

Duwamish River Floating Wetlands 2020 Monitoring Report

UW Green Futures Lab

University of Washington

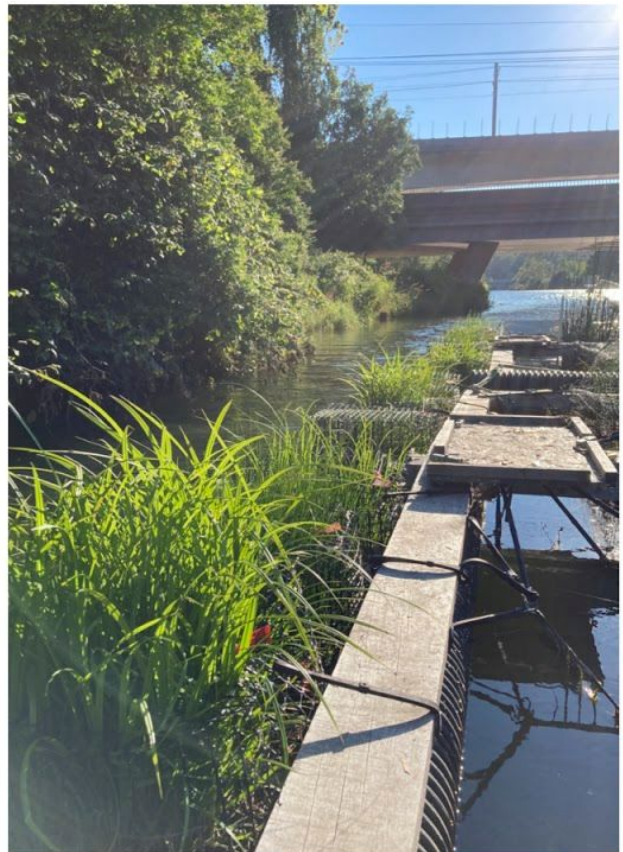
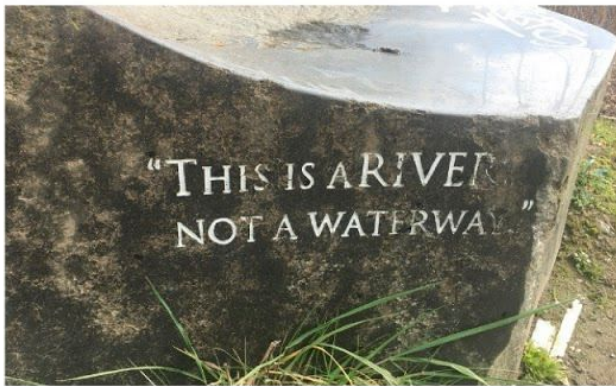


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Project Attribution Table

Project Dates	<p>UW Floating Wetlands workshop: Winter quarter 2020 Construction: Jan - March, 2020 Monitoring Period: March 22 - June 15, 2020 (highly reduced due to COVID-19); June 16 - July 26, 2020 (slightly reduced due to COVID-19)</p>
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Community Scientists	Over 30 individuals. Special thanks to David and Sebastian.
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Acronyms

BOLMAR - *Bolboschoenus maritimus*

CFW - Constructed Floating Wetlands

CXLYNG - *Carex lyngbyei*

CXOBNA - *Carex obnupta*

CFW - Constructed floating wetland

DO - Dissolved oxygen

ELEPAL - *Eleocharis palustris*

FWL - floating wetland

GFL - Green Futures Lab

JSATS - Juvenile Salmon Acoustic Telemetry System

LDR - Lower Duwamish River

RM - River mile

ROV - Remote operated vehicle

SCHACU - *Schoenoplectus acutus*

SCHAME - *Schoenoplectus americanus*

SCHTAB - *Schoenoplectus tabernaemontani*

SCIMIR - *Scirpus microcarpus*

SMEA - School of Marine and Environmental Affairs

T-105 - Terminal 105

T-108 - Terminal 108

TD - Tukwila Dock

UW - University of Washington

WBF - Wetland biofilter

WBF 1.0 - Wetland biofilter 1.0 (introduced in 2019)

WBF 2.0 - Wetland biofilter 2.0 (introduced in 2020)

WM - Waste Management

Glossary

BioBarge - A constructed floating vessel designed for this project that includes a buoyant wooden frame holding the Biofilters and capacity for data collection access. The BioBarges were designed as towable research platforms and provided the external structure for the floating wetlands.

Biofilters - Floating wetlands designed with substrate to support wetland plants, sequester pollutants, and provide habitat (food and shelter) for juvenile salmon, with experimental materials to provide flotation. See Wetland Biofilters 1.0 and 2.0 below.

Fallout trap - Fallout traps are plastic bins designed to trap flying insects. They are filled with a small amount of water mixed with a few drops of biodegradable, unscented dish soap.

Floating wetland - A general term that describes a buoyant substrate that supports wetland plants growing hydroponically, with roots suspended below the water surface. Floating wetlands have been designed and implemented around the world and can take various forms. In this study, floating wetlands (FWLs) and constructed floating wetlands (CFWs) both refer to the wetland system designed for this project, which included barge frames (see BioBarge above) and wetland biofilters anchored both within the frames and outside along the longer edges of the frame (see Section 3 for images).

Plug - A subset of the WBF 2.0 woodstraw that was separately wrapped in tensar and removable from the WBF 2.0 for water quality testing.

Substrate - Describes various substrates of natural organic matter used in the floating wetlands that may provide invertebrate habitat and perform water quality functions, such as chelating and suspended metals.

Wetland biofilter (or biofilter) 1.0 - A 1m³ bright (untreated) 16ga wire gabion containing various biodegradable media including (from the bottom up) willow brush, BioFoam™, WoodStraw™, MycoBoard™, and native wetland plants, with protected refuge space beneath.

Wetland biofilter (or biofilter) 2.0 - A 0.5m³ (roughly) plastic cage formed out of Tensar™, which contains biodegradable media in the form of wood straw and native wetland plants, with flotation provided by pumice bricks.

1. Executive Summary

This report summarizes the results of the 2020 Duwamish River Floating Wetlands research and community science program. Constructed floating wetlands (CFWs) are an innovative form of green infrastructure that may be used to enhance water quality and provide a range of other ecosystem services, including providing wetland and aquatic habitat. In this project, an interdisciplinary team deployed four towable research platforms called “BioBarges,” which were constructed and deployed in 2019 as part of a preliminary, “proof of concept” project. In 2020, new prototypes were added, with each BioBarge supporting 16 CFWs, including four 9-square foot (SF) “Wetland Biofilter 1.0s” and twelve 4-SF “Wetland Biofilter 2.0s.”

The BioBarges were monitored at two field study sites from March to August 2020 in the Lower Duwamish River (LDR), including one located in Seattle and one in Tukwila, Washington. Field monitoring work was severely reduced from March to June due to the ongoing COVID-19 pandemic, but was expanded to nearly the full extent of its original scope in mid-June after King County entered Phase 2 of reopening and robust COVID-19 safety protocols (**Appendix A**) were drawn up and approved by the university and research team.

The goal of the Duwamish Floating Wetlands project was to determine if constructed floating wetlands can increase salmon habitat and improve water quality to support the survival of out-migrating juvenile salmon. The scientific objectives of the monitoring program were to gather information about juvenile salmon interactions with the BioBarges, invertebrate production, plant growth, and water quality improvement. The social objectives of the program were to encourage collaboration between students and community scientists in performing the field research and to connect community scientists to the research and to the river.

The results from the 2020 monitoring season included observations of juvenile salmon interacting with the BioBarges. The fish presence, invertebrate findings, and plant growth suggest that these CFWs are providing salmon habitat opportunities. The constructed floating wetlands supported the growth of both terrestrial and aquatic invertebrates, including Ceratopogonidae and other Diptera which are a known food for juvenile salmon smolts. Terrestrial invertebrate densities and diversity trended higher at the BioBarges than the control locations. All eight species of native sedges survived the growing season with some species doing better in estuary (more saline) conditions and others doing better in freshwater conditions. Some plants declined over the study period at the Seattle field site as the salinity of the Duwamish River increased with the onset of the dry season. Those plants did much better at the Tukwila site in the late season.

In general, there were more sightings of fish at the Biobarges compared to the control dock at the Waste Management site and more sightings of fish at the Biobarges compared to the control and references site (natural shorelines with riparian plant communities) at the Tukwila site. However, these differences were not statistically significant. That said, in both overwater and Gopro fish surveys, juvenile salmon were observed spending substantial time feeding and resting underneath and along BioBarges. Water

quality field measurements showed that temperature, dissolved oxygen, and luminosity levels were within tolerable ranges for juvenile salmon, and at no point during the monitoring period reached lethal levels. However, it was not clear whether the BioBarges reduced or improved these water quality measures. Generally, flow velocity was slower at the BioBarges but other factors could have been influencing this result. Laboratory analysis of the rooting substrates of the CFW's revealed the accumulation of certain metals (e.g. Cu, Pb, Zn) and nitrogen. Cadmium, another metal considered harmful to juvenile salmon survivability, was not detected.

The overall Wetland Biofilters stayed intact better when they had protective elements like a Biobarge structure, dock, or other element protecting it from boat wakes and woody debris. Boat wakes appear to have compromised the structure of several of the WBF 2.0s at Waste Management while woody debris affected a few WBF 2.0s at Tukwila Dock (TD). This was confirmed by higher plant mortality rates at the exposed side of WM (affected by boat wakes) and the sheltered side of TD (affected by woody debris). Overall, the WBF 2.0s had a plant survivability above 50% which showed that they could be established in these conditions. At WM, CXOBNU was the only species that ended the research with a survival rate above 80%, while BOLMAR was the only species below 30% survival. At the Tukwila site, CXOBNU, ELEPAL, CXLYNG, SCIMIR, Mix 1, and Mix 2 were all above 80% survival at the end of the research period. SCHAME and BOLMAR were the only species with less than 30% survival rate at TD.

The COVID-19 pandemic forced a reduction in the scope of the community science program as well as the length of the monitoring period. But while the pandemic may have prevented the research team from joining in-person outreach and education endeavors or community events, community scientists were still successfully recruited and given multiple, varied opportunities to participate in the floating wetlands project. Collectively, more than 30 individuals participated in weekly field monitoring, remote data collection and analysis, socially distanced microscope work, science communication, and other educational activities and independent projects for early career researchers.

This project demonstrated CFWs can provide habitat for juvenile salmon by providing a foundation for enhanced novel ecosystem functions critical to salmonid survival including wetland plants, aquatic and terrestrial invertebrate production and creating rest areas for the salmon. Additionally, water quality showed non-lethal conditions and an uptake in metals and nutrients to remove them from the water. Recommendations for future studies include 1) place BioBarges in sheltered locations with low wave action or boat wakes to prevent structures from being jostled causing them to be structurally compromised; 2) deploy BioBarges at more sites and cover larger areas to increase replication and habitat creation for further monitoring; 3) deploy a Juvenile Salmon Acoustic Telemetry System (JSATS) to more accurately monitor salmonid behavior in the vicinity of the biobarges (assuming the hatcheries upstream have tagged them).



Figure 1.1 Left, water quality lead, George, preparing flow meter to monitor water velocity at Waste Management site Biobarge B. Right shows the Biobarges at the Tukwila Site, (July 19 2020).

2. Introduction

This document will report monitoring results from the monitoring season starting in late March 2020 and continuing to the end of July 2020. The goal of monitoring the floating wetlands is to determine what benefits they provide to out-migrating juvenile salmon and other aspects of the Duwamish River Ecosystem. The Duwamish-Green Watershed (WRIA 9) is home to Chinook, Chum, Coho, Pink, and Winter Steelhead runs that have declined greatly in the last 50 years (WRIA 9 Salmon Habitat Plan). Despite the tireless efforts of multiple government and non governmental organizations these populations continue to decline, with 2009 being the lowest returning salmon year since 1965 (WRIA 9 Salmon Habitat Plan). The authors of this report acknowledge that the Duwamish River runs through the ancestral lands of the Duwamish Indian Tribe and honor the traditional land and water of the Coast Salish Peoples on which this work took place. We understand that, as guests working in Duwamish land, we have ongoing obligations to the Tribe, and we thank them for their continued hospitality.

The lower Duwamish River and transition zone (River miles 1-10) is critical to salmon population survival and return because this is where juvenile salmon forage, shelter and physiologically transition from living in freshwater to saltwater (Ostergaard, 2014). In order for out-migrating juveniles to achieve this

transition they require low gradient intertidal mudflats lined with tidal marsh, which produce a high quality diet of invertebrates. Juvenile salmonids feed on a variety of benthic aquatic invertebrates (nereid worms, gammarid amphipods) and terrestrial invertebrates (chironomids, aphids, and tethinids). (Morley et al. 2012, Cordell et al. 2008, Oxborrow et al. 2017). Juvenile salmonids also require habitats with low water velocity to hide from predators and feed (Ostergaard, 2014; Toft and Cordell, 2017).

Channelization, shoreline hardening, and habitat degradation are all factors that can contribute to salmon population decline in the Duwamish River. Studies have shown higher taxa richness in invertebrates at un-armored sites compared to armored sites (Morley et al. 2012). Furthermore, the historical contamination in the Duwamish River and other poor water quality conditions such as low oxygen and high water temperature can contribute to increased juvenile salmon mortality (Meador, 2014).

These floating wetlands were designed to be implemented along hardened shorelines where traditional riparian restoration is not possible, for example along docks, bulkheads, riprap boulders, and seawalls. This is the typical shoreline condition in the Lower Duwamish River and Estuary (River mile 1-5), which ranges from 40-60% of linear shoreline being bulkhead and 50-80% riprap within the first 7 miles of the river. The possible benefits the floating wetlands can provide to juvenile salmonids is production of terrestrial and aquatic invertebrates, slowing water velocity, providing shelter for salmonids and other fish, lowering temperatures, increasing dissolved oxygen, and uptaking nutrients, heavy metals and other contaminants from the river.

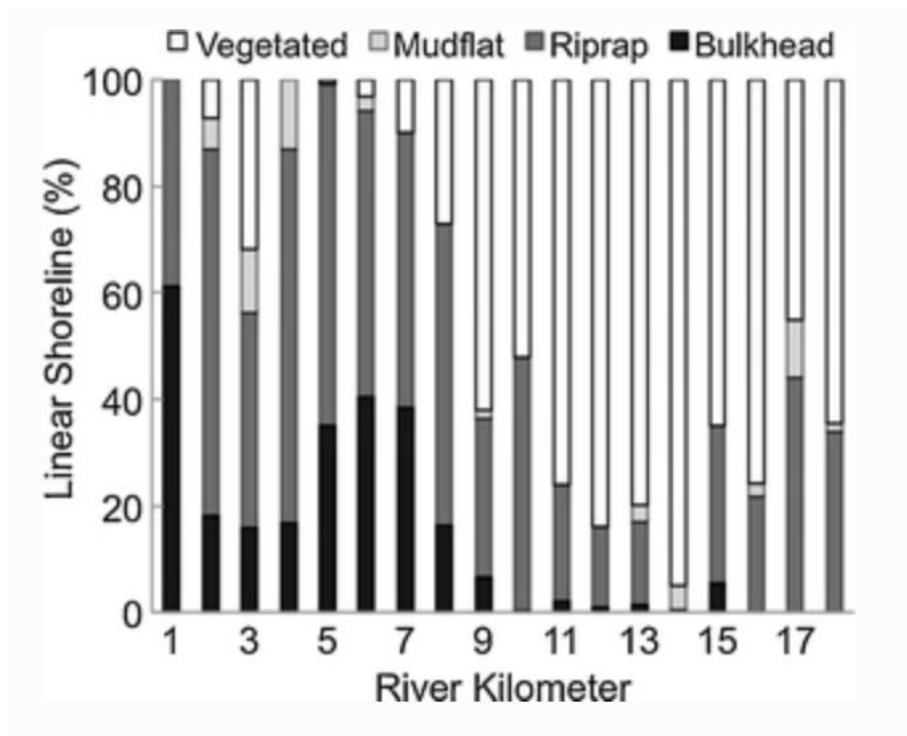


Figure 1. Percent coverage of four major shoreline conditions by river kilometer (Morley et al. 2012).

2.1. Project Background

This is phase 2 of the Duwamish Floating Wetlands and Community Science Project initiated by the University of Washington's Green Futures Lab in 2019. Phase 1 consisted of four biobarges placed in the Lower Duwamish River at T-105 and T-108. The BioBarges showed a proof of concept that these novel ecosystems could be created and added to the existing Duwamish ecosystem. The location did not allow all plants to grow due to salinity levels in the water. Additionally, it was believed that the salmon were already on their direct route out to Elliott Bay and therefore not as likely to be feeding.

Phase 2 builds upon learnings of Phase 1 by moving the BioBarges further upstream to new locations. The research protocols were slightly modified to better study the salmon habitat interactions while the BioBarge design was redesigned by adding WBF 2.0s along the longer sides of the BioBarges to remove hard shadow edges that may have been discouraging salmon from utilizing the structures.

2.2. Study Sites: Waste Management and Tukwila Dock

Based on recommendations from the 2019 research team, this year the BioBarges were deployed further upstream at either end of the transition zone of the Duwamish River, where it was expected that there would be lower salinity levels than there were at last year's field sites in the lower estuary zone, and juvenile fish would still benefit from added food production and refuge. Advice from scientists who had knowledge of juvenile salmon behavior and findings from the 2019 monitoring also led to placement of the BioBarges closer to the shore than they were the previous year, in an attempt to position the barges closer to the salmon's preferred travel corridors in shallower waters.

Two BioBarges (BioBarges A and B) were placed at the end of a private dock owned by Waste Management (WM), on the eastern bank of the LDR by the Georgetown Pump Station (RM 3.5, roughly). The other two BioBarges (BioBarges C and D) were placed at the end of a homeowner's private docks on the western side of the river in Tukwila, near the Seattle/Tukwila border (RM 5.5, roughly).

Placement of the BioBarges against the side of docks led to a modification of initial research inquiries, with a new interest in determining how docks that are modified and "softened" by the installation of floating wetlands might provide more benefit to juvenile out-migrating salmon than unmodified docks with hard edges. We chose a control site and reference site at Waste Management (WM) and Tukwila (TUK) to compare fish usage, invertebrate community, and water quality to that of the BioBarges. The control sites were the opposite end of the docks from the BioBarges, representing the anthropogenic shoreline condition. The reference sites were chosen to represent a softer shore location which would emulate the natural shoreline condition. The reference site at WM was across the Slip 4 inlet from the BioBarges at a public viewing point (Figure 2.2.1). This site was a rocky shore (human-made) with overhanging trees. The reference site at TUK was downriver approximately 15 meters from the

BioBarges (Figure 2.2.2). This reference site was a slope with native shrubs and other riparian plants. There was some large woody debris in the river directly in front of the TUK reference site. In the winter of 2020, an interdisciplinary team worked to develop and implement a monitoring program to study the floating wetlands in the Duwamish River at these locations. This program commenced in late March on a highly reduced basis after COVID-19 safety protocols were drafted and approved by the university and research team. Once King County entered Phase 2 of reopening from the pandemic lockdown, the program was expanded back to nearly its full original scope.

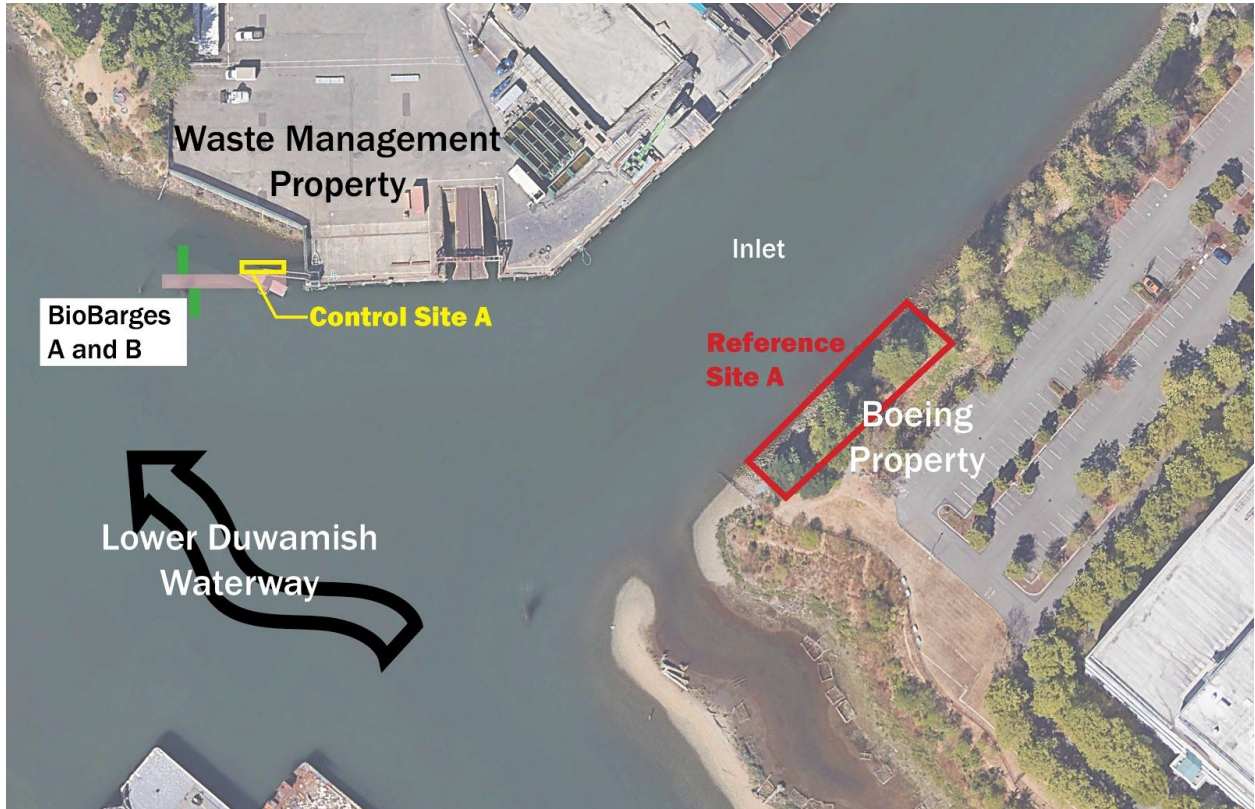


Figure 2.2.1. The location of BioBarges A and B (green rectangles) at the industrial Waste Management site near downtown Seattle. The black arrow designates the direction of the river flow. Biobarge A (top) was moved to the farthest left edge of the dock to protect it from the low tides that initially caused grounding. The control site was upstream of the dock, and the reference site across Slip 4 along a restored shoreline.

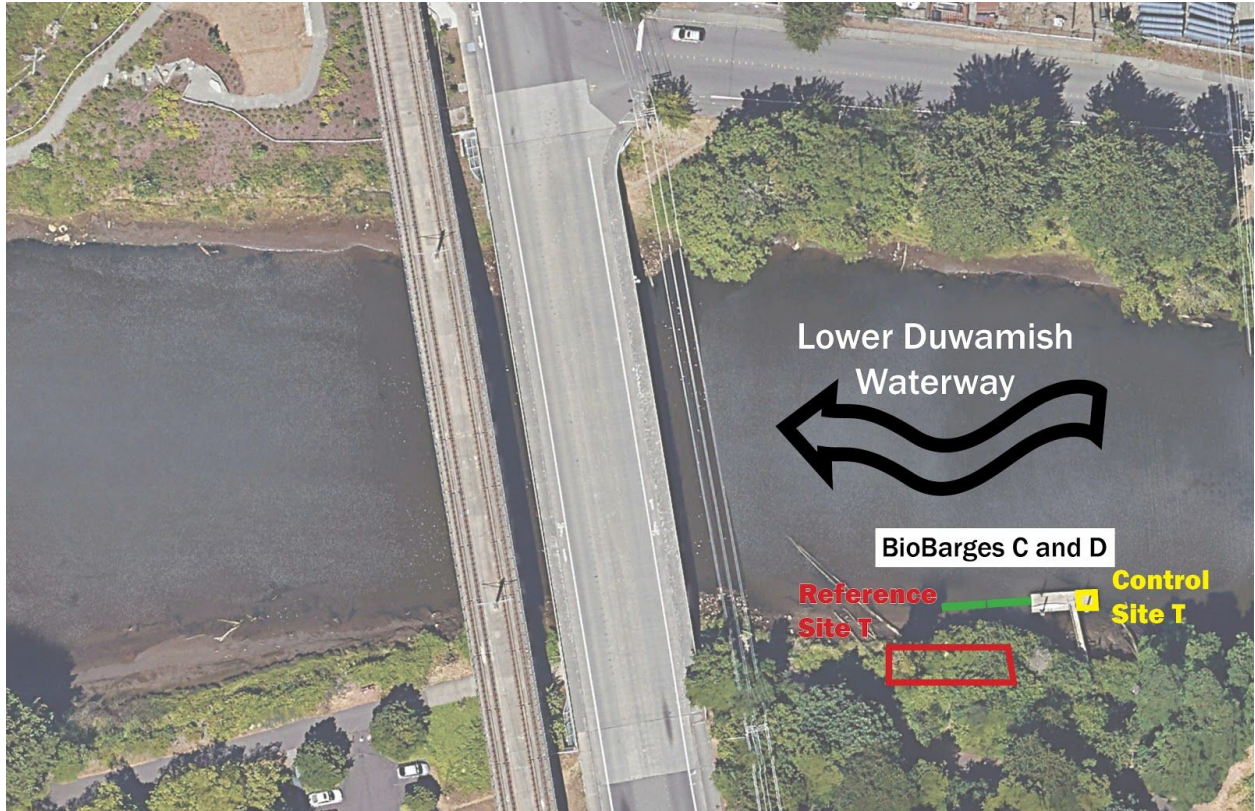


Figure 2.2.2. Locations of BioBarges C and D (green) adjacent to the private dock in Tukwila, Wash. The black arrow designates the flow of the river. The BioBarges were connected to each other to prevent the barges from drifting under the dock on the upstream side from the river current. The fish observation and invertebrate control was on the upstream side of the dock. A dam upriver manages spring runoff from mountain snow.

2.3. Project Area

The project is located in the transition zone of the LDR in Seattle and Tukwila, Washington, between river mile (RM) 3 and 6. The Duwamish River begins at the confluence with the Black River at RM 11 and extends downstream to the river mouth where it meets Elliott Bay. The Duwamish River transition zone extends from RM 9 at the upstream end, to RM 1 (downstream of Kellogg Island) at the downstream end, a reach where salinity levels vary seasonally and with tides. The Duwamish River estuary is vitally important to the region, both as an integral ecological link between the Green River and Puget Sound and as a center of trade and commerce that supports local industry, jobs, recreation, and Washington's economy. The Port of Seattle owns the bed and banks of the Lower Duwamish River, and supports the fifth largest port operation in the US.



FIGURE 2.3.1 - Map of the Lower Duwamish River with River Mile Markers. The base image is from Duwamish Blueprint and it is overlaid with the two research sites in blue.

An estimated 97% of the original marsh, estuarine, and tidal mudflat habitat that made up the Duwamish River estuary has been lost over the past 150 years due to settler-colonial activity that forcibly removed the original inhabitants of the area, the Duwamish Tribe. The shoreline has been dramatically altered: 21,000 feet of shoreline has been lost due to straightening of the channel and 53,000 feet converted to developed shoreline. Only 19,000 feet of vegetated riparian shoreline remains in the Duwamish Estuary (Collins and Sheikh, 2005). The once extensive 3,850 acres of tidal mudflats, marshes, and swamps have been reduced to only 25 acres (USACE, 1997). Decades of industrial pollution eventually led to the lower 5.5 miles of the river being designated an Environmental Protection Agency Superfund cleanup site.

Salmon rear throughout the near-shore coastal estuaries of the Salish Sea. These are some of the most productive ecosystems on the planet, receiving nutrient-rich sediment and water from the freshwater streams that drain the Cascade and Olympic watersheds. The Duwamish Watershed encompasses 480 square miles, supporting salmon and trout as it empties into the heart of Downtown Seattle (EPS). Under natural conditions these estuaries support patchy landscapes of forested uplands, scrublands, and near-shore emergent wetlands. The near-shore emergent wetlands form sinuous edge habitat with colonies of bulrush, sedges, and rushes that tolerate fluctuating tidal changes, mixed fresh and saltwater characteristics, and elevated nutrient runoff in the springtime. In these systems, wetland plants provide an important feeding and refuge habitat for juvenile salmonids. Opportunities for salmon to feed before completing their migration to salt water have been shown to greatly influence marine survival rates (Duffy and Beauchamp 2011).

Decreased habitat quality, fragmentation, and loss of habitat in the estuary and transition zone is a limiting factor for Chinook populations in the Green-Duwamish watershed (WRIA 9 Steering Committee 2005). The transition zone is defined as the area most important for juvenile fish making the physiological transition from freshwater to salt water as they migrate to Puget Sound from upriver. The transition zone encompasses areas that should support increased juvenile salmon survival and life history diversity. These include mudflats, tidal marshes that produce food for fish, and riparian trees and other diverse plants. Creating more transition zone habitat was identified as the top recommendation in the Duwamish Blueprint (Ostergaard, 2014), and is considered to be a critical action for the recovery of Chinook salmon populations in the Green/Duwamish River that are listed as Threatened under the Endangered Species Act. While efforts are underway to reclaim and restore riparian shorelines in order to provide near shore rearing habitat for juvenile salmon, these efforts are confounded by the high costs of land acquisition, remediating contaminated sediments, permitting and regulatory requirements, operation and maintenance. In addition, juvenile salmon must be able to access restored nearshore habitat; narrow channels may restrict access and prevent salmon from gaining the benefits of restoration (Toft and Cordell, 2017).

3. Constructed Floating Wetlands Design

3.1. Design Objectives

Constructed Floating Wetlands (CFWs) are fabricated rafts that float on the water's surface and are planted with native plants. The CFWs provide habitat and surface-area for a wide range of naturally-occurring microorganisms and invertebrates. Under appropriate conditions, it has been shown that as water passes through the CFW, plant roots, bacterial activity and chemical/physical processes can reduce nitrogen levels as well as phosphorus and biological oxygen demand.

Under certain conditions, CFWs have been shown to meet the following core design principles:

- Utilize natural, low-tech treatment technologies;
- Minimize energy use and mechanical system complexity; and,
- Incorporate educational and interpretive value into the system.

The key feature of CFWs is their high surface-area-to-footprint ratio, which enables them to perform functions similar to a natural wetland treatment system, under certain conditions. The larger surface area created by the plant roots increases sedimentation, microbial decomposition, nitrification and denitrification, and alters water chemistry.

CFWs remove pollutants from the water column by four main processes: physical, biogeochemical, microbial and plant utilization. Denitrification by CFWs occurs by producing anoxic conditions through the restriction of oxygen diffusion into the water column and is the primary expected mode of nitrogen removal. Also, roots and plant litter act as sorption sites that develop biofilms which increase denitrification rates and thus nitrate removal rates. Plant uptake is only a small source of overall nitrogen removal.

3.2. Methods for Design, Construction and Prototype Structure Monitoring

A towable pontoon-hull barge design was developed in order to support constructed floating wetlands. These "BioBarges" (Figure 3.2.1) consist of an exterior barge frame constructed of 8" x 2" Alaskan yellow cedar wooden planks, which are attached to 10 inch diameter, corrugated double walled N-12[®] High Density Polyethylene (HDPE) pipe with butt-fused ends, to create a 20' x 10' pontoon-style floating frame. The BioBarges were designed as towable research platforms that can be moved to and used for study in a variety of sites. Each BioBarge had four Wetland Biofilters, free-floating within the interior of the BioBarge, and attached to the frame with bungee straps and carabiners. For the 2020 research season 12 Biofilter 2.0s were added to edges of the Biobarges to soften the edges of the structure, reduce hard shadow edges, and increase plant species diversity on the Biobarges.

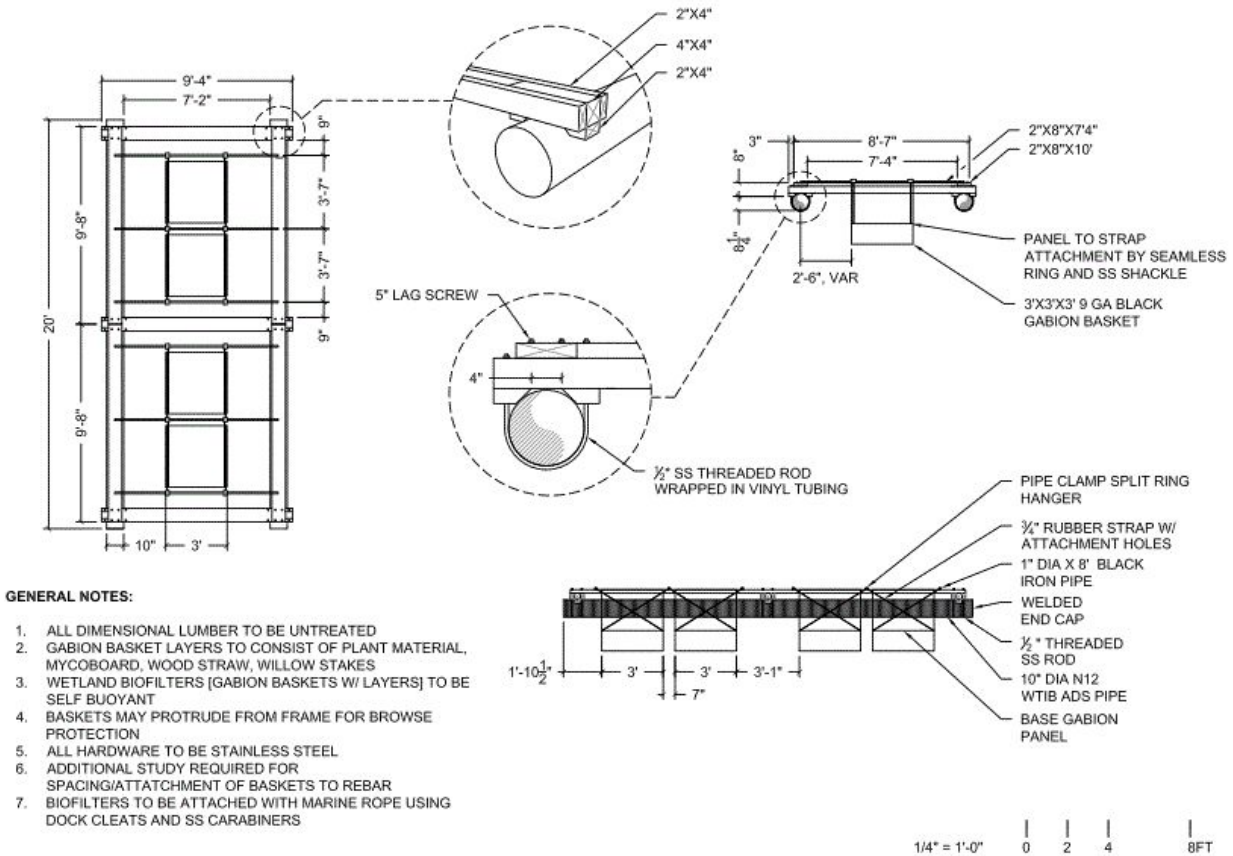


FIGURE 3.2.1 BioBarge design specs with Biofilter 1.0s. (Source: Green Futures Lab)

The BioBarges are capable of supporting four CFW's of approximately 3 feet³ and weighing approximately 300 lbs each (Figure 2). The CFW's consist of buoyant substrates and native bulrush species protected by gabion baskets. They are designed to support emergent and submergent habitat and have the unique capability of providing underwater habitat. The gabion baskets are fabricated of 0.83-meter³ (3-feet³) untreated 16-gauge wire. The gabion baskets provide a durable envelope that protects plants from browse predation by geese and small mammals, allows for their placement in a variety of settings (e.g. adjacent to stormwater outfalls), and also offer protection from aquatic predators.

