The Effectiveness of Compost and Biosolids for Land Remediation on Tailings from an Iron Mine

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ABSTRACT

Mine tailings inhibit the growth of living organisms and give rise to unstable living conditions for the existing flora and microorganisms. The abandoned iron mine site in Londonderry, Nova Scotia is almost completely barren save the occasional tree or bush. The area has not been used for nearly 90 years and should this land be able to be remediated, it could help revive the town or potentially become an area for agricultural purposes. Because they are proven to be somewhat effective on their own, this study attempted to combine microorganism remediation and phytoremediation together in order to execute a thorough bioremediation process. The purpose of this experiment was to test the theory that compost, biosolids and well-chosen native plants can help produce biodiversity on the abandoned Londonderry site. Various combinations of compost and biosolids were poured into plastic pots that had exactly 500mL of tailings from the Londonderry mine site. Roadside mix seeds were added. The replicates were watered every three days for 25 days and then plant height and weight for each replicate was determined. Compost was extremely effective on its own and biosolids were not. However, when biosolids were mixed into the tailings, they were effective at producing high biomass yields. The experiment showed that a threshold point for compost is present. 73.5mL of compost on top of the tailings and 25mL of both compost and biosolids mixed into the tailings to simulate tilling were hypothesized to be the ideal mixture for producing maximum yields. Further studies on the actual site to determine the validity of this hypothesis are required. A soil analysis determined that iron levels were still extremely high and wild blueberries were suggested as the plant to be used for phytoremediation as it is an iron-loving plant and is native to Nova Scotia. A cost analysis revealed that the organic material will cost a mere $4000 to remediate the Londonderry site but labour and transportation costs will likely drive the cost up to $80,000 or higher. However, it is unfair to the Londonderry residents to leave a mine site that was abandoned 90 years ago unremediated. The Government of Nova Scotia should take some accountability and fund the project especially since $100,000 or less is not an obscene amount of money.

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1. INTRODUCTION

1.1 The Damage of Mineral and Metal Extraction

Iron and other metals have been mined for centuries for the usage of humans. Once the mine is closed, the land is usually left in a degraded state due primarily to the toxic residue of chemicals needed for the extraction or high amounts of heavy metals left behind (Adl, 2008). Mine tailings are waste products created from the grinding and chemical treatment of ores in order to isolate the target metal. Tailings are typically dealt with as a water slurry and transported into dammed artificial ponds (Warman, 1988). Most mine sites such as oil sands, gypsum mines and gold mines possess a clearly defined area for tailings ponds. In Alberta, Canada, the lack of remediation strategies for the tailings ponds of the oil sands has become a very contentious issue. It is important to note that there are substantial differences in the properties of various types of tailings. Scientists define tailings as materials that have one or more adverse characteristic such as poor physical properties like soil structure, nutrient deficiencies, high toxicity, salinity, or high acidity or alkalinity (Peterson & Neilson, 1973; Warman, 1988).

Tailings inhibit the growth of living organisms and give rise to unstable living conditions for the existing flora and microorganisms. The soil usually becomes degraded due to a lack of these biological organisms as they accelerate nitrogen fixation and primary productivity of organic material. When they are not present, the soil becomes infertile and loses the structure that was provided by organic material (Adl 2008; Bardgett et al. 2005).Tailings ponds revegetate very slowly unless plant species are introduced to quicken the process. In order for remediation to be permanently effective, native species must be returned to the land and soil structure must improve so that microorganisms can flourish and complete their necessary activities (Adl, 2008; Warman, 1988).

1.2 Londonderry Abandoned Mine Site

The iron mine in Londonderry, Nova Scotia was one of the largest in Canada at the turn of the 20th century. The site was chosen because it possessed what was thought to be an abundant amount of iron ore and a tremendous amount of coal. This meant that the iron ore could be mined and then treated with high temperatures of coal to isolate the iron on the same site – effectively reducing any travel costs. A railway came through the site and iron was brought to Halifax and other major cities in Canada. Londonderry was crucial at providing iron for shipbuilding and other items during World War I. In 1924, the mine was closed due to a lack of iron potential. The town boasted over 5000 people and now, in 2013, it is home to approximately 400 people. The abandoned mine site still has scars throughout the area. Large pieces of iron and crumbled bricks from the coal stoves litter the area. The river is crystal clear surrounding the site and shows no signs of productivity. The tailings site, which is dominated by clinker but contains some coal and iron ore, is almost completely barren save the occasional tree or bush. Clinker is lightweight, iron-removed rock that is created when the iron ore is heated and the iron is removed. It is light grey in colour. The surrounding ground cover stops abruptly near this tailings site even after 89 years. The area has not been used for nearly 90 years and should this land be able to be remediated, it could help revive the town or potentially become an area for agricultural purposes.

1.3 Remediation Methods

There are three primary methods used for land remediation today: chemical remediation, physics remediation and bioremediation (Li et al., 2013). Ameliorant method is the leading form of chemical remediation and it involves adding an organic or inorganic material usually by drilling into the land. The material is chosen after an analysis of the soil or sludge is performed. For instance, cyclonic ash has been used to remediate lands that contain high levels of zinc and cobalt (Curi et al., 2011). The system is relatively new and further studies regarding the impacts, cost effectiveness, and durability of the effects must be conducted (Curi et al, 2011). Electrokinetic physics remediation has generated a large amount of interest though it is one of the newest forms of remediation. It uses an electric current to remove organic or inorganic toxins in the soil. It is an approach that minimally disturbs the surface but can help reduce contaminants deep in the soil (Li et al., 2013). This could be effective when the tailings or chemicals are deep in the ground such as the use of cyanide in deep gold mining but as it is relatively new its impacts have not been documented.

