A Novel Method Using Phycoremediation to Reduce Toxic Metals in Surface Waters

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Project Goal

Constructed wetlands (CWs) and stormwater management ponds (SWMPs) are popular best management practices for reducing flood risk and removing pollution from stormwater runoff. ***The challenge this project addresses is how to effectively manage CWs and SWMPs to provide the known benefits of flood prevention and pollutant removal, while also minimizing the potential for unintended consequences such as methylmercury production and excessive algae growth.***

CWs and SWMPs can increase property values by providing water views (Sander and Polasky, 2009); however, these ponds are often plagued by algal blooms, which are considered an eyesore and malodorous nuisance (Monaghan et al., 2016). Excessive algae growth can also exacerbate the potential for methylmercury production if the pond becomes eutrophic. Algae growth is most commonly combatted by algaecide application.

This project provides a viable alternative control strategy (eliminating the need for algaecides), which is cost effective and simple to implement, with the added benefit of removing pollutants as well as the excess nutrients which cause the blooms.

Figure 1. Filamentous algae growth in stormwater ponds on the campus of Virginia Wesleyan University.

The research and design goals of the project are to

1) Evaluate phycoremediation as a strategy for reducing nutrient and metal pollution from CWs and SWMPs.
2) Design and demonstrate a vermicomposting method for freshwater algae.

To our knowledge, this is the first study to evaluate phycoremediation for nutrients and metals in stormwater ponds and the first study to use freshwater algae as a vermicompost amendment.

Supporting Metal Decontamination Research

It is well documented that mercury is a persistent and toxic pollutant of global concern due to its neurological, immunological and cardiovascular effects. Atmospheric deposition can bring mercury into watersheds via wet and dry deposition (Pirrone et al., 2010). Once in a watershed, Hg can be methylated to methylmercury (MeHg), its more toxic form which bioconcentrates and bioaccumulates in organisms (Selin, 2009). This bioaccumulation is capable of damaging species populations, as well as local fisheries and anyone who consumes seafood.

Cadmium has the ability to replace calcium in bones, which if present in enough quantities, can cause brittle bone structure. Excess cadmium intake can also cause kidney damage and is also thought to be a carcinogen (Morel and Malcolm, 2005). Lead has a similar ability to replace calcium in bones, and it affects the development of the brain in children (Baird and Cann, 2012).

When present in sufficient quantities, copper and zinc also act as toxins in the human body. High intake of copper can create liver complications and problems with reproductive health. While zinc is less toxic, excess quantities still can damage the immune system and negatively affect cholesterol.

Waters that are polluted with mercury or other heavy metals pose a serious threat to wildlife and humans alike.

The remediation of water through algae rather than vascular plants has multiple benefits. Algae is often naturally present in ponds and bodies of wastewater, and is more often that not removed instead of put to use. Algae has a fast growth rate with higher photosynthetic capabilities than vascular plants, and it's renowned for its ability to uptake nutrients and heavy metals from highly-polluted waters. Algae is tolerant to a wide variety of conditions, and there exists multiple potential uses for harvested algal biomass (Renuka et al., 2015).

This project aims to ***develop and demonstrate an innovative, cost-effective solution to improve water quality outcomes from stormwater infrastructure*** by:

1) Reducing aquatic pollutants such as nutrients, heavy metals and mercury; thus, minimizing harmful effects including eutrophication, metal toxicity and mercury exposure by harvesting algae from CWs and SWMPs.
2) Producing high quality compost from vermicomposting waste algae to create a valuable product through the application of sustainable principles, with the potential for economic benefit.

Results

Evaluation of Phycoremediation for Stormwater Ponds

A mesocosm experiment was used to evaluate the uptake of metals and nutrients by filamentous algae collected from stormwater ponds.

Figure 2. Experimental design for mesocosm experiment: Tanks were filled with lakewater; half received filamentous algae, one third were spiked with nutrients, one third with metals, and one third were not spiked.