The Wetland Biofilter 2.0 was designed to be a simplified version of the 1.0, made out of sustainable, easily accessible materials. The Biofilter 2.0 is a 2 feet³ cube constructed from Tensar (Tensar BX1200 Biaxial Geogrid) and filled with ~12 inches of WoodStraw™ and 12 pumice stones, six on each side for flotation, and secured with another layer of Tensar and covered with a Tensar cage 12" higher to complete the cube to prevent plant predation. Sixteen wetland plugs were planted into each Biofilter 2.0s in various configurations. Eight of the Biofilter 2.0s were built with 6" diameter tensar baskets filled with woodstraw for aquatic invertebrate sampling.

The Wetland Biofilter 1.0 was designed to provide a high surface-area-to-footprint ratio to allow plant roots to promote sedimentation, microbial decomposition, nitrification, and denitrification. The matrix

of plant roots and small woody debris within the cage also provides refugia for small fish. The gabion baskets provide a durable envelope that protects plants from browse predation by geese and small mammals, allows for their placement in a variety of settings (e.g. adjacent to stormwater outfalls), and also offer protection from aquatic predators. The substrates consist of materials derived from natural organic matter that provide invertebrate habitat and perform water quality functions, such as chelating and suspended metals. The substrate used within the wetland biofilters include the materials described in Table 1.

Table 1. Descriptions of substrate used for the floating wetlands in the WBF 1.0 prototypes

Substrate	Structure	Function
Sphagnum moss, Usnea lichen	Partially decayed plant matter	packing for plant plugs
MycoBoard™	Fungal mycelium particle board	floatation, plant rhizome anchoring (WBF 1.0)
WoodStraw™ wrapped in burlap	Chipped wood veneer	rooting substrate,
BioFoam™	Air-pop polylactic acid board	Flotation, plant rhizome anchoring (WBF 1)
Willow branches	Native cuttings of willow	‘green brush’ support of periphyton (WBF 1.0)
Pumice Bricks	Rectangle of Pumice	Flotation in WBF 2.0

The Biofilter 1.0s were suspended inside the frame of the BioBarges to occupy 50% of the total open water area, allowing light penetration through the water column for the uncovered areas. This design follows recommendations from the Washington Department of Wildlife and Seattle Department of Construction & Inspections to minimize risks of creating overwater coverage that could adversely affect juvenile salmon by providing ambush habitat for unspecified predators.

The Wetland Biofilters 1.0, shown in **Figure 3.2.2**, consist of 3ft-cubed untreated 16 gauge wire gabion baskets that contained the substrate materials which were layered as follows:

- Four species of Puget Lowland bulrush sourced from Fourth Corners Native Plant Nursery as bare-root and planted into MycoBoard™ with Sphagnum moss packing on 6-inch triangular spacing centers, for a total of approximately 42 plants per Biofilter.
- 3-inches of MycoBoard™; an engineered wood product consisting of wood particles fused together with mushroom mycelium (<https://ecovatedesign.com/>). This material is designed to provide a substrate for the plant rhizomes to anchor into;
- 5-inches of Woodstraw™, an engineered wood-strand (<http://www.woodstraw.com/>). This material is designed to provide a substrate for plants roots to colonize;
- A 2-inch wooden pallet used to support the superior materials;

- 3-inches of BioFoam™, an engineered air-pop foam comparable to polystyrene but derived from biopolymers which are made of vegetable materials (<https://www.synbratechnology.com/biofoam/>). This material provides buoyancy and is biodegradable.
- 6-inches of green brush, or willow branches added to support periphyton growth.

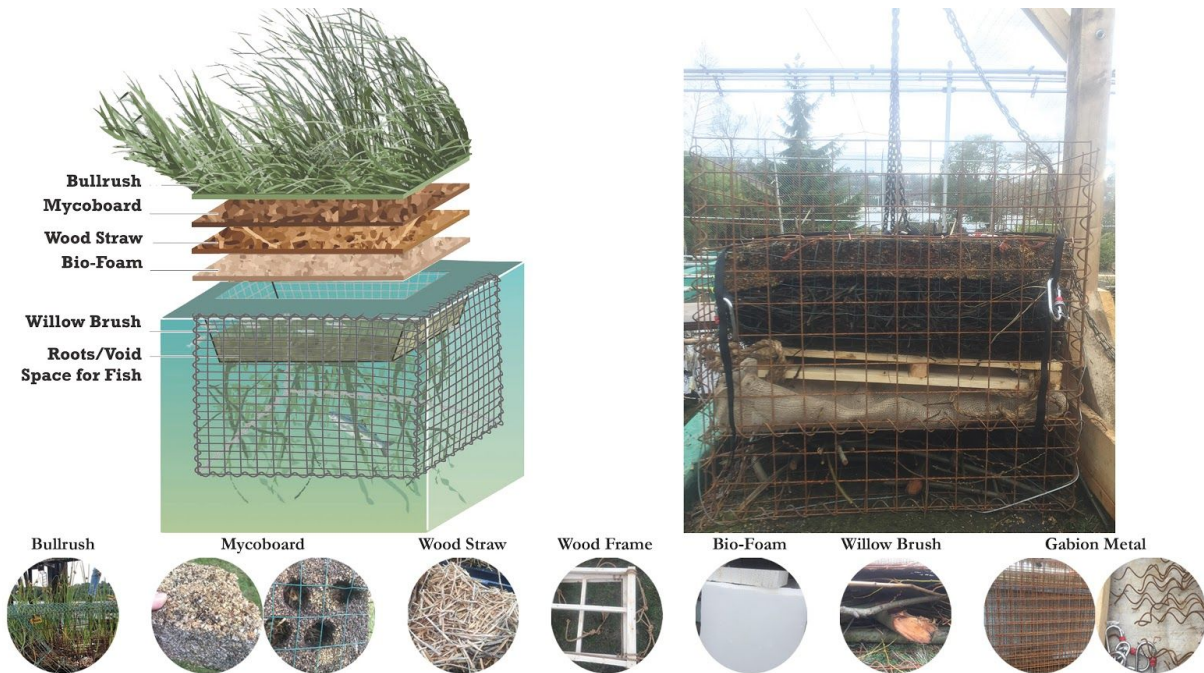


Figure 3.2.2: Wetland Biofilter 1.0

The substrates were designed to support the growth of bulrush, or tule, a rhizomatous wetland macrophyte that includes species endemic to Puget Sound that are capable of tolerating a wide range of salinity, water level fluctuation, water velocities, and sedimentation. Some native tule, such as *Schoenoplectus tabernaemontani*, are capable of growing up to 18-feet tall, as an adaptation to intertidal water level fluctuation (S. Cooke personal communication). Species such as *Schoenoplectus pungens* (also known as *Schoenoplectus americanus*), commonly known as Sweetgrass, also have significant value to Coastal Salish tribes as a heritage fiber used in the production of traditional and ceremonial garments. Bulrush have a long history of use in treatment wetlands, starting in 1957 when Käthe Seidel, a researcher at the Max Planck Institute, successfully demonstrated that constructed wetlands vegetated with *Schoenoplectus lacustris* could clean up polluted water. Most bulrush are also generally unpalatable to predatory browsers like Canada geese.

Sixteen Wetland Biofilters 1.0s were constructed at the University of Washington Hatchery, and planted with four different species of *Schoenoplectus* or *Bolboschoenus*, one species per Biofilter. The wetland plants in the Biofilters were grown in freshwater from June 2018 through April 2019 in outdoor pool

raceways. Between research seasons from August 2019 to March 2020 the Biobarges and Biofilter 1.0s were stored in the river at Harbor Island Marina/T 102.

In the second year of the project, starting in Spring 2020 Biofilter 2.0s were designed and constructed by UW students taking a Landscape Architecture class. Six Biofilter 2.0s, shown in figure 3.2.3, were added to each side of the original Biobarge in order to soften the harsh shadow edge cast by the Biobarge in the water, create a dappled light effect, provide additional invertebrate food source and allow more space to test different wetland plant species. The Biofilter 2.0s were stored at the University of Washington Hatchery, then planted and deployed in the Duwamish River in March 2020.

Plants tested on the WBF 2.0s expanded the species beyond the *Schoenoplectus* and *Bolboschoenus* that were used in year 1 while still keeping within the bulrush family. *Eleocharis*, *Scirpus*, and *Carex* species were tested in the WBF 2.0s. Since mixed results were seen in the highly saline conditions in year 1, a broader range of species were expected to grow the future plant list used on the Duwamish. Monocultures of plants were used to test plant species similar to year 1. Additionally, the species were mixed on some WBF 2.0s to determine if that made a difference in the plant performance.



Figure 3.2.3: Wetland Biofilter 2.0

4. Floating Wetlands Research and Monitoring

4.1. Overview

The 2020 monitoring season of the Biobarges at Waste Management and Tukwila began in March 2020 and ended in July 2020. Despite disruption by the COVID-19 pandemic our team of researchers and community scientists were able to conduct physically distanced, weekly and bi-weekly monitoring of fish, plants, invertebrates and water quality at both sites. The following sections outline the methods and results used in our four categories of inquiry: fish, invertebrates, plants and water quality/heavy metals.

Research Questions for Fish Monitoring:

1. Do juvenile salmonids use Biobarge structures more than the control (dock) or as much as at nearby reference sites?
2. What behaviours do juvenile salmonids exhibit at the Biobarges?
3. Do predatory fish species use the Biobarges as shelter or hunting territory?

4.2. Monitoring Fish Use and Response

4.2.1. Introduction

One of the main goals of the floating wetlands project was to assess the benefits our constructed BioBarges could provide for out-migrating juvenile salmonids and other fish species in the lower Duwamish River. Out-migrating juvenile salmonids, especially Chinook and Coho salmon, rely on freshwater wetlands and riparian habitats for feeding and shelter as they go through the transformation process from parr to smolts (Duffy and Beauchamp 2011). We used weekly overwater fish monitoring and Gopro video sampling to assess differences in juvenile salmonid and other fish presence and behavior at our two Biobarges at each site, compared to a control point representing typical anthropogenic shoreline conditions (dock or bulkhead), and compared to a reference site representing typical soft shore or restored shoreline condition.

4.2.2. Fish Monitoring Method

Overwater Fish Observation

Our fish monitoring program consisted of weekly overwater fish surveys at each site. One researcher accompanied by a community scientist conducted thirty minute observations of the water from both Biobarges, control site and reference site. The observers sat on platforms in the center of the Biobarge

and recorded observed fish within 1.5 meters of the outside of the Biobarge structure. At the control and reference sites the observers stood facing the water and recorded fish observed within 1.5 meters of the shore or dock. The observers recorded the point in the tidal cycle, number of fish sightings, school size, fish species, location within the barge (NA for control and reference) and behaviour of fish. Due to COVID-19 research restrictions, community scientists were first trained in over water fish monitoring protocols and Gopro deployment then conducted monitoring alone from March to June.

Statistical Analysis

Using this data we calculated summary statistics and performed a two-way ANOVA with all fish sightings and salmonid-only sightings comparing the average number of sightings between Biobarge, Control and References sites. We used the ANOVA results to determine whether we observed more fish using the biobarges than the control. In addition, we compared Biobarge to reference sites to see if fish were using the Biobarges as much or more than a restored shoreline area.

GoPro Monitoring

The team deployed GoPro Hero 5 video cameras weekly under one Bio Barge at each site for 2 hour intervals from April 15th to June 21st. The cameras were deployed on the end of a PVC tube, anchored to the middle beam of the Biobarge, extending approximately 1 foot below water pointing perpendicular to the beam and facing upstream. The 2-hour captures were done concurrently with over-water fish monitoring to confirm accuracy of overwater fish identification and give insight into behaviour the observers couldn't see from above. Additionally, community scientists deployed Gopros in 4 hour, 6 hour and 8 hour captures in June and July at both sites to capture salmon behaviour throughout the day and determine if predator fish are using the bio barges for shelter and feeding when observers are not present. Gopros were only deployed at Biobarge B at Waste Management due to the frequency of Bio Barge A hitting the bottom of the river.

Analysis

In order to analyze the Gopro video captures that were taken concurrently with the overwater fish monitoring, we produced a summary table with species and number of fish sighted in the 30-minute over water surveys and species and number of fish sighted in $\frac{1}{4}$ of the 2-hour Gopro video captures. The sighting numbers from the concurrent Gopro captures were divided by 4 to give a metric that is comparable to the overwater fish survey sightings.

The extended Gopro video captures of 4, 6, and 8 hours were watched by the fish research lead and a team of community scientists. The number of fish, species, and behaviour were recorded for each extended Gopro video capture and displayed in a summary table.

4.2.3. Results of Fish Monitoring

Overwater Fish Monitoring

From the beginning of our field monitoring season in April 2020 to July 2020 we observed a total of 224 fish school sightings at the Waste Management site and 103 total sightings at Tukwila. We observed at least 9 species of fish including adult and juvenile Stickleback (*Gasterosteus aculeatus*), juvenile Coho Salmon (*Oncorhynchus kisutch*), juvenile Chinook Salmon (*Oncorhynchus tshawytscha*), juvenile Chum Salmon (*Oncorhynchus keta*), juvenile Pink Salmon (*Oncorhynchus gorbuscha*), juvenile Steelhead (*Oncorhynchus mykiss*), adult and juvenile Shiner Perch (*Cymatogaster aggregata*), Juvenile Sculpin, and Starry Founder (*Platichthys stellatus*).

Barge vs. Control vs. Reference

At the Waste Management site there were overall 65 fish school sightings at Biobarge A and 42 school sightings at Biobarge B. There were 39 sightings at the control site and 78 sightings at the reference site. There were more sightings of fish at the Biobarges than the control dock. However there were more sightings of fish at the reference site. The results of the two-way ANOVA analyses of average fish school sightings per visit at Waste Management, for both all fish species and for just salmonids did not show a statistically significant difference between the number of fish sightings between the Biobarge, control, and reference sites. The p-value for all-fish sightings was 0.364 and for salmonids-only was 0.367; these are both greater than the significance level of 0.05 indicating that it more likely that the differences observed were due to chance rather than due to differences in habitat between the Biobarges, control and reference sites. Figure 4.1 (a) shows boxplots of the number of fish school sightings per visit from the Biobarges, control and reference site at Waste Management and figure 4.1 (b) shows the same but only with the salmonid sightings. Comparing the spread of number of sightings between Biobarge, control and reference, there is substantial overlap when looking at all fish and salmonids only, except for a couple of outliers, 5 and 6 sightings per day for the salmonid-only sightings at the barges.

At the Tukwila site there were overall 31 fish school sightings at Biobarge C and 30 school sightings at Biobarge D. There were 21 sightings at the control site and 21 sightings at the reference site. There were more sightings of fish at both the Biobarges than at the control and reference sites. However, the results of the two-way ANOVA analyses of the mean number of fish school sightings per visit gave us p-values of 0.355 for all fish and 0.561 for salmonids-only; both of these values are greater than 0.05, meaning that these differences are mostly likely due to chance rather than the differences between the Biobarges, control and reference sites. Figure 4.2 (a) shows boxplots of the number of fish school sightings per visit from the Biobarges, control and reference site at Tukwila and figure 4.2 (b) shows the same but only with the salmonid sightings. Comparing the spread of number of sightings between Biobarge, control and reference shows substantial overlap when looking at all fish and salmonids-only.

Table 4.1 Total fish sightings by observation site and type.

Site	Type	Sightings
Waste Management	Barge A	65
Waste Management	Barge B	42
Waste Management	Control	39
Waste Management	Reference	78
Tukwila	Barge C	31
Tukwila	Barge D	30
Tukwila	Control	21
Tukwila	Reference	21

Table 4.2 Statistical tests on average number of fish sightings between Barge, Control and Reference sites (ANOVA Level of significance 0.05)

Fish Species	All Sites	Waste Management	Tukwila
All	0.621	0.364	0.355
Salmonids	0.229	0.367	0.561

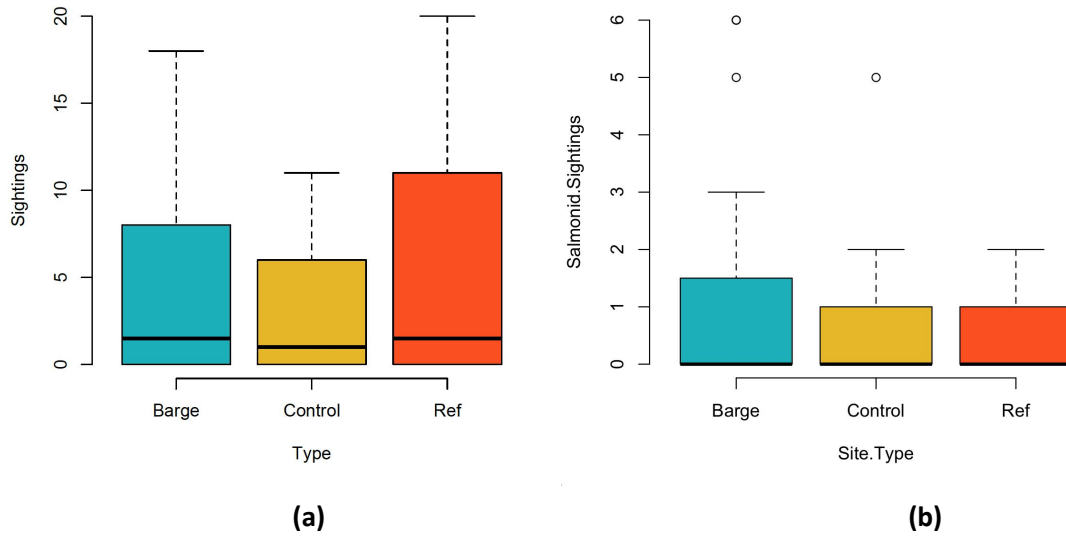


Figure 4.1 (a) Boxplot showing average number of sightings per visit of all fish species at Barge vs Control vs Reference sites at Waste Management and (b) average number of sightings of salmonids in Barge vs. Control vs. Reference Sites at Waste Management.

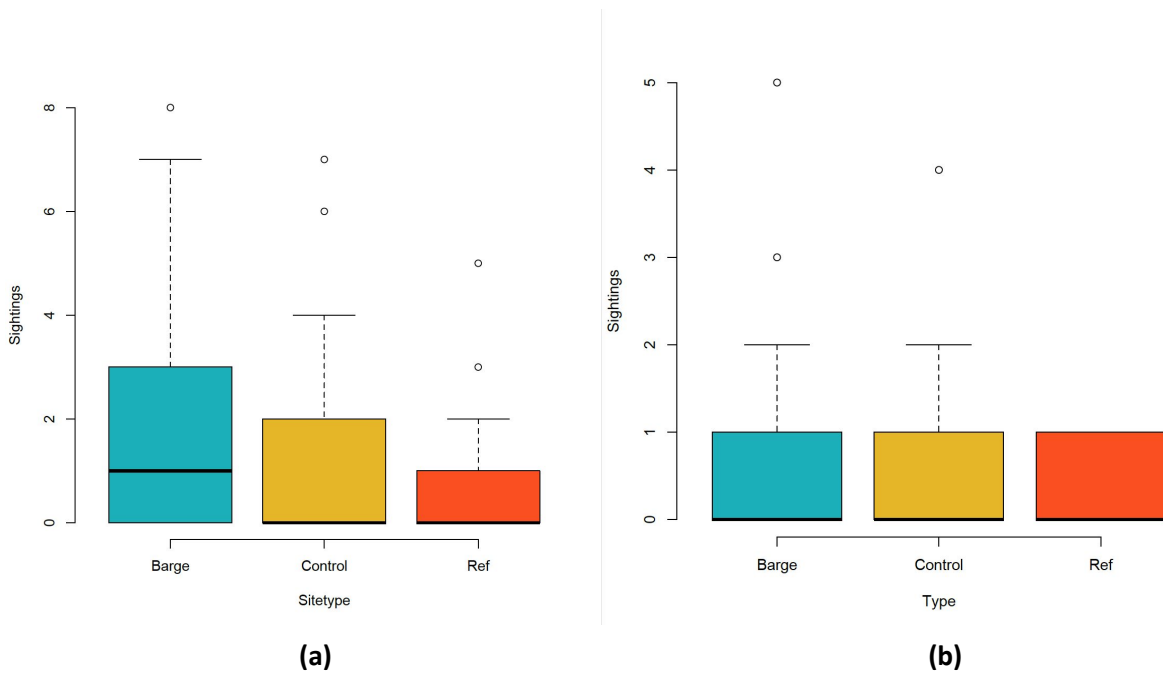


Figure 4.2 (a) Boxplot showing average number of sightings of all fish species per visit in Barge vs Control vs Reference sites at Tukwila and (b) average number of sightings of salmonids at Barge vs Control vs Reference Sites at Tukwila

Seasonality

Focusing on our most common species, in April and May we observed Chum juveniles 15 times at Waste Management (WM) and Coho or Chinook juveniles 8 times at Tukwila (TD). In June the majority of

sightings were Coho or Chinook juveniles with 13 at WM and 21 at TD and adult sticklebacks with 17 at WM and 3 at TUK. In July we observed juvenile and adult sticklebacks 65 times at WM and 46 times at TD with only 7 Coho or Chinook sightings at WM and 3 at Tukwila.

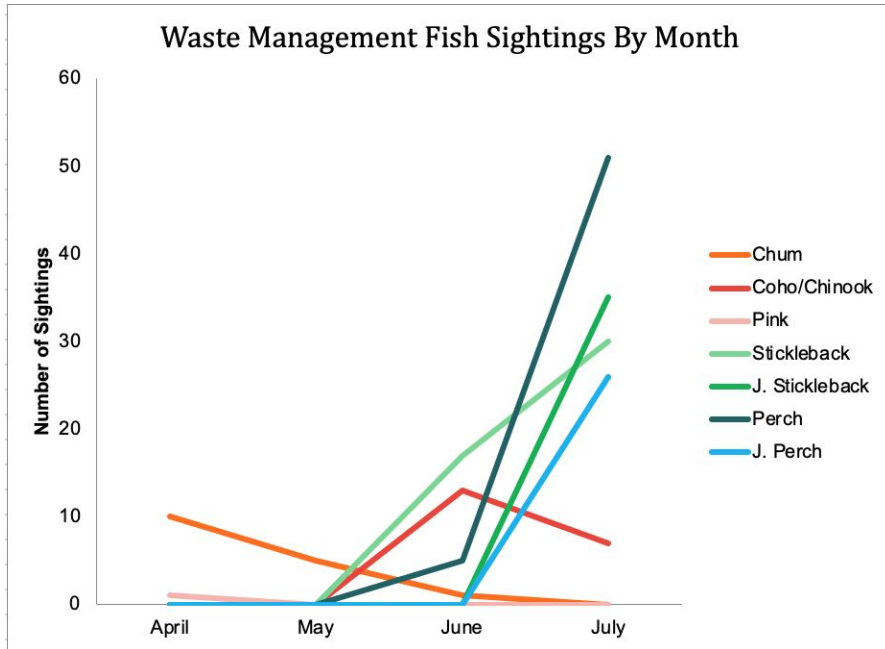


Figure 4.3 Total number of sightings of fish species per month at Waste Management Site (WM).

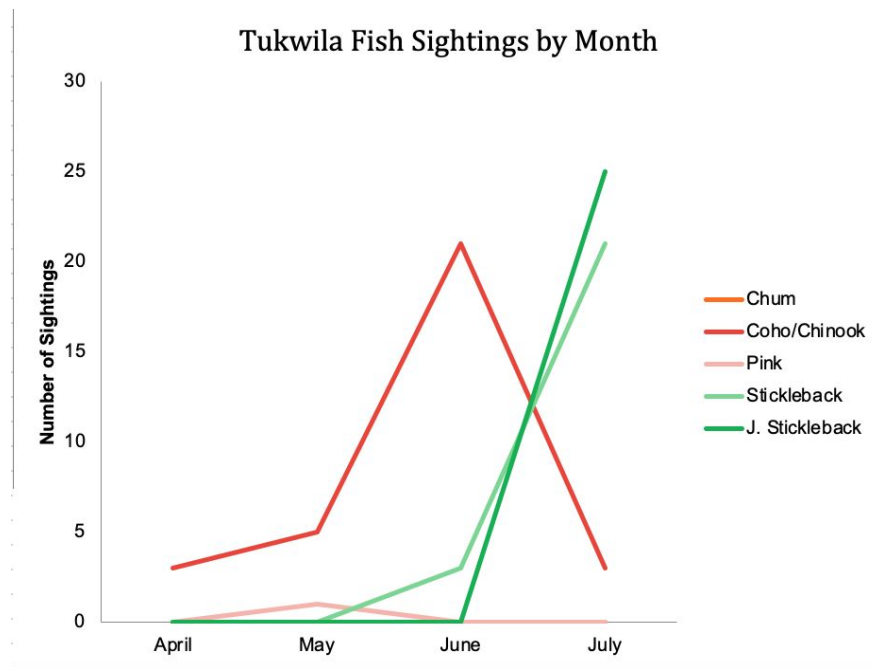


Figure 4.4 Total number of sightings of fish species per month at Tukwila (TUK).

Fish Behavior

From the overwater fish monitoring surveys there were 41 instances of salmonids utilizing the biobarge structure, which we defined as the fish feeding, resting or swimming within the biobarge structure and within 1.5 meters at the edges of the structure which included the biofilter 2.0s. We observed 10 instances of neutral response to the Biobarges which we defined as a fish or school of fish quickly swimming through the structure without pausing to rest or feed and 5 instances of avoidance behaviour which we defined as a fish or school of fish swimming away from the biobarge structure.

Table 4.3 Table comparing total time in minutes salmonids exhibited feeding, resting or swimming behaviour at each site at each observation area type. Barge times divided in half to make them since there were two barges sampled vs one control and one reference at each site.

Site	Type	Feeding (min)	Resting (min)	Swimming (min)
WM	Barge	6.5	28.25	18
WM	Control	29	0	3.5
WM	Reference	0	8	1.96
TUK	Barge	24.25	49	65.5
TUK	Control	28	24.5	44.5
TUK	Reference	71	45	40

Comparing Overwater Fish Monitoring with Gopro Monitoring

We had 14 days of concurrent overwater fish monitoring and gopro monitoring at the Biobarges for 8 days at Tukwila and 6 days at Waste Management. The discrepancy between the number of days at each site was due to technical difficulties and COVID-19 causing delays in research. We did not observe any predatory species, such as the Northern Pikeminnow (*Ptychocheilus oregonensis*) in the Gopro footage.

Table 4.4 Tukwila Overwater Fish Observations vs Gopro Observations Sightings (divided by 4 to give a comparable metric to the overwater monitoring since overwater observations were .5 hours long and concurrent gopro captures were 2 hours long).

Date	Barge	Species	Overwater Sightings	Number of Fish	GoPro Sightings	Number of Fish
4/15/20	D	Coho	1	6		

		Stickleback			.75	.75
		Salmonid			.25	.25
4/22/20	C	Stickleback			2.75	13.5
4/29/20	C					
5/6/20	D	Stickleback			.25	.25
5/13/20	C					
5/27/20	C	Chinook/Coho	1	1	.75	.75
		Salmonid			.25	.25
6/3/20	C	Chinook	1	3	20.75	22.25
		Salmonid			5.5	5.5
		Pink Salmon			.5	.5
		Stickleback			.5	.5
6/3/20	D	Chinook	1	1	12.25	30.75
		Stickleback			4.75	5.5
6/10/20	C	Chinook	1	1	.75	1
		Stickleback			.25	.5
6/17/20	D	Salmonid			.5	.75
		Stickleback			1.5	1.5
7/6/20	C	Chinook/Coho	2			
		Stickleback			.5	.5
		Sculpin	1			
7/13/20	C	Stickleback	3	12	.5	1.25
7/20/20	C	Stickleback	5	90	.75	.75

Table 4.5 Waste Management Overwater Fish Observations vs Gopro Observations Sightings

Date	Barge	Species	Overwater Sightings	Number of Fish	GoPro Sightings	Number of Fish
5/24/20	B	Chinook/Coho			3.25	3.5
		Stickleback			2.75	4.25
		Perch			.75	.75
5/31/20	B	Chinook/Coho			1.75	2.75
		Stickleback			.25	.25
		Perch			.25	.25
6/22/20	B	Chinook/Coho	6	7	0	
		Stickleback	1	1	0	
		Perch	2	2	3	3.75
7/6/20	B	Salmonid	1	20		
		Stickleback	1	2	.25	.25
		Perch			4.25	5.75
7/13/20	B	Stickleback	5	29	1.75	3.5
		Perch	4	5	5.75	8.75
7/20/20	B	Salmonid			.25	.25
		Stickleback	2	20	2.75	3.5
		Perch	3	30	2	2.75
7/27/20	B	Salmonid	0		.25	.5
		Stickleback	4	44	2	2
		Perch	5	32	2.5	4.75

Extended Go-Pro Captures



Figure 4.5 Juvenile Chinook Salmon captured on the extended 8-hour Gopro capture at 6/12/2020 at Tukwila Biobarge D.

From June to July 2020 Go-pro Hero 5 and Gopro Hero 4 were deployed for an extended period of time at the barges at both Waste Management and Tukwila. 8-hour sampling occurred on June 12th, 18th, and 26th at Tukwila and June 13 at Waste Management. 6-hour sampling occurred on July 5th, 19th and 26th at Waste Management. 4-hour sampling occurred at Waste Management on June 21st. The Gopros were deployed using the same orientation used in the 2-hour sampling.

On June 12th the Gopro Hero 5 was deployed by a community scientist at Tukwila Biobarge C from 5:30 AM to 2:30 PM. There were 27 sightings of juvenile Chinook, 6 sightings of other salmonids and 8 sightings of sticklebacks. There were 14 sighted instances of salmonids feeding underneath the Biobarge. A Gopro Hero 5 was also deployed at Tukwila Biobarge D during this time and there were 6 sightings of juvenile Chinook, 12 sightings of juvenile Coho, 25 sightings of Chinook or Coho, 14 sightings of other salmonids, and 5 sightings of sticklebacks. There was one instance of salmonids feeding.

On June 18th the Gopro Hero 5 was deployed by a community scientist at Tukwila Biobarge D from 6:18 AM to 3:18 PM. There were 10 sightings of juvenile Chinook, 2 sightings of juvenile Coho, 2 sightings that were either Chinook or Coho, 6 other salmonids, and 14 sightings of sticklebacks. There were 6 sighted instances of salmonids feeding underneath the Biobarge.

On June 21st a Gopro Hero 4 was deployed by a community scientist at Waste Management Biobarge B and ran for four hours. There was one salmonid sighting, 9 stickleback sightings and 19 perch sightings. Perch sightings tend to be the most common from the waste management extended Gopro captures. There were 6 instances of perch and sticklebacks grazing on algae growing on the Biofilter 1.0.

On June 26th a Gopro Hero 5 was deployed at Tukwila Biobarge C for 8 hours. There were 25 sightings of juvenile Chinook, 32 sightings of juvenile Coho, 18 sightings of other salmonids, 48 sightings of sticklebacks, and 2 adult sculpin. Adult sculpins are possible predators of juvenile salmonids. There were 17 instances of salmonids feeding around the Biobarge, and one instance of a juvenile Coho resting around the Biobarge.

On July 5th a Gopro Hero 4 was deployed at Waste Management Biobarge B for 6 hours. There were 8 sightings of salmonids, 6 sightings of sticklebacks, and 39 sightings of perch.

On July 19 a Gopro Hero 4 was deployed at Waste Management Biobarge B for 6 hours. During this time there were 4 juvenile Chinook sightings, 2 juvenile Coho sightings, 1 salmonid, 15 sightings of sticklebacks, and 133 sightings of perch.

