Floating Treatment Wetland and Biomedia Module for Stormwater Treatment and 6PPD Quinone Removal

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ABSTRACT

Despite decades of estuarine and river restoration efforts, effectiveness monitoring surveys continue to document premature mortality of coho salmon (*Oncorhynchus kisutch*) within the streams of urbanized areas in the Pacific Northwest (PNW). Many researchers have identified stormwater inputs, especially road runoff, to be a primary cause of salmon mortality and poor recruitment while other researchers have found that certain stormwater bio-infiltration methods helped reduce mortality significantly. In December of 2020, 6PPD quinone, a previously unknown chemical derived from tire wear particles, was identified as the particularly potent contaminant responsible for killing coho salmon. Traditional biofiltration measures have been shown to alleviate the toxicity of the stormwater on salmon, however, many highly urbanized areas of Puget Sound cannot accommodate bioswales or green infrastructure for the treatment of road runoff before entering urban streams. For these sites where other types of green infrastructure is impractical, using a mesocosm design experiment, we examined the potential of using floating treatment wetlands (FTWs) with biomedia within as an in-situ treatment for stormwater contaminants including 6PDD quinone. We analyzed three biomedia mixes for the ability to adsorb stormwater contaminants, especially 6PPD quinone resulting in reductions of 82%, 81%, and 86% respectively for each biomedia mix tested. We then investigated the efficacy of the most beneficial wetland species planted within FTWs and the most efficient biomedia mix on the reduction of stormwater contaminants (from this point forward including 6PPD quinone) and coho salmon survival. The results were efficacious with a 79% reduction in 6PPD quinone and 100% survival and no symptoms of 6PPD quinone for any of the coho salmon in the treated stormwater. Further deterioration of coho populations risk extinctions within those streams and rivers in high urban environments, reducing overall genetic diversity of the species.

Keywords: Stormwater contaminants; 6PPD quinone; Green infrastructure; Floating Treatment Wetlands; Biomedia; Coho salmon

INTRODUCTION

The restoration of habitat in rivers, streams and estuaries has been the focus of land managers and agencies throughout the Pacific Northwest (PNW) for decades, with hundreds of millions of dollars spent on these efforts. Monitoring surveys of these restoration efforts, researchers noticed an alarming behavior of returning pre-spawn adult coho salmon (*Oncorhynchus kisutch*) (Scholz et al. 2011). Coho salmon were presenting erratic surface swimming, gaping and loss of equilibrium. The coho died within several hours and females exhibited especially high rates of pre-spawn mortality. After almost a decade of researching water quality conditions, the only connection to the high mortality rates was rain events and urban watersheds (Spromberg et al. 2011).

In one of the first studies, the researchers, now referred to as the Puget Sound Stormwater Science Team (PSSST), exposed healthy coho spawners to: (i) artificial road runoff containing mixtures of metals and petroleum hydrocarbons, at or above concentrations previously measured in urban stormwater; (ii) undiluted road runoff collected from a high traffic roads; and (iii) road runoff pre-treated via bioinfiltration through experimental media columns placed in barrels (McIntyre et al. 2014). The PSSST found that the artificial mixture of contaminants did not cause the mortality syndrome. However, untreated road run-off caused 100% mortality to the coho compared to those coho in the unexposed control tanks. The mortality syndrome was prevented when road run-off was pretreated with green stormwater infrastructure technology. In their experiment run-off was treated by filtration through a biomedia within a large barrel (McIntyre et al. 2015). The media used in that study included a layer of gravel aggregate, 60% sand and 40% compost topped with mulched bark. Due to the success of the treatment, many researchers are now testing numerous stormwater treatment media and infrastructure models in the field (Navickis-Brasch et al. 2022).

Creation of biofiltration swales or ponds to treat stormwater prior to entering water-bodies is not feasible for many waterbodies in highly urbanized areas. The high cost of land in these urbanized areas prohibits construction of stormwater ponds and most urban infrastructure systems allow water to bypass treatment during high flow rain events. In addition, there are countless unmanaged pipes discharging untreated stormwater into the streams and rivers in the Pacific Northwest (Seebacher, personal observation). Together, these factors result in a major limitation and hurdle to urban stream and lake pollution reduction efforts intended to reduce coho mortality. Populations of coho cannot tolerate these high rates of mortality, greater than 50% in many urban streams (Spromberg et al. 2016; McIntyre et al. 2014).