Bioremediation includes plant remediation (phytoremediation) and microorganism remediation (Li et al., 2013). Both phytoremediation and microorganism remediation, which is more commonly called soil remediation, are extremely well documented and explored in the literature review section. Both have little to no risks but their effectiveness varies from project to project. However, both processes are extremely affordable, which suggests that they should be attempted before the more intrusive and less studied remediation practices are undertaken.

1.4 Why use bioremediation?

Because they are proven to be somewhat effective on their own, this study will combine microorganism remediation and phytoremediation together in order to execute a thorough bioremediation process. Bioremediation can be achieved by using compost and biosolids to gain the organic material needed to achieve soil structure and by seeding plants that have an affinity for the contaminants within the tailings. Compost and biosolids mixed are a cost friendly alternative to inorganic material in Nova Scotia (See Section 4.2). Both materials are extremely inexpensive as most waste companies are simply looking to get rid of them so the idea of using them over inorganic material should already be appealing to mining companies. In Nova Scotia, it is illegal to burn compost and biosolids meaning that they must be used in some way. Many farmers in Nova Scotia buy these products very cheaply and use it on their agricultural land (Hargreaves et al., 2009). In 2009, Hargreaves et al. demonstrated that compost accelerated the growth of strawberries in the Halifax area. This exemplifies how soil remediation could positively affect phytoremediation. Biosolids provide much needed nutrients like phosphates to the soil and assist in creating good soil structure (Banga et al., 2009; Debosz et al., 2002). Phytoremediation is favourable because plants are relatively inexpensive and the plant can be chosen for its affinity to contaminant as well as for its nativity to the area (Baker & Brooks, 1989).

Currently, Nova Scotian law on land remediation adheres to the 1996 protocol outlined by the Canadian Council of Ministers of the Environment (CCME) where the main objective is to promote the “equal protection of human health and the environment.” (CCME, 1996). A national classification system is used to determine if land is degraded and must undergo remediation but in most cases neutralizing the potentially toxic material to humans is more important than returning the environment to the condition it was found in. It is normally acceptable to fill in the area with inorganic material to block pathogens and toxic material from escaping into the atmosphere (CCME 1996). Adl concludes, "The success of ecological restoration by seeding and watering alone does not correspond with, or indicate, successful establishment of soil biodiversity." (Adl, 2008). There is no chance that an ecosystem could rebuild with only inorganic material available. Bioremediation using compost and biosolids meets the standards of Nova Scotian law and goes well beyond the environmental targets set by the CCME.

2. PURPOSE STATEMENT AND HYPOTHESIS

The purpose of this experiment will be to test the theory that compost, biosolids and well-chosen native plants can help produce biodiversity on the abandoned Londonderry site. It is expected that a mixture of compost and biosolids will be able to neutralize the toxins, provide organic material that will allow for microorganisms to return to the soil, and allow for growth of the plants. Should this pot experiment yield positive results, it is the researcher's hope that the process will be completed on a large scale to remediate the Londonderry site and others like it around the world.

3. CONSULTATION OF THE LITERATURE

3.1 Phytoremediation

The process of phytoremediation has been around for a long time. It can be described as mining by plants because the plant is chosen for its ability to grow and flourish in areas that have high levels of the contaminant. These plants are called hyperaccumulators (Baker & Brooks, 1989). The hyperaccumulators soak up the contaminant and are harvested. The plants must be monitored closely to ensure that they do not get contaminated themselves and are safe for harvesting. The benefits of this technique are that it is less intrusive and allows nature to fix itself. In ideal circumstances, the plants will be chosen because they are native to the area and for their affinity to the contaminant. This allows for a much quicker return to the landscape before the anthropogenic interference (Baker & Brooks, 1989). The United States Environmental Protection Agency states that "Native plant communities are best in providing the ecological diversity and long-term sustainability of the landscape" (2007).

Gay's River was a lead/zinc mine that ceased operations in 1982. In 1988, Dr. Warman conducted a potting experiment to see what plants were able to grow in the tailings considering the tailings consisted of no organic matter. The tailings were placed in equal portions in the pots and six plant species were tried. Fertilizer was added in some of the pots to stimulate growth. The potting experiment suggested that alfalfa (Medicago sativa L.) and red clover (Trifolium pratense L.) were the most effective plants. Once the potting experiment was completed, Warman was given 24 experimental plots on the tailings site where the same results were achieved. Warman's study offers as a guideline for the methods section of this paper. However, fertilizer will not be included in the study as compost and biosolids will hopefully provide the nutrients needed and to keep costs low so that this remediation technique will be more appealing to companies that must remediate their mines. In his data collection section, Warman achieved useful results with a tissue analysis for micro and macronutrients. This will be included in the experiment as well.

Warman provides a brief introduction to phytoremediation but Cunningham and Bert went into greater detail for as to why it must be relied on heavily for land remediation (1993). Phytoremediation, in short, uses green plants to pull out the contaminants from the soil. The authors explain in detail that plants will consume the nutrients in the soil. Once the contaminants in the soil have been determined through a soil analysis, there are usually many plants available that are known to like growing in those conditions. Once these plants grow, they will naturally pull these contaminants out of the soil. This study highlights the importance for a metal and chemical analysis to be done so that the right plant can be chosen for the remediation. When the right plant is chosen, native species will be able to return at an accelerated rate. The authors conclude: "In certain situations, sites remediated with a plant-based technology are expected to have significant economic, aesthetic, and technical advantages over traditional engineering solutions."