Table 4.6: Fish sightings from extended Gopro video captures

Date	Site	Length of Deployment	Chinook	Coho	Chinook/Coho	Salmonid	Stickleback	Perch	Sculpin	Bass
6/12/2020	Tukwila C	8 Hours	27	0	0	6	8	0	0	0
6/12/2020	Tukwila D	8 Hours	6	12	35	14	5	0	0	0
6/18/2020	Tukwila C	8 Hours	10	2	2	6	14	0	0	0
6/21/2020	WM B	4 Hours	0	0	0	1	9	19	0	0
6/26/2020	Tukwila C	8 Hours	25	32	0	18	48	0	2	0
7/5/2020	WM B	6 Hours	0	0	0	8	6	39		0
7/19/2020	WM B	6 Hours	4	2	0	1	15	133		0

4.2.4. Fish Monitoring Discussion

Our overwater fish observations show that out-migrating juvenile salmon do use the Biobarge structures for shelter and feeding. During our observation period we saw salmonid species swimming, feeding and resting around our Biobarge structure 41 times. Additionally, later in the season, juvenile and adult Stickleback and Perch used our Biobarge structures extensively for shelter and feeding. However, at both Waste Management and Tukwila the ANOVA results showed that there was not a significant difference between the number of fish sightings and salmonid-only sightings between our barge, control and the reference sites. Likewise with the overwater behavioural observations the salmonids did not spend statistically significantly more time at the barges feeding and resting than at the control and reference sites. However, at Tukwila and Waste Management salmonids did spend more time resting and swimming at the barge compared to the control and the reference site. This indicates that salmonids and other fish species in the Lower Duwamish River did use the Biobarges as habitat, however the data suggests that they did not preferentially spend time at the Biobarges compared to the control and reference conditions. Table 4.3 further shows this since at Waste Management salmonids spent 29 minutes in total feeding at the control and only 6.5 minutes feeding at the barges. The control was the other end of the dock from the Biobarges and fish were seen feeding on algae and periphyton growing on the sides of the dock in the control site. Likewise at the Tukwila site salmonids spent 28 minutes feeding at the control, this is because the salmon spent a lot of time in the shallow spot along the dock foraging and swimming. This may be because the flow was optimal for them or it was easy for observers to see the fish here since there were no obstructions and the water was shallow. This is an area for further studies to investigate since there were more sightings of fish at the Biobarge structures but there was no statistically significant difference. Using more sites and replicates could help elucidate what kinds of rearing habitat juvenile salmonids prefer and benefit from in the Green/Duwamish River. Furthermore, further research can aid in design modifications to artificial floating wetlands structures to better improve habitat conditions for out-migrating juvenile salmon.

Our field monitoring season began on April 9th and continued to July 27th 2020. At Waste Management, Chum and Pink salmon sightings peaked in April and declined to zero in June. Sightings of Coho and Chinook peaked in June. Sticklebacks increased from May to July. Adult and juvenile perch and juvenile Sticklebacks increased greatly starting in June to July. At the Tukwila site sightings of Pink salmon peaked in May. Coho and Chinook sightings peaked in June and declined in July. Adult and juvenile sticklebacks increased from June to July. The sighting patterns are mostly consistent with previous studies and the life history patterns of salmonids and other fish. June and July are the breeding seasons for Sticklebacks and Perch, therefore we saw many more juvenile sticklebacks and perch in July. Plots of the fish frequency and timing can be found in figures 4.3 and 4.4.

In a previous study on out-migrating juvenile salmonids in the Green/Duwamish River the authors found that juvenile Chum salmon were most abundant in April, pink salmon in March and April, wild Chinook salmon in April, and hatchery Chinook salmon in late May (Toft & Cordell 2016). In our study we saw a similar pattern with Chum and Pink salmon spotted early in the season in April and May, however in our

study, sightings of Chinook peaked in June instead of April and late May. This could be due to the learning curve of our Community Science observers (observing independently due to Covid-19) at the beginning of our monitoring period making it so that at the beginning they did not spot the Chinook that are typically further down in the water compared to the Chum and Pink juveniles that practice more surface-oriented feeding. Ideally our monitoring period would have begun in early March instead of early April to ensure that we could observe the true peak of Chum and Pink out-migrating season. In future studies the Biobarges should be deployed earlier or kept in the river all year long to provide most benefit to the out-migrating juveniles of all species.

Go-Pro Monitoring

In order to more fully understand how juvenile salmonids and fish interact with and benefit from the Biobarge structures our team deployed Go-pro cameras beneath the Biobarges. These cameras were deployed to find out whether there were diurnal patterns of fish usage and whether the biobarge structures were used by predatory fish as shelter to hide and prey upon out-migrating juvenile salmon. Additionally, we deployed Gopros at the same time as our over-water fish monitoring sessions to understand if the overwater monitoring method is an accurate and effective way to monitor fish usage of artificial wetlands, given that overwater fish monitoring has visibility issues and is quite difficult for beginners to learn.

Overall, the concurrent Gopro monitoring sessions had more sightings of fish and more species recorded than the concurrent overwater fish monitoring periods. For example, on June 6th at Tukwila Biobarge D the overwater fish monitoring yielded one sighting of one Chinook whereas, the concurrent gopro footage for 30 min contained 20.7 sightings of chinook with 22.25 individuals total, 5.5 sightings of unidentified salmonid with 5.5 individuals total, .5 sightings of Pink with .5 individuals total and .5 Sticklebacks with .5 individuals total. This discrepancy in species and number of individuals sighted could be due to difference in training or understanding of community scientists conducting the overwater monitoring or analysis of Gopro footage. This discrepancy could also be caused by the different vantage point between the overwater observers and the gopro; furthermore certain species of fish prefer to use different areas of the water column. For example, Pink and Chum Salmon and juvenile Sticklebacks are surface oriented feeders, contrastingly Coho and Chinook Salmon and Perch typically feed a bit deeper in the water column. Due to the different vantage points provided by the over-water monitoring and extended data collection possibilities of the Gopro cameras, both of these techniques for fish monitoring are useful to understanding how fish use floating wetland structures.



Figure 4.7 Chinook juvenile feeding next to a Biofilter 1.0.

From the extended Gopro footage captures there were 41 instances of juvenile salmonids feeding under our Biobarge structures and 54 instances of sticklebacks feeding on periphyton on the barges. Additionally, adult perch were seen 26 times sheltering and swimming inside of the Biofilter 1.0 structure space, below the substrate. All of these observations indicate that salmonids, sticklebacks and perch use the biobarge structures for feeding and sheltering.



Figure 4.8 Sculpin entering Biofilter 1.0 at Tukwila captured on Gopro on June 26th 2020.

In the 48 hours of extended Gopro video captures we observed only two instances of a possibly predatory fish, sculpin, entering the biobarge structure. A small sculpin was also found swimming out of a WBF 1.0 when the BioBarges were disassembled. We did not observe any other predatory fish species such as the Northern Pikeminnow, Largemouth Bass, and Smallmouth Bass. This indicates that these predatory species would not preferentially use the Biobarge floating wetland structures as territories for feeding, meaning the structures do not pose a substantial threat to juvenile salmon. In addition there

was no obvious pattern in time of day of fish usage or behavior around the barge structures. Some studies have shown that juvenile salmonids make most of their downstream migration movements at night time, with a study from the Columbia River concluding that 80.7% of Chinook juveniles, 88.6% coho, 78.3% sockeye juveniles passed during night time (Dean et al. 2011). This may be the reason why most of our salmonid sightings were small numbers of chinook and coho feeding rather than large schools of juveniles migrating downstream. In future studies, it would be beneficial to deploy cameras with night time capabilities or use hydroacoustic cameras to monitor the salmon's nighttime usage of the barges. In the future it may be a possibility to deploy a Juvenile Salmon Acoustic Telemetry System (JSATS) to more accurately monitor salmonid behavior in the vicinity of the biobarges (assuming the hatcheries upstream tagged them with PIT (Passive Integrated Transponders) tags or coded wire tag data. This would help track which juvenile salmonids are using the wetland structures and which populations may be drawing benefits from them.

4.3. Invertebrate Monitoring

4.3.1. Introduction

A large percentage of salmon diet within the Duwamish River is composed of aquatic and terrestrial invertebrates (Cordell et al. 2001, Cordell et al. 2011). In this study we used Fallout Traps for collecting terrestrial invertebrates and substrate Plugs to collect aquatic invertebrates. The purpose is to measure the extent that our floating wetlands impact the taxonomic richness and overall abundance of this food source, and to compare that data with measurements taken at proximal hardened sites and restored shorelines.

Research Questions for Invertebrate Collection

- How do terrestrial invertebrate taxa richness and individual abundance differ between our control site, our restored site, and our biofilter 1.0s?
- How do aquatic invertebrate taxa richness and individual abundance differ between the Waste Management and the Tukwila sites? How do they differ partway through monitoring versus the end of the monitoring period?

4.3.2. Methods

Terrestrial Invertebrate Sampling Approach

Terrestrial invertebrates were collected each week over the course of our monitoring period, between May 24th, and July 26th, 2020. Collection was alternated biweekly between the Waste Management (WM) and Tukwila (Tuk) sites for a total of five sample dates at each site. 24 hours before each collection date 15 fallout traps (0.34m by 0.21m plastic bins) were placed at that week's site, five each at

the Control, Biobarge, and Restored locations within the site. Each fallout trap was filled with enough water to fully submerge a brick placed within for stability (at the Control and Restored locations), and a few drops of unscented, biodegradable dish soap to kill the invertebrates. It should be noted that two dates of samples were collected prior to May 24th, but were not included in analysis as the collection method was still being finalized for fieldwork.

Fallout Trap Placement

At WM five fallout traps were placed randomly among 12 predetermined positions on the outside of Biobarge-B's WBF 1.0s using bungee cables, as seen in figure 4.3.2.1 below. Each trap was placed high enough above the water line to not risk becoming swamped due to wave action.



Figure 4.3.2.1: Fallout trap randomization locations at Waste Management Biobarge-B.



Figure 4.3.2.2: A community scientist demonstrating fallout trap attachment to a biofilter 1.0.

At WM, the base of the floating dock was chosen as the Control location, as seen outlined in yellow in figure 4.3.2.3 below. The fallout traps were placed equidistantly apart along the edge of the dock and weighed down with bricks to prevent spillage during high winds or high wave action.



Figure 4.3.2.3: Control (yellow), Biobarge (green), and Restored (red) location at WM site.

Five fallout traps were placed along the shoreline, across the water from the biobarges at our Restored location, Reference Site A on the Boeing property, outlined in red above. The traps were placed equidistant apart near existing vegetation, above the high water line to prevent loss or flooding, and weighed down with brick.

At the TD site five fallout traps were randomly placed around the 12 predetermined positions on the WBF 1.0s on Biobarge-D using bungee cables and above the water line, as seen in figure 4.3.2.4 below.



Figure 4.3.2.4: Fallout trap randomization locations at Tukwila Biobarge-D.

The Control location at TD was located on the east end of the dock, upstream from where the Biobarges were situated, outlined in yellow in figure 4.3.2.5 below. Five fallout traps were placed equidistant apart and weighed down with bricks, as the WM setup.



Figure 4.3.2.5: Control (yellow), Biobarge (green), and Restored (red) locations at TD site.

Reference Site 1 at TD served as our Restored location, outlined in red in figure 4.3.2.5 above. Five fallout traps were placed near vegetation, above the high water line, and weighed down with brick, as

the WM setup. It should be noted that the restored location at TD has a higher density of vegetation than the restored location at WM.

Terrestrial Invertebrate Sample Collection

During collection the content of each fallout trap was strained through a 106-micron (0.106 mm) sieve and washed into a sample jar where it was fixed using a 50:50 Propanol/Water solution. We would typically use 70% isopropyl alcohol as a fixing agent, but supply constraints due to Covid-19 forced us to make this substitution. All sample jars were stored at room temperature in the lab until they could be processed. On June 7th and again on July 19th, 2020 one fallout trap from WM Biobarge was lost during collection due to spillage.

Terrestrial Invertebrate Sample Processing and Analysis

Invertebrate samples were identified to family where possible. In some cases identification to superfamily or order was required because of limitations in taxonomic expertise and/or the quality and condition of the sample.

An excel spreadsheet was created where we listed the Date Collected, Site (WM or Tuk), Location (Control, Biobarge, or Restored), Taxa observed, and Count of invertebrates collected. The average taxa richness and average invertebrate abundance was then calculated and compared for each site location. Here, average taxa richness for each location is the sum of the taxa collected on each date divided by the number of sampling dates for that site (five). Average invertebrate abundance for each location was calculated by summing the total number of individual animals collected on each date and dividing the total by the number of sampling dates for that site (five). This tells us the variety of taxa observed and the quantity of invertebrates found at each site.

Aquatic Invertebrate Sampling Approach

Aquatic invertebrates were collected from substrate plugs built into eight of the WBF 2.0s, and from the substrate of WBF 1.0s. The plugs were placed in two WBF 2.0s on each barge corresponding with the *Carex obnupta* (CXOBNA) plants, as seen on figure 4.3.2.6 below. Half of the WBF 2.0s were collected between June 29th and July 1st, 2020, for the early sampling, and the other half were collected between July 27th and July 31st, 2020, for the late sampling.

WBF 1.0s were collected from biofilters corresponding to the *Schoenoplectus acutus* (SCHACU) plants, as seen on figure 4.3.2.6 below, on July 28th and July 29th, 2020 for Biobarages A and B, and then again between August 14th and August 27th, 2020 for Biobarages C and D, coinciding with the Biobarge decommission dates.

Biobarge A Layout

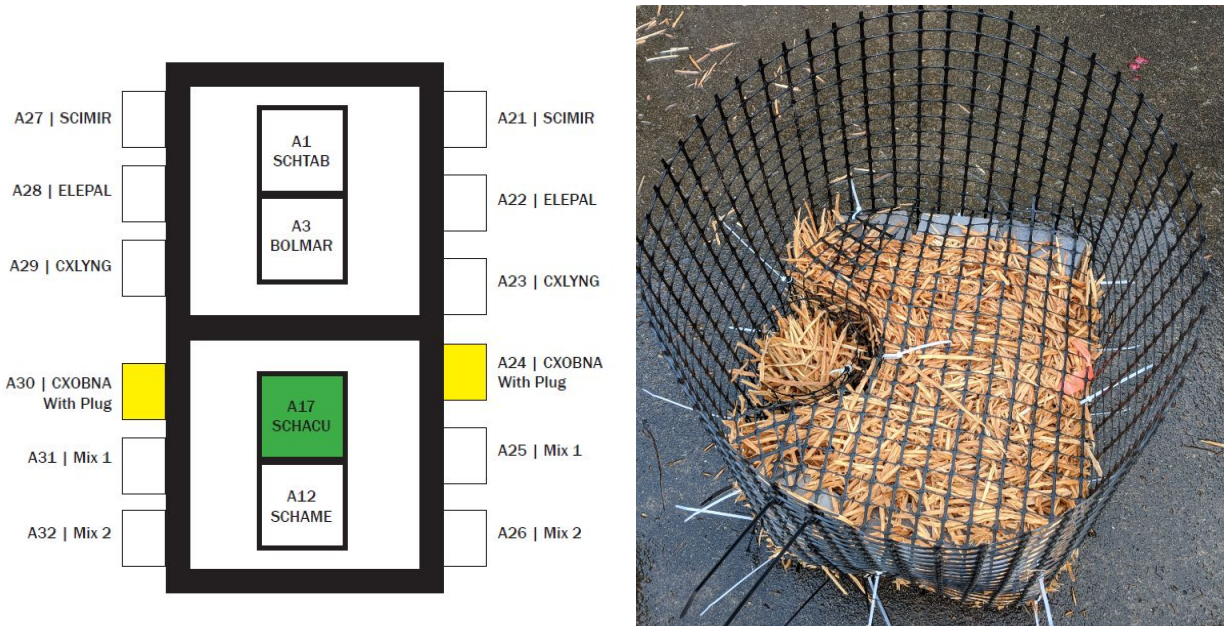


Figure 4.3.2.6: Left - Invertebrate plugs located in WBF 2.0s associated with CXOBNA plants (highlighted in yellow) and in WBF 1.0s associated with SCHACU plants (highlighted in green). Right - Invertebrate plug in WBF 2.0.

Aquatic Invertebrate Plugs and Sampling

During construction a 6"-diameter section of each WBF 2.0 was removed and replaced with a comparably-sized plug composed of the same 2.0 woodstraw substrate and sealed within its own Tensar cage. The plugs were then placed within the parent WBF 2.0 for the duration of their sampling period, after which they could be removed for aquatic invertebrate analysis without damage to the biofilter or disturbance of the remaining biota.

Invert plugs were removed from WBF 2.0s by using garden shears to sever the zip-ties holding the Tensar cages in place. Each plug was lifted from the biofilter, while a 106-micron sieve was held underneath to catch any escaping invertebrates. The substrate was then removed from its tensar cage and placed into a large, sealable plastic sample bag, which the sieve was then rinsed into. Sample bags were transported to the lab and frozen to preserve the invertebrates until processing.

It should be noted that both invertebrate plugs were mistakenly collected during the early sampling period from Biobarge-D on July 1st, 2020 at TD. Both Biobarge-C plugs were subsequently collected during the late sampling on July 31st, 2020 at TD to maintain consistency of two plugs per sample date.

Aquatic Invertebrate Sample Processing and Analysis

Prior to processing, sample bags were thawed in a refrigerator over a period of several days to make rinsing and separating easier. Three sieves of increasing mesh size (125-micron, 500-micron, and 2000-micron) were stacked, and the plug substrate was placed in the top (2000-micron) sieve and thoroughly rinsed with cold water. Rinsed substrate larger than 3cm was removed from the sample and discarded into a compost bin, leaving three separated size-ranges of invertebrates (125 – 500-micron, 500 – 2000-micron, and 2000+ micron) remaining, as well as small (< 3cm) fragments of substrate.



Figure 4.3.2.7: Left - Stacked sieves with substrate, Right - Folsom Plankton Sample Splitter.

After separation, each sieve was rinsed into a separate sample jar; each of which was labeled as SubSample-1 (SS1). Each sample jar was then diluted to 500 mL and the sample was split using a Folsom Plankton Sample Splitter. Each sample was then diluted again to 500 mL and split, becoming SubSample-2 (SS2); each of which represented $\frac{1}{4}$ of the original sample for that size range.

After splitting the 2000-micron SS2s were identified and tallied. The 125-micron and 500-micron SS2s were again diluted to 500 mL, and a 10 mL SubSample-3 (SS3) was collected from each diluted SS2 using sample pipettes. Each SS3 represented $\frac{1}{50^{\text{th}}}$ of its associated SS2 sample, which again represented $\frac{1}{4}$ of its associated parent sample, making each SS3 represent $\frac{1}{200^{\text{th}}}$ of the parent 125 or 500-micron sample. Given the expected abundance of aquatic invertebrates this method was essential for ease of identification and counting. The SS3s were placed in a sampling dish and then identified and tallied, after which each sample was placed into a sample jar and fixed using a 50:50 Propanol/Water mixture.

An excel spreadsheet was created where we listed the Date Collected, Site (WM or Tuk), Location (which biofilter on which Biobarge), WBF (1.0 or 2.0), Size (125-micron, 500-micron, or 200-micron), Taxa, and Count of invertebrates collected.

From Count we calculated the Total Estimated Abundance (TEA), multiplying the Count of each size range by the proportion of the parent sample it represented (125-micron and 500-micron Counts were multiplied by 200, 2000-micron Counts were multiplied by 4). TEA was then used to calculate taxonomic distribution using a temporal and spatial comparison for the 2.0s between early and late collection, and between WM and TD, respectively. For the 1.0s TEA was used to compare taxonomic distribution spatially between WM and TD. Because the 1.0s had been in the field for a year longer than the 2.0s, it was not feasible to make a comparison between the invertebrates preference for 1.0 vs 2.0 substrates.

4.3.3. Results

Terrestrial Invertebrates

Table 4.3.3.1: Total Count of terrestrial invertebrate taxa and Individuals by site location and date.

Site by Date	Control Taxa	Control Individuals	Biobarge Taxa	Biobarge Individuals	Restored Taxa	Restored Individuals
WM 5/24/2020	16	51	10	46	25	59
Tuk 5/31/2020	12	40	7	26	22	119
WM 6/07/2020	6	7	12	32	20	53
Tuk 6/14/2020	15	37	10	38	28	82
WM 6/21/2020	9	31	25	117	26	89
Tuk 6/28/2020	9	35	11	115	32	209
WM 7/05/2020	9	12	14	36	22	53
Tuk 7/12/2020	8	16	13	45	25	139
WM 7/19/2020	11	19	6	11	24	195
Tuk 7/26/2020	10	16	15	54	12	112

Aside from at the Biobarges, the locations at the TD site appear to have higher taxonomic richness than corresponding locations at WM, and all TD locations show higher invertebrate abundance. Overall richness and abundance appear greater in Restored locations than at Biobarges, and greater at Biobarges than at Control locations. Table 4.3.3.1 was used to create Figure 4.3.3.1 and Figure 4.3.3.2 below, which show the average taxa richness and invertebrate abundance, respectively, for each site location.

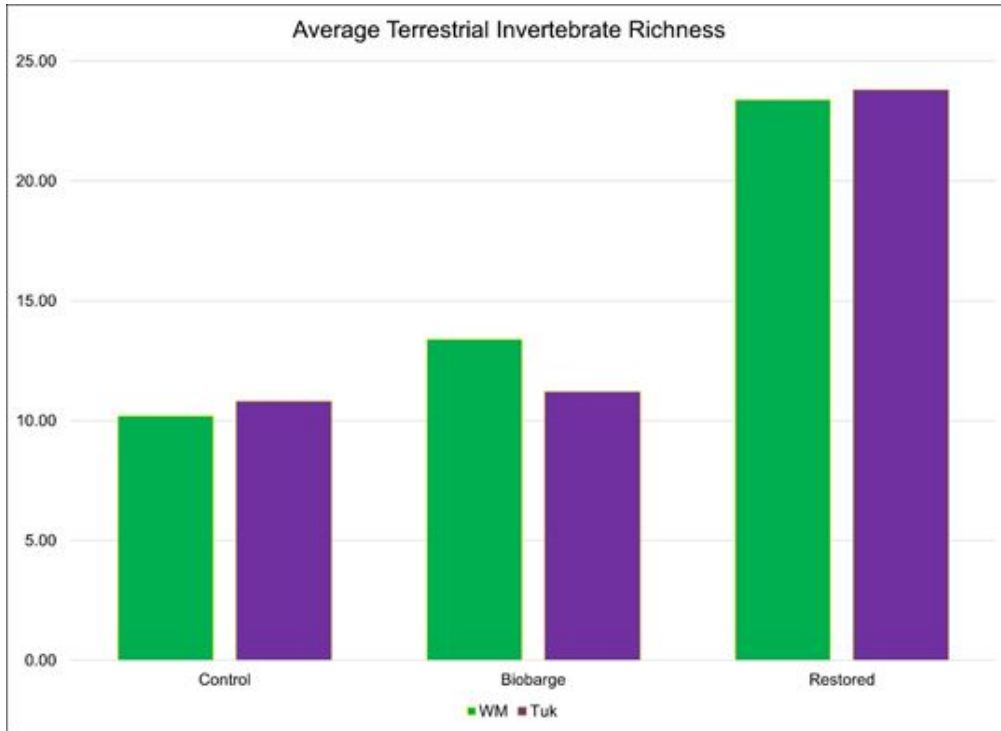


Figure 4.3.3.1: A comparison of Average Terrestrial Invertebrate Richness between site locations.

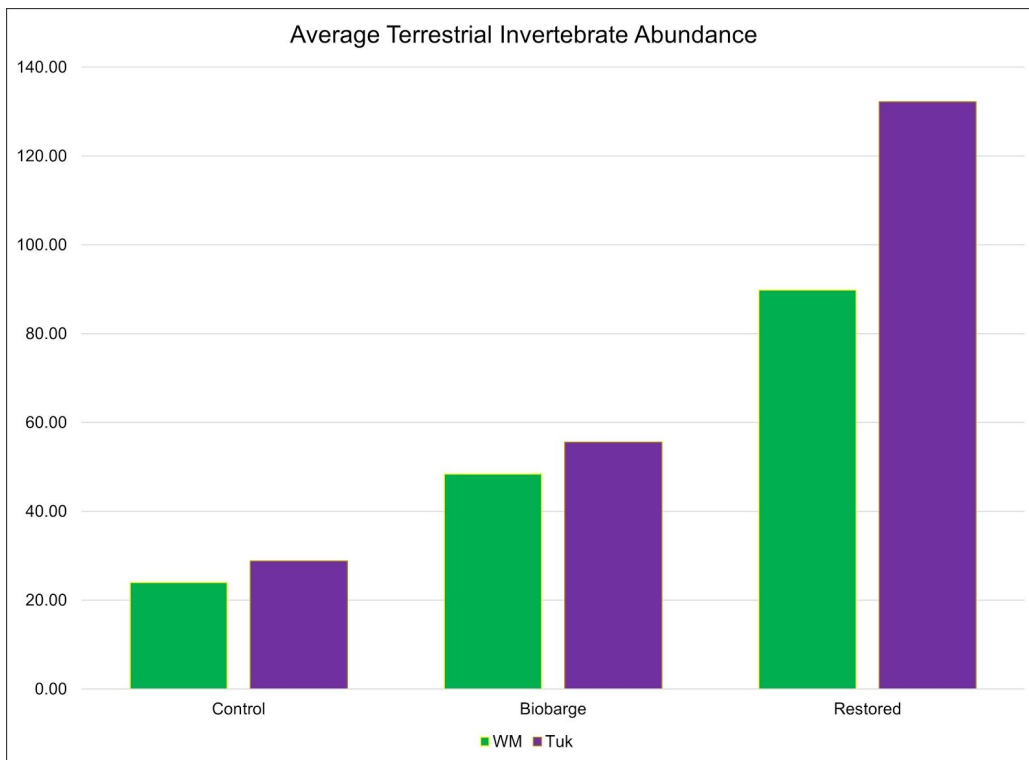


Figure 4.3.3.2: A comparison of Average Terrestrial Invertebrate Abundance between site locations.

Table 4.3.3.2: p-value comparisons of taxa richness and invertebrate abundance between sites and locations.

	WM Richness p-values	TD Richness p-values	WM Abundance p-values	TD Abundance p-values
Control vs Restored	0.000281531	0.015407512	0.048219135	0.009184023
Biobarge vs Control	0.407259255	0.833209834	0.250817598	0.16343699
Biobarge vs Restored	0.031078425	0.018089476	0.239825601	0.022721496

To determine if the trends shown in figures 4.3.3.1 and 4.3.3.2 had any statistical significance, an Anova and accompanying t-tests were used to assess any difference between the means. We expected the lower p-values shown between the Control and the Restored locations, but we saw that despite the observed trends, the increase in taxonomic richness and individual abundance between Control and Biobarges at both sites was not statistically significant.

Figure 4.3.3.3 below shows average invertebrate abundance by site location, with the composition of the major invertebrate taxa displayed as a percentage of the whole. While figure 4.3.3.2 above allowed us to see the overall abundance trend, it was important to assess how much of that abundance was composed of invertebrates that were a potential food source for the salmonids.

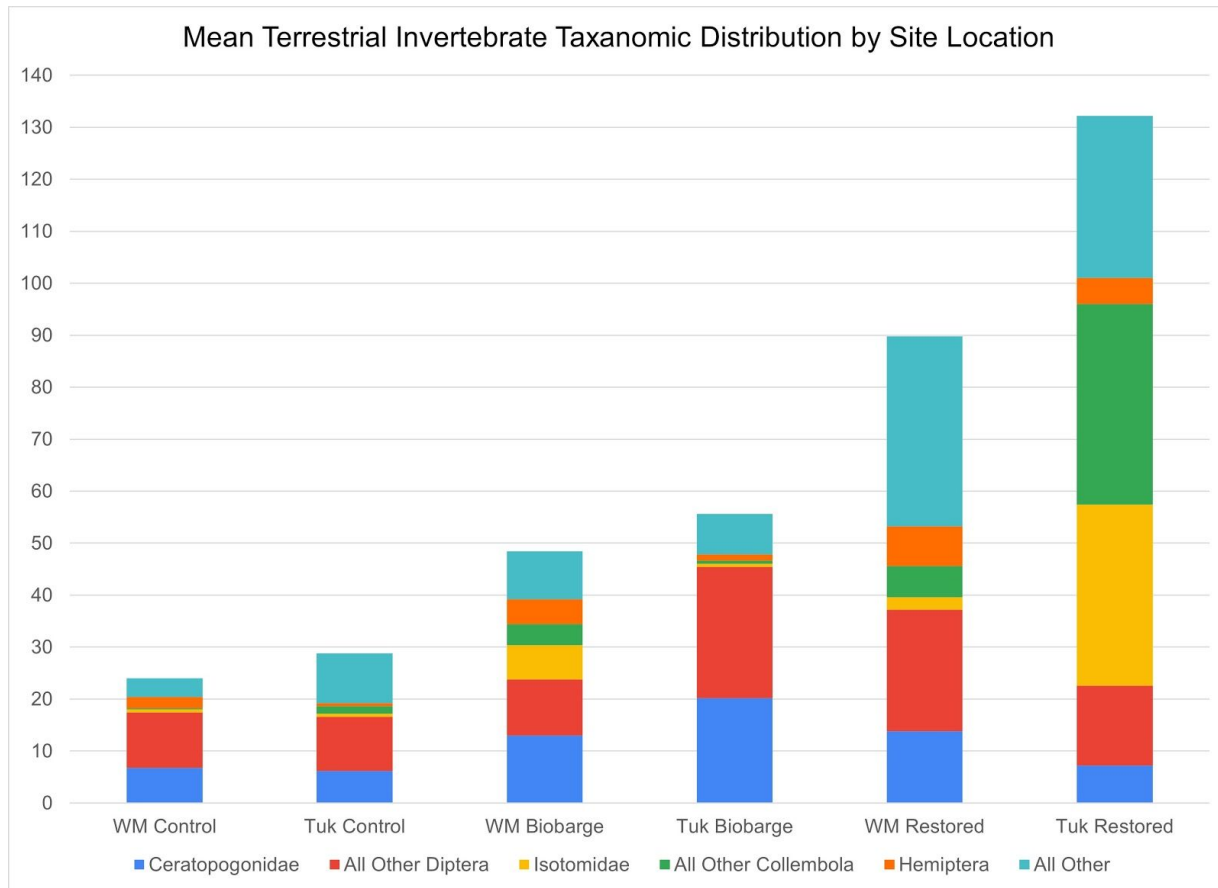


Figure 4.3.3.3: Average terrestrial invertebrate taxonomic distribution by site location.

Looking at figure 4.3.3.3 we see that Ceratopogonidae and All Other Diptera, the most common salmon food source, are the most abundant invertebrates at almost every site location, with higher abundance of Diptera at the Biobarges than the Controls at both sites, and higher abundance of Diptera at the Biobarges than at the Restored location at TD. The next step was to determine whether there was any statistical significance to this observation, shown in table 4.3.3.3 below. This table shows all p-values above a 0.05 threshold. Since what was seen above was trending in a way that showed a higher presence of Diptera at the Biobarge than at the control but no statistical significance was shown, it can be hypothesized that there was an abundance threshold that the study did not meet to allow the p-values to show significance. Further research on this abundance threshold needs to be done to determine how many samples we need to have statistically significant results.

Table 4.3.3.3: p-value comparison of average Diptera abundance between site locations. No significant difference between Diptera abundance was observed.

	WM Diptera Abundance p-values	TD Diptera Abundance p-values
Control vs Restored	0.057746142	0.417302208
Biobarge vs Control	0.59772726	0.0844016
Biobarge vs Restored	0.27433027	0.170254332

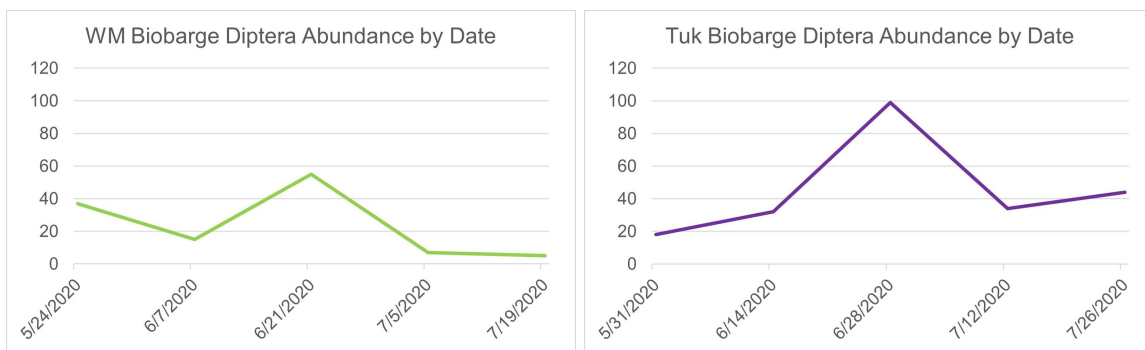


Figure 4.3.3.4: A comparison of Diptera abundance between WM and TD Biobarges. Between 6/21 and 6/28/2020 a noticeable spike in abundance occurs at both sites.

Aquatic Invertebrates

Contrary to what we saw for terrestrial invertebrates, at WM we observed a higher abundance of aquatic invertebrates than at the TD site. Figures 4.3.3.5 and 4.3.3.6 below show that early monitoring of aquatic invertebrates saw copepods as the most abundant taxa throughout the monitoring period at both sites, though their abundance was greater at WM than TD for both the 1.0 and 2.0 WBFs. In the WBF 2.0s Diptera saw a high abundance during early monitoring, but saw a decline by late collection. Corophiidae saw high abundance in WM 2.0s both early and late into monitoring, but abundance was low in WBF 1.0s. Conversely, Corophiidae saw low abundance at TD 2.0s during the breadth of monitoring, but saw high abundance in TD 1.0s. Gammaridae was relatively consistent throughout monitoring in WBF 2.0s, but was noticeably absent at WM 1.0s.