Floating Treatment Wetlands (FTWs) with the treatment biomedia within and underneath, may offer a manage-

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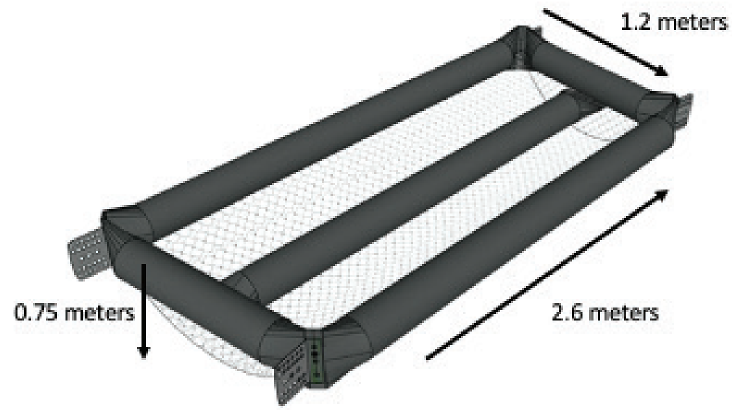

Figure 1. Floating treatment wetland and biomedia module design example. (Photo credit: Lizbeth Seebacher and diagram credit: Galen Fulford, Biomatrix Water)

ment option for implementation in creeks, streams, lakes or stormwater ponds at the point of stormwater entry (Figure 1). Future FTWs can be designed so that the biomedia is placed within the module while floating, and wetland plants are planted on the top of the module.

Results from a pilot project revealed reduced coho mortality using a biomedia mix recommended by the Washington State Department of Ecology. In order to build upon these results, the goal of this project was to test the efficacy of FTWs and an improved biomedia mix in reducing contaminant loads from stormwater and enhancing the survival of pre-spawn and juvenile coho while also correlating those findings to projected reductions in the impacts of stormwater on other salmonids and aquatic organisms. The term stormwater and road runoff are used interchangeably.

Prior studies have found that FTWs significantly reduce metals and nutrient loads in stormwater (Supplemental Table S1). The use of FTWs for stormwater treatment is to allow for the treatment of stormwater at the point of stormwater entry into waterbodies. This type of green infrastructure can be utilized where the land for stormwater ponds or bioswales are not possible or can be used in addition to other types of treatment. For this project, the contact time is not expected to be sufficient for the uptake by wetland plants, however, we added wetland plants to aid in providing potential habitat for invertebrates and shorebirds as well as to provide a more attractive green infrastructure module in urban environments.

For the pilot project, we tested FTWs planted with wetland plants with a traditional biomedia mix on 135 juvenile coho salmon. Our initial results demonstrated 31% survival for those coho salmon in the treated stormwater and a mean of 13 hours to death versus 3-4 hours to death and 100% mortality for those unfortunate coho in the untreated stormwater tanks. Following these results, we tested three new biomedia mixes and set of wetland plant species in a mesocosm experiment.

Our specific objectives were to: 1) determine which native wetland plant species perform best with regard to survival in FTW conditions, and 2) determine the most effective biomedia mix for stormwater contaminant and 6PPD quinone removal, then test the chosen wetland species and the most efficacious biomedia mix on stormwater and juvenile coho survival.

By addressing these objectives we hope to attain a BMP biomedia mix, suite of wetland species and FTW design which can reduce stormwater contaminants to levels below which will allow for coho salmon survival. Different site types, such as stormwater ponds, lakes, and streams with direct stormwater entry, will all need a unique FTW-biomedia module design in order to function properly and decrease stormwater contaminants. These designs are the subject of future research.

METHODS

Wetland plant species were chosen based on their facultative wetland indicator ratings. Temporary FTWs were designed and built out of balsa wood, burlap and coconut coir. Wetland species were planted within and placed along the shoreline of Lake Washington within the Union Bay Natural Area (UBNA) at the University of Washington (UW) to

Table 1. Three biomedia mixes with five to six media were tested for stormwater contaminant reduction with a focus on 6PPD quinone.

Biomedia Mix #1	Percent	Biomedia Mix #2	Percent	Biomedia #3	Percent
Oyster shells - whole	10%	Oyster shells - whole	10%	Oyster shells - whole	10%
Biochar - cation/anion blend	30%	Biochar - cation/anion blend	30%	Biochar - cation/anion blend	20%
Wood chips - alder	25%	Wood chips - alder	25%	Wood chips - alder	25%
Leca clay - NR 2-4 mm	25%	Leca clay - HMR .5-2 mm	25%	Leca clay - NR 2-4 mm	15%
Coconut coir	10%	Coconut coir	10%	Coconut coir	10%
				Peat - sphagnum	20%

allow them to mature and create a larger root system and introduce a biofilm on the root system. Of the twenty-one species assessed within FTW conditions during the pilot study, fourteen were chosen to continue testing based on ability to survive in the FTW conditions. Of these, 8 were emergent wetland plant species, 2 were woody wetland species, 2 submerged species and 2 floating leaved species. The plants were ordered primarily online in bare root form and planted in the spring of 2020 and allowed to grow through the summer into early fall.

To assess the stormwater contaminant reduction of new biomedia mixes, three new biomedia mixes were chosen for testing on stormwater, based on a literature review of successful use in prior studies. The biomedia mixes in Table 1 were tested for stormwater contaminant removal capabilities. Each media was chosen for specific purposes.

