of acidic rock drainage generation include oxygen, ferric iron, water and aerobic sulphur bacteria (e.g. *Thiobacillus sp*.), oxygen remains the most critical factor (Davé, 1992). The long-term solution to controlling acid rock drainage is to prevent its formation by excluding oxygen from coming into contact with the sulphide materials. Exclusion of oxygen can be achieved through the use of dry covers that act as an oxygen transport barrier by retaining moisture and providing a low diffusion barrier to atmospheric oxygen. Alternatively, the dry covers can act as an oxygen-consuming barrier that performs as a sink thus reducing the oxygen concentration (SENES, 1994). In Canada, where feasible, water covers are considered the most effective option for acid rock drainage prevention and long-term storage of acid generating wastes (Yanful and Simms, 1997).

The placement of tailings in submerged environments has been utilized at various mines in Canada. Historically sulphidic tailings have been deposited into lakes (Robertson *et al*., 1997) or the marine environment (Horne, 1993). At new sites, tailings management practices involve the design and construction of tailings impoundments with engineered shallow water cover for subaqueous tailings deposition (Filion *et al*., 1994; Cole *et al*., 1997). Existing tailings impoundments are decommissioned using insitu flooding with constructed containment structures (Yanful and Simms, 1997).

Even with a water cover, however, there is concern that some oxidation and acid generation could still occur resulting in a deterioration of the water cover quality (Aubé *et al*., 1995). Dissolved oxygen could be transported through the water column to the tailings by diffusion, convection or circulating currents (Li *et al*., 1997). Tailings resuspension by wave action exposes sulphide particles to dissolved oxygen in the water column (Yanful and Simms, 1997).

The establishment of aquatic vegetation on the flooded tailings would improve the effectiveness of the water cover. Along the shoreline, emergent aquatic plants would reduce wave action and shoreline erosion while vegetation root systems would increase the resistance of sediment to erosion. Beds of submerged plants in deeper areas would control tailings resuspension and precipitate suspended solids from the water column. Aquatic plants provide biological treatment by removing metals and nutrients from the water column. With time, an organic layer would develop on tailings as the aquatic plants died and decayed. The decomposition of the organic matter by aerobic bacteria would slow the diffusion of oxygen into the tailings and subsequently decrease acid generation. Metals released from the tailings and in the water column could be removed and retained in the sediment by organic complexation or be precipitated as sulphide complexes through the activities of sulphate-reducing bacteria. In the case of drought, the organic layer would act as a sponge preventing oxygen diffusion onto the tailings surface as water levels dropped within a tailings impoundment.

This paper examines the invasion of submerged macrophytes into flooded nickel tailings at Falconbridge's New Tailings Area. The study objectives were to assess the establishment, growth and spread of submerged aquatic plants in the New Tailings Area and identify site conditions, water quality or sediment characteristics affecting aquatic growth.

Site Background

The Smelter Complex of Falconbridge Limited is located approximately 15 km northeast of Sudbury, Ontario, Canada. Mining and milling at the Falconbridge site began in the late 1920's and early 1930's and ceased in 1990. The ore milled contained nickel and copper as pentandite and chalcopyrite with pyrrhotite as the main sulphide mineral with varying amounts of magnetite and pyrite.

The New Tailings Area, located about 2 km northeast of the Falconbridge Smelter, was utilized for tailings deposition between 1978 and 1988. Until 1985, about 3.2 million tonnes of tailings with an average sulphur content of 7% were deposited. Starting in 1985, low sulphur tailings (1% sulphur) were produced by removing the pyrrhotite and in 1986, coarse material was cycloned off for underground back fill. Dam 12 was constructed across the impoundment to form the Upper Terrace, where the low sulphide slimes were deposited. Approximately 1.1 million tonnes of low sulphide tailings were deposited between 1985 and 1988 (Golder Associates, 1997).

Closure work on the New Tailings Area commenced with the construction of Dam 1 and Dam 12 downstream of the original dams, which split the site into the 53 ha Upper Terrace and 30 ha Lower Terrace. The Lower Terrace is 1100 m long and varies in width from 200 m to 350 m. Tailings were originally contained in the northern half of the Lower Terrace but approximately 300,000 cubic meters of material was relocated by dredging into the southern half and flooding was completed in 1996. Water flows into the Lower Terrace from Fault Lake Spring at the north end and from the spring fed Upper Terrace between the original tailings and dredged tailings. Maximum water depth on the original tailings and dredged tailings is approximately 1 m. Water depth ranges from 1 to 2 meters in the 100 m area between the dam and dredged tailings and from 2 m and 4.5 m in the 250 m area between the dredged tailings and original tailings.