3.2 Microorganism Remediation

Adl's 2008 review serves as nice contrast to Warman's experiment. His review effectively outlines the importance of soil structure in land remediation while Warman focuses more on the plants. Adl explains that the land is usually left in a degraded state due primarily to the toxic residue of chemicals needed for the extraction or high amounts of heavy metals left behind. These materials inhibit the growth of living organisms and give rise to unstable living conditions for the existing flora and microorganisms. The soil becomes degraded due to a lack of these biological organisms as they accelerate nitrogen fixation and primary productivity of organic material. When they are not present, the soil becomes infertile and loses the structure that was provided by organic material.

Adl’s review serves as a good reference point for explaining the difference between microorganism remediation and phytoremediation. He explains that bioremediation is the process of promoting biodiversity in degraded land where a key is the formation of soil aggregates called peds. Healthy soil is clumpy and each little clump is what soil scientists call peds. Good ped formation is important as it makes a habitat for microorganisms. The habitat is made because the peds come in different shapes and sizes so when there are millions packed together, there is space in between them. Microorganisms are integral in bioremediation as they have the ability to incorporate organic and inorganic pollutants in cells, thus reducing the amount of toxicity in the soil. The peds also allow water to percolate through the soil and reach plant roots. Adl advocates for the use of compost as it can act as the glue needed to bring inorganic material together and create good ped formation.

Though Adl and Warman differ slightly on the approach, they both recognize the importance of land remediation. In 2008, they combined with Jen Hargreaves to determine the effect of municipal compost in agriculture. They outline that municipal solid waste compost is increasingly being used in agriculture. It has shown to be effective as a soil conditioner as the organic material in the compost helps promote good soil structure. The review, like Adl’s paper, demonstrates that the compost acts an organic glue that allows the soil to form peds. Warman's influence is also quite apparent as it is noted that the municipal solid waste compost acts as a fertilizer for the plants as it is quite rich in nitrogen.

The authors do a good job at describing the inherent risks and benefits of using municipal solid waste compost. They show that it is a cheap alternative to fertilizer and quickly improves soil structure. It is clear that municipal solid waste compost is not a desirable item and therefore it is sold cheaply to whoever has a purpose for it. This means that farmers, people seeking to remediate land, and even local gardeners can obtain a helpful organic tool for an attractive price. However, they outline the major risks associated with using the solid waste compost. First and foremost, the compost contains a higher concentration on heavy metals that can percolate through the soil and into groundwater. An increased amount of heavy metals can cause difficulty in plants to grow and is sometimes the reason that lands must be remediated in the first place. Secondly, the authors state that some forms of the waste can have high levels of salt. Adl shows that this negatively affects soil structure. It is important to select source separated compost to avoid these risks.

In 2009, Banga et al. conducted a review of Halifax Regional Municipality's (HRM) biosolids and their effectiveness on agricultural land. It is of particular importance to this study because a recent local analysis of biosolids is incredibly convenient. The authors are clear that there is a lot of debate and controversy surrounding biosolids. Particularly in Nova Scotia, the use of biosolids is a contentious issue that divides political provincial parties. The reason the issue is so contentious is because in

Nova Scotia, it is illegal to burn biosolids to get rid of them. This means that they must be distributed somehow and the burden is usually placed on farmers. Most farmers like using biosolids as they are considered to: “enhance soil properties including tillage, friability (crumbliness), texture, fertility and water holding capacity” (Banga et al., 2009).

The authors note that biosolids present a cost-effective alternative to commercial fertilizer use in Nova Scotia. They continue, “When processed, the biosolids product greatly resembles common soil in appearance and is easy to store, transport and apply.” However they do a good job at recognizing the drawbacks of using biosolids. Political parties resistant to using biosolids for agricultural use maintain that concentrations of heavy metals are very high in biosolids. When used in agriculture they can seep into the product and potentially make it unsafe for human ingestion. They advocate for the precautionary principle until more studies are conducted. What we have seen to combat this is that biosolids are limed, meaning that their pH levels are increased substantially to around 12. This ensures that most harmful metals and pollutants are destroyed but the high pH makes it very difficult for some plants to grow. The authors suggest a compromise must be made and national standards must be introduced. Also suggested was source separation or at least more adequate testing at the treatment site. Source separation is not as realistic for biosolids as it is with compost but it is available and relatively inexpensive in Nova Scotia. This project will be using source separated biosolids.

A study by Moreno-Penarada et al. in 2004 is useful because it used sewage sludge that was not limed. The effects of the sewage sludge were tested on a limestone quarry that was being remediated. The authors are adamant that the effectiveness of biosolids is improved when topsoil is added on top of it. The authors' hypothesis that sewage sludge would improve total biomass and cover proved to be statistically significant. However, the proportion of legumes was lower in areas where sewage sludge was applied. The authors determined that species richness was extremely lower in sludge pots. This gives rise to a hypothesis that some species take well to biosolids and others do not. Also this study does not combine biosolids with compost which may be because of a lack of facilities in the area of study.

3.3 Combining phytoremediation and microorganism remediation

Adl demonstrates through an analysis of the literature that compost helps the soil achieve good ped formation**:** "The success of ecological restoration by seeding and watering alone does not correspond with, or indicate, successful establishment of soil biodiversity." Both Warman and Adl come to the same conclusion that there is no chance that an ecosystem could rebuild with only inorganic material available. Adl is emphatic in his belief that land remediation must begin with soil remediation and specifically good soil structure. Warman places more emphasis on phytoremediation and finding the right plant for the specific area.