Biochar, wood chips, and coconut coir was included as an organic for adsorption of 6PPD quinone. Past research on biochar imply successful adsorption of metals such as lead, copper, cadmium, chromium and nickel. Additionally, biochar tends to be basic, which can reduce metal mobility (McWayne 2019; Wilfong et al. 2021; Gupta et al. 2020). Organics such as coir, wood chips, and peat moss have the ability to remove heavy metals via ion exchange and include humic substances, cellulose, and lignin that have been shown to bind metals via surface complexation as well as ion exchange (Lim et al. 2015; Trenouth and Gharabaghi 2015; Ho et al. 2000; McWayne 2021). Leca clay Filtralite NR (2-4 mm balls) was included for nutrient adsorption to keep TN and TP levels potentially leached from the organic material in check. Sphagnum peat moss was included as an organic with a positive charge due to the hydrogen atoms on the surface, which would attract 6PPD quinone which has a slight negative charge (McWayne 2021). At the time of this experiment, the contaminant killing coho salmon was now known. The research and resulting journal article on 6PPD quinone was published in December of 2020 (Tian et al. 2020).

Figure 2. Field design for biomedia mesocosm experiment. Each of the three biomedia mixes were placed in a 20 gallon container with stormwater for 24 hours, control tanks were untreated stormwater (lower right). (Photo credit: Lizbeth Seebacher)

Replicate samples (n=4) of biomedia was placed within a wrap of burlap fabric in order to keep the biomedia from floating or sinking in the tank (Figure 2). In spring of 2021, stormwater was collected from the same major arterial highway in Tacoma, Washington and transferred immediately to the UW. Fifteen gallons of stormwater were placed into cleaned and sterilized twenty-gallon HDPE tanks. The tanks were randomly assigned a biomedia mix treatment or labeled as a control tank (stormwater left untreated). Small pumps were placed in each tank to circulate the water.

After 24 hours, the biomedia bags were removed, and water samples were collected from the center of the tank using sterile glass bottles provided by the laboratory and placed in a cooler with ice packs. The samples were transported immediately to the Center for Urban Waters laboratory in Tacoma, WA for 6PPD quinone analysis in sterilized amber glass 20 ounce bottles, and to the Eurofin

Figure 3. Biomedia mix #3 was placed under (left photo) a floating treatment wetland with selected wetland plants placed on top (right photo). Stormwater treatment = 24 hours. (Photo credit: Lizbeth Seebacher)

Laboratory in Tacoma, Washington, a lab accredited by the state's regulatory agency, the Department of Ecology for the following analytes (pH, DO, $CaCO^3$, Br, Mg, Al, Sb, Ar, Ba, Be, Cd, Cr, Co, Cu, Pb, Mn, Mo, Ni, Se, Ag, TI, V, Z, Diesel and Heavy Oil)

To evaluate the stormwater contaminant reduction of the chosen wetland plant species and best performing biomedia mix on coho salmon survival, the wetland plants were grown in new temporary FTWs within lake water from Lake Washington throughout the summer of 2021 to mature and develop a large root system. Just prior to the experiment in the fall of 2021, biochar and Leca clay balls were rinsed well with distilled water and dried before combining with the other biomedia within burlap fabric. All equipment was disinfected with an iodine solution. Stormwater was collected from the same location near the City of Tacoma immediately after a rain event and taken to the UW where we placed 45.5 liters of stormwater into each of the twenty-gallon tanks (75.71 liters). Replicate tanks (n=4) were then randomly assigned to be treated stormwater or untreated. The stormwater was "treated" for 24 hours with an FTW with an estimated root mass of 25% of the tank and ten liters of biomedia floating underneath (Figure 3).

At +20 hours in the experiment, we acquired ~90 juvenile coho from the Puyallup tribal hatchery and transported the coho to the UW. After the 24-hour treatment, the FTWs and biomedia were removed and the treated and untreated stormwater was moved to ten-gallon fish tanks, control tanks included hatchery water, each with a pump and bubbler. Six juvenile coho were then randomly placed within each of the fish tanks and exposed for 22 hours.

The water quality was monitored every hour for temperature, dissolved oxygen (DO), and pH to make sure that all tanks remained within the range that fishery biologist suggested for juvenile coho. We also strived to match the hatchery water temperature (11º C). The temperature ranged from 11.4º C to 14.7º C, DO ranged from 6.5 to 10.3 mg/L and pH from 6.6 to 7.4 through the duration of the experiment within all tanks (treated stormwater, untreated stormwater and control). We monitored fish survival and behavior (fin splaying equilibrium, mouth gaping, surface swimming) every half hour for two minutes per tank for treated, untreated tanks, and control tanks.

After the 22-hour exposure, the fish were removed from the fish tanks. The surviving fish from the treated tanks were humanely euthanized with MS222 as required by our permit from the Washington Department of Fish and Wildlife (WDFW) and Office of Animal Welfare at the University of Washington. The fish from the control tanks (hatchery water) were returned to the Puyallup Hatchery as permitted by the WDFW.