In 1998, transplant trials were conducted in the New Tailings Impoundment to assess the establishment of *Elodea canadensis, Potamogeton richardsonii, Potamogeton pusillus*, *Myriophyllum sibiricum* and *Potamogeton gramineus*. In total, 540 mini-sandwiches (0.5 x 0.5 m) and large sandwiches (1.0 x 1.0 m) were constructed by placing a 5 cm layer of plant biomass between two layers of 2.5 cm mesh chicken wire. Sandwiches were placed at two sites in the Upper Terrace and four sites in the Lower Terrace. *Potamogeton richardsonii* was successfully established, but growth of the other species was limited due to the transplant method or site conditions (Wilkinson *et al.*, 2001). While evaluating the transplant sandwiches it was observed that submerged aquatic plants had naturally colonized the Lower Terrace and a program to monitor the spread of these species was initiated.

Methods

In 1999, a baseline transect was established running northwest from the decant tower along the edge of the Lower Terrance and marked at 100 m intervals. Transects perpendicular to the baseline were established across the dredged tailings at 200 m and 300 m and across the original tailings at 600 m, 800 m and 1000 m. Every 10 m along the transects, a 0.25 m^2 plot was established. In each plot, water depth was measured, percentage cover estimated, above ground biomass harvested, sorted, bagged and stored in a cooler until transported to the laboratory. This work was conducted in shallow areas by snorkeling and in deeper areas (>1.0 m) by SCUBA. The vegetation survey was repeated in the 2001.

In the laboratory, plant samples were washed with distilled water, dead plant material and debris were removed and plants were air-dried. Samples were oven dried at 70^0C to a consistent weight. Nitrogen in the shoots was determined by the Kjeldahl method. For the other elements, samples were ashed, digested and analyzed using inductive couple plasma atomic emission spectrophotometry (ICP-AES). U.S. National Institute of Standards and Technology certified reference material (peach leaves SMR 1547) was digested with the analytical run.

Statistical analyses were performed using statistical analysis software SPSS. Data sets were $\log_{10}$ transformed when required to meet assumptions of normality and homogeneity of variance. Differences in biomass and shoot nutrients were tested by one-way analysis of variance. Tukey's multiple range test was used to differentiate means where appropriate. A probability level of <0.05 was used in all comparisons. The relationship between biomass and shoot nutrients was investigated using Pearson correlation coefficients.

Results

Biomass Production

In the transect survey, 121 plots were assessed along five transects. In 1999, aquatic plants were present in 84 plots. Mean biomass production per plot was 40.6 g DW/m^2 with most biomass being produced along Transects 200, 300 and 1000. In 2001, aquatic plants were present in 116 plots and mean biomass production increased to 103 g DW/m^2. Biomass production increased on all transects with the largest increase occurring along Transects 600 and 800 where biomass production went from 3.8 and 4.5 g DW/m^2 in 1999 to 78.0 and 168.5 g DW/m^2 in 2001 respectively (Table 1).

Table 1. Mean biomass along Lower Terrace transects in 1999 and 2001.

Transect	Plots/Transect	1999		2001	
		Plots with vegetation	Total Biomass g DW/m^2	Plots with Vegetation	Total Biomass g DW/m^2
T200	28	22	87.4	27	93.9
T300	24	14	44.9	23	63.9
T600	19	12	3.8	19	74.5
T800	32	22	4.5	32	168.5
T1000	18	14	65.3	17	82.6

In 1999, *Potamogeton pusillus* was present in 59 plots with a mean biomass of 59.6 g DW/m^2. Extensive weedbeds had formed along Transects 200 and 300 where the maximum biomass was 308 g DW/m^2. *Potamogeton pusillus* establishment had begun on the original tailings (Transects 600, 800 and 1000) but only below Dam 12 were extensive weeedbeds observed. In 2001, *Potamogeton pusillus* was present in 106 sites with a mean biomass of 54.4 g DW/m^2. *Potamogeton pusillus* biomass increased along all transects except Transect 200 where biomass production fell from 80.8 to 50.3 g DW/m^2 (Table 2). Biomass production was highest along Transect 800 with maximum biomass production of 296 g DW/m^2, similar to the levels observed along Transect 200 in 1999.