In 2011, the author along with Adl and Saunders proved that compost and biosolids along with sand could produce good soil structure and grow plants. From this experiment, it was determined that because compost and biosolids are readily available at a low cost in Nova Scotia, this combination should be used to help in land remediation. Therefore, combining soil remediation with phytoremediation using native plants was determined to be a potential way to remediate the Londonderry site because the clinker will replace the sand as the inorganic material.

While Warman puts emphasis on fertilizer to allow the plants to grow and create organic material, Adl suggests that it is more important and effective to put the organic material into the soil before any attempt to achieve plant growth begins. This experiment will use Adl's suggestion and give the tailings a mixture of compost and biosolids to create the organic material because it is more cost efficient and requires less maintenance. Furthermore, fertilizer does not create good ped formation that is necessary to ensure the long-term sustainability of the area. However, the success of Warman's alfalfa and clover seeds is convincing enough to include plants to help the remediation process. By combining both authors' ideas, the experiment will have a better chance of success.

4. MATERIALS AND METHODS

4.1 Treatment Preparation

Source separated compost and source separated biosolids were supplied from Fundy Composting. They were mixed in volumetric portions outlined in Figure 1. The mixtures were then poured into plastic pots that had exactly 500mL of tailings from the Londonderry, Nova Scotia site already inside. The tailings were taken from the Londonderry site on November 16th. Four bags were filled from four different locations on the upper part of the tailings area because the tailings were smaller in size on the upper levels. The tailings were stored in the greenhouse at the Dalhousie University

Truro Agricultural Campus in buckets until January 6th when the experiment was started. Each pot was labelled using letters. There were 11 different mixtures and each mixture had three replicates except for the control (mixture K) that had four replicates. For example, mixture "A" consisted of three pots (labelled A1, A2, and A3) that had 500mL of tailings and 5mL of biosolids on top. Mixture "D" consisted of three pots (labelled D1, D2, and D3) that had 500mL of tailings and 25mL of compost on top. The control, "K", had four replicates and the pots only contained 500mL of the tailings taken from the Londonderry mine site. Mixtures A-C contained only biosolids on top of the tailings and mixtures D-F contained only compost on top. Mixtures G-J all had volumetrically measured amounts of either compost or biosolids that were blended into the 500mL of tailings. This was done by emptying the 500mL of tailings and the defined amount of compost or biosolids into a container with a lid and shaking it until the contents were sufficiently mixed together (approximately 30 seconds). This simulated the effects a tiller would have on the Londonderry site. Compost or biosolids were also placed on top of the mixtures.

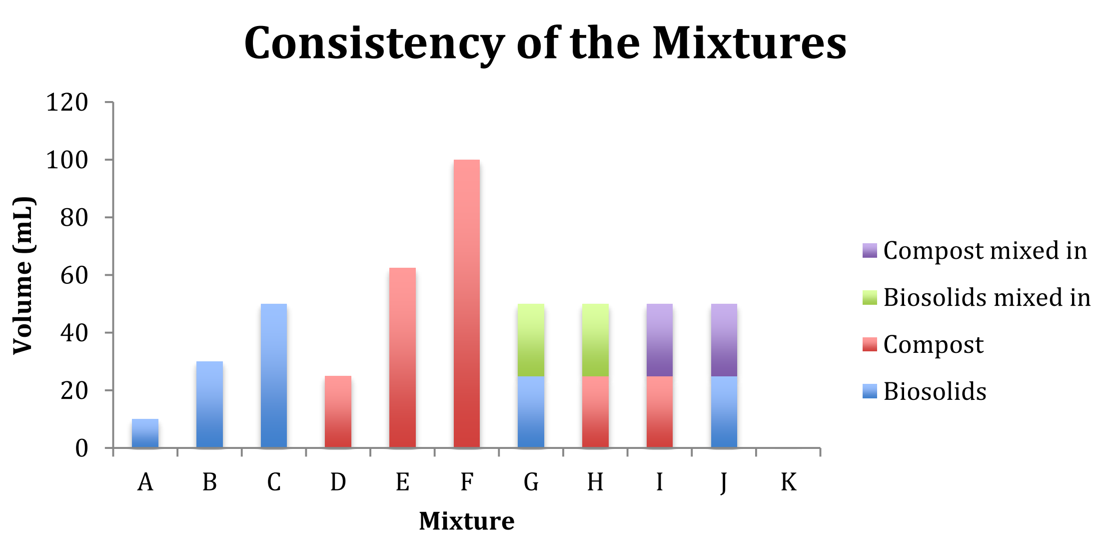

Figure 1: Volumetric portions of compost and biosolids of the mixtures

Next, 0.15g of roadside mix was weighed and added to each replicate. The roadside mix consisted of 25% *Festuca rubra* (creeping red fescue), 25% *Festuca arundinacea* (tall fescue), 15% *Phleum pratense* (timothy grass), 25% *Lolium multiflorum* (annual ryegrass), and 10% *Trifolium hybridum* (alsike clover). The replicates were then watered with 30mL of water and then placed in the greenhouse in the Life Sciences Centre at Dalhousie University in Halifax, Nova Scotia. The greenhouse maintained a constant temperature of 25 ºC that is comparable to the Summer climate for Nova Scotia. The mixtures were subjected to 16 hours of artificial lighting daily from 6AM to 10PM. For the experiment, the day when the seeds were placed in the pots and then put in the greenhouse was considered Day 0.