Following fish removal, water samples were taken from the middle of each tank and analyzed for the following stormwaer contaminants ($CaCO^3$, 6PPD Quinone, Br, Ca, Mg, Al, Sb, Ar, Ba, Be, Cd, Cr, Co, Cu, Pb, Mn, Mo, Ni, and Ag).

STATISTICAL ANALYSIS

The second objective was to compare three different biomedia mixes treatments on stormwater contaminant removal. A One-Way ANOVA was performed to test if the mean levels of contaminants are the same in each of the three treatments and untreated stormwater. Rejecting a hypothesis indicates that at least two groups have different means. The p-values were adjusted for multiple comparisons using a Bonferroni correction. A post-hoc analysis using Tukey's Honestly Significant difference test was performed to compare averages of each treatment with untreated stormwater.

RESULTS

The wetland plant species listed in Table 2 were grown in temporary FTWs in order to determine their ability to survive in the partially to fully submerged conditions of floating treatment wetlands. Six species were chosen for use in the next phases of the project.

The second objective of the study was to determine the most effective biomedia mix for stormwater contaminant and 6PPD quinone removal and then test the chosen wetland species and the most efficient biomedia treatment mix on stormwater and juvenile coho survival.

The three biomedia performed similarly to each other in reducing five significant stormwater contaminants (Figure 4). One-way ANOVA showed significant reductions in zinc ($p = <0.001$), lead ($p = <0.001$), copper ($p = <0.001$), and heavy oil ($p = <0.001$) and 6PPD quinone ($p = <0.001$) within the treated stormwater relative to the untreated stormwater. On average, the Biomedia #3 mix provided an 86% reduction in 6PPD quinone.

Table 2. Feasibility of wetland plants species for use in FTWs.

Wetland Plant Species	Plant performance in FTW conditions
Eleocharis acicularis	Very difficult to grow – discontinued
Schoenoplectus tabermaemontanii±	Especially easy to grow from rhizomes
Juncus effusus±	Easy to grow from rhizomes, very hardy
Typha latifolia±	Easy to grow from rhizomes, very hardy
Azolla filiculoides	Can be too aggressive, not found in streams
Bouteloua curtipendula	Difficult to grow
Salix sitchensis	Easy to propagate, but too large for test FTWs
Elymus canadensis (glaucus) ±	Difficult to grow in FTWs, changed to glaucus
Ceratophyllum demersum	Not found in streams, only in lake systems
Leersia oryzoides±	Dense root system, favorable growth in FTWs
Deschampsia caespitosa±	Relatively easy to grow, difficult to find locally
Elodea canadensis	Difficult to find locally, does not grow well in tanks
Populus deltoides	Too large for current FTW design
Lemna minor	Difficult to grow, not found in streams

± Included in FTW – Biomedia modules for coho salmon survivorship study.