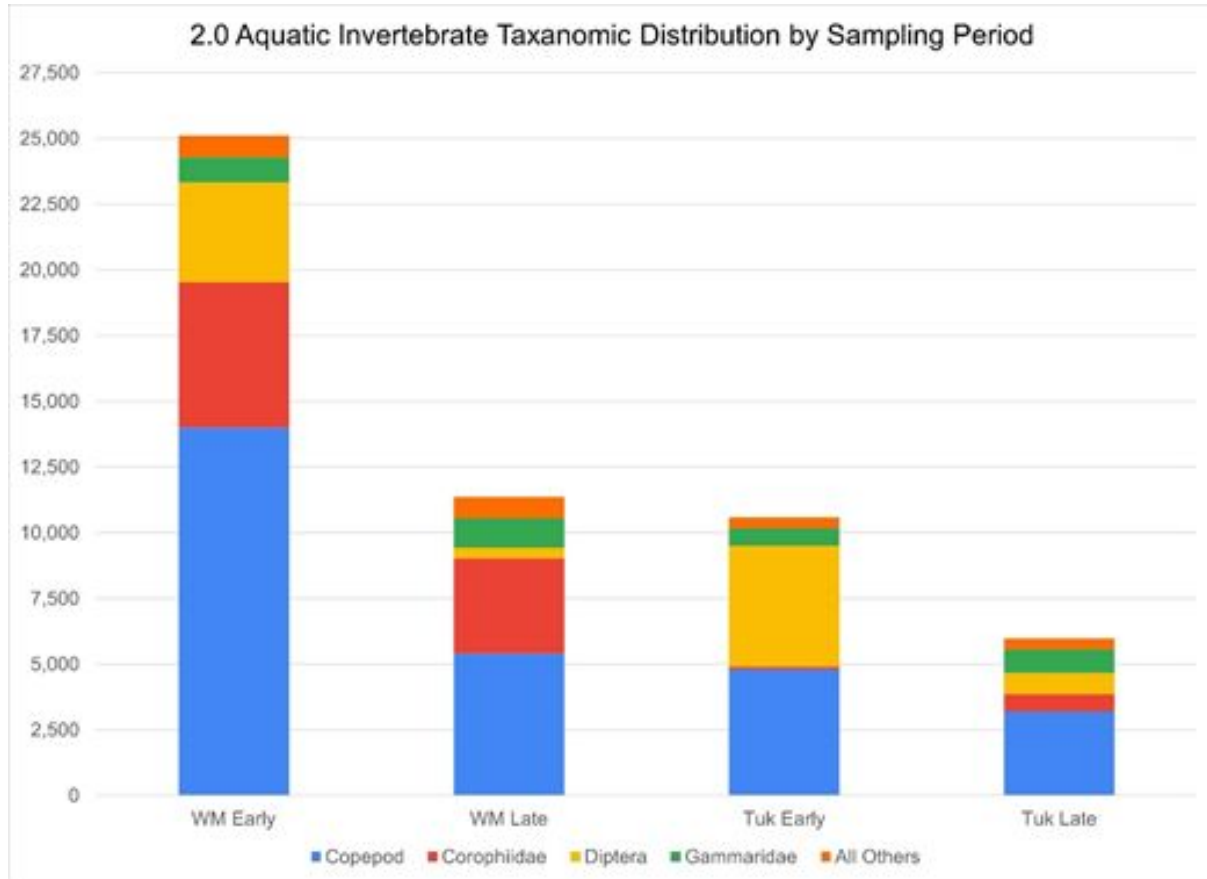


Figure 4.3.3.5: TEA comparison of total aquatic invertebrates by collection period and site, separated by major taxa. More aquatic invertebrates were determined to be present at WM than TD, and a decrease in TEA between collection periods was observed at both sites.

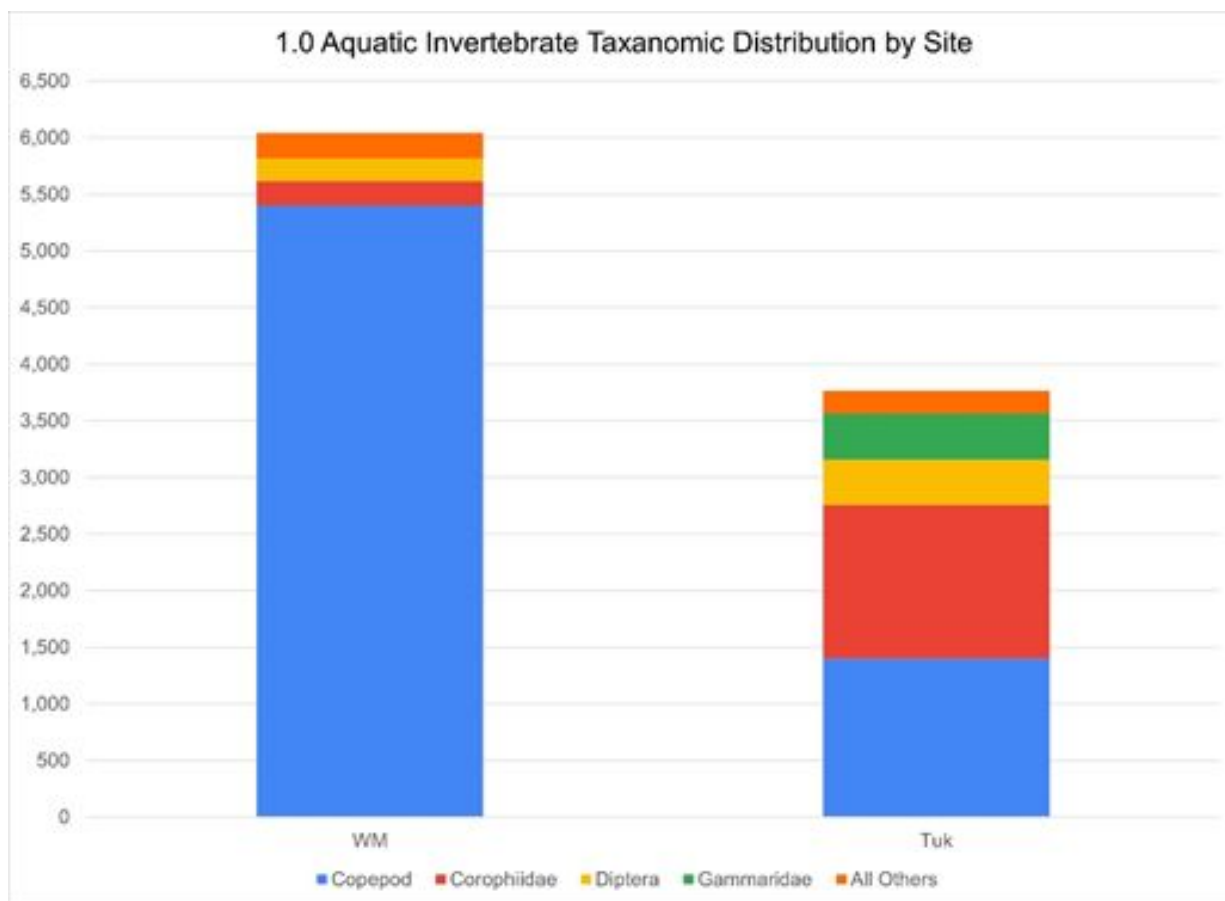


Figure 4.3.3.6: TEA comparison of aquatic invertebrates collected from WBF 1.0s by site, separated by major taxa, showing greater invertebrate presence at WM.

4.3.4. Discussion of Invertebrate Monitoring Results

Our findings show that while Biobarges appear to have a positive impact on terrestrial invertebrate recruitment and availability to salmon (figures 4.3.3.1 and 4.3.3.2), the difference in the capacity of the Biobarges compared to the control locations is not statistically significant (table 4.3.3.2). A future study might extend the monitoring period or increase plant biomass on the barges to see if this will impact the significance and make the Biobarges more representative of the restored locations.

Figure 4.3.3.3 showing the taxonomic distribution of terrestrial invertebrates was included to see if important food-taxa followed the same trend of abundance as previously seen in figure 4.3.3.2. We first notice that Diptera, and more specifically Ceratopogonidae, make up the bulk of the terrestrial invertebrates at most of the site locations. At WM Diptera followed the same trend as figure 4.3.3.2, but at TD we saw that Biobarge Diptera exceeded restored Diptera, and that Isotomidae and Other Collembola comprised the majority of invertebrates. An anova with t-test concluded that this

observation was not statistically significant, but the presence of the trend leads us to believe that a study involving more sites over a longer monitoring period might produce different results.

Among aquatic invertebrates collected from WBF 2.0s we see a decreasing abundance from early collection to late collection at both WM and TD sites, Figure 4.3.3.5. Because samples were taken only during these two collection periods, we cannot say with any certainty what factors may have contributed to this decline. We also saw a greater abundance of aquatic invertebrates from both the WBF 1.0s and WBF 2.0s at WM than at TD. A comparison with abiotic factors such as water temperature and/or salinity might help explain this observation.

Figure 4.3.3.5 also shows a taxonomic distribution of aquatic invertebrates, similar to figure 4.3.3.3, and has revealed that larval Diptera abundance was high during early collection (6/29/2020) at both sites and had drastically decreased by late collection. A look at terrestrial Diptera abundance by date (figure 4.3.3.4) shows a distinct spike in Diptera abundance between 6/21 and 6/28/2020 at both sites. It is likely that Diptera are using the Biobarges as a nursery habitat, and further studies into the timing of Diptera reproduction might inform the temporal placement of future BioBarges to maximize their food-production capacity.

4.4. Water Quality Monitoring

4.4.1. Introduction

The BioBarges were designed to enhance juvenile salmon habitat in the industrialized Lower Duwamish River and deployed to provide additional habitat opportunities. Thus, water quality monitoring focused on parameters specific to juvenile salmon survival: water temperature, dissolved oxygen levels (DO), conductivity, and subsurface luminosity.

Research Questions for Water Quality

- Do the floating wetlands improve, or at least not interfere with, water quality conditions critical to juvenile salmon survival (temperature, DO, luminosity)?
- Does the presence of floating wetlands affect other water quality measures: turbidity (suspended matter in water for salmon), conductance (information on tide levels), salinity (salt water influence on plant health)?
- Do the floating wetlands contribute to reducing the following river contaminants: arsenic (As), barium (Ba), chromium (Cr), copper (Cu), manganese (Mn), molybdenum (Mo), nickel (Ni), lead (Pb), zinc (Zn), and carbon (C)?
- Does the presence of floating wetlands affect the river flow, thus providing respite from strong river currents?

The regional Salish Sea sets the conditions of the Elliott Bay water intruding into the Duwamish River, with a "nearly consistent salinity of 28 psu" and seasonal temperature range from 8°C to 12°C (McKeon

et al, 2020). Freshwater input upriver from the biobarges from the Green River varies between 4°C and 18°C (McKeon et al, 2020). Collectively, these converging inputs and river slope create a salt wedge (salt water below the top layer of fresh water) in the LDW.

4.4.2. Methods

Just as in 2019, measurements focused on the habitat qualities of juvenile salmon: temperature, dissolved oxygen, temperature, and salinity. Light was continuously measured at 12 locations with Hobo Pendant mx 2202 meters, which also measured temperature. These were placed 3 feet above and below the BioBarges B, C, and D, and connected to biofilters at the surface on Biobarges B, C, and D. At Tukwila, a Pendant was deployed 3 feet below the dock as a control (Figure 4.4.2.1).

Dissolved oxygen and temperature levels were continuously measured with a PME miniDOT, initially deployed in the middle of BioBarge A at WM and the middle of BioBarge D. However, when we returned to field research in May and observed BioBarge A grounding during low tide, the miniDOT was relocated to BioBarge B on May 9. Therefore, only data after May 9th was used at WM to remove biased data when the miniDOT was out of the water.

A YSI EXO2 sonde was used to spot-check additional water quality measurements that might affect salmon: salinity, pH, conductance, and turbidity. Measurements were taken at the middle and edge of each BioBarge at depths of 0.5m and 1.0m. And to compare salinity at BioBarges B and D and the controls at each location, measurements were taken at four depths: 0.25m, 0.5m, 0.75m, and 1.0m (Figures 4.4.4.2 and 4.4.4.3). These measurements were used to compare conditions at different spots of the BioBarges and with the control locations on the same day and when the tide conditions were the same.

Some data was spot-checked during on-site monitoring days, and other data gathered continuously with battery-powered instruments deployed at the beginning of the monitoring period and retrieved at the end (Table 4.4.2.1). These in situ devices were checked throughout the monitoring period to ensure data was continuously collected; however, due to COVID-19 restrictions, some device monitoring could not be confirmed for several weeks before it was discovered data was not collected. The COVID-19 restrictions also prevented spot-check monitoring between March 21 and May 10 (Table 4.4.2.1).

A puck analysis of the biofilters' substrate (woodstraw and plants) was done again this year to determine if the biofilters were adding metals, carbon, and nitrogen to the water, or if they were absorbing contaminants from the Duwamish River. A subset of puck species, primarily from the WBF 2.0s, also were measured for biomass, an indicator of primary productivity and a proxy for the amount of carbon present; generally, 50 percent of a given biomass sample is considered carbon.

Table 4.4.2.1. Water Quality monitoring schedule, by BioBarge (A, B at Waste Management; C, D at Tukwila), and control points 1 (Waste Management) and 2 (Tukwila).

Spot-monitoring (all dates 2020)			Continuous monitoring	
Monitoring Days: Sonde and SWOFFER	YSI EXO2 Sonde: Conductance, turbidity, salinity, and pH	SWOFFER 2100: River current.	PME miniDOT: Temperature, dissolved Oxygen (DO)	Hobo Pendants mx2202 meter: Luminosity
March 21	A,B,C,D, 1, 2		Deployed March 27: A, D	Deployed March 26-27: A, B, C, D, 1, 2
No on-site monitoring or verification of continuous monitoring from March 21 to May 9 due to Washington state COVID-19 restrictions. PME miniDOT and Hobo Pendants at Waste Management relocated May 9 from BioBarge A to BioBarge B due to low-tide grounding of BioBarge A.				
May 10	A,B,C,D, 1, 2			
May 17	A,B,C,D, 1, 2			
May 24	A,B,C,D, 1, 2			Verified monitoring: D, 1
May 31	A,B,C,D, 1, 2			
June 7	A,B,C,D, 1, 2			
June 14	A,B,C,D, 1, 2	A,B, 1	Verified monitoring at B, D	
June 21	A,B,C,D, 1, 2			Verified monitoring: B, C, D, 2
June 28	A,B,C,D, 1, 2	A,B,C,D, 1, 2		
July 5	A,B,C,D, 1, 2	A,B,C,D, 1, 2		Verified monitoring: D, 2
July 12	A,B,C,D, 1, 2	A,B,C,D, 1, 2		Verified monitoring: B, D, 1
July 19	A,B,C,D, 1, 2	A,B,C,D, 1, 2		Verified monitoring: D
July 27	A,B,C,D, 1, 2	A,B, 1		

Much like the 2019 deployment, in situ devices were similarly placed in the middle and edges of the BioBarges (Figure 4.4.2.1).

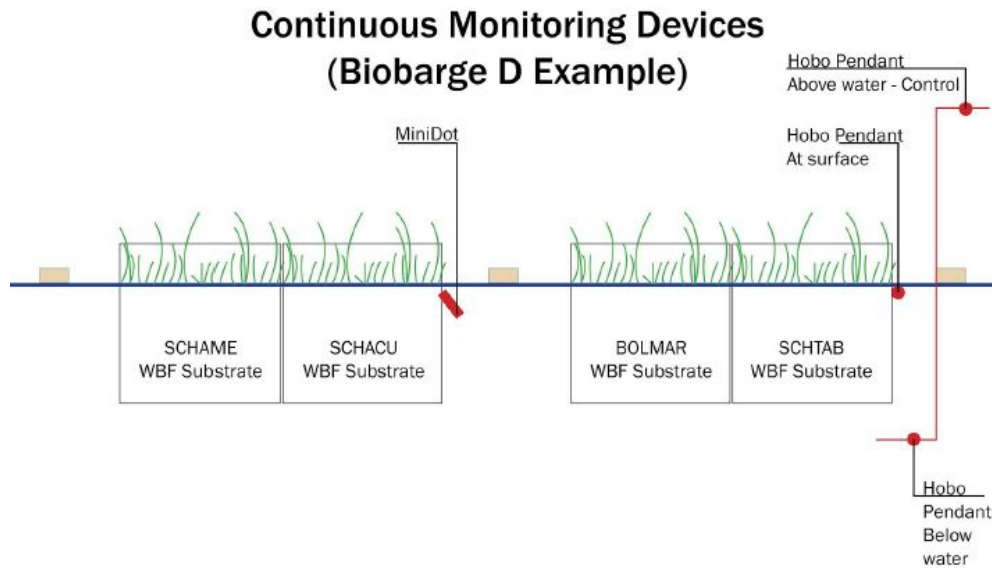


Figure 4.4.2.1. The location of some of the continuous monitoring devices at both locations.

Spot checking water samples with the handheld sonde and river current with the handheld SWOFFER were collected at the same locations at specific biofilters and the controls at WM and Tukwila (Figures 4.4.2.2 and 4.4.2.3).

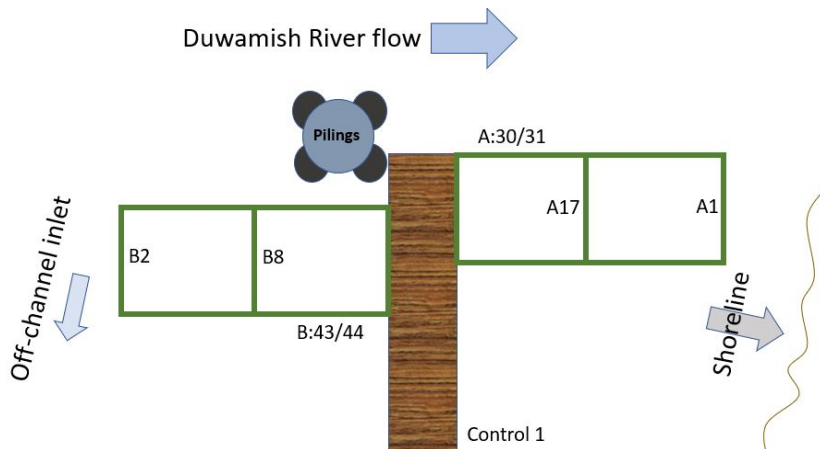


Figure 4.4.2.2. Waste Management Sonde and SWOFFER measurement locations at biofilters, by their identification code of B2, B8, B:43/44, A1, A17, A:30/31. Those locations showed the outer edge of the BioBarge, middle condition of the WBF 1.0s, and the middle condition of the WBF 2.0s. (Not to scale; Control 1 was twice the distance as shown.) The miniDOT initially was deployed at Biofilter A17, but after low-tide grounding was observed, the miniDOT was relocated to Biobarge B8 in May. Hobo Pendants from Biobarge A were also redeployed to Biobarge B.

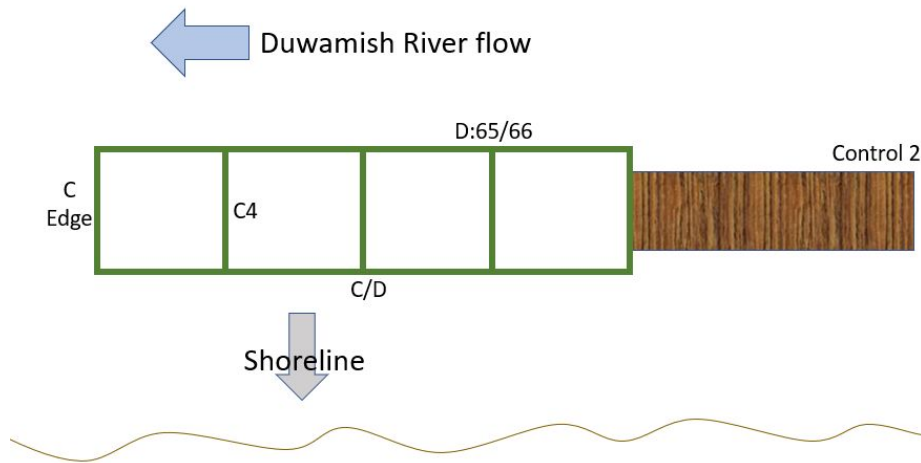


Figure 4.4.2.3. Tukwila Sonde and SWOFFER measurement locations at biofilters, by their identification code C Edge, C4, C/D, and D: 65/66. Hobo Pendants also were deployed on both BioBarges, with the luminosity control beneath the dock. Some Pendants were lost during the deployment, but most data was retrieved through the end of the monitoring period.

Table 4.4.2.2. Water quality methods and parameters measured.

Equipment	Research question	Parameter
Hobo Pendant mx 2202	How do light levels at the floating wetlands compare to desired salmon habitat?	Luminosity
miniDOT usb Oxygen Logger	How do oxygen levels at the floating wetlands compare to desired salmon habitat?	Dissolved oxygen
YSI EXO2 sonde	How do various water quality parameters change based on depth, location, control vs. BioBarge, and middle to the edge of BioBarge?	Salinity, conductance, turbidity, pH
SWOFFER 2100	Do the BioBarges affect the flow of the Duwamish River?	River flow
Plugs analyzed in UW Soil Analytics Lab	What metals and nutrients change from control to biofilter and help remove contaminants from the Duwamish River?	Metals (Ar, CA, etc.) and nutrients (Carbon, Nitrogen)

4.4.3. Results: Overview

As noted in Table 4.4.3.1, pH does not change significantly as depth increases, especially as summer stratification takes hold. As consistent with year 1 results, salinity and specific conductivity increased as the depth increased. The Biobarge appeared to have a larger impact on lowering salinity and specific conductivity during year 2 than in year 1.

Table 4.4.3.1. Sonde data for salinity, turbidity, specific conductivity, and pH. Waste Management in black text, Tukwila highlighted in green when different.

Summary Sonde Data	As depth increases...	BioBarge vs. Control	Middle toward Edge of BioBarge
Salinity	Increases No significant difference	Lower at BioBarge No significant difference	Increases No significant difference
Turbidity	No significant difference	No significant difference	No significant difference
Specific Conductivity	Increases No significant difference	Lower at BioBarge No significant difference	Increases No significant difference
pH	No significant change	No significant difference	No significant difference
Temperature	No significant change	No significant difference	No significant difference

4.4.3.1. Results: Water Temperature

Temperature plays a role in the survival rates of juvenile salmon, with 26.7°C considered the highest lethal temperature for chinook salmon (Richter and Kolmes, 2005), while Hicks (2000) suggested a daily maximum temperature of 22°C is best to protect fish from acute lethality.

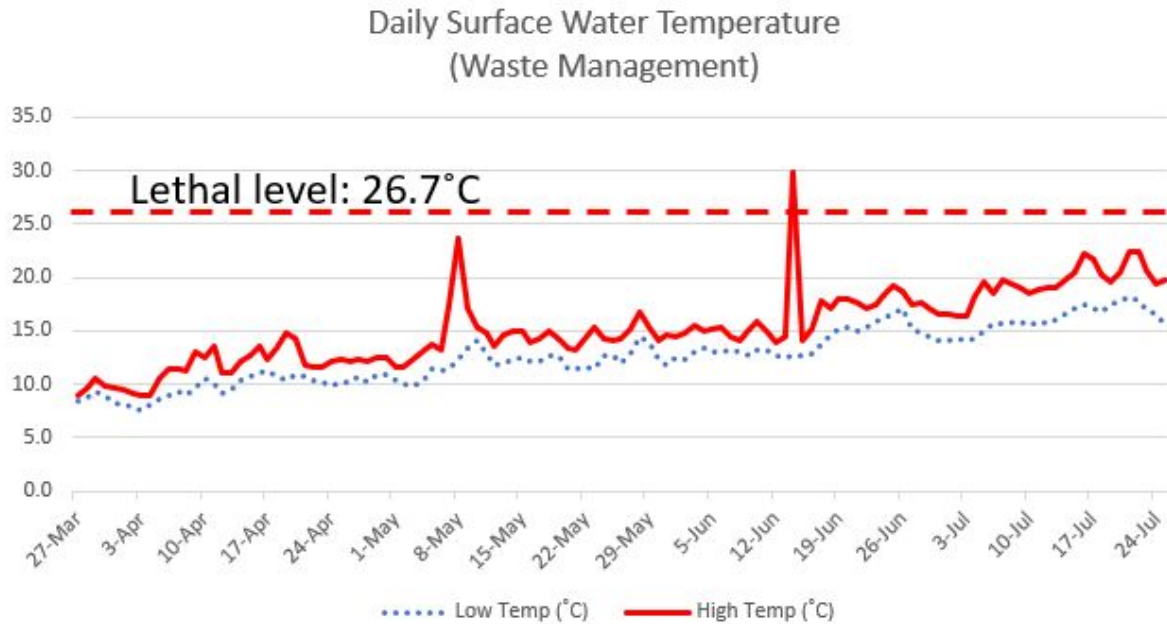


Figure 4.4.3.1.1. Daily surface water temperatures at Waste Management. The May 8 spike is related to removing the miniDOT from BioBarge A and relocating it to BioBarge B. Temperature data from nearby instruments do not indicate a May 8 temperature spike. The June 14 spike is related to removing the device briefly from the BioBarge to verify continuous monitoring and download preliminary data.

We recorded temperature levels with a miniDOT at both study locations. The data from WM, however, may be skewed prior to May 8, due to BioBarge A grounding during low tide (Figure 4.4.2.1.1); therefore, data prior to May 8 may be inaccurate during the extreme low tides when the BioBarge was in contact with the riverbed. The miniDOT was relocated to BioBarge B for the remainder of the study period.

Temperatures at Tukwila followed a similar pattern, ranging from 7.5°C to 21.5°C during the monitoring period (Figure 4.4.3.1.2).

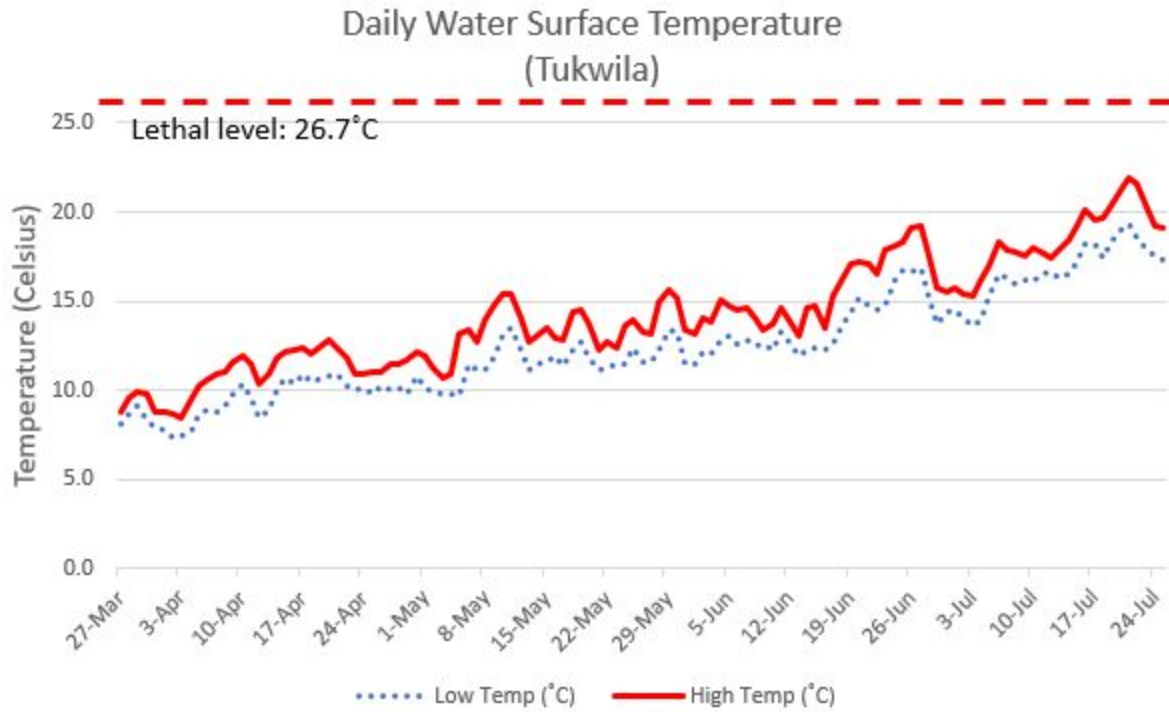


Figure 4.4.3.1.2. Daily surface water temperatures at Tukwila. The high temperature bump in mid May maps to an atypical heat wave May 9-10 when Seattle air temperature reached a high of 87°F (31°C) both days, far above May average high temperature of 64.7°F (18.2°C), according to the National Weather Service.

4.4.3.2. Results: Salinity

Salinity data was collected with spot checks using the handheld YSI Sonde between March 21 and July 27 at both locations, and with varying tide levels. During COVID-19 restrictions, no data was collected after March 21 until May 10. The salinity consistently was near 0 psu at the Tukwila site, with the exception of an outlier reading July 19, which matches an outlier reading at the WM site the same day of 17 psu (Figure 4.4.3.2.1), when either mixing increased salinity up to the surface, or the subsurface salt wedge penetrated unusually far upriver.

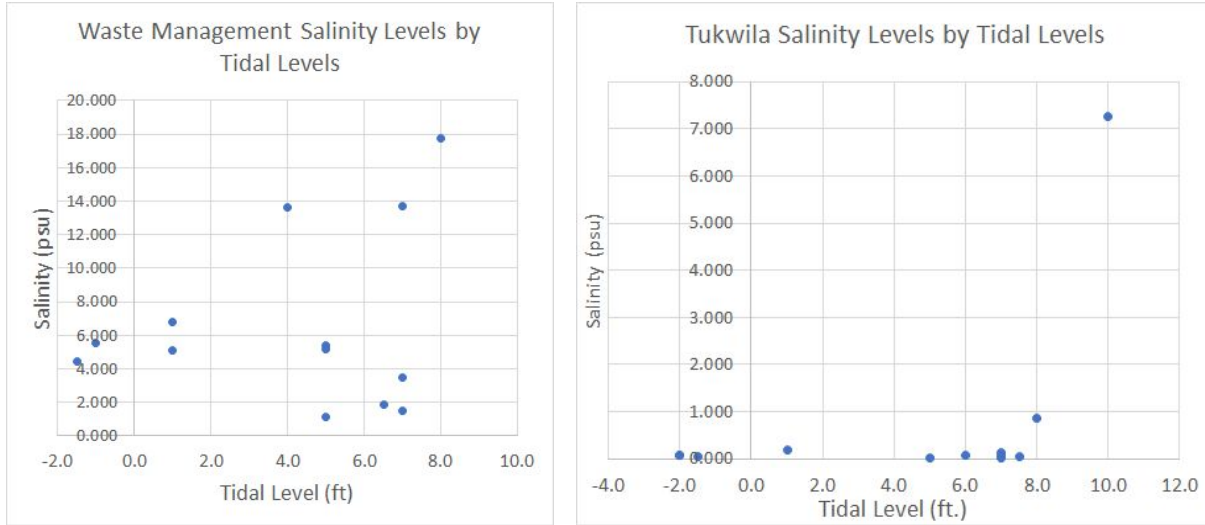


Figure 4.4.3.2.1. Mean salinity data from both sites as recorded with the YSI sonde. The WM data was recorded at BioBarge B and the control site. The Tukwila data was recorded at BioBarge C and the Control Site.

The WM site, being nearer to Elliott Bay, was expected to have higher salinity levels, which mostly ranged between 3 to 8 psu (Figure 4.4.3.2.1). We investigated if the varying tide levels correlated with salinity levels, but found no such correlation.

The sonde also recorded specific conductivity data, which is a more sensitive measure than salinity. Specific conductivity data reflected the salinity data, with higher levels at WM and near-zero freshwater readings at Tukwila. Regarding specific conductivity, there was no statistically significant difference between the BioBarges and the controls at either WM or Tukwila.

4.4.3.3. Results: Dissolved Oxygen

Dissolved Oxygen levels were monitored continuously with PME miniDOT loggers submerged beneath BioBarge B at Waste Management (Figure xx) and BioBarge D at Tukwila (Figure xx).

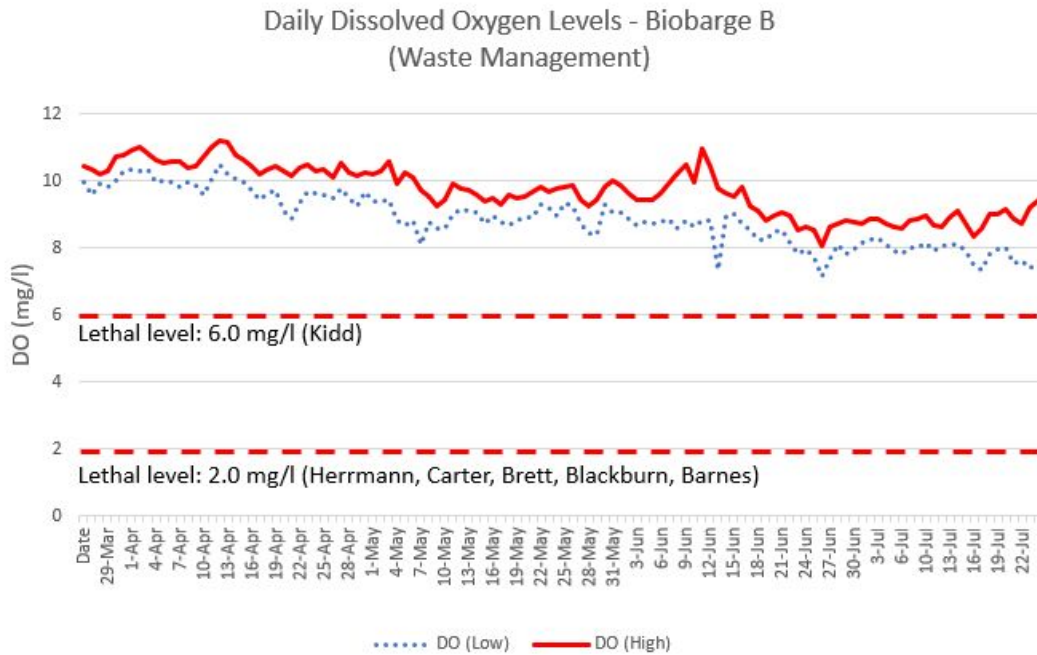


Figure 4.4.3.3.1. Dissolved oxygen levels beneath BioBarge B at Waste Management.

The DO readings at Tukwila (Figure 4.4.3.3.2) followed a similar pattern and ranged from 10.9 to 6.7 mg/l. Salmon prefer DO levels below 11.0 mg/l, but DO levels below 6.0 mg/l are lethal for salmon (Kidd, 2011). Lethal DO thresholds for juvenile salmon have been reported at 2 mg/l (Herrmann et al, 1962, and Carter, 2005), and for DO levels between 2 mg/l and 5 mg/l growth and swimming ability may be reduced (Brett and Blackburn, 1981; Barnes et al, 2011).