4.2 Data Collection

January 18th was considered to be Day 0. On Day 2 (January 20th), data was recorded and then it was recorded every three days after that until Day 25. Whenever data collecting occurred, all replicates were watered with 15mL of water except on Day 0 and Day 2 where they were given 30mL of water. The 15mL was used to simulate typical Nova Scotian precipitation levels. On data collecting days, the height of the tallest plant for each replicate was measured using a ruler. The ruler was placed at the level of the soil and the tallest point was noted and presented in Table 1. On Day 25, the final day, the total wet biomass of each individual mixture was weighed. For each replicate, all of the plant biomass was cut as close to the level of the soil as possible. The biomass of each replicate was weighed individually and presented in Table 1. The root strength of each replicate was determined by giving a value of basic, medium, and full. Basic meant the roots could be pulled out easily and full means that the whole pot could be lifted off the ground when holding the plant biomass. Medium root strength was determined to be when the pot could be lifted off the ground briefly or moved when holding the plant biomass. The data was also noted in Table 1. A chemical analysis of the tailings was completed by the Chemistry Department at the Dalhousie Agricultural Campus in Truro, Nova Scotia between January and March 2014. Finally a simple pH test was conducted on January 18th using a basic soil pH calculator.

Table 1: Summary statistics of each replicate and height values on data collection days

Height (cm)	Day 5	Day 8	Day 11	Day 14	Day 17	Day 20	Day 23	Day 25	Above Weight (g)	Root Strength
A1	0.2	1.4	4.8	8.3	8.6	10.9	12.2	12.6	0.23	basic
A2	0.3	2.1	5.4	6.4	7.1	7.7	8	8.1	0.24	basic
A3	0	2	5.2	6.6	7	7.2	7.7	7.8	0.14	basic
B1	0.3	5.8	9.4	10.2	10.9	11.6	12.1	12.4	0.41	basic
B2	0.4	5.6	9.3	10.3	11.6	12.8	13.8	14	0.57	basic
B3	0.4	8.2	13.7	15.1	15.3	15.3	15.4	15.4	0.4	basic
C1	0.6	6.8	11.4	13.4	15.1	15.6	16.2	16.4	0.43	medium
C2	0.5	4.7	7.9	8.2	9.7	10.6	11.4	11.6	0.44	medium
C3	0.5	7.1	11.4	12.4	12.8	12.8	13	13.2	0.36	medium
D1	0.7	6.4	9.9	10.6	10.8	11	11.1	11.4	0.6	basic
D2	0.4	6.6	9.4	9.7	11.7	12.5	13	13.3	0.66	medium
D3	0.5	6.9	9.4	9.7	11.5	12.4	13.4	13.5	0.58	basic
E1	0.7	7	12	14	16.1	16.9	17.7	18.9	1.17	full
E2	0.6	7.2	10.4	12.7	14.1	14.6	15.3	15.7	0.89	full
E3	0.6	6.7	10.3	12.8	14.9	15.8	16.2	17	1.12	full
F1	0.4	6.3	10.6	12.2	13.3	13.8	14.1	14.2	1.03	full
F2	0.6	6.2	10.9	14.1	15.2	15.7	16.2	16.6	0.98	full
F3	0.9	6.4	10.9	12.7	14	14.8	15.4	15.8	0.82	full
G1	0.5	4.1	7.8	11.2	11.6	11.7	11.7	12	1.31	full
G2	0.5	5.2	8.1	11.5	11.8	12	12	12.3	1.12	medium
G3	0.5	5	8.3	13.4	13.6	13.9	14.2	14.5	0.82	medium
H1	0.6	7.1	10.4	13.3	14.6	15	15.3	15.7	1.23	full
H2	0.4	6.4	10	13.1	14.4	15.1	15.3	15.8	1.12	medium
H3	0.4	6.6	9.9	13.1	14.1	14.3	14.7	15.2	0.86	full
I1	0	4.9	8.1	12	15.1	15.9	16.6	16.7	1.52	full
I2	0.2	6.1	10.2	13.9	15.7	17.2	17.9	18.2	1.54	full
I3	0.4	5.8	8	11.6	12.7	13.4	13.8	14.1	0.98	full
J1	0.2	4.7	8.1	11.2	11.2	11.3	11.4	11.8	1.02	full
J2	0.3	4.2	8	11.2	12.6	12.9	13.2	13.6	1.86	full
J3	0.2	4.4	8.2	10	10.6	10.8	10.8	11.4	0.63	medium
K1	0	2.1	3.7	6	7.2	7.6	8	8	0.21	basic
K2	0.2	3.7	5.2	7.4	8.7	9.4	10.1	10.2	0.64	basic
K3	0.2	3.4	5.1	6.3	7.7	8	8.3	9	0.62	basic
K4	0	2	3.8	6.1	7.6	8.3	8.6	8.9	0.33	basic

5. RESULTS

In all replicates, only three of the five plants in the roadside mix germinated. Tall fescue (*Festuca arundinacea)* and timothy grass (*Phleum pratense*) did not germinate. After 25 days, some of the plants were beginning to yellow on the tip. All replicates, except for “I1” and “A3” that germinated by Day 8, had germinated by Day 5. All replicates grew quickly in height at the beginning and then began to slowly level off around Day 25 (Table 1). The height averages and the standard deviation of each mixture show that there is a 2cm variation or less between the replicates except for mixture A (Figure 2). The weight of the biomass averages and standard deviation show that there is a wide variation between replicates (Figure 3).

Mixture B had a higher average height and biomass weight than mixture C even though C contained a higher quantity of biosolids. However, this difference was not statistically significant (Appendix 3). Mixture E had a higher average height and biomass weight than mixture F even though F contained a much higher quantity of compost (Figures 1-3). This difference was also not significant in the analysis of variance test (Appendix 4). Mixture E had the highest average height and the fifth highest average biomass weight. Mixture I had the highest average biomass weight and the second highest average height. Mixture J had the second highest average biomass weight but a very high standard deviation between its replicates (Figure 3). Finally, the control K had a higher biomass weight average than all three of the mixtures with only biosolids on top of the tailings (mixtures A-C).