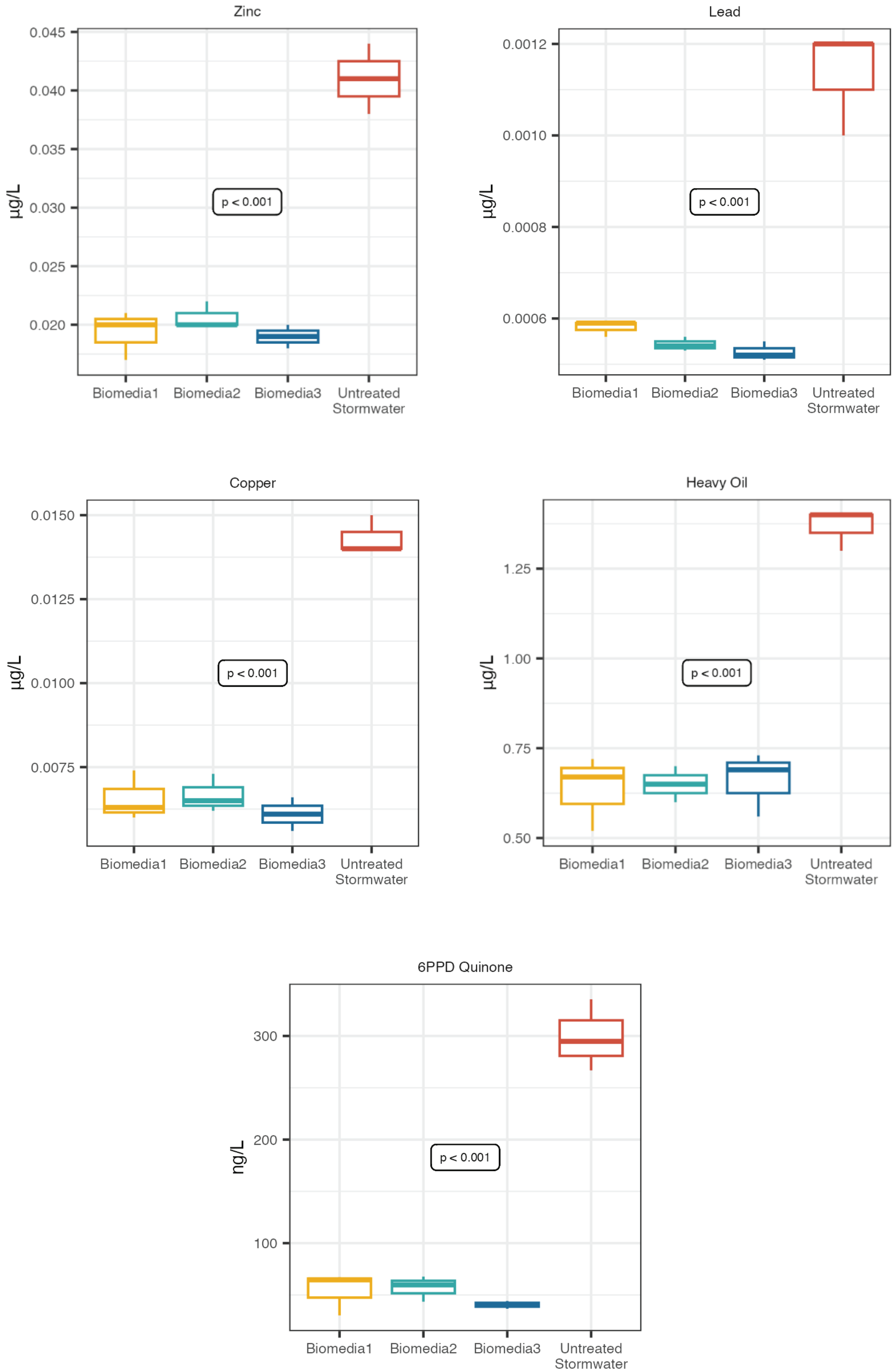

Figure 4. Biomedia mix study lab analysis results. Each box in the plots indicates the 1st and 3rd quantile and median, the whiskers indicate the interquantile range up to the minimum and maximum value. The p-values noted via a one-way ANOVA testing the difference between all four groups. Stormwater was treated for 24 hours.

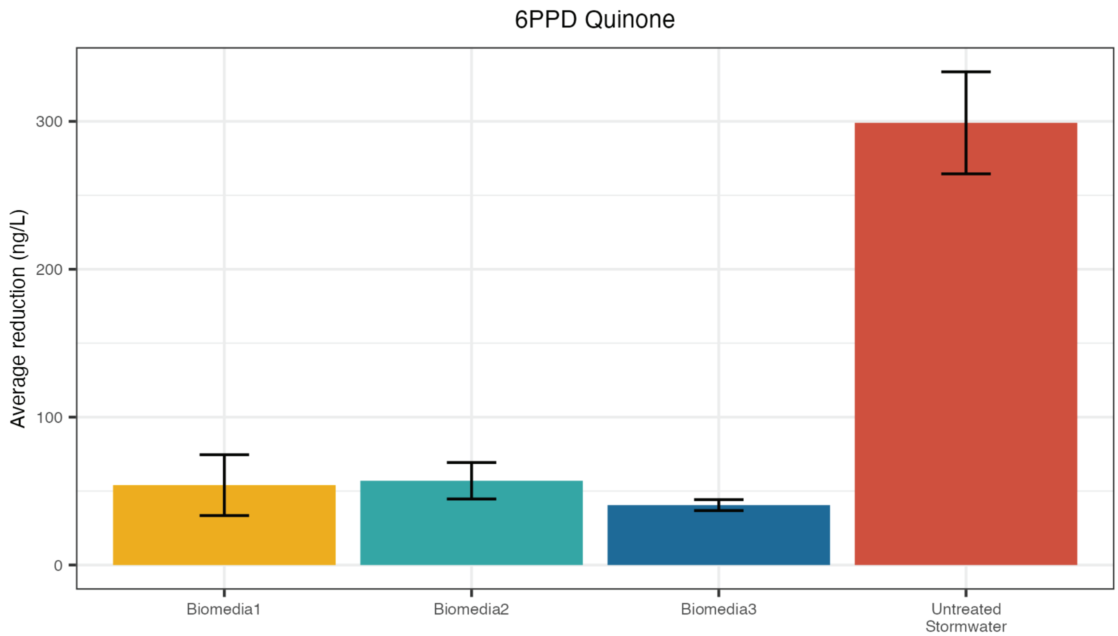

Figure 5. 6PPD quinone reduction for each biomedia mix compared to untreated stormwater. Results in nanograms per liter (ng/L). Stormwater was treated for 24 hours.