In 1999, *Chara* was present in 46 plots with mean biomass of 25.5 g DW/m^2. The majority of plots were located on the original tailings. The maximum biomass production was 231 g DW/m^2 along Transect 1000 where water from Fault Lake Spring, which contains extensive beds of *Chara* discharged into the Lower Terrace. In 2001, *Chara* was present in 86 plots and mean biomass was 73.8 g DW/m^2. Biomass production increased along all transects with the greatest increase occurring along Transect 800 where biomass production peaked at 463 g DW/m^2

In the Lower Terrace *Potamogeton pusillus* and *Chara* are the dominant species but other species were present. In 1999, *Vallisneria americana* was present in 68 plots primarily on the original tailings; however, mean biomass production was only 0.24 g DW/m^2. *Potamogeton friesii* was present in six plots with four plots located along Transect 1000 below Dam 12, where two plots also contained *Eleocharis aciculari.* Mean biomass production for *Potamogeton friesii* and *Eleocharis aciculari* was 27.6 and 35.1 g DW/m^2. *Potamogeton friesii* was present in two plots along Transect 300 in 2001 with mean biomass production of 16.1 g DW/m^2.

Table 2. Mean biomass and number of plots with *Potamogeton pusillus* and *Chara* along Lower Terrace transects in 1999 and 2001.

Transect	*Potamogeton pusillus*				*Chara*			
	1999		2001		1999		2001	
	Plots with vegetation	Biomass g DW/m^2	Plots with vegetation	Biomass g DW/m^2	Plots with vegetation	Biomass g DW/m^2	Plots with vegetation	Biomass g DW/m^2
T200	21	80.9	26	54.7	6	6.5	17	39.3
T300	14	43.7	20	50.3	4	1.2	13	12.2
T600	6	2.1	15	10.8	9	1.7	19	63.7
T800	12	2.7	29	80.8	17	1.7	27	87.7
T1000	6	2.2	16	22.2	10	50.0	10	60.4

Water depth was less than a meter except at nine plots along Transects 200 and 300 where depths reach 2.25 m (Table 3). In water less than one meter deep, biomass production increased at all depths with biomass production peaking at 134.1 g DW/m^2 between 0.51 and 0.75 meters. Biomass production in water <0.25 m deep increased from 2.8 to 37.6 g DW/m^2 due to *Chara* establishment in the shallow plots on the original tailings. The only plots without vegetation in 2001 were located on the dredged tailings in less than 0.5 m of water. Screen analysis indicated that sediment from two of these plots contained 89% and 95% sand. Biomass production decreased from 265.2 to 118.1 g DW/m^2 between 1.01 and 1.25 meters. In 1999, no aquatic plants were observed at depths greater than 2 m but in 2001 plant establishment reached 2.25 meters.

Table 3. Mean biomass collected at different depths in the Lower Terrace in 1999 and 2001.

Depth m	Plots/Depth	1999		2001	
		Plots without Vegetation	Biomass g DW/m^2	Plots without Vegetation	Biomass g DW/m^2
<0.25	11	10	2.8	3	37.6
0.26 - 0.50	28	9	20.8	2	77.4
0.51 - 0.75	48	8	41.6	0	134.7
0.76 - 1.00	25	5	39.2	0	100.0
1.01 - 1.25	5	0	265.2	0	118.1
1.51 - 1.75	1	1	0	0	124.8
2.00 - 2.25	3	3	0	0	53.6

Shoot nutrients

Macronutrients and micronutrients in *Potamogeton pusillus* shoots grown in 1999 and 2001 on the dredged tailings (Transects 200 and 300) and original tailings (Transects 600, 800 and 1000) were compared (Table 4). In 1999, nitrogen, sulphur and potassium concentrations in the shoots were significantly higher on the original tailings than on the dredged tailings but shoot nutrient concentrations decreased in 2001 and the dredged and original tailings were not significantly different. Phosphorus concentrations in plants grown on the original and dredged tailings were not significantly different but concentrations in 2001 where significantly lower than in 1999. Magnesium and sodium levels on the original tailings were significantly lower in 2001 than in 1999, but the 2001 levels were not significantly different from the levels observed on the dredged tailings in 1999 and 2001. Calcium concentrations on the original tailings and dredged tailings in 2001 were not significantly different but were significantly higher than the levels observed in 1999.