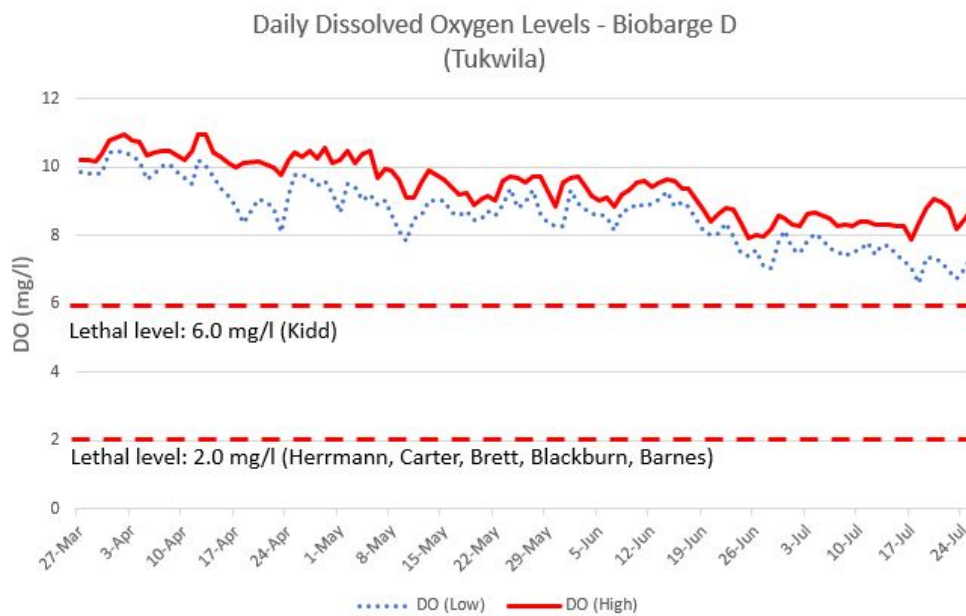


Figure 4.4.3.3.2. Dissolved Oxygen levels beneath BioBarge D at Tukwila.

We also examined if tide level affected DO levels, but found no correlation (Figure 4.4.3.3).

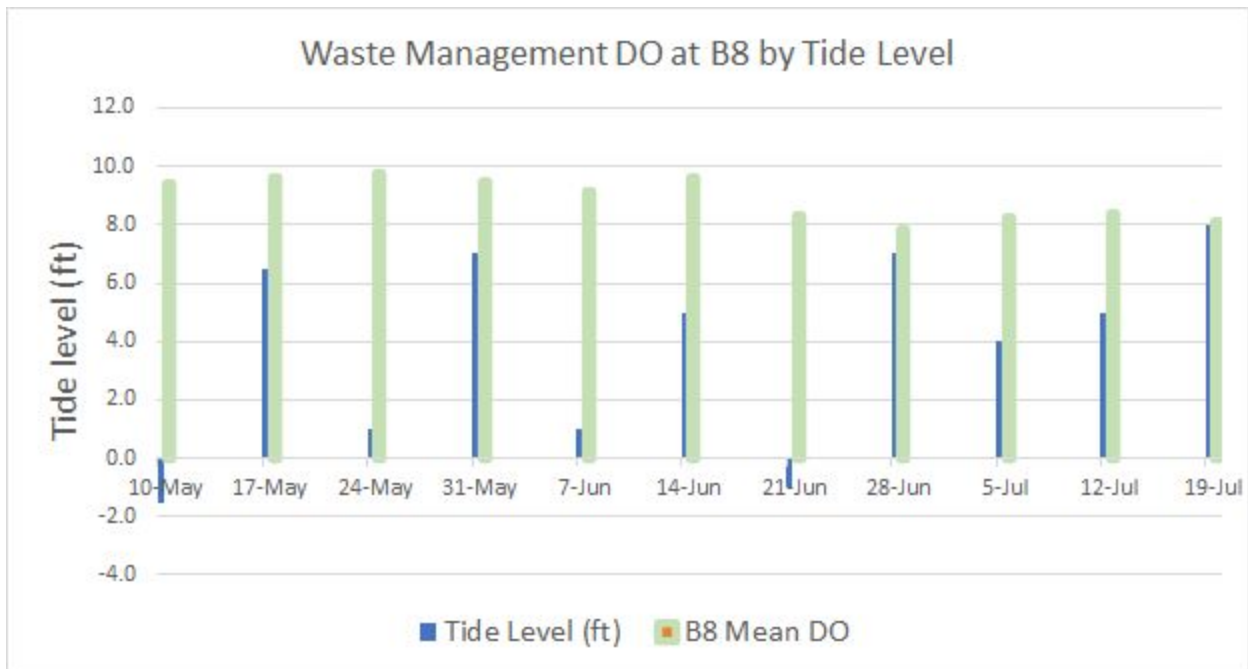


Figure 4.4.3.3.3. Dissolved oxygen measurements from the sonde during various tide levels at WM. With DO levels consistently above the lethal levels of 2.0 and 6.0 mg/l, there were ample levels of oxygen beneficial to juvenile salmon. No correlation between DO and tide level was observed at the Tukwila BioBarges either.

4.4.3.4. Results: Luminosity

Juvenile salmon prefer to feed in areas of dappled light, as opposed to dark areas, which juvenile salmon have been observed to avoid (Ono and Simenstad, 2014). Due to some issues with the Pendants not recording data as expected, or lost during deployment before data could be collected, we were unable to gather data for the full reporting period at WM. Still, partial data is available, and we have data for the full reporting period from Tukwila.

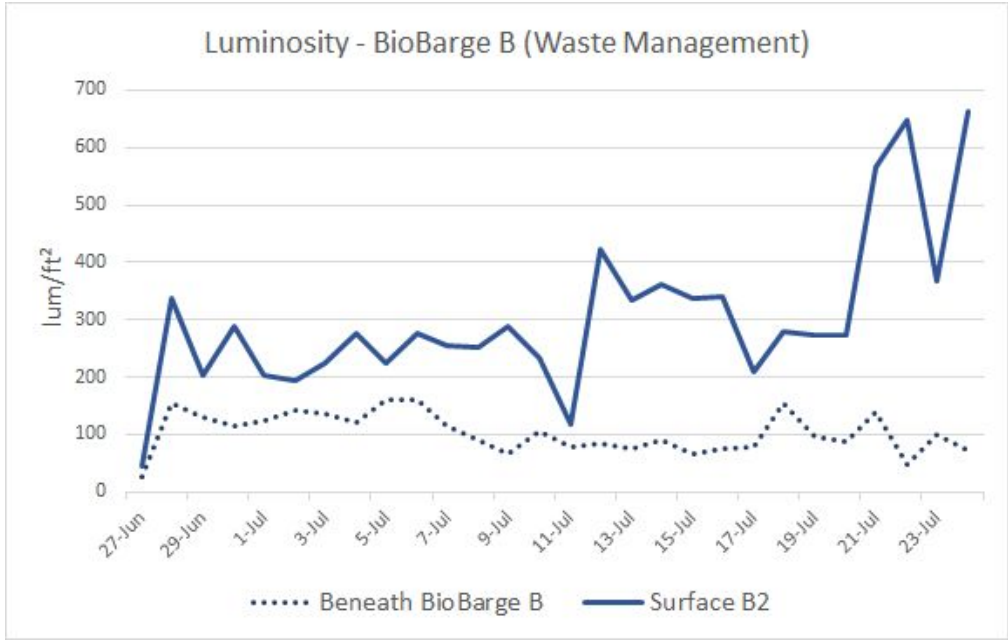


Figure 4.4.3.4.1. Luminosity levels at WM recorded at the surface of biofilter B2 and 3 feet beneath BioBarge B, where a variety of fish were observed. The values recorded at the luminosity control on top of the Biobarges were omitted because they average 3,305 lum/ft².

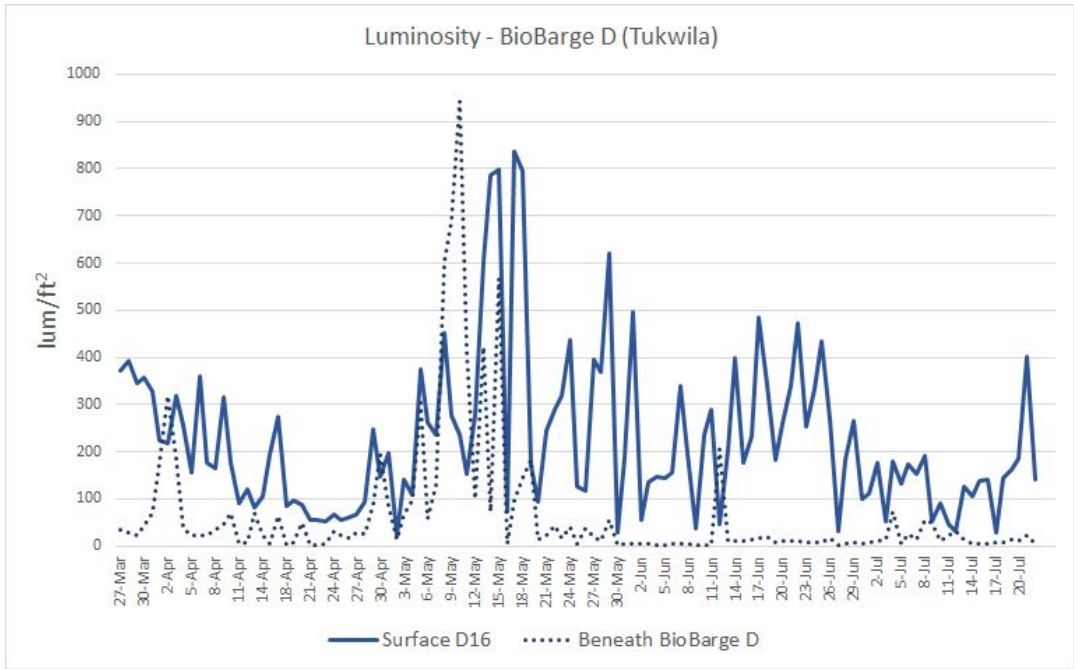


Figure 4.4.3.4.2. Luminosity levels at Tukwila recorded at the surface of biofilter D16 and 3 feet beneath BioBarge D, where a variety of fish were observed. The values recorded at the luminosity control on top of the Biobarges were omitted because they were only available from June 21 to July 11, averaging 7,521 lum/ft².

The surface and subsurface luminosity levels differed between WM and Tukwila, but at both locations were significantly lower than the levels recorded by the above-water control sensors. Juvenile salmonids have been found to exhibit "concealment" behavior -- seeking refuge from predators -- during bright light situations (Thurrow et al, 2020). And Goetz found juvenile bull trout -- which share salmon habitat and are relative cousins -- were primarily nocturnal to feed and conceal. The extreme spikes in some data may have been due to perturbations from handling to download data.

Overall, the luminosity was lower beneath the Biobarge than that shown from the surface level meters. The surface level sensor was at water level, so this tells us that generally closer to the surface salmon have easier ways to see predators during the day. The shade beneath the WBFs may provide places for predators to hide, but no predators were seen on the project (see fish results). Furthermore, the WBFs may block the view from underneath the biofilters to the area salmon are feeding or resting. Additionally, the biobarge shade could provide protection if night lights are a concern for salmon being seen by predators. The amount of shade protection needed by juvenile salmon varies based on location and amount of ambient night light in the area.

4.4.3.5. Results: pH Levels

Starting May 31, pH levels also were recorded with a new pH sensor installed in the sonde (Figure 4.4.3.5.1). Sockeye salmon are sensitive to low pH (6.8 and below), in which they gain significantly lower mass, sustained organismal stress response, and higher subsequent saltwater mortality, resulting in "potentially decreasing the probability of survival in the marine environment" (Kennedy and Picard, 2012). The pH levels also were not problematic for the WBF plants.

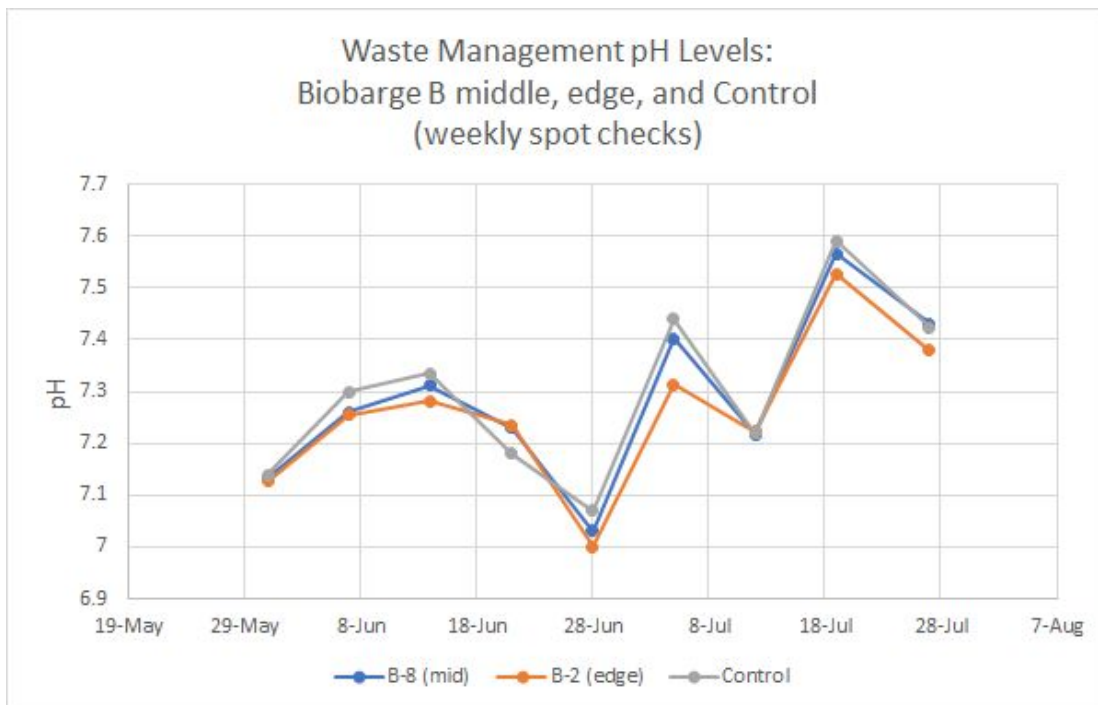


Figure 4.4.3.5.1. Waste Management pH levels near biofilters B2, B8, and the control site.

The biobarges deployed at Waste Management did not have pH levels lethal for Sockeye salmon (below 6.8), based on weekly spot checks. The Tukwila pH values ranged from 7.02 to 7.36, also above required levels.

4.4.3.6. Results: SWOFFER River Flow

A handheld SWOFFER was used to spot-check the river flow during the summer. Data was collected at different times of day and different tide levels, so the data cannot be compared from week to week. However, on a given day, values can be compared between biobarges and control sites. The configuration of the BioBarge placements at each location also may have affected the river current's interaction with the BioBarges. At WM, BioBarge B was located next to several pilings at the end of the dock, and this may have factored into SWOFFER data there (Figure 4.4.2.2). Also at WM, the control site may have been too far into the inlet, resulting in generally slower flow. Therefore, it is hard to say the reduction in river flow was due to the biobarge instead of the location of the reading. Regardless, the river flow within 1- to 2-feet of the biofilters at the WM BioBarges was slower than at the depths closer to the riverbed (Table 4.4.3.6.1). This tells us that the area juvenile salmon are swimming (1-2 ft depth) is generally slower than further down in the water column.

Table 4.4.3.6.1. SWOFFER data from Waste Management. The green/up symbol indicates a rising tide, and the red/down symbol indicates decreasing tidal levels. Readings at each location were taken approximately 40 percent from the bottom of the river, and 1-2 feet beneath the surface. Numerical values are in km/sec.

	Tide Level (ft)	Tide	Biobarge A (40%) Avg	Biobarge B (40%) Avg	Control 1 (40%)	Biobarge A (1-2 ft) Avg	Biobarge B (1-2 ft) Avg	Control 1 (1-2 ft)
6/14/2020	5.0	▲	0.17	0.13	0.08	0.17	0.10	0.12
6/21/2020	-1.0	▼	No data			No data		
6/28/2020	7.0	▲	0.10	0.11	0.06	0.03	0.08	0.04
7/5/2020	4.0	▲	0.00	0.10	0.00	0.00	0.03	0.00
7/12/2020	5.0	▼	0.14	0.11	0.05	0.07	0.14	0.12
7/19/2020	8.0	▲	0.07	0.09	0.02	0.03	0.04	0.00
7/27/2020	7.0	▲	0.01	0.03	0.07	0.06	0.07	0.05

The location of the BioBarges at Tukwila, at the downriver side of the private dock, also may have contributed to the data collected the four times we were able to take measurements. The river flow at the control was considerably faster than at the BioBarges (Table 4.4.3.6.2), also perhaps because the private dock may have protected the BioBarges to some degree from the current. There was also conjecture from the dock owner that woody debris upstream of the dock slowed down the water in comparison to the speed of the main channel of the water. Investigation was not done to prove this difference.

Table 4.4.3.6.2. SWOFFER data from Tukwila. The green/up symbol indicates a rising tide, and the red/down symbols indicate decreasing tidal levels. Readings at each location were taken approximately 40 percent from the riverbed, and 1-2 feet beneath the surface. Numerical values are in km/sec. "ND TS" indicates "No Data, Too Shallow" to take a reading.

	Tide Level (ft)	Tide	C-Edge, C4 (40%) Avg	C/D, D65/66 (40%) Avg	Control 2 (40%)		C-Edge, C4 (1-2 ft) Avg	C/D, D65/66 (1-2 ft) Avg	Control 2 (1-2 ft)
6/14/2020	5.0	▼	No Data				No Data		
6/21/2020	-2.0	▼	No Data				No Data		
6/28/2020	6.0	▼	0.11	0.16	0.30		0.03	0.13	0.28
7/5/2020	1.0	▲	ND TS	0.19	0.26		0.01	0.08	0.64
7/12/2020	7.0	▼	0.07	0.03	0.18		0.01	0.04	0.22
7/19/2020	10.0	▲	0.01	0.00	0.01		0.01	0.00	0.00
7/27/2020	8.0	▼	No Data				No Data		

Still, with few data points, the data collected from the 1- to 2-foot surface mostly indicated a slower flow at the Biobarges than at the depth closer to the river bed, and significantly slower than the control, which was upstream at the north end of the dock.

4.4.3.7. Results: Metals Analysis

A total of 31 samples of various layers of the biofilters were extracted for metals and biomass analysis (Table 4.4.3.7.1). The samples tested for metals were compared to 4 control samples. The plant control for the WBF 1.0 plants was specific to SCHACU, grown on the balcony of the Green Futures Lab, and the plant control for the WBF 2.0 plants was specific to CXOBNA, grown in a nursery and still in plug form.

Table 4.4.3.7.1. The number of samples tested by type of material. Biofouling that occurred at BioBarges A, B, and D also was sampled.

Sample types	Taken from BioBarge...	# Tested for metals	# Tested for biomass
Plant (WBF 1.0s)	A, B, C, D	4	1
Plant (WBF 2.0s)	A, B, C, D	6	9
Willow (WBF 1.0s only)	A, B, C, D	5	0
Substrate (WBF 1.0s only)	A	1	0
Woodstraw (WBF 2.0s only)	A, B, C, D	7	4
Mycoboard and woodstraw	B, C, D	3	0

(WBF 1.0s only)			
Biofouling (WBF 1.0s)	A, B	2	0
Biofouling (WBF 2.0s)	A, B, D	3	0

The 31 samples from different layers of the WBF 1.0s and WBF 2.0s (woodstraw, mycocard, willow, and plants), and were tested for metal intake, carbon percentage (an indication of primary production), and nitrogen percentage. The metals test was performed for the following elements: aluminium (Al), arsenic (As), B, barium(Ba), calcium (Ca), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), potassium (K), magnesium (Mg), manganese (Mn), molybdenum (Mo), sodium (Na), nickel (Ni), phosphorus (P), lead (Pb), sulfur (S), selenium (Se), zinc (Zn), silicon (Si), and silver (Ag).

Samples from all four BioBarges indicated uptake of a variety of metals, especially those considered harmful to juvenile salmon (copper, lead, and zinc), compared to their respective controls. Cadmium, also considered harmful, was not detected in any of the samples, Pb in some samples, and Cu and Zn detected in most samples. Of these harmful metals, data indicated an increase in metals uptake at the Biobarges compared to the control samples (Table 4.4.3.7.2). The WBF 1.0 plant control was *Schoenoplectus acutus*, and the WBF 2.0 plant control was *Carex obnupta*.

Table 4.4.3.7.2. Cu, Pb and Zn uptake by WBF 1.0s and WBF 2.0s by percentage increase compared to the controls. The controls only had trace levels of Pb, so a value of 0.01 was used to calculate the percentage increase.

Sample type	Cu	Pb	Zn
WBF 1.0s	29%	1,957%	1.2%
WBF 2.0s	29%	2,113%	-15%

Pb levels were detected in each of the WBF materials, with an 8.5% uptake increase in the WBF 1.0s compared to the 1.0 SCHACU control (Table 4.4.3.7.3).

Table 4.4.3.7.3. Median Pb uptake by sample type in parts per million (ppm).

WBF 1.0 plants	WBF 2.0 plants	Willow	WBF 2.0 Woodstraw	WBF 1.0 Mycocard+woodstraw
19.75	21.14	19.75	5.23	18.84

Of the five biofouling samples, Pb was detected in two of them for an average 59.22 ppm. Scaling these ppm values to the full BioBarge would be imprecise because the overall amount of biofouling on the WBFs was not measured.

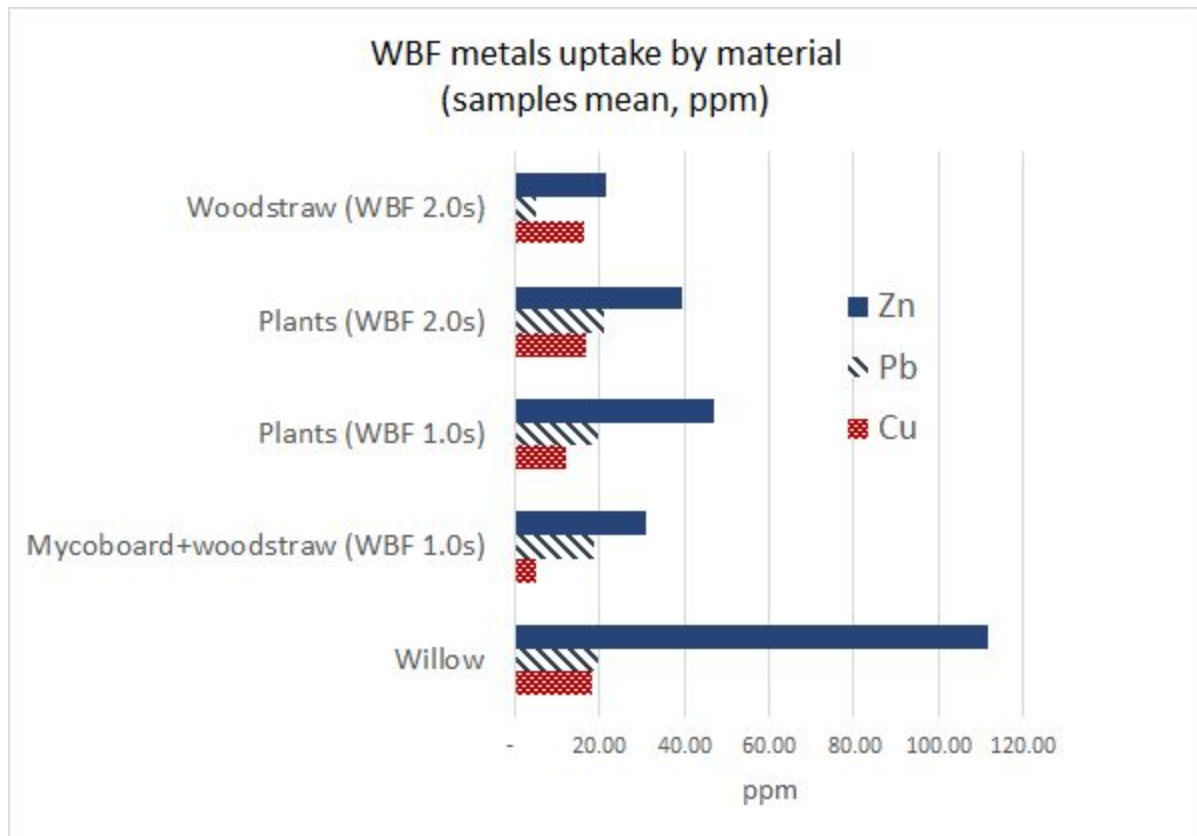


Figure 4.4.3.7.1. The mean Cu, Pb, and Zn uptake by the materials tested (ppm).

For biomass, plugs were extracted from 14 biofilters from all four BioBarges (13 2.0s and one 1.0) and air dried, from which 2 in.³ samples were taken, weighed and analyzed in a lab specializing in metals sampling. The samples were set out to air dry for approximately one to two weeks -- some longer than others. After moisture was removed through the drying process, the sample weights decreased by an average 10.5 percent.

All 31 samples were measured for carbon percentage and nitrogen percentage, and could be compared to the controls for plants and woodstraw (Table 4.4.3.7.3).

Table 4.4.3.7.3. Carbon and nitrogen percentage increase/decrease by material, compared to the controls.

Material	+/- Carbon	+/- Nitrogen
Woodstraw	-5.7%	300%
WBF 1.0 plants	-1.2%	36.8%
WBF 2.0 plants	-15.2%	20.6%
All plants	-0.152	1.466

4.4.4. Discussion of the Water Quality Results

Though COVID-19 restrictions severely restricted planned weekly data collection with handheld instruments, data from the miniDOTs and Pendants deployed through the duration of the March-July research period did not reveal any conditions detrimental to juvenile salmon survivability. Overall, water temperature, salinity levels, pH levels, and light levels all were found to be conducive to survivability.

In a study examining juvenile salmon preference between different saline and temperature conditions, fish distribution correlated more so to salinity and temperature rather than food availability (Webster and Dill, 2006). When food was equally distributed between two habitats varying by salinity, juvenile salmon preferred the more saline habitat, and when food was equally distributed between two habitats varying by temperature, juvenile salmon preferred the colder habitat (Webster and Dill, 2006). While the two locations at Tukwila and WM generally had low salinity levels, water temperatures remained cool and conducive to favorable habitat conditions for juvenile salmon.

Of the metals considered threatening to juvenile salmon survivability -- Cd, Cu, Pb, Zn -- Cd was not detected in any of the 31 BioBarge material samples, while Cu, Pb, and Zn levels were higher in the BioBarges compared to the control samples, with the exception of the WBF 2.0s having 15% less Zn than its control.

While SWOFFER measurements were limited, the BioBarges did have varying positive impact on slowing the river current. This corresponded with the fish results, anticipating that slower water flows provide places for fish to "rest," as observed in our visual inspections.

While measuring metals was a focus of this protocol, it is interesting to note *Bolboschoenus maritimus* was found to remove phosphorus and nitrogen in saline wetlands (De Lange and Paulissen, 2015). BOLMAR was not specifically measured in this report.

4.5. Plant Monitoring

4.5.1. Introduction

Eight different species of wetland plants were chosen to grow on our floating BioBarges. All eight species are perennials in the sedge family (Cyperaceae), and all eight species are native to the area. Many have been used and continue to be used by Indigenous nations, including Salish peoples for various purposes, from food, to basketry, hatmaking, and weaving mats. Crucially, all eight sedge species can propagate rhizomatically, allowing them to create large colonies quickly. This is particularly helpful for restoration projects where the aim is to use plants to stabilize a soft shoreline and protect it from erosion.

Chosen species needed to work well in a highly dynamic riparian environment characterized by large tidal ranges and fluctuating salinity levels, particularly at the Waste Management (WM) site about 3.5 miles upstream from Elliot Bay. In 2019, four sedge species proven to grow in both freshwater and more saline environments were planted in the wetland biofilters (WBFs). However, plant health seemed to plateau or decline as the study progressed, salinity levels increased, and warmer summer temperatures set in.

These findings and concerns about salinity affecting plant performance drove in large part this year's successful search for field sites further upstream in the hopes of finding lower salinity conditions.

Research Questions for Plant Monitoring

- Do our floating substrates support viable growth and survival of wetland plants in the Duwamish?
- Which species of plants perform better on floating wetlands, if performance is defined at each field site as plant growth (established height and percent cover), successful phenological cycle, and mortality rate?
- Does a mix of plants perform better than “monocultures,” if performance is defined as plant growth (height and percent cover) and mortality rate?
- Are there site-specific differences in plant and species performance between the lower estuary site (Waste Management) and the lower river site (Tukwila Dock)? How does plant performance relate to the conditions at each of these sites?
- Can wetland plants on floating wetland structures attain enough height and form to provide a dappled, shadowed edge on floating wetlands?

4.5.2. Materials and Methods

Configuration

Two BioBarges were deployed at each study site. Each barge contained four WBFs 1.0 in the center, and 12 WBFs 2.0 along the longer sides of the barge (Fig. 4.5.2.1, below):

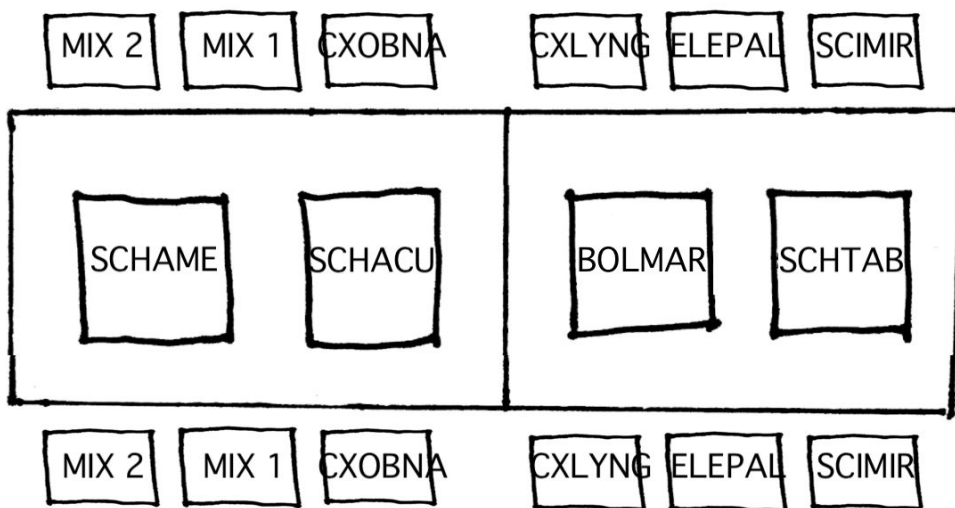


Figure 4.5.2.1. BioBarge Wetland Biofilter Configuration. Four Biofilters 1.0 are positioned in the center; 12 Biofilters 2.0 are arranged along the longer sides of the barge.

Planting Scheme

1. Plant species used on WBFs 1.0:
 - a. BOLMAR - *Bolboschoenus maritimus*;
 - b. SCHACU - *Schoenoplectus acutus*;
 - c. SCHAME - *Schoenoplectus americanus*; and
 - d. SHTAB - *Schoenoplectus tabernaemontani*.
2. Plant species used on WBFs 2.0:
 - a. CXLYNG - *Carex lyngbyei*;
 - b. CXOBNA - *Carex obnupta*;
 - c. ELEPAL - *Eleocharis palustris*; and
 - d. SCIMIC - *Scirpus microcarpus*.
3. Each WBF 1.0 contained single-species plantings of BOLMAR, SCHACU, SCHAME, or SHTAB that were left over from the 2019 research period. Some WBFs 1.0 received infill planting of the matching species to recover losses from mortality ($34 \leq n \leq 48$).
4. Each WBF 2.0 received either single-species plantings ($n = 16$) of CXLYNG, CXOBNA, ELEPAL, or SCIMIC, or an equal mix of all four ($n = 4 \times 4 = 16$). Each of the longer sides of every BioBarge had six WBFs 2.0 attached to them; four of them contained single-species planting while the other two contained mixed-species plantings. In MIX 1, the four species were planted in separate quadrants, while in MIX 2, the four species were planted at random (see Fig. 4.5.2.2, below).

5. All WBFs 2.0 with single-species plantings of CXOBNA were given an easy-to-remove plug of substrate for invertebrate data collection. Each plug was planted with one CXOBNA individual.

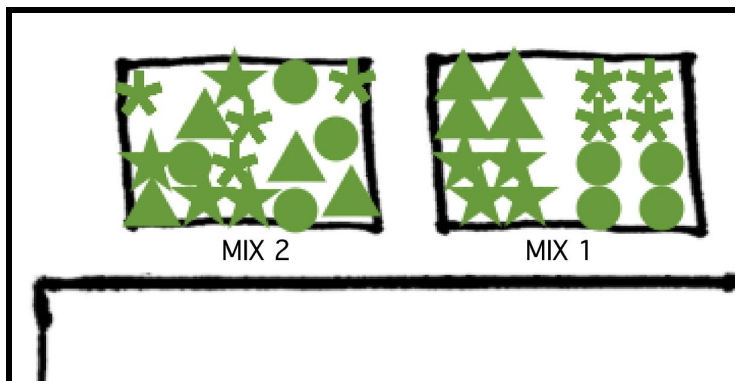


Figure 4.5.2.2. Mixed Species Configurations on 2.0 Wetland Biofilters. In MIX 2 (left), the four species were planted at random, while in MIX 1 (right) the four species were planted in separate quadrants.

March to June: Restricted Monitoring Due to COVID-19 Lockdown

Research was heavily restricted due to the COVID-19 pandemic between March to mid-June, and no plant monitoring took place aside from two community scientists who visited the Biobarges once a week in a socially distanced fashion to take “top-down” photos of each Wetland Biofilter (WBF). These photos were then assessed visually and processed in ImageJ, a photo analysis program, to assess “percentage of foliage cover,” i.e. what proportion of the substrate was being shaded by plant growth on each WBF. The plants had significant growth during this time period that was not collected and not recorded in the later growth results.