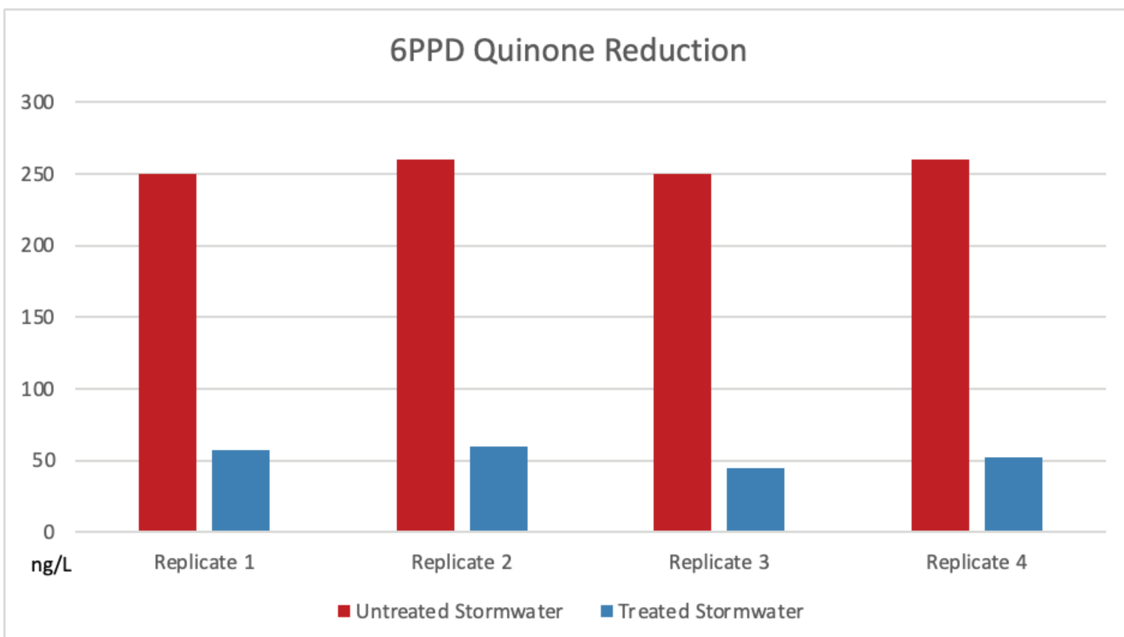

Figure 6. 6PPD quinone reduction in treated vs. untreated stormwater. Results in nanograms per liter (ng/L).

Figure 4 indicates the results for each of the three biomedia, from the lab analysis for zinc, lead, copper, heavy oil and 6PPD quinone when compared to the untreated stormwater.

Figure 5 provides the results of the biomedia experiment for 6PPD quinone analysis. There is a significant contaminant reduction with biomedia versus untreated stormwater. (ANoVA, $F(3,8)=71.8$, $p<0.001$) Biomedia mix #3 was the most consistent and on average performed best on 6PPD quinone reduction with a mean of 40.5 ng/L versus 54 ng/L for Biomedia mix #1, 57 ng/L for Biomedia mix #2 and 299 ng/L 6PPD quinone for the untreated stormwater. Appendix 1 presents the lab analysis results for all stormwater contaminants tested.

After determining the best performing wetland species with regard to survival in FTW conditions and most successful biomedia mix for stormwater contaminant removal, these species and biomedia mix (biomedia mix #3) were tested for coho survival and stormwater contaminant reduction.

The results from this experiment provided a signicant reduction (ANoVA, $F(1,6)=2127.63$, $p<0.001$) of 79% of the newly discovered contaminant, 6PPD quinone (Figure 6) from a mean of 255 ng/L to a mean of 53 ng/L, a one

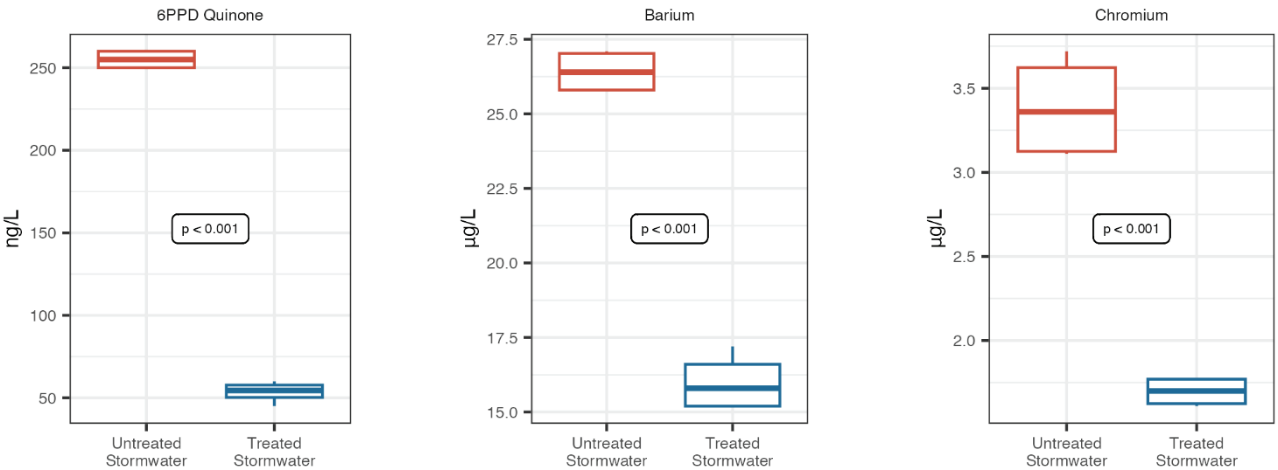

Figure 7. Stormwater contaminants with significant reduction in treated vs. untreated stormwater.