The difference in the average height and biomass weights between mixtures is statistically significant to a 95% level of confidence (Appendices 1-2). Therefore, it is significant to say that compost on its own on top of the 500mL of tailings produced higher biomass heights and weights than biosolids on their own. Compost on its own produced equal or higher height and biomass averages than the mixtures that had compost or biosolids blended into the tailings. Biosolids were inefficient on their own on top of the tailings but were effective when mixed into the tailings. Finally, the analysis of variance for both height and biomass weight between replicates was inconclusive due to the small sample size for each mixture.

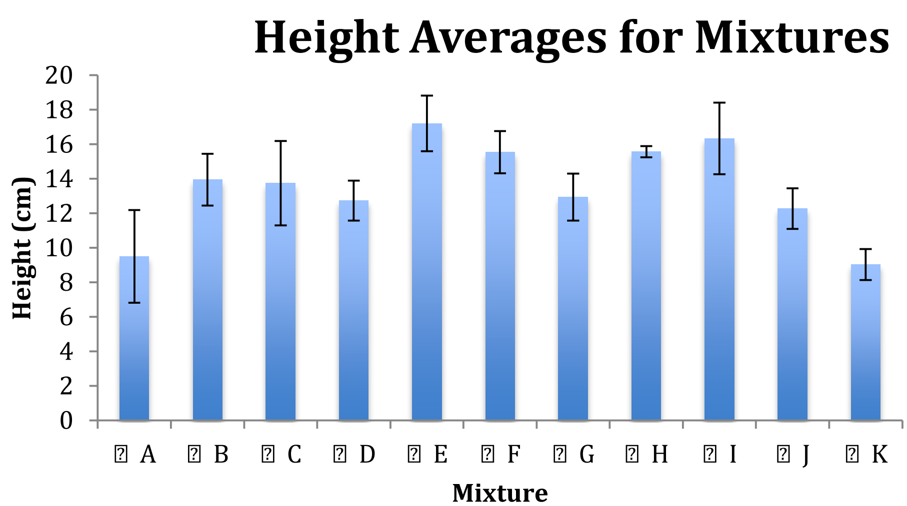

Figure 2: Height averages of each mixture with the standard deviation represented in the error bars

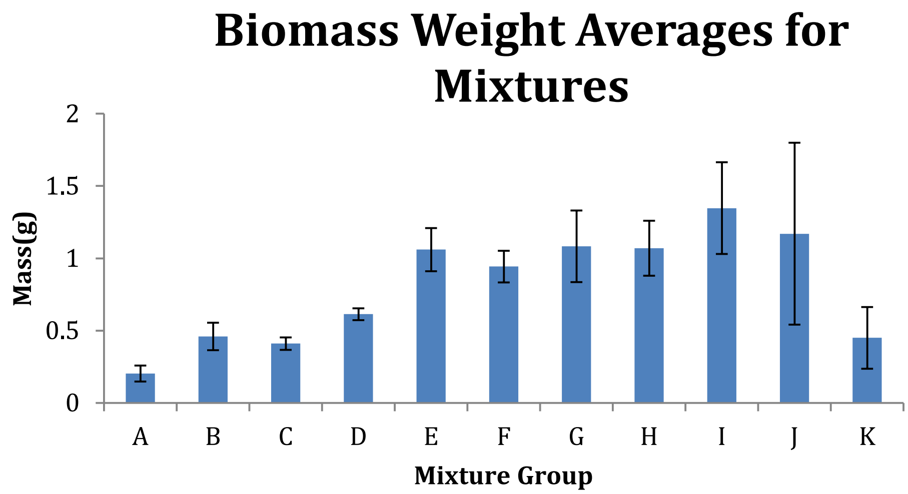

Figure 3: Biomass weight averages of each mixture with the standard deviation represented in the error bars

The chemical analysis of the tailings from the Londonderry abandoned mine site show that there are extremely high amounts for iron and silicon. The trace amounts of aluminum are also somewhat high. However, this agrees with the slightly acidic pH value of 5.6 found using the soil pH calculator. Though the mine site also produced coal, there was no arsenic present.

Table 2: The percentage of elements that make up the tailings at the Londonderry abandoned mine site

Element	Amount (mg/kg)
Fe	27
Si	21
Al	2.6
Ca	2.4
K	2.3
Mn	0.94
S	0.8
P	0.5
Mg	0.09
Cl	0.25
Ti	0.4
V	0.09
Cr	0.04
Zn	0.1
Zr	0.02
Ba	0.2
Pb	0.1

6.DISCUSSION

6.1 Determining the right plant for remediation

Timothy grass and tall fescue are mostly grown in Europe and may not have adapted well to the amount of light that they were subjected to. Both plants prefer to grow in shadier areas and 16 hours of direct light may have prevented them from growing. Further studies could be completed to determine if less light would allow these plants to grow however this exemplifies the need to find native plants in the study. A limitation of the study was that the soil analysis of the Londonderry tailings was done while the experiment was being conducted. Therefore a hyperaccumulator plant was not able to be chosen. The soil analysis was expected considering the pH of the tailings was determined to be around 5.6. As the pH becomes more acidic, more iron and aluminum are typically expected. However, the amount of iron in the soil is extremely high. In 2010, the American company Wallace Labs found that iron amounts in soil over 10mg/kg are considered very high. Because the value in the tailings is almost triple the very high amount, plants with an affinity to iron should be used for the Londonderry site. The combination of the high iron amounts in the soil mixed with the very low amounts of organic matter in the tailings is the likely cause of the lack of growth on the mine site that has been abandoned for 89 years.