June to July: Expanded Monitoring During Phase 2 of COVID-19 Lockdown Easing

From mid-June to late July, full rounds of data collection occurred once a week for six weeks. Data collection alternated each week between Waste Management (WM) and the Tukwila Dock (TD) for a total of three full rounds of data collection at each site. Data collected from each WBF included:

- condition of the Biofilter (intact, degrading, failing);
- plant performance metrics (plant height, percent foliage cover, and total mortality);
- length of the most laterally protruding shoot to the nearest cm (as well as the species of the most protruding individual for the mixed-species WBFs); and
- as many field notes and phenological observations (e.g. flowering, seed development, leaf senescence, grazing, weather, presence/absence of weeds, biofouling, insects, birdsong, turbidity, water color, etc.) as possible.

Plant Height

During the June/July monitoring period, the height of the tallest plant in each WBF was measured to the nearest cm. For mixed-species 2.0 WBFs, the species of the tallest individual was also recorded. Because there were only three full rounds of data collection at each site, change in height could only be tracked

over a one-month period at both WM and TD. Height was not measured when individual plants were first planted into the WBFs, but they began from a plug form with little to no foliage visible. Therefore the full growth of all species occurred while on the site.

Comparisons of plant height to an expected height value for each species is tricky since literature range values for the expected maximum heights of many of the plants species varied between 20-50 cm depending on the reference. Plant height monitoring in June/July was used as a metric to determine overall growth. A comparison can be made to national averages of the plant species from USDA or King County native plant resources.

Percent Foliage Cover

Visual estimates of percentage of foliage cover (rounded to the nearest 5%) were taken in the field and standardized according to the research lead's best judgment.

Because there were only three full rounds of data collection at each site, change in foliage cover could only be tracked in person over a one-month period at both WM and TD. However, change in foliage cover was tracked from week to week using top-down photos of each Biofilter from April to July and then quantifying percent cover in each image using the ImageJ software program (see **Appendix C**). Photos were "ground-truthed" with visual assessments in the field between June and July. This field data was used to cross-check and standardize ImageJ analysis for weeks where only photos were available.

Using the photos, a complete data set tracking percent cover between April to July was established for one site (TD). However, major inadequacies in the photos taken at the WM site prevented quantification of the change in foliage cover beyond the one-month field monitoring period in June and July. To keep things consistent, statistical analysis was performed only on data from the one-month field monitoring period for both sites. However, the full dataset from TD was used to create a visualization of the increase in foliage cover from April to July.

Total Mortality

Total mortality was a straightforward metric to capture, measured as a percentage of individual plants lost by the end of the project. This was determined by counting the number of remaining plants in each WBF during each field monitoring session and then comparing the numbers counted in the final monitoring session to the number of individuals initially planted.

The raw data for these categories is available in **Appendix B**.

Data Analysis

While many forms of data were collected, data for the three plant performance metrics (plant height, percent foliage cover, and total mortality) were found to be the most systematic and consistent in its collection and therefore most amenable to statistical analysis. We focused on analyzing these data for this reason, and because plant performance is central to most of our research questions. Most of the

analyses focused on the WBF 2.0s since there was more uniformity between the numbers of plants on them.

Location Variables

Throughout the monitoring period, observations in the field strongly suggested the importance of fine-grained differences in WBF location in influencing plant performance. **Figure 4.5.2.3** below shows how the BioBarges were positioned at the WM site, with BioBarge A placed between the dock and the shore and BioBarge B between the dock and the river. Both A and B also had an “exposed” side where six 2.0 WBFs faced out into the river and were directly in the path of incoming boat wakes, along with a “sheltered” side where the other six 2.0 WBFs are shielded by the BioBarge itself from incoming wakes. The 2.0 WBFs on both BioBarges’ exposed sides seemed to experience more damage than the 2.0 WBFs on the sheltered side.

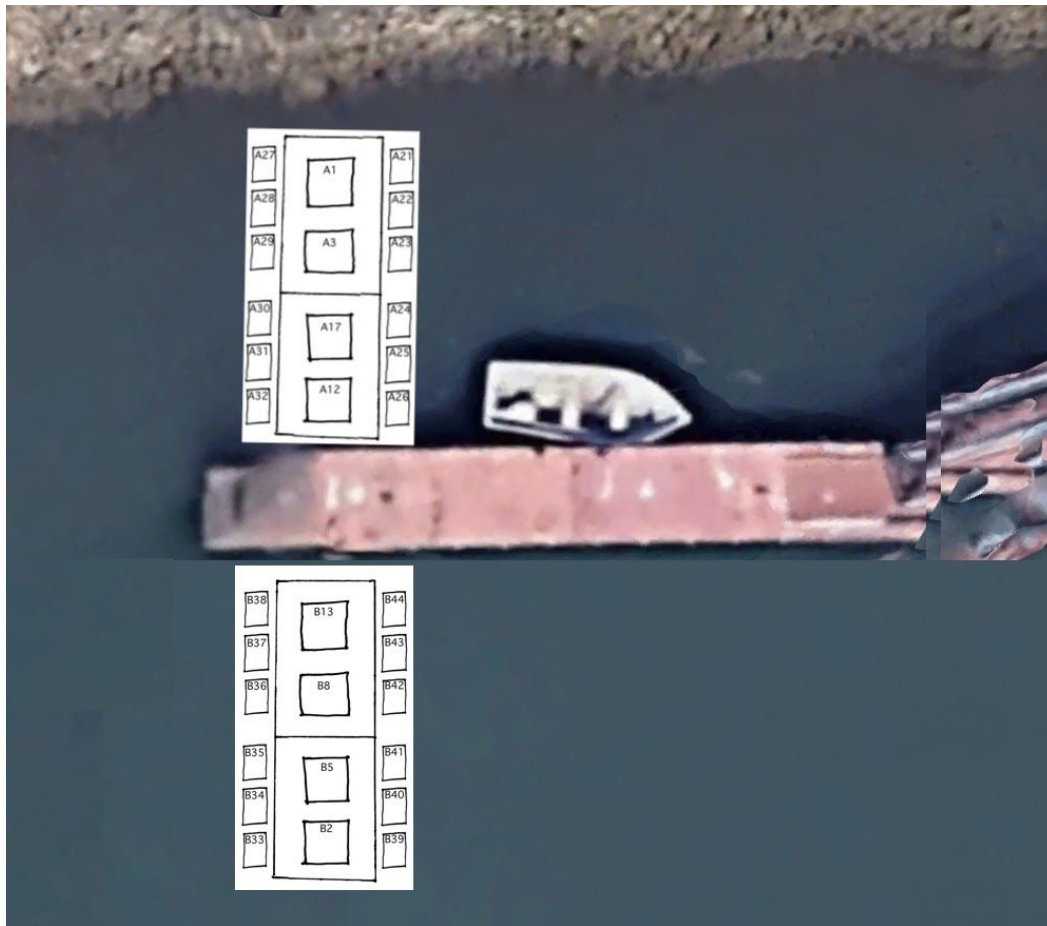


Figure 4.5.2.3. Placement of BioBarges at Waste Management. The left side of each BioBarge is the “exposed” side that is directly hit by boat wakes; the right side of each BioBarge is the “sheltered” side. For reference, the river flows from southeast to northwest in this photo, at about a 45-degree angle relative to the BioBarges.

At the Tukwila Dock (TD), the navigable width of the river is much smaller and vessel traffic mostly amounts to the occasional smaller, hand-powered watercraft, so boat wakes did not damage BioBarges C and D (**Fig. 4.5.2.4** below shows how the BioBarges were positioned at TD). However, the 2.0 WBFs on the “sheltered” side of the BioBarges were subjected to more physical wear and tear due to being hit by submerged masses of small woody debris during extreme low tides.

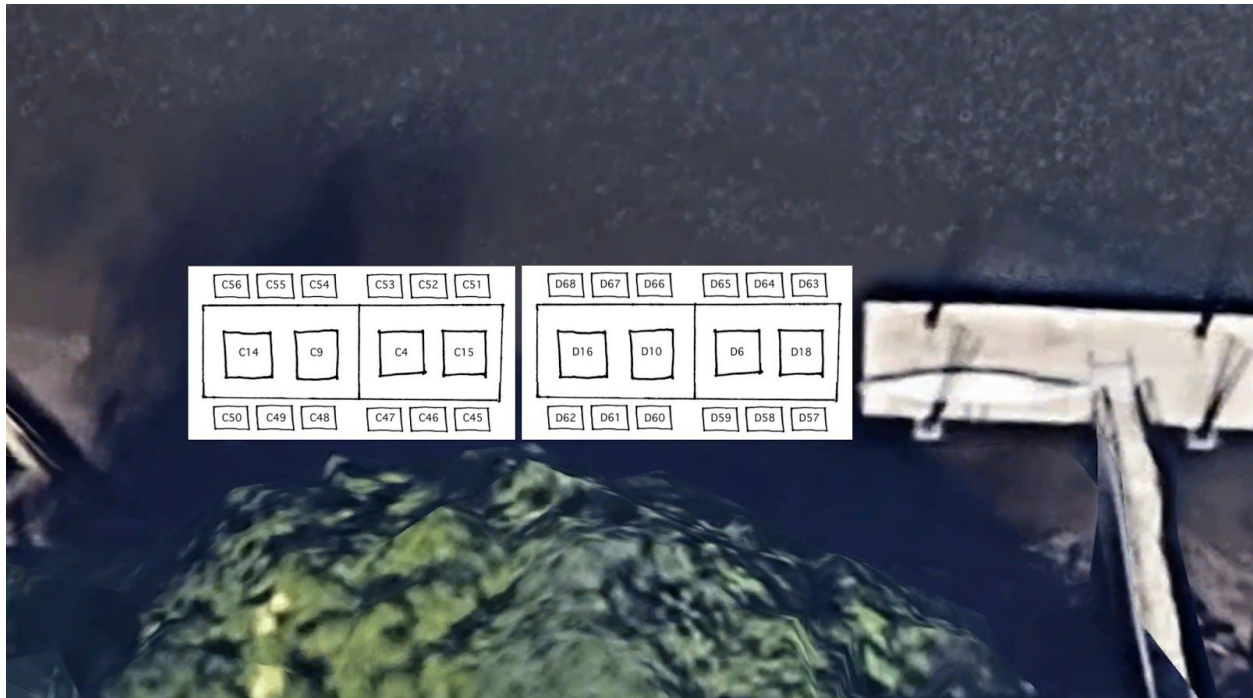


Figure 4.5.2.4. Placement of BioBarges at the Tukwila Dock. The top side of each BioBarge is the “exposed” side that faces out to open water; the bottom side of each BioBarge is the “sheltered” side, though the sheltered side experienced more mechanical disturbance. For reference, the river flows from east to west in this photo.

For these reasons, two location variables were incorporated into our statistical analyses of plant performance along with between-species comparisons. The placement of an individual plant on one BioBarge versus the other was coded as a variable (i.e. A versus B, or C versus D), as was the placement of an individual plant on one side of a BioBarge versus another (i.e. “sheltered” versus “exposed” sides).

ANOVA and Model Selection

Statistical analysis was performed to determine whether any of the observed differences in our plant performance metrics, either between species or between the different levels of our two location variables, were significant. Two-way ANOVA models were fitted and assessed to see if there was any significant correlation between plant performance and our species and location variables. The most parsimonious and best-fitting model was chosen through the use of Akaike information criterion (AIC) analysis and the examination of residual plots.

4.5.3. Results

Overall Plant Performance

Plant Height

The plant average heights on the last day of measurement, presumably the tallest point in their growth, were compared with average heights provided by the USDA plant data or King County native plant guides. See Table 4.5.3.1 This shows that some plants like SCIMIR and CXLYNG did much better at TD than at WM. This could be an indication that less salinity is better for these species. Additionally, at both sites, SCHAME performed near its average height classification. This was exciting to see as this species did not perform well in the year 1 locations. The two mixes of the WBF 2.0s had different species perform better at each location. This indicates that salinity levels mattered to SCIMIR, allowing it to do much better at TD than at WM.

Table 4.5.3.1: Plant height comparisons to published average heights. The yellow shows WM locations and the white shows TD locations. A side by side comparison allows the plant growth between locations of the same species to be compared.

Location - WBF prototype	Species	Mean height (cm) on final day of plant collection	Average height in cm per USDA	Average Height in cm per King County	Percent of full growth (at mature plant growth)
WM - 1.0	BOLMAR	75.5	150		50.3%
TD - 1.0	BOLMAR	30.5*	150		20.3%*
WM - 1.0	SCHACU	146.5	300		48.9%
TD - 1.0	SCHACU	199	300		66.3%
WM - 1.0	SCHAME	99	100		99.0%
TD - 1.0	SCHAME	102	100		102%
WM - 1.0	SCHTAB	128	305		42.0%
TD - 1.0	SCHTAB	110	305		36.1%
WM - 2.0	CXLYNG	52.25		90	58.1%
TD - 2.0	CXLYNG	82.25		90	91.4%
WM - 2.0	CXOBNU	31.75		90	35.3%

TD - 2.0	CXOBNU	53.75		90	59.7%
WM - 2.0	ELEPAL	42.25	120		35.2%
TD - 2.0	ELEPAL	77.25	120		64.4%
WM - 2.0	SCIMIR	35.5		90	39.4%
TD - 2.0	SCIMIR	99		90	110%
WM - 2.0	Mix 1 - CXYLYNG	47.7		90	53.0%
TD - 2.0	Mix 1 - SCIMIR	82.75		90	91.9%
WM - 2.0	Mix 2 - CXYLYNG	48.3		90	53.7%
TD - 2.0	Mix 2 - SCIMIR	75		90	83.3%

*-there was concern that the BOLMAR at TD was removed or pulled out from animals since there was no growth at the last measurement. There appears to be a data discrepancy on the last day of data collection. The July 11th data collection was used for this species. There was also one WBF 1.0 that never showed any BOLMAR growth and may not have gotten replanted. It could also be an indication that BOLMAR does not do well in fresh water conditions. Further information into this result is needed.

Plant Survival

At the beginning of the 2020 research, the WBF 2.0s were each planted with 16 plugs. Additionally, the WBF 1.0s were replanted as needed, using the same holes as the 2019 research. During the 2020 research, the number of living plants were counted in each WBF to determine how well the plants survived. The inverse of this number, then gave a mortality rate for the plants that was later statistically evaluated at each site.

A mean of the survival percentages gave a mean survival percentage for each species at each location. See Table 4.5.3.2. At TD, all the 2.0 species and mixes showed a survival rate above 80%. The table confirms higher survival rates of the 2.0 species at TD, while the 1.0 species did not do as well in that setting. This could be from the strong salt water the WBF 1.0s were in last year and it was too much of a shock to the freshwater condition at TD. Another possibility is that species didn't get as fully replanted as anticipated during Spring 2020. The good news is that the only two species below a 30% survival rate at TD are BOLMAR and SCHAME. In comparing that with the plant height, it tells us that the SCHAME that did well at TD performed great but there were not many plants that did well. At WM, BOLMAR was the only species below 30%, but CXOBNU was the only species above 80%. As documented in the statistics later, the poor turnout at WM could be due to some of the wake disturbance in the 2.0s. The CXOBNU height at WM didn't do as well, so this tells us that it may be a plant that needs more time to grow and adjust to the condition. When looking at the Plant Survival and the Plant Height together, it can tell us a bigger picture on the plant performance. Overall, the mean plant survival percentage for the WBF 2.0s was over 50%. Those with lower numbers tended to be the WBFs impacted by boat wakes.

Table 4.5.3.2:

Location - WBF prototype	Species	Plant Survival on final day of plant collection / total plants planted at the beginning of 2020				Mean Plant Survival Percentage
WM - 1.0	BOLMAR	26/31	2/46			10.4%
TD - 1.0	BOLMAR	0/41	8/46			9.2%
WM - 1.0	SCHACU	19/21	16/34			63.6%
TD - 1.0	SCHACU	29/46	20/47			52.7%
WM - 1.0	SCHAME	20/49	32/39			59.1%
TD - 1.0	SCHAME	9/42	13/42			26.2%
WM - 1.0	SCHTAB	35/31	19/41			75.0%
TD - 1.0	SCHTAB	14/39	24/41			47.5%
WM - 2.0	CXLYNG	13/16	15/16	2/16*	16/16	71.9%
TD - 2.0	CXLYNG	14/16	14/16	11/16	13/16	81.3%
WM - 2.0	CXOBNU	12/16	15/16	15/16	13/16	85.9%
TD - 2.0	CXOBNU	13/16	14/16	15/16	15/16	89.1%
WM - 2.0	ELEPAL	16/16	7/16	9/16*	12/16	68.8%
TD - 2.0	ELEPAL	13/16	16/16	14/16	15/16	90.6%
WM - 2.0	SCIMIR	14/16	3/16*	8/16	8/16	51.6%
TD - 2.0	SCIMIR	16/16	16/16	16/16	16/16	100%
WM - 2.0	Mix 1	14/16	6/16	9/16	8/16	57.8%
TD - 2.0	Mix 1	16/16	15/16	11/16	11/16	82.8%
WM - 2.0	Mix 2	11/16	6/16*	10/16	5/16	50%
TD - 2.0	Mix 2	14/16	14/16	12/16	12/16	81.3%

* These WBF 2.0s were described later as being the most significantly hit by boat wakes at WM. The substrate began to pull out of the structures and plants were lost to the river. The low survival numbers impacted the mean survival percentage for that species.

Further plant results break down the comparison of the three times data was collected at each site. It should be noted that the following information shows specific information and seasonality in the data but does not consider the overall growth from March. The data indicates plant performance being less on sides that were impacted by external forces. The exposed side at WM showed less plant growth because of the strong wakes, while the sheltered side at TD showed less plant growth from getting hit by woody debris on the bottom of the river.

Plant Performance - Waste Management

Change in Height

SCHTAB showed the largest increase in height at WM (about 30 cm), while SCHAME and MIX 1 showed a modest increase (about 10 cm) over that time. ELEPAL's height decreased by a few cm (Fig. 4.5.3.1, below). All other species exhibited little to no change in growth, displaying a similar plateau in health as was seen during last year's monitoring. SCHACU appeared to have achieved its maximum height by the time measurement began.

It should be noted that all plants started at zero or slightly above at the beginning of the season. Plug plants in the 2.0s and replanted 1.0s had a small amount of growth, but nothing substantial. Figure 4.5.3.1 indicates the ultimate growth achieved during the planned monitoring period.



Figure 4.5.3.1. Change in plant heights by species over a four-week Period and ultimate height achieved at the end of the monitoring period, at Waste Management.

The scatter plot below (**Fig. 4.5.3.2**) displays the change in height between 20 June and 18 July 2020, observed for each 2.0 WBF at WM, sorted by species and position on the BioBarge:

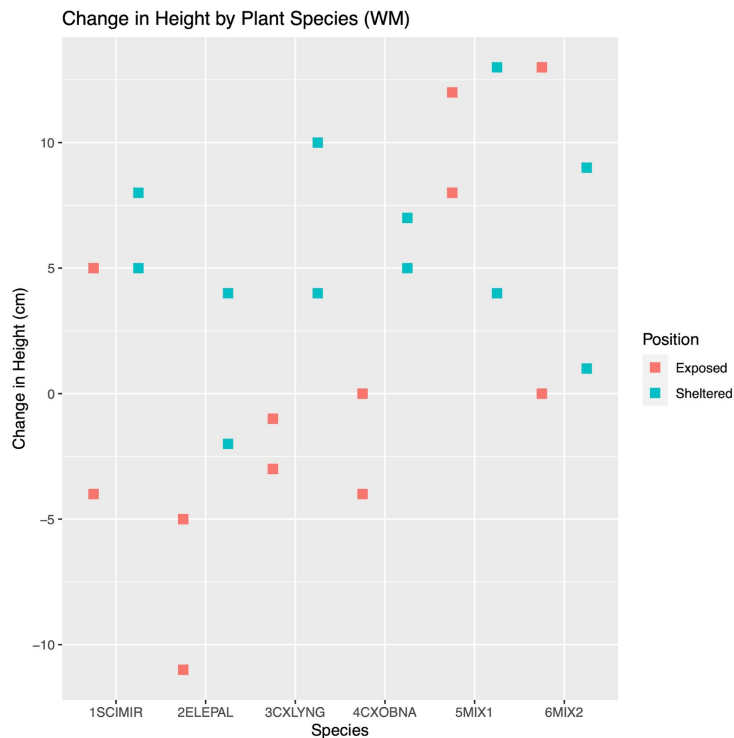


Figure 4.5.3.2. Change in Height by Species and Biofilter Placement Over a Four-Week Period at Waste Management.

Although the scatter plot does it make evident how much more poorly plants on the exposed WBFs performed compared to the sheltered WBFs, the data is not easy to interpret. A second plot mapping out the mean changes in height for each factor level that was ultimately examined using ANOVA is presented below (**Fig. 4.5.3.3**). The map of means indicates high variability between species, with MIX1 performing the best and ELEPAL performing the most poorly overall; indeed, ELEPAL was the only species to exhibit a mean decrease in height. Sheltered WBFs exhibited an overall greater increase in height compared to exposed WBFs, and plants on BioBarge B exhibited an overall larger increase in height than on BioBarge A.

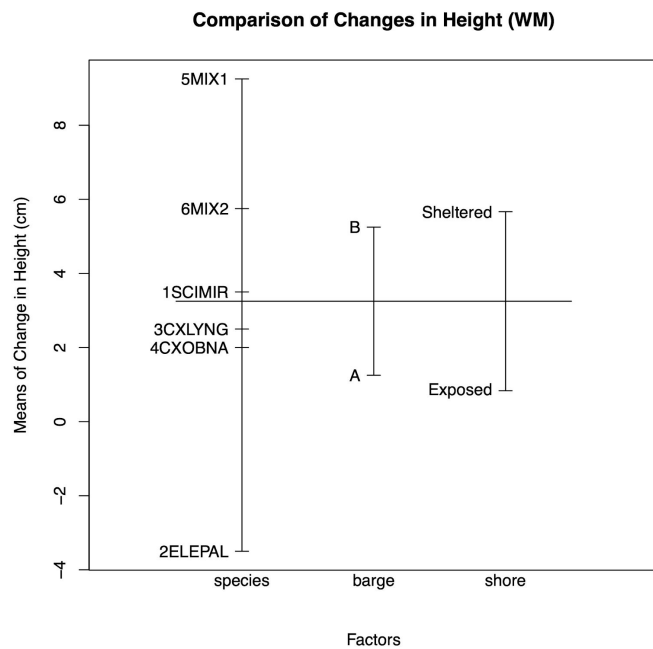


Figure 4.5.3.3. Mean Changes in Height by Species, BioBarge, and Biofilter Placement Over a Four-Week Period at Waste Management.

The best two-way ANOVA model shows a statistically significant difference in mean height change dependent on the position of the Biofilter on either the exposed side of the BioBarge or the sheltered side, with a p -value of 0.0138. There is also a statistically significant difference depending on which BioBarge the 2.0 WBF was attached to ($p = 0.0339$). Finally, there is a statistically significant difference between species ($p = 0.0191$), but Tukey testing shows that the only statistical significant inter-species difference exists between ELEPAL, the worst performer, and MIX 1, the best performer (adjusted $p = 0.0094$):

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
species	5	360.0	72.00	4.400	0.0191 *
shore	1	140.2	140.17	8.566	0.0138 *
barge	1	96.0	96.00	5.867	0.0339 *
species:shore	5	126.3	25.27	1.544	0.2543
Residuals	11	180.0	16.36		

Tukey multiple comparisons of means
 95% family-wise confidence level

Fit: aov(formula = height ~ species * shore + barge, data = dat)

\$species	diff	lwr	upr	p adj
2ELEPAL-1SCIMIR	-7.00	-16.7549421	2.754942	0.2204171
3CXLYNG-1SCIMIR	-1.00	-10.7549421	8.754942	0.9990997
4CXOBNA-1SCIMIR	-1.50	-11.2549421	8.254942	0.9939266
5MIX1-1SCIMIR	5.75	-4.0049421	15.504942	0.3945504
6MIX2-1SCIMIR	2.25	-7.5049421	12.004942	0.9642067
3CXLYNG-2ELEPAL	6.00	-3.7549421	15.754942	0.3538624
4CXOBNA-2ELEPAL	5.50	-4.2549421	15.254942	0.4379144
5MIX1-2ELEPAL	12.75	2.9950579	22.504942	0.0093867
6MIX2-2ELEPAL	9.25	-0.5049421	19.004942	0.0662898
4CXOBNA-3CXLYNG	-0.50	-10.2549421	9.254942	0.9999697
5MIX1-3CXLYNG	6.75	-3.0049421	16.504942	0.2493485
6MIX2-3CXLYNG	3.25	-6.5049421	13.004942	0.8565907
5MIX1-4CXOBNA	7.25	-2.5049421	17.004942	0.1943047
6MIX2-4CXOBNA	3.75	-6.0049421	13.504942	0.7739349
6MIX2-5MIX1	-3.50	-13.2549421	6.254942	0.8172048

Change in Foliage Cover

Below, **Figure 4.5.3.4** shows that at WM only the plants on the 1.0 WBFs showed an overall positive change in percent cover over time. All the plants on the 2.0 WBFs displayed decreasing percent cover. However, this does not include data and growth prior to June when many of these plants grew. It is also possible that increasing salinity affected this plant growth.

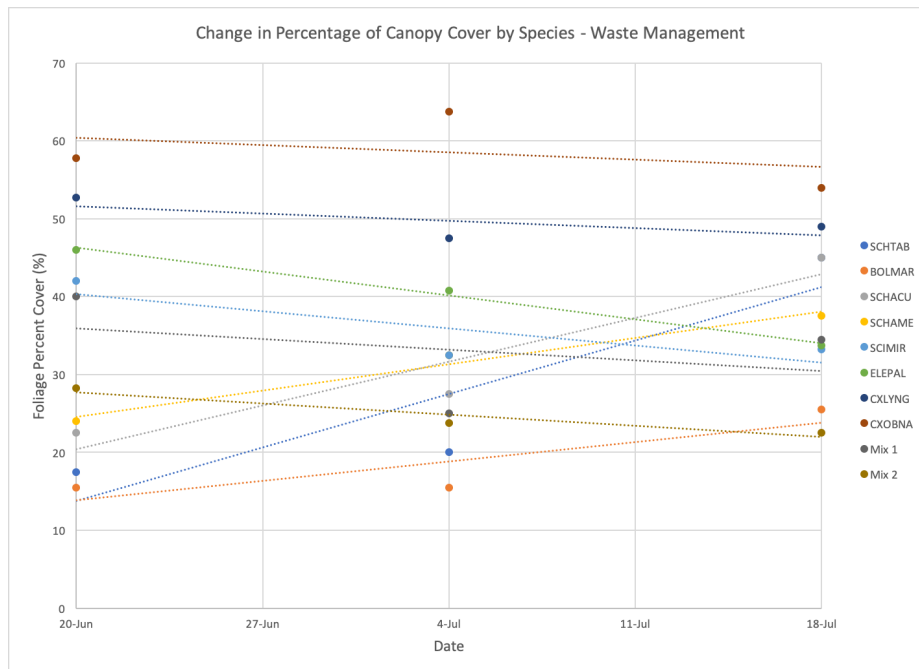


Figure 4.5.3.4. Change in Foliage Cover as a Percentage Over a Four-Week Period at Waste Management. Changes in foliage cover are tracked by species.

The scatter plot below (**Fig. 4.5.3.5**) displays the change in percent cover observed for each 2.0 WBF at WM, sorted by species and position on the BioBarge:

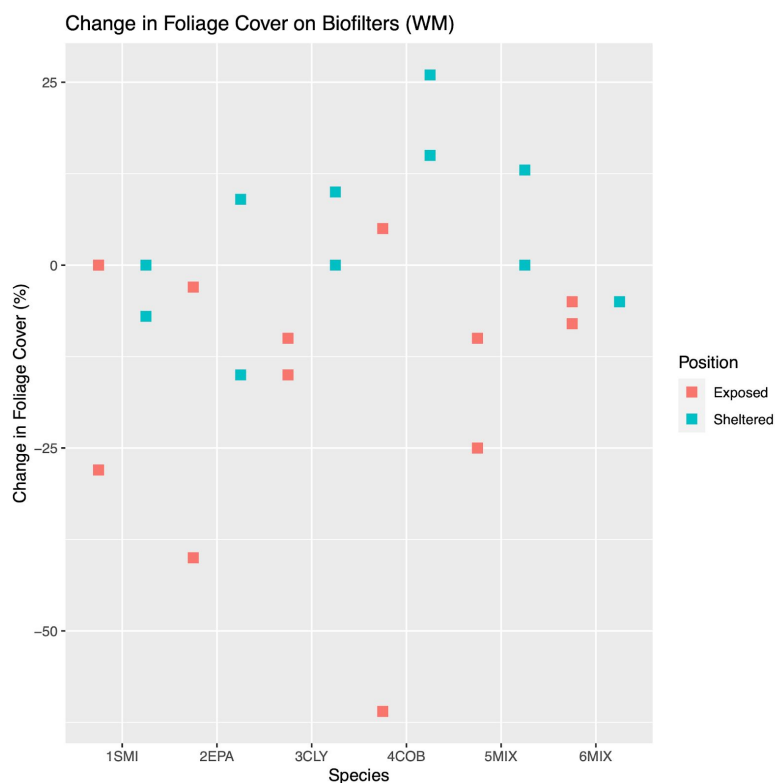


Figure 4.5.3.5. Change in Foliage Cover by Species and Biofilter Placement Over a Four-Week Period at Waste Management.

Although the scatter plot shows how much the species cover increased or declined in the exposed WBFs compared to the sheltered WBFs at WM, the data is not easy to interpret. Generally, the exposed WBFs had more decline than the sheltered WBFs at WM. A second plot mapping out the mean changes in foliage cover for each factor level examined using ANOVA is presented below (**Fig. 4.5.3.6**). The map of means indicates that every single species performed worse on the exposed side than the sheltered side of the BioBarge, with SCIMIR and ELEPAL being hit the hardest from exposure locations. The single positive mean value (which denotes an increase in foliage cover) is for sheltered WBFs (versus exposed WBFs). Plants on BioBarge A did slightly worse in change of percent cover than on BioBarge B:

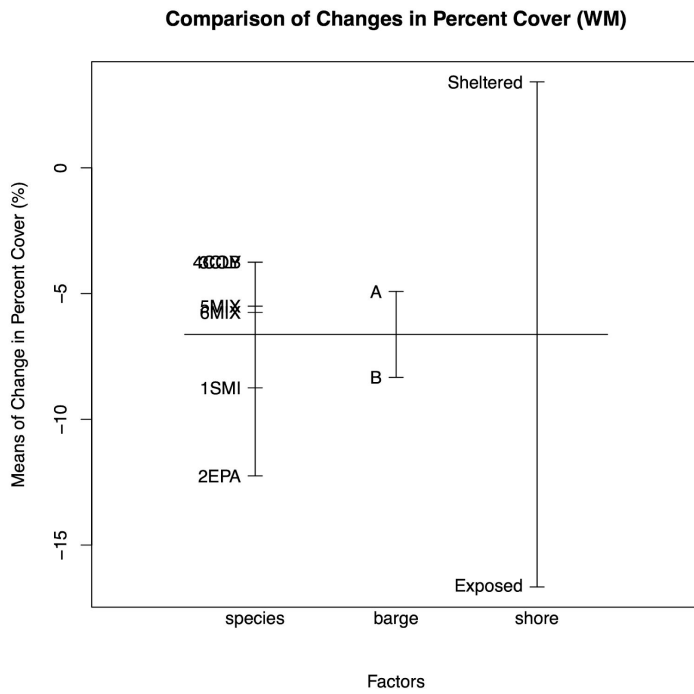


Figure 4.5.3.6. Mean Changes in Foliage Cover by Species, BioBarge, and Biofilter Placement Over a Four-Week Period at Waste Management.

The best two-way ANOVA model shows a statistically significant effect of the position of the 2.0 WBFs (either on the exposed side of the BioBarges or the sheltered side), with a *p*-value of 0.0182:

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
species	5	219	43.8	0.135	0.9810
shore	1	2420	2420.0	7.463	0.0182 *
species:shore	5	1269	253.8	0.783	0.5811
Residuals	12	3891	324.3		

Total Mortality

The scatter plot below (**Fig. 4.5.3.7**) displays the mortality rates observed for each 2.0 WBF at WM, sorted by species and position on the BioBarge:

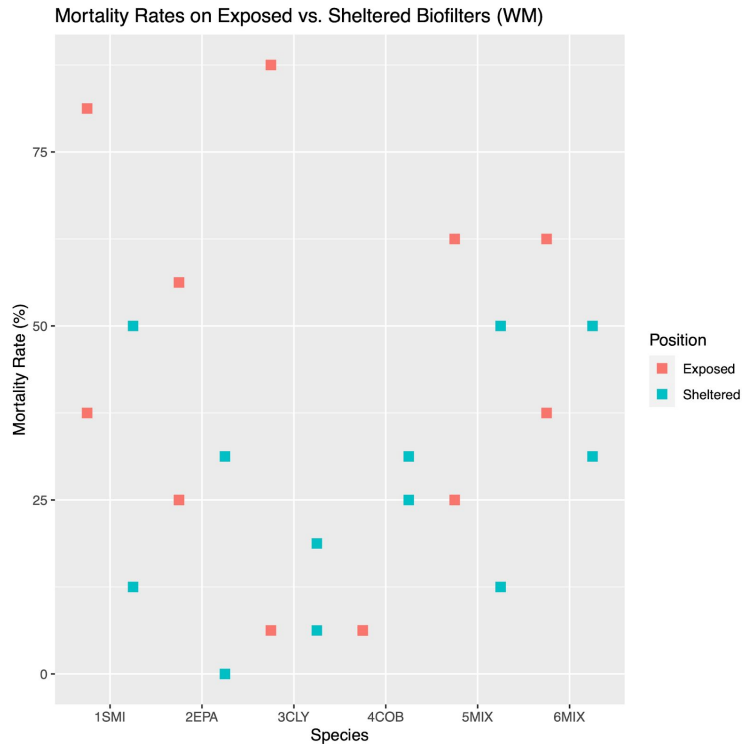


Figure 4.5.3.7. Total Mortality Rate by Species and Biofilter Placement Over a Four-Month Period at Waste Management.