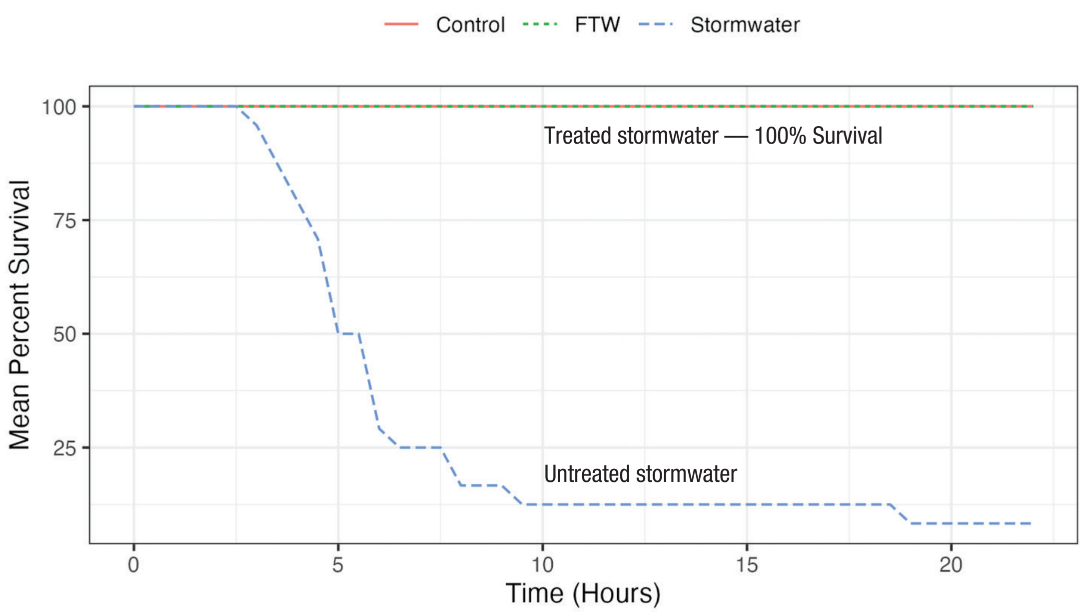

Figure 8. Time to death for Coho in treated and untreated stormwater. This line graph shows the time to death for the Coho in the untreated stormwater. The top line, or 100% survival included all treated tanks and control tanks (six fish in each tank – four replicate tanks for the treated and untreated stormwater and control tanks)

way ANoVA, $F(1,6)$, $p<0.001$. Other significant stormwater contaminant reductions included Barium and Chromium (Figure 7). Appendix 2 presents the lab analysis results for all stormwater contaminants tested in the FTW/Biomedia mix experiment on coho salmon

The coho in the four replicate untreated tanks began to show symptoms in hour two and the first death was in hour three. Symptoms included: loss of equilibrium, mouth gaping, loss of buoyancy, and sinking. As Figure 8 indicates, within hour four, five of the 24 (six fish per tank, four replicate tanks) coho were dead and by the fifth hour, half of the 24 coho had died. By the sixth hour of exposure, only four of the 24 coho survived but succumbed by the 8th hour except for the two fish that survived the full 22-hour experiment.

CONCLUSION

This research project is one of the first to report specific reductions in 6PPD quinone via in situ treatment of stormwater. No other published work to date contains 6PPD quinone reduction analysis, along with coho (*Oncorhynchus kisutch*) survival data.

This mesocosm experiment has allowed us to ascertain the most effective biomedia mix of the mixes we examined for 6PPD quinone reduction with the least amount of leaching of metals and nutrients. We will not be able to experience 24 hours of contact time of the stormwater with the biomedia in the field, however, the next phase of this project will test different FTW/Biomedia module designs at several field sites to determine the ratio of biomedia to stormwater and contact time necessary to reduce 6PPD qunione significantly for practical application.

The results from this research correspond with the results found by the Puget Sound Stormwater Science Team (PSSST) for coho mortality and time to death when exposed to direct road runoff. The first coho began showing symptoms of 6PPD quinone toxicity in hour two, and the first death was in hour three. It has since been discovered that the new stormwater collection site under the offramp of Interstate 5 is slightly "weaker" for stormwater contaminants, including 6PPD quinone. The amount of traffic on the offramp during our sampling period was not as high as expected.