For micronutrients, boron concentrations were significantly higher in 2001 than in 1999 but concentrations were not significantly different from levels observed on the dredged tailings in 1999 and 2001. Iron and magnesium concentrations on the original tailings and dredged tailings were not significantly different but were significantly higher in 2001 than in 1999. Copper was significantly higher on the dredged tailings in 2001 than in 1999 and was higher than the levels observed on the original tailings. On the original and dredged tailings zinc was significantly lower in 2001 than in 1999. Nickel concentrations in *Potamogeton pusillus* were significantly higher on the dredged tailings than the original tailings but there was no difference between years at these sites.

Table 4. Mean nutrients in *Potamogeton pusillus* shoots harvested from the same plots on the dredged tailings and original tailings in 1999 and 2001 (significant differences indicated by letter superscripts).

Macro Nutrient	Dredged Tailings		Original Tailings		Micro Nutrient	Dredged Tailings		Original Tailings	
	1999 (n=28)	2001 (n=28)	1999 (n=20)	2001 (n=20)		1999 (n=28)	2001 (n=28)	1999 (n=20)	2001 (n=20)
N (%)	1.85^{b}	1.44^{bc}	2.65^{a}	1.33^{c}	Fe (µg/g)	938^{c}	4864^{a}	2434^{b}	6708^{a}
S (%)	1.28^{b}	1.26^{bc}	1.85^{a}	1.07^{c}	Al (µg/g)	1632	1254	1118	1169
P (%)	0.19^{a}	0.14^{b}	0.21^{a}	0.11^{b}	Mn(µg/g)	267^{b}	697^{a}	272^{b}	842^{a}
K (%)	2.25^{ab}	2.32^{ab}	2.57^{a}	2.04^{b}	B (µg/g)	436^{a}	487^{a}	210^{b}	386^{a}
Mg (%)	0.35^{b}	0.33^{b}	0.42^{a}	0.33^{b}	Cu (µg/g)	32.9^{b}	38.3^{a}	27.6^{b}	34.0^{b}
Ca (%)	1.82^{b}	2.47^{a}	1.32^{c}	2.44^{a}	Zn (µg/g)	56.6^{a}	53.6^{b}	58.3^{a}	45.4^{b}
Na (%)	0.64^{b}	0.70^{b}	0.84^{a}	0.59^{b}	Ni (µg/g)	3282^{a}	3020^{a}	1543^{b}	1460^{b}

Discussion

Plant Establishment

Aquatic plants will rapidly spread in a flooded tailings impoundment if light penetration, nutrient concentrations and substrate characteristics are suitable. Five years after flooding, aquatic plants had formed an extensive cover in the Lower Terrace. This, however, may have been quicker than would normally occur in other tailings impoundments. Fault Lake Spring, which discharges into the Lower Terrace, has an extensive bed of aquatic plants and provided plant material for the colonization of the Lower Terrace. Many flooded tailings impoundments just receive surface runoff from the surrounding watersheds. Transplanting aquatic plants into the flooded tailings impoundments can assist the natural colonization process by introducing larger volumes of plant material than would naturally invade the site. At Noranda's Brenda Mine (Kelowna, British Columbia), 850 sandwiches (1 m^2) containing a submerged plant mixture of 75% *Elodea canadensis*, 15% *Potamogeton crispus*, 3% *Myriophyllum exalbescens* and 2% *Ceratophyllum demersum* were distributed on copper/molybdenum tailings at water depths ranging from 1 to 4 m. After three years, aquatic vegetation produced weedbeds with a cover varying from 60 to 100% (St-Germain *et al.*, 1997).