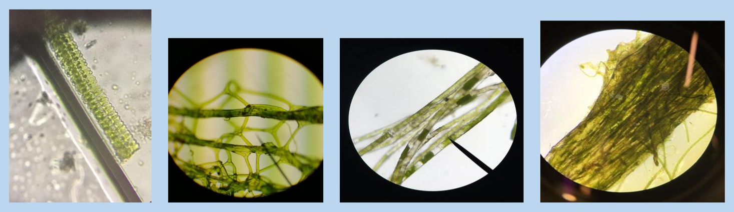


Figure 3. Filamentous and microscopic green algae present, includes: *Mougeotia, Oedogonium, Spirogyra, Desmidium, Hydrodictyon, Micrasterias*

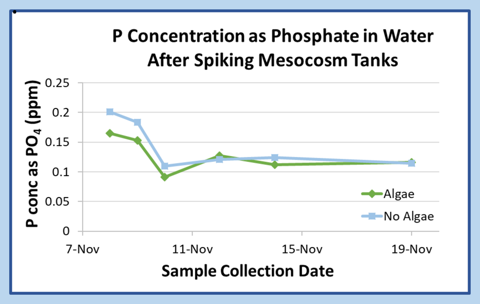
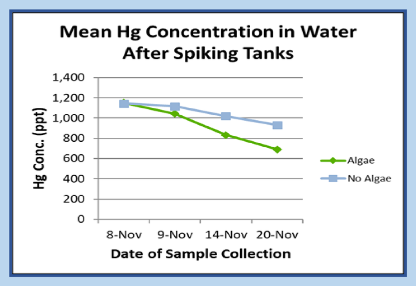
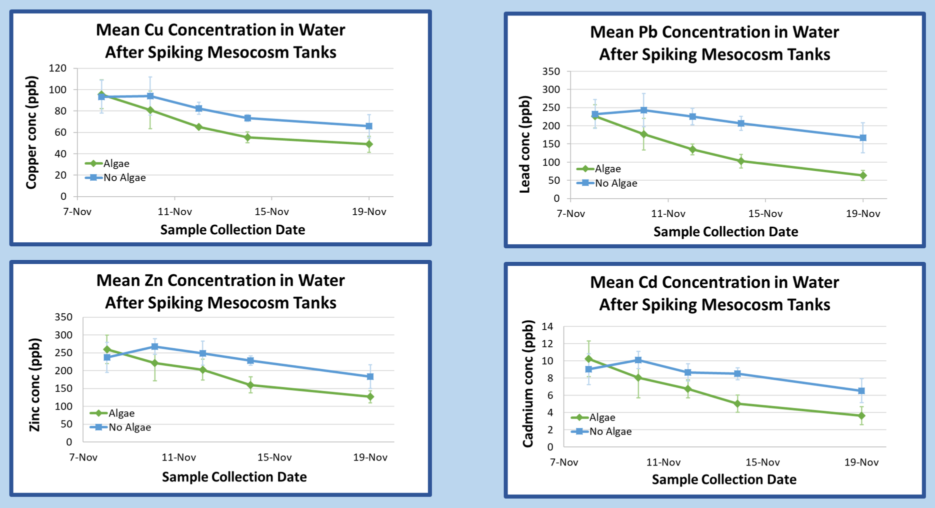


Figure 4. Mesocosm tanks with filamentous algae initially showed a more rapid decrease in phosphorous compared to those without algae.

Figure 5. Mesocosm tanks with filamentous algae saw a more rapid decrease in total mercury and other heavy metals from the water column than tanks with no algae. Algae measurements confirmed that the metals were taken up by algae.





% Removed from the Water Column						
	Hg	Cu	Zn	Pb	Cd	P (PO_4^{3-})
With algae	26%	~50%	~50%	76%	63%	46%
Without algae	16%	34%	27%	44%	35%	46%

Vermicompost from Filamentous Freshwater Algae

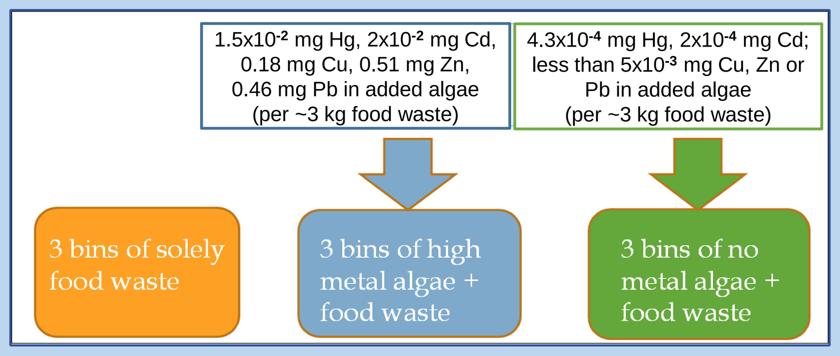


Figure 6. Vermicompost was created in nine bins, all of which contained cafeteria food waste. Six of the bins received filamentous algae from the mesocosm tank experiment (half of which had been spiked with metals).

Figure 7. Vermicompost bins were stored in a climate controlled environment throughout the composting process. Finished compost and leachate produced were collected for further analysis.