Generally, the chart tells us that there is less mortality rate in the sheltered WBFs than in the exposed WBFs. Because the scatter plot is not easy to interpret, another plot mapping out the mean mortality rates for each factor level examined using ANOVA is presented below (**Fig. 4.5.3.8**). The map of means indicates that CXOBNA had the lowest mortality rates while MIX1 and SCIMIR had the highest. Plants seem to have survived better on sheltered WBFs than on exposed WBFs, and they also survived better on BioBarge A than on BioBarge B:

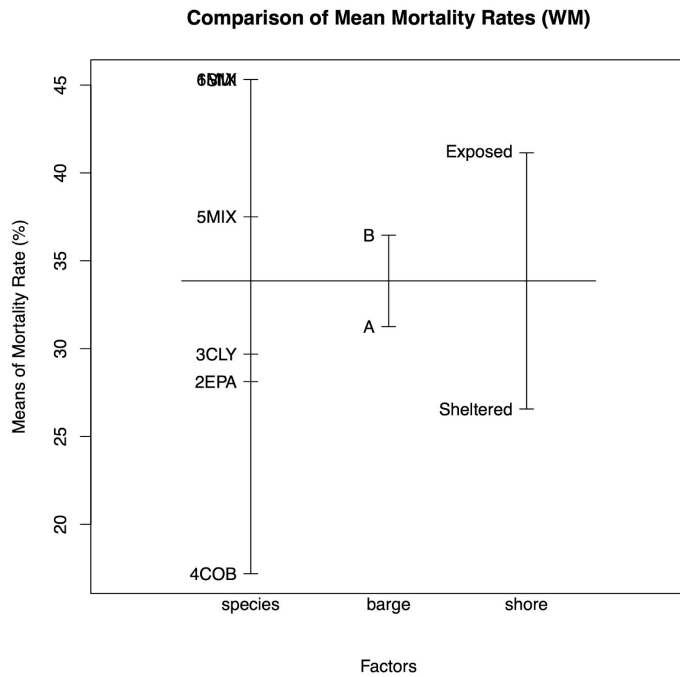


Figure 4.5.3.8. Mean Mortality Rates by Species, BioBarge, and Biofilter Placement Over a Four-Month Period at Waste Management.

None of the assessed two-way ANOVA models showed a statistically significant effect related to plant species, placement on one BioBarge versus another, or placement on the exposed side of the BioBarge versus the sheltered side at WM:

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
species	5	2415	483.1	0.684	0.645
shore	1	1276	1276.0	1.807	0.206
barge	1	163	162.8	0.231	0.641
species:shore	5	2044	408.9	0.579	0.716
Residuals	11	7767	706.1		

Plant Performance - Tukwila Dock

It should be noted that the words exposed and sheltered are used to describe locations and do not reflect the results of the data. Overall, the sheltered side was more impacted by woody debris which impacted the data than the exposed side.

Change in Height

SCIMIR showed the largest increase in height at TD (about 35 cm), with SCHTAB a close second (about 30 cm). All other species showed increases in height except for BOLMAR which showed an increase until July 11th, then decreased to zero. Further information on the BOLMAR situation is needed to

understand why this occurred. SCHACU had achieved over 50% of its expected height and stabilized at this height. (Fig. 4.5.3.9, below):

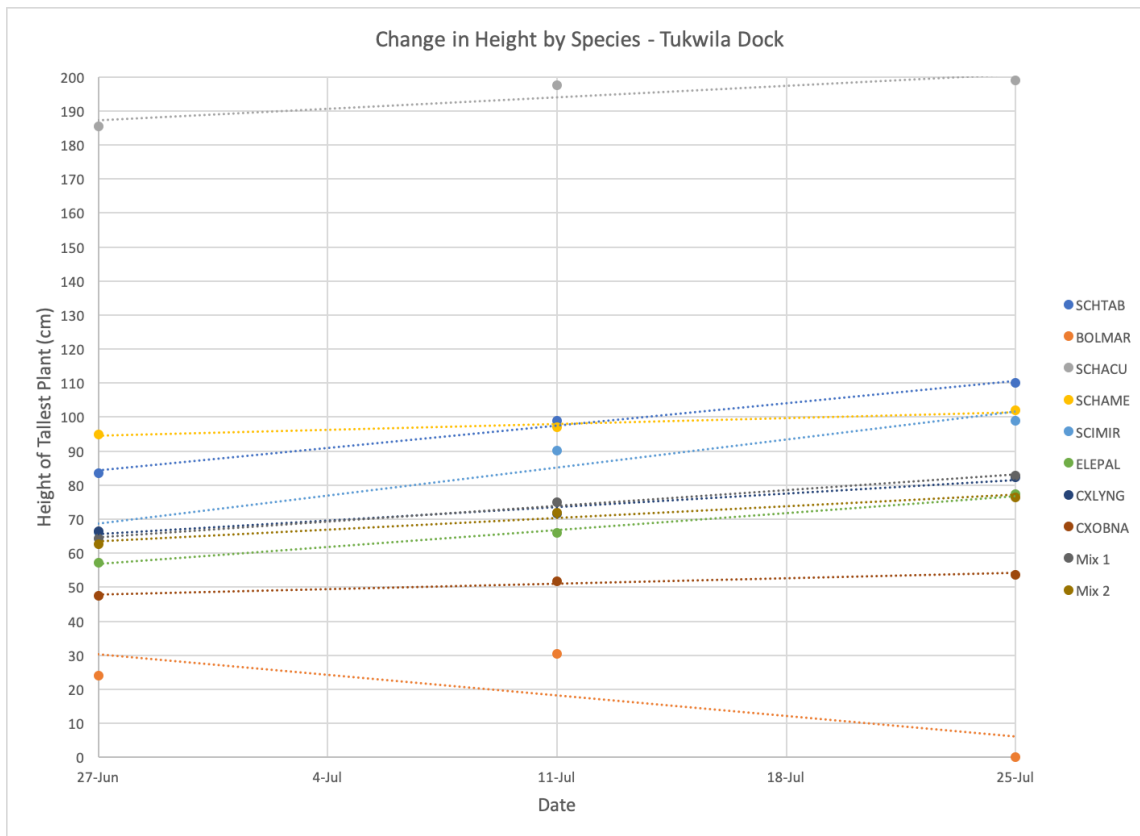


Figure 4.5.3.9. Change in Plant Heights by Species Over a Four-Week Period at the Tukwila Dock and ultimate height achieved at the end of the monitoring period.

The scatter plot below (Fig. 4.5.3.10) displays the change in height observed for each 2.0 WBF at WM, sorted by species and position on the BioBarge.

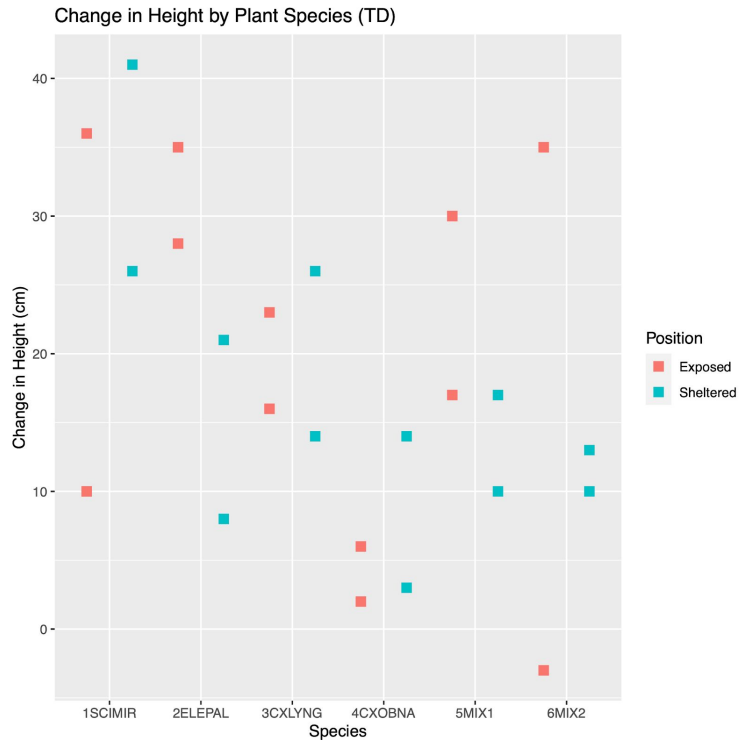


Figure 4.5.3.10. Change in Height by Species and Biofilter Placement Over a Four-Week Period at the Tukwila Dock.

This scatterplot does not show an obvious difference between the exposed side of the biobarge and the sheltered side. A second plot mapping out the mean changes in height for each factor level that was ultimately examined using ANOVA is presented below (**Fig. 4.5.3.11**). The map of means indicates high variability between species, with SCIMIR and ELEPAL performing the best and CXOBNA performing the most poorly; no species exhibited a mean decrease in height. This is showing the seasonality of the species and when it is likely to do well. That CXOBNA did not show a strong change in height during that time period does not mean it did not do well in this setting. Exposed WBFs exhibited a slightly better than average increase in height compared to sheltered WBFs which performed slightly lower than average, and plants on BioBarge D exhibited an overall larger increase in height than on BioBarge C.

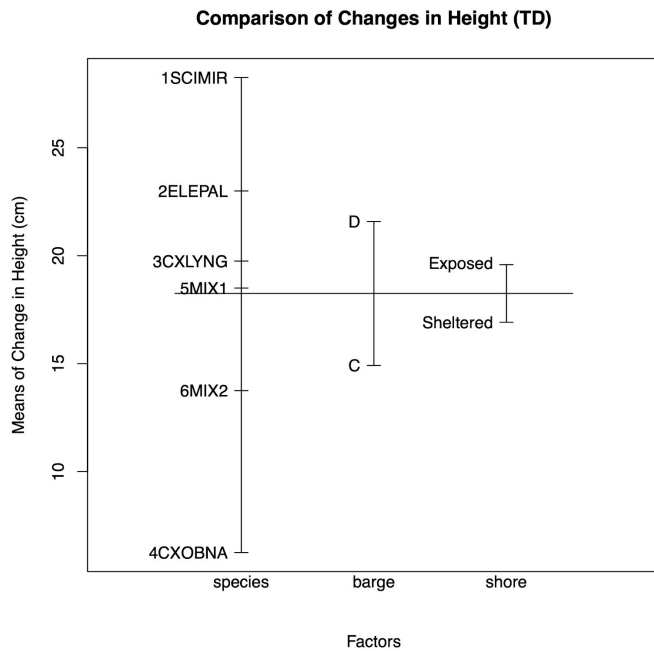


Figure 4.5.3.11. Mean Changes in Height by Species, BioBarge, and Biofilter Placement Over a Four-Week Period at the Tukwila Dock.

The best two-way ANOVA model shows a slight association between species ($p = 0.0735$), but Tukey testing shows that there exists only one statistically significant inter-species difference, and that it is between CXOBNA, the worst performer, and SCIMIR, the best performer (adjusted $p = 0.0496$), in change in height during this time period. These are not comparing the species to their average expected growth, rather are comparing actual growth of species to species. As indicated on Table 4.5.3.1 it is not expected that all the species would achieve the same ultimate height.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
species	5	1156.5	231.30	2.703	0.0735 .
barge	1	266.7	266.67	3.116	0.1029
species:barge	5	806.3	161.27	1.884	0.1709
Residuals	12	1027.0	85.58		

Tukey multiple comparisons of means
95% family-wise confidence level

Fit: aov(formula = height ~ species * barge, data = dat2)

\$species	diff	lwr	upr	p adj
2ELEPAL-1SCIMIR	-5.25	-27.222495	16.72249496	0.9615986
3CXLYNG-1SCIMIR	-8.50	-30.472495	13.47249496	0.7802166
4CXOBNA-1SCIMIR	-22.00	-43.972495	-0.02750504	0.0496491
5MIX1-1SCIMIR	-9.75	-31.722495	12.22249496	0.6761664
6MIX2-1SCIMIR	-14.50	-36.472495	7.47249496	0.2979861
3CXLYNG-2ELEPAL	-3.25	-25.222495	18.72249496	0.9953492
4CXOBNA-2ELEPAL	-16.75	-38.722495	5.22249496	0.1811874
5MIX1-2ELEPAL	-4.50	-26.472495	17.47249496	0.9799525
6MIX2-2ELEPAL	-9.25	-31.222495	12.72249496	0.7190046
4CXOBNA-3CXLYNG	-13.50	-35.472495	8.47249496	0.3649273
5MIX1-3CXLYNG	-1.25	-23.222495	20.72249496	0.9999540
6MIX2-3CXLYNG	-6.00	-27.972495	15.97249496	0.9345699
5MIX1-4CXOBNA	12.25	-9.722495	34.22249496	0.4607446
6MIX2-4CXOBNA	7.50	-14.472495	29.47249496	0.8528379
6MIX2-5MIX1	-4.75	-26.722495	17.22249496	0.9747245

Change in Foliage Cover

Weekly photo data was compiled to track foliage cover over a three and a half month period (**Fig. 4.5.3.12**, below). SCIMIR showed the largest increase in foliage cover. The SCIMIR species also has the broadest leaf and inflorescence arrangement which would anticipate a larger foliage cover. Plant species on 2.0 WBFs generally showed greater increases in foliage cover than the 1.0 WBFs' plant species; the only species on the 1.0 WBFs that performed comparably to the 2.0 species was SCHACU. Generally, WBFs that started out with higher percent cover values (i.e. WBFs with larger individual plant mass) exhibited a much larger change in foliage cover.

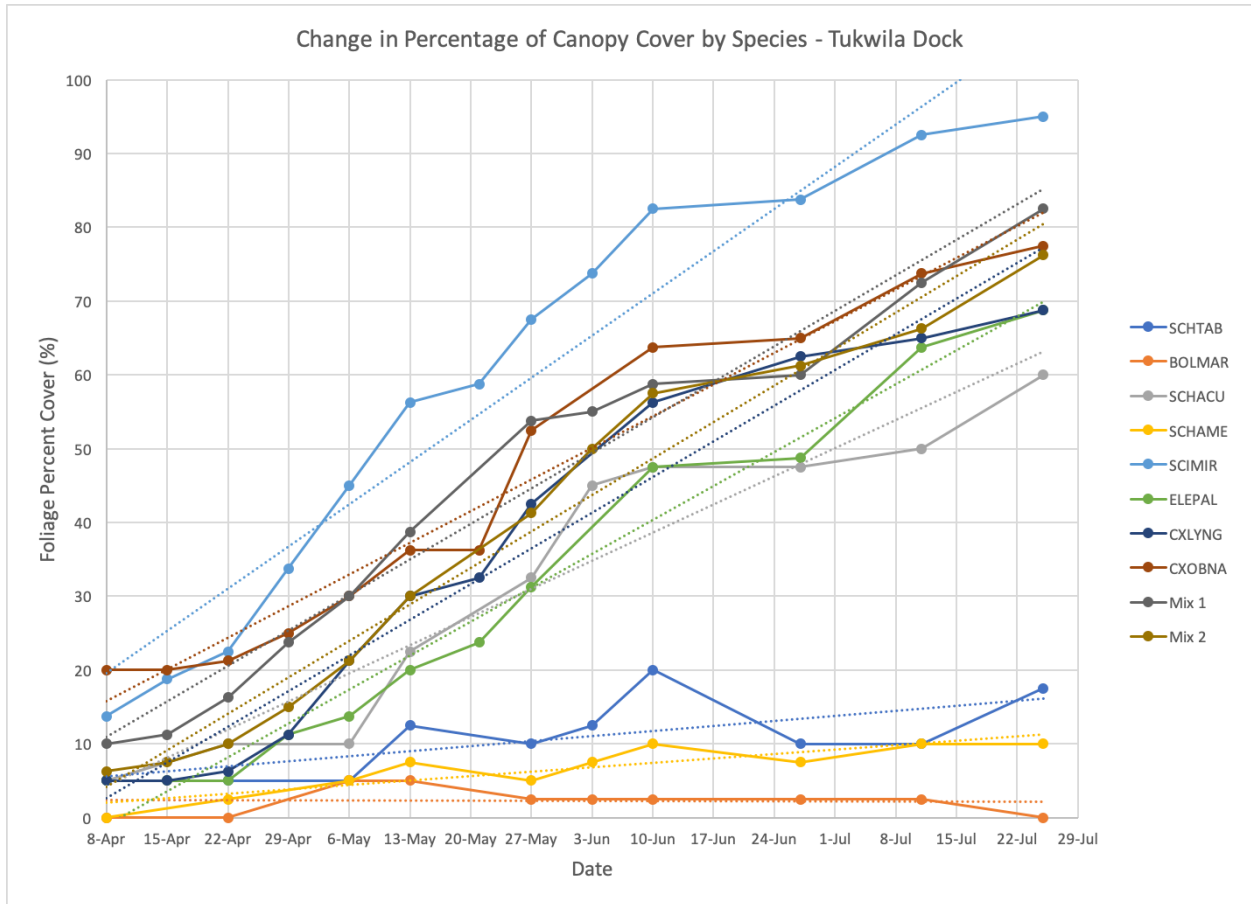


Figure 4.5.3.12. Change in Foliage Cover Over a Sixteen-Week Period at the Tukwila Dock.

The scatter plot below (**Fig. 4.5.3.13**) displays the change in foliage cover observed for each 2.0 WBF at TD, sorted by species and position on the BioBarge. Note that for this portion of the analysis, only the four-week field monitoring period from June to July is being examined so that our statistical approach remains consistent with the approach we took when analyzing change in foliage cover for WM. Sheltered WBFs (impacted by substrate conditions) trended to the lower range of percent change while the exposed WBFs showed more growth.

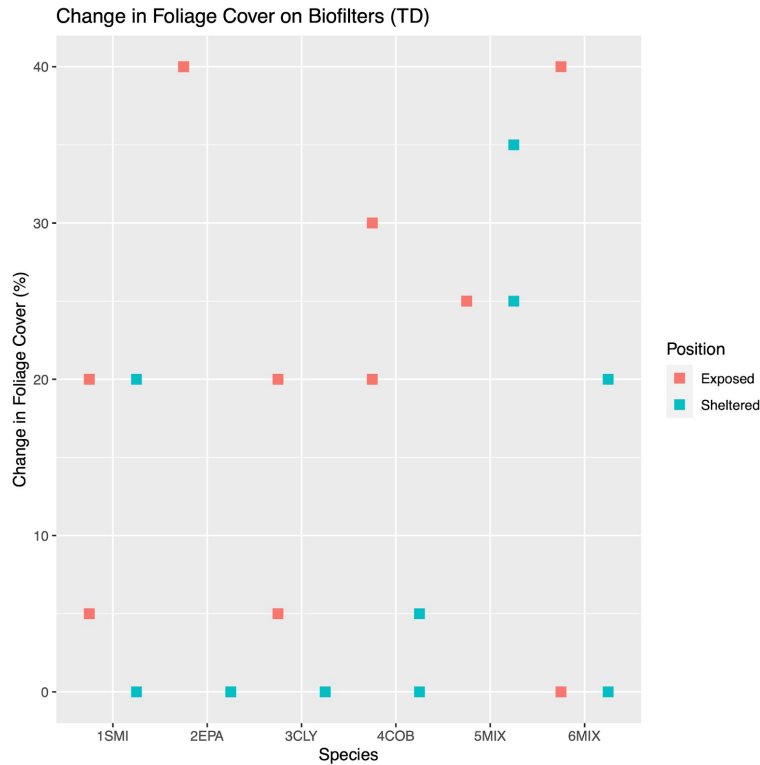


Figure 4.5.3.13. Change in Foliage Cover by Species and Biofilter Placement Over a Four-Week Period at the Tukwila Dock.

Because the scatter plot is not easy to interpret, a second plot mapping out the mean changes in foliage cover for each factor level examined using ANOVA is presented below (**Fig. 4.5.3.14**). The map of means indicates that while every single species exhibited an increase in foliage cover, MIX1 and ELEPAL had the largest positive change. Plant foliage cover seems to have increased by a much larger amount on exposed WBFs than on sheltered WBFs. Plants also increased in foliage cover a bit more on BioBarge D than on BioBarge C. Again, good to note this analysis is of the seasonality that the measurements were taken and do not reflect the full plant growth from the beginning of March.

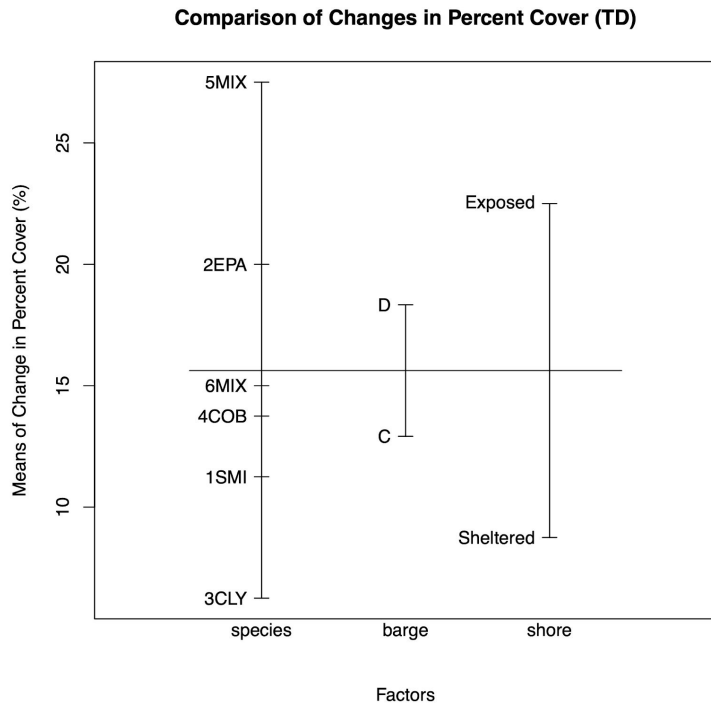


Figure 4.5.3.14. Mean Changes in Foliage Cover by Species, BioBarge, and Biofilter Placement Over a Four-Week Period at the Tukwila Dock.

The best two-way ANOVA model shows a statistically significant effect of the position of the Biofilter (either on the exposed side of the BioBarge or the sheltered side), with a p -value of 0.0116.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
species	5	1084	216.9	1.693	0.2108
shore	1	1134	1134.4	8.854	0.0116 *
species:shore	5	1259	251.9	1.966	0.1565
Residuals	12	1538	128.1		

Total Mortality

The scatter plot below (**Fig. 4.5.3.15**) displays the mortality rates observed for each 2.0 WBF at TD, sorted by species and position on the BioBarge. There is little difference shown between the exposed and sheltered WBFs in the scatter plot.

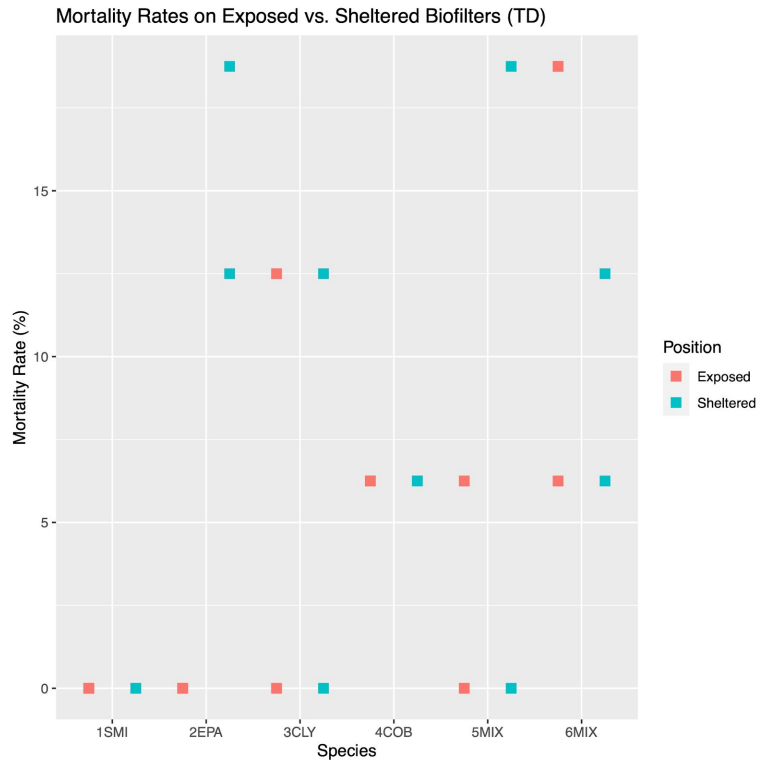


Figure 4.5.3.15. Total Mortality Rate by Species and Biofilter Placement Over a Four-Month Period at the Tukwila Dock.

Another plot mapping out the mean mortality rates for each factor level examined using ANOVA is presented below (**Fig. 4.5.3.16**). The map of means indicates that SCIMIR had the lowest mortality rates while MIX2 had the highest. SCIMIR has done well overall in the freshwater condition. Plants also seem to have survived better on exposed WBFs than on sheltered WBFs. They also survived better on BioBarge C than on BioBarge D.

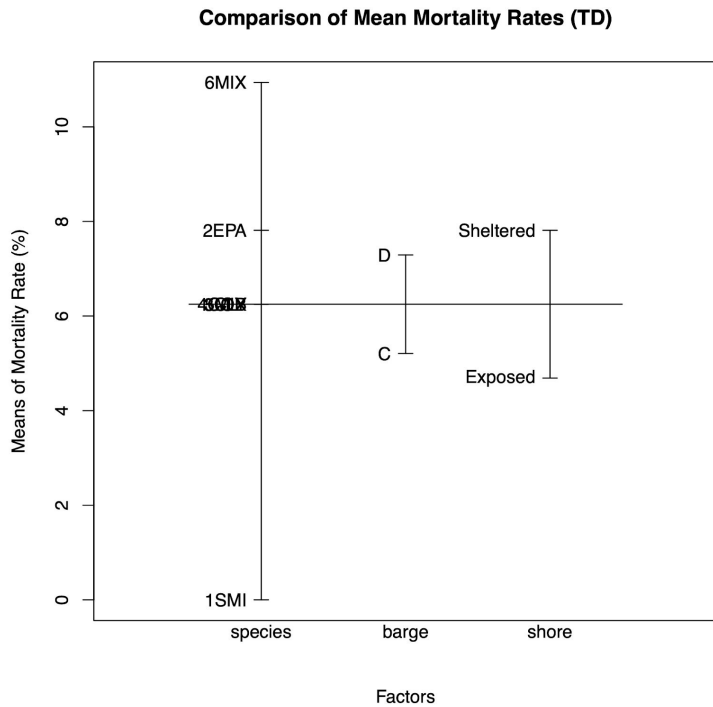


Figure 4.5.3.16. Mean Mortality Rates by Species, BioBarge, and Biofilter Placement Over a Four-Month Period at the Tukwila Dock.

None of the assessed two-way ANOVA models showed a statistically significant effect related to plant species, placement on one BioBarge versus another, or placement on the exposed side of the BioBarge versus the sheltered side.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
species	5	253.9	50.78	1.3	0.327
shore	1	58.6	58.59	1.5	0.244
species:shore	5	234.4	46.88	1.2	0.366
Residuals	12	468.7	39.06		

4.5.4. Discussion

Overall, most species did better in freshwater conditions at TD than in partial salinity at WM. SCHACU, CXLYNG, CXOBNU, ELEPAL, SCIMIR, and both mixes were closer to their average species performance at TD. BOLMAR, SCHACU, and SHTAB showed better results at WM which is an estuarine condition. SCHAME seemed to do very well at both locations. This shows the amount of salinity in the site can affect the plant species. This research could help in future selection of plants based on the known salinity of the site.

Placement of the 2.0 WBFs turned out to be a hugely important factor affecting plant performance at WM and TD. At WM, we surmise that this is related to the high frequency and intensity of boat wakes experienced by the BioBarges. Boats traveling at or below the speed limit would not disturb the BioBarges significantly, but speeding boats, particularly large ones, would send powerful wakes directly into the “exposed” side of each BioBarge, jostling them heavily against each other and the wooden frame of the BioBarge itself. **Fig. 4.3.2.1** shows how the Biobarges are positioned. Several 2.0 WBFs on the exposed side of the BioBarges ended up cracking open entirely, losing a good deal if not all of their substrate and most of their plants as well (**Fig. 4.5.4.1**, below). It is believed that the cumulative effect of multiple strong boat wakes was what caused some 2.0 WBFs to fail.

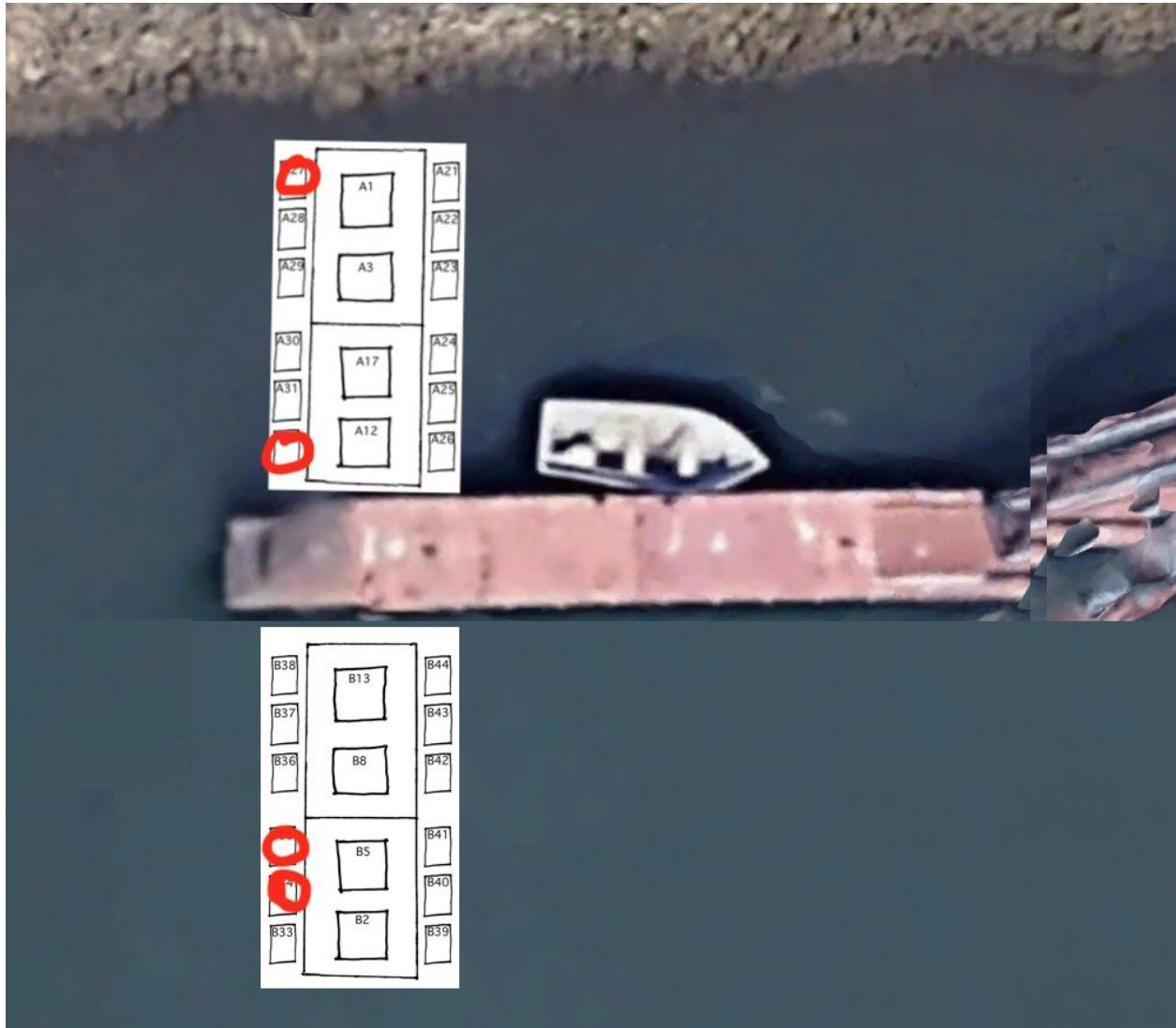


Figure 4.5.4.1. Placement of BioBarges at Waste Management. The red circles denote 2.0 WBFs that were severely damaged and were either in the process of losing all of its wood straw or lost it all entirely by the end of the monitoring period.

At WM, many plants in the 2.0 WBFs showed decline in plant performance during the five-week monitoring period in June and July. Possibilities as to why 1.0 WBF plant species were less affected include the fact that the plants had a full year longer to establish and were more resilient to stressful conditions, and the finer substrate could hold more moisture.

At Tukwila Dock, plants performed better on 2.0 WBFs that were on the exposed side of each BioBarge (i.e. facing out toward the water) than on sheltered 2.0 WBFs (i.e. situated between the shore and the main frame of the BioBarges). The woody debris from the shoreline subjected the 2.0 WBFs to more impact than what was seen on the exposed side (with smaller wakes than at WM).

As for total mortality, analysis of our species and location variables reveal no significant effects.

For differences between species at TD, we found that SCIMIR was the species that performed the best overall. SCIMIR had the highest increase in height, lowest mortality rate, and the highest percent cover. SCIMIR, CXYNG, and SCHAME nearly achieved or exceeded their average expected height. All the WBF 2.0s achieved almost a 70% or greater in percent cover. The percent cover of WBF 1.0 species was significantly behind the WBF 2.0s, likely because the individual plants were originally planted further apart. BOLMAR struggled the most to grow in this location. Additionally, it is believed that one of the BOLMAR WBFs was never replanted in 2020 to be able to regrow this year.

Lateral Plant Growth

The lateral growth over the side of the WBF 2.0 structures was measured to determine if the WBFs were helping create a dappled edge. Last year, the research team commented that the hardened edge of the flotation and wood structures could have been a barrier to fish. This year, the design changed to add the WBF 2.0s on the outside of the structure in hopes of not having such a hard edge. The lateral growth measures told us if none, few, some, or many plants were overhanging. For BioBarges A and B at WM, 50% of the WBF 2.0 structures had at least a few plants overhang. For BioBarges C and D at TUK, 100% of the WBF 2.0s had at least a few overhanging plants with more structures showing some or many. Overall, when the WBF 2.0 plants did well, there was lateral overhang found on the structure.