Per Tian and others (2020, 2022) coho salmon are especially sensitive to 6PPD quinone (2-anilino-5-(4-methylpentan-2-yl)amino)cyclohexa-2,5-diene-1,4-dione). In the 2022 revised toxicity paper, the authors include a table where 6PPD quinone is listed as the second most toxic chemical with the most sensitive species *O. kisutch* (coho salmon) and an LC50 of 0.10 ppb. According to the Tian, et.al, 2020, the PSSST had determined that the LC50 of coho was 0.8 ug/L or 800 ng/L, however, based on updated research results (Tian et al. 2022), the revised toxicity assessment is now LC50 of 100 ng/L (80-100 ng/L with a 95% confidence level).

Indisputably, coho salmon populations cannot withstand the mortality rates they are currently suffering within urban watersheds in western Washington. Until the source of this contaminant can be eliminated, effective treatment of our surface water will not be possible. The biomedia tested in our mesocosm study resulted in 100% survival and no 6PPD quinone symptoms. The 6PPD quinone was reduced by 79% in the mesocosm study from a mean of 255 ng/L to 53 ng/L allowing for 100% survival of coho within the treated stormwater. Can this experimental approach be applied for real world applications – that is the next step.

By utilizing the Floating Treatment Wetland/Biomedia module, we are able to place the biomedia directly into the receiving water body at the location of stormwater entry to remove or reduce contaminant load in stormwater. This "in situ" method of stormwater treatment should not take place of other Green Infrastructure devices, but be available for those sites that do not allow for the typical Green Infrastructure methods, such as bioswales or stormwater ponds or they can be used in conjunction with other approaches to improve efficacy. Improved treatment of stormwater is necessary to increase survival of pre-spawn and juvenile coho and to reduce the impacts of stormwater on other salmonids and aquatic organisms.

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APPENDIX 1

Stormwater contaminant lab results for biomedia mix experiment after 24 hours of treatment.

Analyte	Units	Biomedia 1	Biomedia 2	Biomedia 3	Untreated Stormwater
6PPD Quinone	ng/L	54.00	56.97	40.50	299.00
pH	mg/L	7.48	7.37	6.97	7.53
DO	mg/L	5.37	5.13	3.86	9.42
Hardness (CaCO3)	mg/L	107.67	163.33	110.00	41.67
Bromide	mg/L	0.23	0.09	0.26	0.11
Magnesium	mg/L	4.67	5.80	5.00	0.51
Aluminum	µ/L	356.67	346.67	370.00	393.33
Antimony	µ/L	2.33	2.23	2.30	2.17
Arsenic	µ/L	31.66	23.67	29.67	0.90
Barium	µ/L	43.67	58.00	48.00	34.00
Beryllium	µ/L	<MDL	<MDL	<MDL	<MDL
Cadmium	µ/L	<MDL	<MDL	<MDL	<MDL
Chromium	µ/L	26.00	55.33	19.67	6.53
Cobalt	µ/L	0.35	0.23	0.49	0.26
Copper	µ/L	6.57	6.67	6.10	14.33
Lead	µ/L	0.58	0.54	0.53	1.13
Manganese	µ/L	80.67	101.00	130.00	10.50
Molybdenum	µ/L	4.93	5.20	4.77	1.80
Nickel	µ/L	2.43	1.53	3.03	1.50
Selenium	µ/L	8.70	3.00	8.23	<MDL
Silver	µ/L	<MDL	<MDL	<MDL	<MDL
Thallium	µ/L	<MDL	<MDL	<MDL	<MDL
Vanadium	µ/L	29.80	29.67	29.00	2.03
Zinc	µ/L	19.33	20.67	19.00	41.00
Diesel	µ/L	356.67	380.00	443.33	523.33
Heavy Oil	µ/L	636.67	650.00	660.00	1366.67

APPENDIX 2

Stormwater contaminant lab results for FTW/Biomedia Mix on Coho experiment after 24 hours of treatment.

Analyte	Units	Treated Stormwater	Untreated Stormwater
Hardness (CaCO3)	mg/L	36.75	24.00
6PPD Quinone	ng/L	53.00	255.00
Bromide	mg/L	0.09	0.05
Calcium	mg/L	8.53	9.48
Magnesium	mg/L	3.75	0.19
Aluminum	μ/L	190.75	237.75
Antimony	μ/L	1.11	1.10
Arsenic	μ/L	5.03	0.64
Barium	μ/L	16.00	26.43
Beryllium	μ/L	<MDL	<MDL
Cadmium	μ/L	<MDL	<MDL
Chromium	μ/L	1.70	3.39
Cobalt	μ/L	0.28	0.13
Copper	μ/L	5.21	5.38
Lead	μ/L	1.47	2.39
Manganese	μ/L	134.10	7.98
Molybdenum	μ/L	1.02	0.76
Nickel	μ/L	1.03	0.57
Silver	μ/L	<MDL	<MDL
Selenium	μ/L	8.70	3.00
Silver	μ/L	<MDL	<MDL
Thallium	μ/L	<MDL	<MDL
Vanadium	μ/L	29.80	29.67
Zinc	μ/L	19.33	20.67
Diesel	μ/L	356.67	380.00
Heavy Oil	μ/L	636.67	650.00