Figure 8. The vermicomposting process successfully decomposed the filamentous algae (dark green in image on left) as well as the food waste (brown in image on left; eggshells can also be seen).

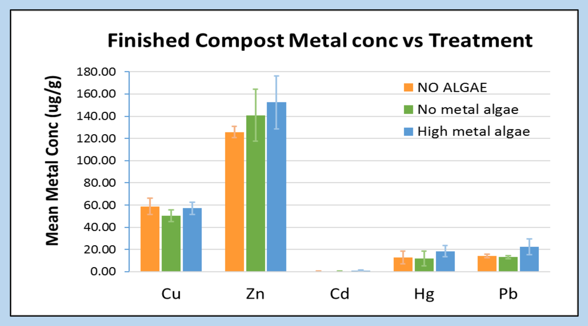


Figure 9. Heavy metal concentrations in vermicompost with high metal algae treatments appear slightly elevated; however, the difference from other treatments is not statistically significant.

Heavy metals limits (ug/g) for European countries which do have compost rules					
Metal	Austria	Belgium	Canada	Germany	Netherlands
Cd	1	5	3	1.5	1
Cu	100	100	100	100	90
Pb	150	600	150	150	120
Hg	1	5	0.8	1	0.7
Zn	400	1000	500	400	280

Compost Standards and Guidelines, Brinton, Ed. 2000.

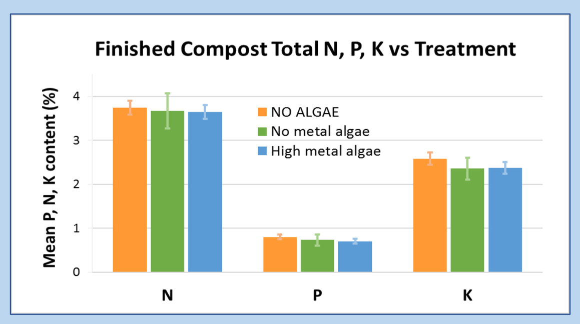


Figure 10. Nutrient levels in finished vermicompost are consistent across treatments and higher than typical compost NPK ratios: 1-5% : 0.3-0.5% : 0.4-0.8% (B.C. Agricultural Composting Handbook. 1998).

Values for total N, P, K from Agricultural Analytical Services Laboratory, Penn State University.

- Algae was effectively decomposed with food waste to produce finished vermicompost (Fig. 8).
- Metal concentrations in finished compost, including high-metal algae treatment, are well within limits laid out by European compost rules, except for mercury. Primary source of the mercury is unknown, but appears to be from the food waste.
- Metal concentrations in vermicompost leachate was negligible.
- Vermicompost is nutrient-rich compared to typical expectations for compost, and is consistent across all three treatments.

Conclusions

- First study to evaluate phycoremediation for nutrients and metals in stormwater ponds.
- Filamentous algae enhanced initial reduction of nutrient phosphorous from mesocosm tank water.
- Filamentous algae successfully removed total Hg, Cu, Cd, Zn, and Pb from mesocosm tank water, demonstrating its potential for bioremediation of stormwater and wastewater ponds.
- First study to use algae as a vermicompost amendment.
- The vermicomposting process successfully degraded freshwater filamentous algae with food waste, demonstrating the potential for larger scale composting of waste algae.

Future Work

- Experimental successes showing significant reduction of metals in mesocosm tank water will be followed up with further metals analysis of algae and sediments collected to determine final fate of pollutants.
- Preliminary success with vermicomposting algae will be repeated with higher algae content while making efforts to optimize the vermicompost process conditions.
- Further experiments with finished compost will investigate germination and plant growth. In addition to studying the success as a soil amendment, the levels and fate of metals and potential uptake into plants will be explored.
- Economic viability of widespread application of these practices across campus will be investigated in terms of feasibility, cost/benefit analysis.
- Thus far, this project has involved over 36 undergraduate students and lesson plans on environmental science implemented for local 4th grade students.
- We are currently replicating the vermicompost experiment using higher algae percentages in each compost bin. Our current compost bins contain 18% algae (by mass) or ~ a 1:5.5 ratio of algae to food waste. The bins in this original experiment contained 1% algae, or ~ a 1:83.2 ratio of algae to food waste. The algae we have chosen for this secondary experiment was all sourced from local wastewater ponds on the Virginia Wesleyan campus.
- Through adding more than five times the mass of algae that was added in this original experiment, we hope to get a better picture of the ramifications of using large percentages of algae in the vermicomposting process.

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