Aquatic plants can colonize a range of tailings. At Rio Algom's Panel Wetland (Elliot Lake, Ontario), uranium tailings that spilled into a small basin in the late 1950's have developed into a natural wetland (Davé, 1993). In areas with shallow water cover (0.1 to 0.5 m), cattails, grasses, sedges and sphagnum have formed a dense cover with submerged species in deeper water. In Flin Flon, Manitoba, *Carex* sp., *Podostemun ceratophyllum* Michx. and *Eleocharis* sp. have colonized copper tailings deposited into a shallow lake in 1943 and 1944 (Rescan, 1990). Kalin and Smith (1987) documented the natural colonization of *Characeae* in abandoned gold tailings ponds in Timmins, Ontario.

Changes in the aquatic community have been observed in the Lower Terrace in the five years since flooding. On the original tailings, in 1999 *Vallisneria americana*, *Potamogeton friesii*, *Eleocharis aciculari* along with *Potamogeton pusillus* and *Chara* were observed. *Potamogeton richardsonii* had been successfully introduced in 1998 and was observed to be spreading in 1999 (Wilkinson *et al*., 2001). In 2001, however, *Potamogeton pusillus* and *Chara* were the dominant species. *Chara* is a macroalgea that is anchored to the substrate by rhiziods and forms a high-density mat that can reach 50 cm in height. The density of the mat produced by *Chara* inhibits low growing species and even well established patches of *Potamogeton richardsonii* were lost due to the competition. *Potamogeton pusillus* produces long stems with thin linear leaves that extend and float near the surface, which allows the plant to successfully compete with *Chara* for light.

<u>Nutrients</u>

Nutrients essential for submerged aquatic plant growth are absorbed through their leaves in the water column and through their roots in the sediment. Dissolved products of the relatively abundant salts, calcium, magnesium, sodium, potassium and chloride are primarily acquired from the water column. Nitrogen and phosphorus along with micronutrients are primarily acquired from the sediment, as these elements are usually present in low concentrations in the water column (Barko *et al.* 1991). The uptake of nutrients, however, will vary depending on site conditions. Under oligotrophic conditions, plants will extract most of the nutrients from the sediment with subsequent transport to the shoots. Under eutrophic conditions, passive or active transport from the water column can result in luxury uptake of nutrients above the levels required to support growth with metals being bioaccumulated to concentrations many times greater than the levels surrounding the plant (Hutchinson 1975).

Nitrogen and phosphorus are generally deficient in mine tailings (Williamson *et al.*, 1982) and are often limiting in natural systems (Barko *et al*. 1991). Therefore, it was hypothesized that nitrogen and phosphorus deficiencies would restrict aquatic plant growth in the New Tailings Impoundment. In 1999, however, *Potamogeton pusillus* shoot nitrogen and phosphorus concentrations were 2.18 % and 0.20 % well above the 1.3 % and 0.13 % that are considered the critical concentrations in aquatic plants (Hutchinson, 1975). In 2001, nitrogen and phosphorus levels had decreased to 1.43 % and 0.12 %. Sytsma and Anderson (1993) indicated that in aquatic plants the nitrogen to phosphorus ratio is typically 7 but in the Lower Terrace the ratio was 12.9 with the higher ratio indicating that phosphorus is the limiting nutrient.

Potamogeton pusillus biomass production, however, was negatively correlated with shoot nitrogen and phosphorus. When the aquatic plants were initially established, biomass production was low, but nitrogen and phosphorus were readily available and luxury uptake occurred. This was observed on the original tailings in 1999 and in 2001 on plots deeper than 2 m, where nitrogen and phosphorous concentrations were 3.35% and 0.30% in *Potamogeton pusillus*. As biomass production increased, nitrogen and phosphorus concentration decreased in the plant tissue, as was observed on the original tailings. Eventually, as sediment nutrients were depleted, biomass production decreased. On the dredged tailings biomass decreased at 22 sites from 166.3 g DW/m^2 in 1999 to 74.6 22 g DW/m^2 in 2001 and on 15 of these plots nitrogen levels fell below 1.3 %. Barko *et al.* (1988) observed that in repeat growth studies on the same sediment that nitrogen was depleted from the sediment resulting in growth reduction of *Hydrilla*.