Blueberries are the prime example of iron-loving plants. Since they are native to eastern Canada, they would be a good native plant to return to the area. Nova Scotia already produces more blueberries than any other province and is Nova Scotia's official berry. Cumberland County produces over 70% of the blueberries in Nova Scotia (Government of Nova Scotia, 2004). Londonderry sits right on the outskirts of Cumberland County. Blueberries require lots of iron and flourish in areas that have good drainage. Provided that compost could be added to the mostly inorganic tailings to create good ped formation and achieve good drainage, wild blueberries would be ideal for the abandoned mine site. Furthermore, it is important to note that the control on its own with only the addition of water provided enough support to allow the roadside mix to geminate. This suggests that the area may not need a lot of support and fertilizer to grow the wild blueberries. An educated farmer would allow the blueberries to spread themselves and rotate the crops on a two year cycle between a vegetative year and a cropping year (Government of Nova Scotia, 2004). This could provide economic incentive for the remediation process to begin. If possible, further research on the actual abandoned mine site following a plot system as outlined in Warman's Gays River experiment using blueberries or other iron loving plants such as strawberries or rhododendrons would be highly beneficial.

6.2 Statistical Inferences

The analysis of variance study for both height and biomass weight was inconclusive due to the small amount of replicates in each mixture. Because there were only three replicates for each mixture, the test showed to a 95% confidence level that the replicates would be different. If there were more replicates for each mixture, it would have been likely that the analysis of variance test could have produced functional data. However, the analysis of variance was statistically significant to a 95% confidence level for both biomass height and weight when only the averages of the mixtures were considered. This means that the null hypothesis that each mixture was different is accepted. Furthermore, when 2cm of freedom for height and 0.2g of freedom for weight were allowed, the null hypothesis was also accepted. If the study were to be conducted on the actual mine site, it is suggested that more replicates be used so that the degrees of freedom do not need to be altered. However, because the degrees of freedom are not outlandishly large, we will proceed with the rest of the analysis under the assumption that the mixtures are different from each other.

With this being said, a closer look between the biomass weight averages between mixtures B & C was conducted. The null hypothesis that the averages were different was rejected, meaning that they are the same (Appendix 3). Since both contained just biosolids on top of the tailings, the addition of 20mL of biosolids for mixture C did not yield any differences than the 30mL already in mixture B (see Figure 1 for mixture amounts). Therefore there is a point where adding too much biosolids will actually reduce plant growth. However, the effectiveness of biosolids is highly debateable since the control produced more biomass in grams than the biosolid mixtures A-C. The source separated biosolids are not effective when placed on top of the tailings but are somewhat effective when mixed in with the tailings from the Londonderry site.

A closer look between the averages biomass weight for mixture E (62.5mL of compost on top of the tailings) and mixture F (100mL of compost on top) was also conducted. The null hypothesis was also rejected in this case, meaning that statistically speaking they are the same (Appendix 4). Since the compost mixtures (D-F) were amongst the highest produces of biomass height and weight, the threshold that maximizes plant growth was determined and presented in Figure 4. Using a logarithmic function, the point that produces the maximum yields is 73.5mL. Due to budget and time limitations, a second experiment using this amount was not able to be completed.

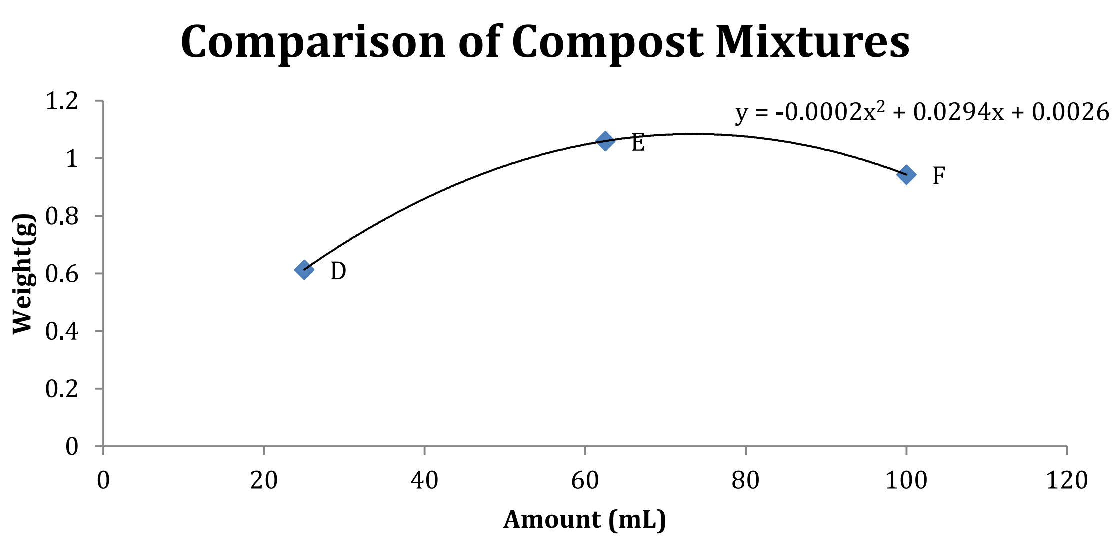

Figure 4: The threshold point to find maximum biomass yields is determined using the average biomass weight of mixtures D-F as data points

6.3 Conclusions

Biosolids were not effective on top of the tailings. One problem with source separated biosolids is that it looks somewhat like mulch (long, thin pieces of wood) and may have actually inhibited some of the plants from growing effectively. Mulch is put on top of soil to block weeds from growing and the biosolids may have acted in the same fashion. Compost, on the other hand, was extremely effective on its own and more studies should be conducted to see if the threshold point of 73.5mL produces maximum yields. The compost effectively acted as the glue between the inorganic material and allowed the roots to grow strong. This is demonstrated in Table 1 where the root strength for all mixtures with compost of top was full. This means good root structure was achieved. It remediated the soil and allowed for high plant yields. Adl states that the first step in remediation is achieving good soil structure and compost provided that (2008). Finally, mixing both compost and biosolids into the tailings produced high levels of plant biomass. Further studies must be undertaken to determine the threshold amount needed to obtain maximum yields. Since this study used the same amount of 25mL when mixing either compost or biosolids into the tailings, finding a threshold amount is not possible. For future studies, mixture I produced high yields so the combination of 73.5mL of compost on top with 25mL of compost mixed into the tailings should be tried. Also, some biosolids could be mixed into the tailings as well to see if a combination would help. Different variations must be tried on the Londonderry site to uncover the best combination to achieve the highest yields.

6.4 Sustainability

The Londonderry mine site has been abandoned for 90 years and no remediation has been attempted on it. This study has presented a hypothesis for the mixture that will obtain the highest yields and has suggested blueberries as the plant for phytoremediation based on the fact that it is native to the area and requires high amounts of iron. Though a cost-benefit analysis is not possible because the economic as well as well as social and environmental are highly theoretical and outside the scope of this study, it is possible to calculate the cost of remediating the Londonderry mine site using the suggested number of 73.5mL of compost with 25mL of compost mixed into the tailings. For the sake of argument we will assume that 25mL of biosolids mixed into the tailings is also effective. The Londonderry mine site is approximately 100 by 150 metres or 15000 square metres. This translates to 161,458 square feet.

Fundy Composting sells their compost by the cubic yard, which equals 650 square feet spread out at 0.5 inches. When 73.5mL was put in the pot on top of the tailings, the average height was approximately 0.5 inches. Therefore 248 cubic yards of compost are needed on top of the tailings. Using these same numbers, 81 cubic yards of both compost and biosolids will be needed to be tilled into the tailings. Therefore 329 cubic yards of compost will be required. Fundy composting sells source separated compost at a wholesale price of $9.00 per cubic yard and biosolids at a price of $4.40 per cubic yard. The total cost of the organic material required is $3321.5. Trucking costs range from $20-100 per cubic yard of organics so most of the costs will come from there and the labour to till the organics into the tailings. If we assume a cost of $50 in trucking per cubic yard of organics, the cost will be $20,500. The labour is hard to estimate as the party funding the project (assumingly the Government of Nova Scotia) will have the option of using heavy machinery or light machinery with manual labour. An estimate would be somewhere around $50,000.

In all, the project could most likely be completed within a $100,000 budget. Furthermore, the community of Londonderry could form a community organization to help raise funds and awareness for the project. Volunteering and offering part of the area as a community garden would strengthen neighbourhood ties and stimulate some economic development into the area. Londonderry now has a population of 200-500 people and could greatly benefit from a chance to make a little bit of profit from the blueberries or even from a garden where they can harvest their own berries. Finally, it is unfair to the Londonderry residents to leave a mine site that was abandoned 90 years ago unremediated. The Government of Nova Scotia should take some accountability and fund the project especially since $100,000 is not an obscene amount of money.

7. ACKNOWLEDGEMENTS

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APPENDIX

Table A.1: The analysis of variance of the average heights of the 11 different mixtures.

Height
Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
A	3	28.5	9.5	7.23
B	3	41.8	13.93333	2.253333
C	3	41.2	13.73333	5.973333
D	3	38.2	12.73333	1.343333
E	3	51.6	17.2	2.59
F	3	46.6	15.53333	1.493333
G	3	38.8	12.93333	1.863333
H	3	46.7	15.56667	0.103333
I	3	49	16.33333	4.303333
J	3	36.8	12.26667	1.373333
K	4	36.1	9.025	0.815833

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	226.0865	10	22.60865	8.739357	9.91E-06	2.274728
Within Groups	59.50083	23	2.586993			
Total	285.5874	33				

Table A.2: The analysis of variance of the average biomass weights of the 11 different mixtures.

Weight
Anova: Single
Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
A	3	0.61	0.203333	0.003033
B	3	1.38	0.46	0.0091
C	3	1.23	0.41	0.0019
D	3	1.84	0.613333	0.001733
E	3	3.18	1.06	0.0223
F	3	2.83	0.943333	0.012033
G	3	3.25	1.083333	0.061033
H	3	3.21	1.07	0.0361
I	3	4.04	1.346667	0.100933
J	3	3.51	1.17	0.3951
K	4	1.8	0.45	0.045667

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4.493855	10	0.449385	7.260713	4.46459E-05	2.274728
Within Groups	1.423533	23	0.061893			
Total	5.917388	33				

Table A.3: The two-way analysis of variance of the average biomass weights of mixtures B and C to determine if they were statistically different

B and C
Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
B	3	1.38	0.46	0.0091
C	3	1.23	0.41	0.0019

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.00375	1	0.00375	0.681818	0.455363018	7.708647
Within Groups	0.022	4	0.0055			
Total	0.02575	5				

Table A.4: The two-way analysis of variance of the average biomass weights of mixtures E and F to determine if they were statistically different

E and F
Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
E	3	3.18	1.06	0.0223
F	3	2.83	0.943333	0.012033

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.020417	1	0.020417	1.18932	0.336758729	7.708647
Within Groups	0.068667	4	0.017167			
Total	0.089083	5				