Fertilizer amendments could be applied to overcome nutrient deficiencies and increase biomass production. Helicopter or aircraft could apply granular fertilizer over the whole Lower Terrace. This approach was used at Brenda Mine to increase nutrient levels in the tailings pond before aquatic plant transplants were undertaken (St-Germain *et al.*, 1997). Fertilizer amendments, however, cause algae blooms that would affect the established plants and nutrient discharge from the sites is a concern. Another option would be to use fertilizer spikes inserted into the tailings. Duate and Kalff (1988) showed that the use of 200 gram spikes containing slow release 3-1-1 inserted into lake sediment in June and July increased biomass production on average 2.1 times.

Physical Factors

One of the most important limiting resources for submerged macrophytes is light. Aquatic plants require light for growth and thus the maximum depth of plant growth is regulated by light availability. Chambers and Kalff (1985) observed that in lakes with Secchi depths of less than 1 m, insufficient light prevented growth. In 1999, plants were not established at depths below 2 m in the Lower Terrace. Water sampling indicates high-suspended solid levels in the Lower Terrace due to shoreline erosion and mixing of bottom sediments. In 2001, water clarity improved due to the stabilization of the original tailings by the aquatic plants, which allowed aquatic plant establishment at depths below 2 m.

Biomass production in the shallow areas (<0.25 m) of the Lower Terrace was lower than the biomass production at other depths due to several factors. In exposed shallow areas, wave action affects aquatic plant establishment, therefore, aquatic plant establishment tends to be higher in sheltered areas (Foote and Kadlec 1988). In 1999, on the original tailings, aquatic plants initially invaded in the sheltered areas below Dam 12 and the north end of the Lower Terrace. Sediments with a high sand content tend to have low aquatic plant growth due to nutrient deficiencies (Barko *et al*,. 1991). The only plots in 2001 without vegetation were either along the shoreline where erosion by storm events and wave action resulted in sediments with a high sand content or were dredged tailings mounds that contained between 86% and 94 % sand. Aquatic plant distribution and productivity is also influenced by water depth. In water <0.25 m *Chara* was the dominant species with *Potamogeton pusillus* being present in a single plot but *Potamogeton pusillus* biomass production increased once water depths reach 0.5 meters.

Conclusions

Five years after flooding, submerged aquatic plants have formed an extensive cover on the nickel tailings in the Lower Terrace. *Potamogeton pusillus* and *Chara* dominate the site and several species observed in 1999 were not observed in 2001 due to competition. Biomass production increased along each transect but areas on the dredged tailings where *Potamogeton pusillus* was well established in 1999 had lower biomass production in 2001. *Potamogeton pusillus* shoot analysis indicated that nitrogen and phosphorus levels were close to the 1.3 and 0.13% critical concentrations that indicate potential nutrient deficiencies. The nitrogen phosphorus ratio is higher than 7 to 1, which indicated that phosphorus was the more limiting of the two elements. Sediments have not been examined to determine if the potential deficiencies are due a general lack of phosphorus or if the phosphorus is bound in the sediment with other elements and is not available for uptake by the plants. Fertilizer could be applied by air to the whole tailings pond or fertilizer spikes could be inserted directly into the sediment. Both methods have advantages and disadvantages.

Given the right conditions, aquatic plants can be successfully established on flooded tailings. The Lower Terrace may have been revegetated faster than would normally occur naturally because water flowing from Fault Lake Spring provided a source of plant material. The natural colonization process could be accelerated by introducing aquatic plants in tailings impoundments. Also, when decommissioning existing tailings impoundments or designing new tailings facilities consideration should be given to improving the site potential to support wetland plants. Ponds can be designed with a range of water depths that would be suitable for shoreline, floating and submerged plant species. Creating a series of bays would help protect plants from wave action and provide different site conditions along the shoreline. The creation of islands within the tailings impoundment would reduce fetch, improve esthetic appearance and provide wildlife habitat.

Regular surveys of the New Tailings Pond are required to document the continual development and long-term changes in the aquatic macrophyte community. Growth rates, bioaccumulation of metals, and decomposition rates for the various aquatic plant species on flooded tailings need to be studied. In the sediment layer, research is required on the decomposition rate of organic matter by aerobic bacteria and how effectively metals from the tailings or water column are retained in the sediment layer by organic complexation or precipitated as sulphide complexes through the activities of sulphate-reducing bacteria. This research will help increase the understanding of tailings restoration and wetland development on flooded mine tailings.

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