Summary and Limitations

Considering the survival rate of plants growing at the end of the monitoring period, it appears that the second generation designs of the floating wetlands (2.0) can successfully support wetland plant growth, with at least 50% of all species surviving. Those with lower survival rates tended to be those that were mechanically impacted. While the plant survival rates were variable for the WBF 1.0 designs, we did find strong roots in the plants that were there when disassembling the structures at the end of the research. Lateral growth was produced on at least half at WM and all at TD.

In general, better plant performance was observed at TD than WM, but context-dependent factors like frequent boat wakes at WM and submerged woody debris at TD prevent us from being able to determine whether it was truly the broader physical, chemical, and biological regimes characteristic to each stretch of the river driving these differences in performance. Instead, differences in performance

seem to be largely driven by locations of the WBFs on the BioBarges and the salinity levels between the two sites. Flowers or seeds were seen on all WBF 1.0s at TD, which were mostly a year older than the 2.0s. SCHACU and SCHAME were the two species with flowers at WM. ELEPAL was the only species with flowers from the WBF 2.0s.

For the statistically significant interspecies differences for changes in height that were detected at WM and TD, caution should be taken before interpreting those detected differences as a true indicator of differences in species performance since they only tell the story between a 5-week period in June and July. Larger results would have been shown if we had started the plant monitoring in March as originally planned before the global pandemic. Also, while preliminary power analysis work suggests that our sample sizes were generally sufficient for testing differences between barges as well as between the “exposed” and “sheltered” sides of barges, a much larger sample size is required to detect with confidence the sort of magnitude of difference in height increases that this study encountered between species ($n > 70$ individual *for each species*). Additionally, comparisons between the expected and achieved ultimate height of each species could be further analyzed.

5. Design and Monitoring Recommendations

Table 5.1 below provides a summary of the recommendations for each component of the floating wetlands monitoring program. The following sections provide more detail on each recommendation. Some crosscutting recommendations (e.g., location of study sites) are relevant to more than one area. It should be noted that some of the recommendations are related to the conditions caused by COVID-19 monitoring limitations.

Table 5.1. Overview of Design and Monitoring Recommendations

<p>Design and Construction</p>	<ul style="list-style-type: none"> ● BioBarge location and anchoring: Place BioBarges in areas with low wave action or boat wakes to prevent structure from being jostled, causing it to be structurally compromised. Sheltered locations will also provide greater ease of movement and stability for researchers and community scientists. ● Biofilter/BioBarge design for monitoring: Consider a more stable structure for researcher and community scientist monitoring, to provide greater access for researchers and community scientists of a wider range of ages and fitness levels, including those who are differently abled. ● Materials: Would strongly recommend finding alternatives to Tensar that are recyclable and/or biodegradable, not just for concerns about plastic use and plastic waste but also for aesthetic reasons. These projects should be installed with community in mind, and community considerations can and should include aesthetic considerations. Also, Tensar proved to be not resistant enough to the type of physical wear and tear the 2.0 WBFs received at the WM site, whereas the metal cages used for the 1.0s were just fine despite the strong wave action.
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	<p>All 1.0s at WM remained intact.</p> <ul style="list-style-type: none"> ● Scale: Instead of constructing large BioBarges that require high levels of coordination and effort to transport and monitor, consider small scale structures that can be attached to places like finger docks and bulkheads, e.g. an installation of three to six WBFs each the size of the WBFs 2.0 attached to a single finger dock to provide greenery/aesthetic interest. While the ecosystem benefits of such an installation may be small, if there was such an installation on every finger dock inside a harbor or marina, the cumulative ecosystem benefits could be significant. ● Substrate monitoring: Consider a more systematic approach to substrate monitoring, particularly for metals testing and invertebrate sampling. Suggestions include weighing total substrate and assessing its volume during the construction phase, instead of attempting to estimate such values <i>post facto</i>.
Fish Use and Response	<ul style="list-style-type: none"> ● Timing of monitoring: Begin monitoring in early March and continue to July in order to observe interactions of early migrating salmonids with the barges. ● Data collection: Continue in person over-water fish monitoring, with more rigorous training prior to data collection to ensure higher identification accuracy, especially when using a community science approach. Continue using underwater cameras to compare and supplement overwater and underwater data. ● Telemetry-based continuous monitoring: Deploy a Juvenile Salmon Acoustic Telemetry System (JSATS) to more accurately monitor salmonid behavior in the vicinity of the biobarges (assuming the hatcheries upstream tagged them). ● Design and placement for fish: Deploy BioBarges at more sites and cover larger areas to increase replication for further monitoring. Place BioBarges in areas with high water velocity to slow it down and provide benefits for juvenile salmonids. ● Location of study sites: Both Biobarge sites seemed appropriate since they had sightings of salmonids using the BioBarge structure. However, the different placement of the barges prevented effective direct comparison. Additionally, control sites may have been too close to barges causing confounding factors.
Invertebrate Production	<ul style="list-style-type: none"> ● Location of study sites: Control site may be too close to Biobarges and placement of fallout traps at reference sites was too far from water to truly reflect impact of riparian vegetation, however they were placed here to prevent traps washing away at high tide. ● Fallout trap methodology: Increase stability and ease of deployment and retrieval of fallout traps on barges since two traps on the barges were lost due to difficulty of securing them to the barge and retrieval.

	<ul style="list-style-type: none"> ● Sampling frequency and processing: Get started on identification during collection period. Terrestrial invertebrate collection frequency appropriate, more collection dates needed for aquatic invertebrates to have statistical significance or temporal understanding.
Water Quality	<ul style="list-style-type: none"> ● Location of study sites: The Tukwila site was predominantly freshwater, so maybe a saltier site may be more conducive to juvenile salmon adjusting to the ocean environment? ● Designing and measuring shade/light: With the exception of some Pendants lost during deployment or not recording data for the entire March-July monitoring period, the design and placement of the Pendants seemed logical. ● Site comparison: The WM site was heavily industrial while the Tukwila site was upriver in a less trafficked riparian environment that is proximate to residential communities. Plug design and analysis: Have the control plugs measured for biomass as well as metals, so a biomass comparison can be made with the plugs from the biofilters. ● Measuring river flow: The handheld SWOFFER worked well to spot-check river flow on a handful of occasions during the summer months, but it would be good to know how the river's flow changed from spring to summer, as snowmelt decreased. It also would be good to know the river flow as the hatchery salmon were released.
Plant Growth	<ul style="list-style-type: none"> ● Monitoring methods: Conduct power analyses using the data gathered during the June/July 2020 monitoring period to inform future research. Preliminary work suggests that statistical power was sufficient for testing for the observed magnitude of differences between the “sheltered” and “exposed” sides of BioBarges, but that a much larger sample size is needed to reliably detect significant interspecies differences in performance ($n > 70$, where n signifies individual plants). ● Plant size/age: Plants that were larger to begin with at planting seemed to perform better than plants that were smaller, and plants in the 1.0 WBFs (i.e. planted in 2019) generally seemed more resilient than individuals outplanted this year. However, there was no consistent information on plant size and age on the day of outplanting onto the 2.0 WBFs. ● Species selection: Consider ELEPAL, SCIMIR, CXLYNG, SCHAME, and CXOBNU in freshwater conditions and SCHACU, SCHAME, SCHATB, and BOLMAR in estuary conditions. Different results may be found in plants as they mature. ● Location of study sites: As mentioned under “Design and Construction,” BioBarges should be placed in areas with low wave action or boat wakes to prevent structures from being jostled, causing physical wear and greatly reducing plant performance. Careful consideration of site selection, including an

	<p>assessment of exposure to strong waves and boat wakes, as well as an assessment of how tidal range interacts with river bottom topography to cause physical damage or desiccation, is highly recommended.</p> <ul style="list-style-type: none"> ● Research design: Standardize the 1.0 WBFs by completely replacing substrates and plants before the project begins in order to ensure that data collected from the 1.0 WBFs will be amenable to statistical analysis.
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6. Community Science and Outreach

6.1. Summary of the Community Science Program

The main role of the community science lead was to foster movement, motivation, and alignment of project agenda and community scientist interest. The community science branch of the Duwamish Floating Wetland Project brought together ecological design, scientific research, and community participants including the Rose Foundation, the Port of Seattle, King County, Duwamish River Cleanup Coalition, UW Doris Duke Conservation Scholars Program, Pacific Science Center, University of Washington undergraduate interns, and a collective of community scientists from across the Puget Sound Region.

Several cross-cutting themes emerged from the series of meetings and formed the goals of the community science program.

<p>Goals of the Community Science and Outreach:</p> <ul style="list-style-type: none"> ● Engage community scientists from the Duwamish Valley communities with students and researchers from the University of Washington to participate in water quality and habitat monitoring of the floating wetland Biobarges ● Infuse equity and access at the forefront of the research and monitoring engagement ● Remain mindful of project capacity and realistic commitments ● Record data with intent to be delivered both to trained scientists and to community scientists and the public ● Hold diversity (such as age, gender identity, gender expression, race, ethnicity, physical ability, sexual orientation, income, culture, religion, and education) as the core strength of the community science and outreach
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6.2. Approach to Participant Engagement

During the 2020 field season, Community Science (CS) Lead, Ashley D. Mocerro Powell, formed community-based organizational partnerships and built upon foundational work of the 2019 CS Lead. Through this work the CS lead enhanced our programming and community collaboration efforts utilizing best practices and insight from previous experience as a grassroots community organizer and educational frameworks such as: Culturally Sustaining Pedagogies, Principles of Environmental Justice, and Jemez Principles for Democratic Organizing. Varied recruitment methods were used, including accessible interest forms and one-on-one [digital] interactions to identify community members' needs for transportation, field gear, comforts around water etc. Priority was given to individuals who identified they lived, worked, or attended school in the surrounding Duwamish Valley neighborhoods by indicating their zip code and answering preliminary locality questions on the interest form.

6.2.1. Impacts of COVID-19

COVID19 restrictions presented very challenging conditions for field monitoring in 2020. We assembled a "skeleton crew" April-June 2020, harnessing the capacity of enthusiastic community scientists who live near the floating wetlands, used remote monitoring equipment, and implemented strict COVID19 protocols to monitor and maintain the floating wetlands during the "Stay at Home" period. This was challenging and time consuming. Even with COVID Level 2 protocols, in-person interaction with community scientists was limited. With closure of the UW Wetland Ecology Lab, we had to purchase microscopes and set up our own invertebrate lab.

However, community scientists were key in our ability to monitor during Covid19 Phase I, with a private resident who permitted our team to use his property to deploy 2 of our 4 Biobarges, and serving as a CS. Chief Sealth High School students related to our project steward gathered data while accompanying their father on maintenance checks during the "Stay at Home" directive also served as CSs. Each community scientist was able to go out into the field at least two times to experience two research areas (fish, invertebrates, water quality, or plants) and/or devote several hours to a remote project with the guidance of our field research team. The remote community science work included analyzing Gopro footage and calculating percent cover of plants using the ImageJ program, as well as confirming that Pendants were recording data and retrieving data files to upload to our shared Google drive. All community science training for field work was conducted in a blend of in-person and online meetings, while remote work was conducted entirely online. The latter made the project accessible to community members who did not feel safe to go out into the field (Covid19 concerns) or due to geographical location. We had scientists participate from towns in Washington and California, expanding the reach of our program outside the Greater Seattle area. Throughout the summer our team posted weekly updates on social media (Facebook and Instagram), and created a LinkTree to streamline all related media in one space for the public to view.

6.3. Results of the Approach

6.3.1. Field Research Season

From the recruitment processes we successfully onboarded 31 community members as community scientists, including 2 summer Doris Duke Conservation Scholar Fellows (*out of 35 who initially expressed interest for 2020*). We performed monitoring of the floating wetlands in each of the 4 areas of research (fish, invertebrates, water quality, and plants), with the SMEA graduate student field research team and staff working with community scientists. Each community scientist was able to be trained in and help collect data for at least two of our four areas of research and visit the field two times or extensively analyze data remotely.

The remote analyses were needed for analysing Gopro footage and percent cover of plants. This remote analysis required zoom training sessions to learn the required software and digital office hours with field research team members/grad students.

A guide for community scientists on how to identify the eight sedge species planted in the WBFs was created and provided to all community scientists (see **Appendix D** for the guide).

Additionally, several community scientists were trained in terrestrial and aquatic invertebrate sample processing and species identification. This work was conducted physically distanced in-person on UW campus. Community scientists were onboarded under guidance of a field research team member/grad student. Schedules and work stations were staggered to maintain Covid19 safety and accommodate individual comfort levels. Several softwares appropriate to the data collected were used to manage and analyze the various data types.

6.3.2. Outreach and Engagement

In order to share our experiences and findings from the 2020 field season our team created a website documenting the Duwamish Floating Wetlands project. Additionally the summer Fellows posted on Facebook and Instagram. Our team published multiple blog posts describing the Duwamish Floating Wetlands project, featuring our grad students, published in Spring 2019 and 2020 on the UW School of Marine and Environmental Affairs student blog *Currents*. We presented at the Green-Duwamish Watershed Symposium, Feb 2020 and presented at Young Women Empowered STEM Exploration Day, Feb 2020 Doris Duke Conservation Scholars Program at UW and Virtual Conservation Scholars Summit Seattle MESA Summer Program, 2020. Lastly our team presented to the Sweetgrass Project Urban Shores Working Group, composed of governmental policy-makers, regulators, scientists, designers and citizen advocates.

6.3.3. Participation in Community Events

Due to COVID19 many of the planned community events were cancelled or postponed during our field season. COVID19 cancelled all tabling and in-person public events including our educational group tours for spring and summer.

6.4. Further Discussion for Community Science

Throughout our 2020 field season we exceeded our targeted metrics for the community science program, engaging 31 community scientists ranging from ages 15-55; 8 UW students; and 8 faculty/staff in the monitoring process. Despite the COVID19 restrictions, we were able to train community scientists in the techniques needed to gather and analyze meaningful data in all four areas of study: water quality factors related to salmon health; plant growth; fish use and behavior; and invertebrate biodiversity and counts. We have disseminated education and outreach materials, created and contributed to digital educational media, given numerous presentations, and have published professional articles on the project.

Community Science programs are not only popular, but also are an important part of restoration efforts in order to gain social acceptance that might influence policy and programs supporting water quality and restoration efforts. The partnership of professionals, academics, students and community members creates a complex yet rich scientific process that requires significant dedicated time for ethical discussions and meaningful community dialogue.

6.4.1. Recommendations for Future Programming

For future wetland restoration monitoring projects the community science engagement approach proves to be an effective and educational program. If possible it would be ideal to start training programs earlier so that the community scientists are familiar with species identification, especially for monitoring protocols with a steep learning curve, such as overwater fish monitoring, invertebrate identification, and Gopro video analysis.

7. Conclusions

The Green Futures Lab Duwamish Floating Wetlands project has produced many insights into the design, deployment, performance, ecological, and human community benefits of constructed floating wetlands. From weekly monitoring of the floating wetlands at two very different sites in the Lower Duwamish River, we were able to observe how the Biobarges performed structurally and biologically under varying conditions. In addition, our team was able to evaluate research design and protocols for studying the benefits of artificial floating wetlands. Furthermore, we developed protocols for physical-distanced and remote monitoring during the COVID-19 pandemic.

From our in-person overwater fish monitoring and Gopro videos we observed all five species of juvenile salmonids —Chinook, Chum, Coho, Pink, and Steelhead/Rainbow trout – that are native to the Green/Duwamish river, using our Biobarges to take refuge, feed, establish territories and migrate through. The positive and neutral reactions observed from fish far exceeded any observed avoidance behavior. From the Gopro video monitoring we only observed two possible predatory sculpins sheltering within the Biobarge. We did not observe any other predatory fish using our BioBarges for foraging. The Biobarges did not have statistically significantly higher numbers of fish sightings or feeding and resting behaviours but this indicates that the fish and salmonids did use the Biobarges just as much as they used the reference sites. From the over water fish surveys we observed salmonids feeding at the Biobarges for a total of 30.75 minutes and resting there for 1.28 hours.

Other fish species heavily used our Biobarges for feeding and shelter. The Biobarges supported large populations of adult and juvenile sticklebacks and perch which were observed feeding on the periphyton growing on the barges. Additionally, adult perch were frequently observed sheltering and swimming within the empty Biofilter 1.0 structures. Furthermore, during the 2020 field season one Muskrat (*Ondatra zibethicus*) made a nest and gave birth to young within a Biofilter 1.0 structure at our Tukwila site.



Figure 7.1 Left shows Muskrat on nest inside a Biofilter 1.0 at Tukwila 6/25/2020, the right depicts juvenile Sticklebacks resting in Biobarge at Tukwila 7/27/2020.

Aquatic invertebrates heavily exploited the substrate as habitat within the 1.0 and 2.0 Biofilters with copepods and larval Diptera being especially numerous. Of the terrestrial invertebrates, Ceratopogonidea and Other Diptera showed the most abundance between important food-taxa. While the terrestrial invertebrates did not show a significant difference between taxa richness and individual

density between the Control locations and Biobarges, the upward trend observed leads us to believe that a longer monitoring period with more replicate Biobarges might better reflect the Restored locations.

Water quality results reflected habitat conducive to juvenile salmon survival. None of the key measurements for temperature, salinity, dissolved oxygen, or pH levels indicated harmful environmental conditions for survival. The biofilters also removed harmful metals and nitrogen from the water column, and provided biomass for primary productivity, thus supporting invertebrates upon which salmon rely for food. The BioBarges also diffused light beneath the surface, providing refuge from predators, and calmed the sometimes swift current, providing opportunity to rest and save energy.

Although plant performance varied based on species and site location, all plants were able to establish on the biobarges. In general, WBF 1.0 species performed best at WM and WBF 2.0 species did well at TD. The exception was SCHARME which reached average height at both locations. Attention to specific location and surrounding conditions showed an impact to plant performance with wake action impacting some WBF 2.0s at WM and woody debris impacting WBF 2.0s at TD. Caution should be taken before drawing conclusions from the statistically significant interspecies differences for changes in height within each site; more research with a much higher sample size (around $n = 70$) is needed to provide robust conclusions about interspecies differences in performance.

There is still much more research to be done on what kind of constructed floating wetlands could be most beneficial to enhancing riparian and estuary habitat for salmonids. However our research shows promising performance of constructed floating wetlands. Salmonids and other species of fish used our Biobarge structures for shelter and foraging. The Biobarges also produced substantial populations of terrestrial and aquatic invertebrates. Additionally, the bulrush wetland plants grew well and achieved high survival and percent cover. The WBF 1.0 and 2.0 plants, and woodstraw did contain more Cu, Zn and Pb than the controls, indicating that these structures may uptake harmful heavy metals from the environment. As cities try to improve the ecological function of urbanized rivers and estuaries, constructed floating wetlands can be a useful tool in their restoration efforts.

Acknowledgments

The authors of this report acknowledge that the Duwamish River runs through the ancestral lands of the Duwamish Indian Tribe and honor the traditional land and water of the Coast Salish Peoples on which this work took place. We understand that we are settler scientists and guests working in and profiting off our study in Duwamish lands and that we have ongoing obligations to the Tribe. We thank the Duwamish Tribe for their continued hospitality.

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References

Collins, B. and A. Sheikh. 2005. Historical Habitats in the Green and Duwamish River Valleys and the Elliott Bay Nearshore, King County, Washington. King County Department of Natural Resources and Parks, Seattle, WA.

Cordell, J., L. Tear, and K. Jensen. 2001. Biological Monitoring at Duwamish River Coastal America Restoration and Reference Sites: A Seven-Year Retrospective. University of Washington Wetland Ecosystem Team.

Cordell, J. R. et al. 2011. Functions of restored wetlands for juvenile salmon in an industrialized estuary. *Ecological Engineering*. 37: 343-353.

Cordell, J. R., Toft, J. D., Munsch, S. H., & Goff, M. 2017. Benches, Beaches, and Bumps: How Habitat Monitoring and Experimental Science Can Inform Urban Seawall Design. In D. M. Bilkovic, M. M. Mitchell, M. K. La Peyre, & J. D. Toft (Eds.), *Living Shorelines: The Science and Management of Nature-Based Coastal Protection* (pp. 421–438). CRC Press.

Dean A. Brege, Randall F. Absolon & Ritchie J. Graves (1996) Seasonal and Diel Passage of Juvenile Salmonids at John Day Dam on the Columbia River, *North American Journal of Fisheries Management*, 16:3, 659-665, DOI: [10.1577/1548-8675\(1996\)016<0659:SADPOJ>2.3.CO;2](https://doi.org/10.1577/1548-8675(1996)016<0659:SADPOJ>2.3.CO;2)

De Lange, H.J., Paulissen, M.P.C.P. Efficiency of three halophyte species in removing nutrients from saline water: a pilot study. *Wetlands Ecol Manage* 24, 587–596 (2016).
<https://doi.org/10.1007/s11273-016-9489-8>

Duffy, E. and D.A. Beauchamp (2011). Rapid growth in the early marine period improves the marine survival of Chinook salmon (*Oncorhynchus tshawytscha*) in Puget Sound, Washington. *Canadian Journal of Fisheries and Aquatic Sciences*. <https://doi.org/10.1139/F10-144>

EPS - Encyclopedia of Puget Sound. A publication of the [Puget Sound Institute](#) at the [University of Washington Tacoma](#). Major funding is provided by the [U.S. Environmental Protection Agency](#).

Ferguson, H. and Sandoval, C. Copper toxicity in fish. *Fish Pathology*. Sept. 4, 2020.
<https://fishhistopathology.com/home/2020/09/04/copper-toxicity-in-fish/>

Goetz FA. Bull trout life history and habitat study. Final Report. USFS Contract to the Deschutes National Forest. 1990; Oregon State University. Corvallis.

Henning, J. A., R. E. Gresswell, and I. A. Fleming. 2006. Juvenile salmonid use of freshwater emergent wetlands in the floodplain and its implications for conservation management. *North American Journal of Fisheries Management* 26:367–376

Hicks, M. 2000. Evaluating standards for protecting aquatic life in Washington's surface water quality standards. Draft discussion paper and literature summary. Revised 2002. Washington State Department of Ecology, Olympia, WA, 197 pp.

Kennedy, C.J., Picard, C. Chronic low pH exposure affects the seawater readiness of juvenile Pacific sockeye salmon. *Fish Physiol Biochem* 38, 1131–1143 (2012).
<https://doi.org/10.1007/s10695-011-9599-4>

Kidd, S. 2011. Water Quality Monitoring Grant Report. Salem. Retrieved from
https://www.pdx.edu/soe-gk12/sites/www.pdx.edu/soe-gk12/files/Chem_Data_information.pdf

Meador, J.P. (2014). Do chemically contaminated river estuaries in Puget Sound (Washington, USA) affect the survival rate of hatchery-reared Chinook salmon? *Canadian Journal of Fisheries and Aquatic Sciences* 71:162-180.

McKeon, M.A., Horner-Devine, A.R. & Giddings, S.N. Seasonal Changes in Structure and Dynamics in an Urbanized Salt Wedge Estuary. *Estuaries and Coasts* (2020).
<https://doi.org/10.1007/s12237-020-00788-z>

Morley, S.A., J.D. Toft, and K. Hanson. 2012. Ecological effects of shoreline armoring on intertidal habitats of a Puget Sound urban estuary. *Estuaries and Coasts* 35:774-784.

Ono, K., & Simenstad, C. A. (2014). Reducing the effect of overwater structures on migrating juvenile salmon : An experiment with light. *Ecological Engineering*, 71, 180–189.
<https://doi.org/10.1016/j.ecoleng.2014.07.010>

Ostergaard, E., et al. (2014). *Duwamish Blueprint: Salmon Habitat in the Duwamish Transition Zone*. Prepared by the Duwamish Blueprint Working Group for the WRIA 9 Watershed Ecosystem Forum. Seattle, WA.

Plumb, J. M., and P. J. Blanchfield (2009). Performance of temperature and dissolved oxygen criteria to predict habitat use by lake trout (*Salvelinus namaycush*). *Canadian Journal of Fisheries and Aquatic Sciences* 66:2011–2023.

Richter, A., and S. A. Kolmes. 2005. Maximum temperature limits for Chinook, Coho, and Chum salmon, and steelhead trout in the Pacific Northwest. *Reviews in Fisheries Science* 13:23–49.

Sauter, S., McMillan, J., & Dunham, J. (2001). Issue Paper 1: Salmonid Behavior and Water Temperature. In EPA Region 10 Temperature Water Quality Criteria Guidance Development Project (pp. 1–36).

Retrieved from:

<https://www.epa.gov/sites/production/files/2018-01/documents/r10-water-quality-temperature-issuepaper1-2001.pdf>

Thurrow RF, Peterson JT, Chandler GL, Moffitt CM, Bjornn TC (2020) Concealment of juvenile bull trout in response to temperature, light, and substrate: Implications for detection. *PLoS ONE* 15(9): e0237716.

<https://doi.org/10.1371/journal.pone.0237716>

Toft, J. and J. Cordell (2017). *Densities of Juvenile Salmon at Restored Sites in the Duwamish River Estuary Transition Zone, 2016*. Prepared for WRIA 9. School of Aquatic and Fishery Sciences, University of Washington. Seattle, Washington.

U.S. Army Corps of Engineers (USACE). 1997. Green/Duwamish River Basin. General investigation ecosystem restoration study reconnaissance phase. January 1997. Seattle, WA.

Webster, S.J., Dill, L.M. 2006. The energetic equivalence of changing salinity and temperature to juvenile salmon. *Functional Ecology*, 20, 621-629. doi: 10.1111/j.1365-2435.2006.01128.x.

Woelfle-Erskine, C., L. G. Larsen, and S. M. Carlson. 2017. Abiotic habitat thresholds for salmonid over summer survival in intermittent streams. *Ecosphere* 8(2):e01645. 10.1002/ecs2.1645

WRIA 9 Steering Committee (2005). Green/Duwamish and Central Puget Sound Watershed Water Resource Inventory Area 9 (WRIA 9) Steering Committee. *Salmon Habitat Plan – Making Our Watershed Fit for a King*. Prepared for the WRIA 9 Forum.

Appendices

Appendix A – General Covid-19 Protocols for Field Monitoring

1. Each person must arrive separately via personal car.
2. Each person must wear a mask.
3. Each person shall have their own gear as much as is feasibly possible (clipboards, measuring tape, datasheets, pencils) and shall not share materials with the other person. This shall include PPE for the WM site (hi-vis vests, hard hats, gloves, glasses or safety goggles, and steel-toed boots) and PFDs (life jackets) for both sites. Any shared items must be disinfected beforehand and passed along with gloved hands.
4. People will wear gloves at all times, particularly when handling shared equipment or working together, and disinfect hands when arriving at the field site and after removing gloves.
5. Shared equipment (e.g. GoPros, site access keys, and padlocks) shall be disinfected before handing off to others.
6. There will be no rowboat use at either site. Both are too small to social distance effectively, even in the larger boat at Waste Management (WM), because people are exerting themselves and breathing slightly harder to row the boat.
7. The barges are walkable/reachable by dock at both sites. The WM dock is long enough that it's easy to position on it and keep a safe distance apart. The Tukwila Dock (TD) is much smaller so one person would need to walk down to the dock and get positioned onto a BioBarge before the second person is allowed to go down to the dock.
8. Logistically, plant monitoring could be conducted at the same time as fish monitoring, provided that all data gathering sites are accessed on foot. Two people can collect plant data from the two BioBarges at a safe distance away from each other, and then monitor for fish for 30 minutes from those same barges. At the TD, two people could conduct fish monitoring at the control and reference sites at the same time.
 - a. Plant monitoring could also be conducted at the same time as water quality monitoring. Two people can stand safely apart from each other on each BioBarge, and one person takes plant data while the other takes water quality data. Once they are both done they can switch positions.
9. Although plant monitoring can be performed by one person alone, there should always be two people on site in case one person injures themselves, or falls off a dock. A second person can also assist with recording notes while the first person gathers data and calls out numbers or observations.

Appendix B – Plant Monitoring Datasheets

Duwamish Floating Wetlands - Waste Management Site								Recorder: CS Olympic, James Lee		
Plant Monitoring Field Datasheet								Measurer: James Lee, CS Olympic		
Date:	6/20/2		Weather:	Sunny, 30% cloud cover.					Key:	few = 1-3, some = <50%, most = >
						Plants Field Notes				
Wetland Biofilter		Species	Total # Originally Planted (# of holes)	# plants planted in 2019	# plants planted in 2020	Broadleaf Volunteers? (note: none, few, some, most, all)	Grazing? (note: none, few, some, most, all)	Flowers? / Seeds? (note: none, few, some, most, all)	Percent Cover (use reference diagram)	Vegetation Notes (e.g. mushrooms, health, biofouling, algae/wrack, driftwood, etc.)
A1	1.0	SCHTAB	31	31		none	none	none	26-50, D	
A3	1.0	BOLMAR	31	31		few	none	all	26-50, D	
A17	1.0	SCHACU	21	21		few	none	some	11-25, D	
A12	1.0	SCHAME	49	49		some	none	some	11-25, D	
A21	2.0	SCIMIR	16		16	none	none	none	76-100, C	
A22	2.0	ELEPAL	16		16	none	none	some	76-100, D	
A23	2.0	CXLYNG	16		16	none	none	none	51-75, C	
A24	2.0	CXOBNA	16		16	none	none	none	51-75, D	some algae
A25	2.0	Mix 1	4 each		16	none	none	few E	51-75, M	
A26	2.0	Mix 2	4 each		16	none	none	few E	51-75, M	
A27	2.0	SCIMIR	16		16	none	none	none	26-50, D	lots of algae, driftwood
A28	2.0	ELEPAL	16		16	none	none	none	51-75, M	some algae
A29	2.0	CXLYNG	16		16	none	none	none	51-75, C	some algae
A30	2.0	CXOBNA	16		16	none	none	none	76-100, D	
A31	2.0	Mix 1	4 each		16	none	none	none	11-25, M	
A32	2.0	Mix 2	4 each		16	none	none	none	11-25, M	lots of algae
ADDITIONAL NOTES:										
4:30 pm Baby ducklings spotted near shoreline with mother duck swimming southward alongshore.										
4:50 pm Osprey returning to nest.										

Duwamish Floating Wetlands - Waste Management Site								Recorder: Bradey Bononcini		
Plant Monitoring Field Datasheet								Measurer: James Lee		
Date:	7/4/20		Weather:	Cloudy.				Key: few = 1-3, some = <50%, most = >		
						Plants Field Notes				
Wetland Biofilter		Species	Total # Originally Planted (# of holes)	# plants planted in 2019	# plants planted in 2020	Broadleaf Volunteers? (note: none, few, some, most, all)	Grazing? (note: none, few, some, most, all)	Flowers? / Seeds? (note: none, few, some, most, all)	Percent Cover (use reference diagram)	Vegetation Notes (e.g. mushrooms, health, biofouling, algae/wrack, driftwood, etc.)
A1	1.0	SCHTAB	31	31		none	none	few	25	
A3	1.0	BOLMAR	31	31		few	none	all	30	plants trapped by cage
A17	1.0	SCHACU	21	21		none	none	some	15	browning
A12	1.0	SCHAME	49	49		none	none	some	15	browning
A21	2.0	SCIMIR	16		16	none	none	none	50	browning, algae
A22	2.0	ELEPAL	16		16	none	none	some	70	browning, algae
A23	2.0	CXLYNG	16		16	few	none	none	70	algae, biofouling
A24	2.0	CXOBNA	16		16	none	none	none	75	browning, algae
A25	2.0	Mix 1	4 each		16	none	few	few E	20	browning, algae
A26	2.0	Mix 2	4 each		16	few	few	none	40	browning, algae
A27	2.0	SCIMIR	16		16	none	none	none	25	browning, lots of algae
A28	2.0	ELEPAL	16		16	none	none	some	40	lots of browning, lots of algae
A29	2.0	CXLYNG	16		16	none	few	none	50	lots of browning, lots of algae
A30	2.0	CXOBNA	16		16	none	none	none	80	algae, dried mud on plants
A31	2.0	Mix 1	4 each		16	none	none	none	20	browning, algae, dried mud on pla
A32	2.0	Mix 2	4 each		16	none	none	none	20	browning, lots of algae
ADDITIONAL NOTES:										
10:40 am seagull flew by										
11:15 am Sun came out; weather became warm.										

Duwamish Floating Wetlands - Waste Management Site								Recorder: James Lee		
Plant Monitoring Field Datasheet								Measurer: CS		
Date:	7/18/2		Weather:	Sunny, cloudless, but windy.					Key:	few = 1-3, some = <50%, most = >
						Plants Field Notes				
Wetland Biofilter		Species	Total # Originally Planted (# of holes)	# plants planted in 2019	# plants planted in 2020	Broadleaf Volunteers? (note: none, few, some, most, all)	Grazing? (note: none, few, some, most, all)	Flowers? / Seeds? (note: none, few, some, most, all)	Percent Cover (use reference diagram)	Vegetation Notes (e.g. mushrooms, health, biofouling, algae/wrack, driftwood, etc.)
A1	1.0	SCHTAB	31	31		none	none	few	50	
A3	1.0	BOLMAR	31	31		none	none	all	50	plants trapped by cage
A17	1.0	SCHACU	21	21		none	none	some	40	browning
A12	1.0	SCHAME	49	49		none	none	some	25	browning
A21	2.0	SCIMIR	16		16	none	none	none	70	browning, algae
A22	2.0	ELEPAL	16		16	none	none	few	75	browning, algae
A23	2.0	CXLYNG	16		16	few, big	few	none	70	algae, biofouling, grass-type volun
A24	2.0	CXOBNA	16		16	none	none	none	65	browning, algae
A25	2.0	Mix 1	4 each		16	none	none	few E	60	browning, algae, grass-type volun
A26	2.0	Mix 2	4 each		16	none	few	none	40	browning, algae
A27	2.0	SCIMIR	16		16	none	none	none	5	browning, lots of mortality due to
A28	2.0	ELEPAL	16		16	none	none	some	20	lots of browning, lots of algae
A29	2.0	CXLYNG	16		16	none	few	none	60	lots of browning, lots of algae
A30	2.0	CXOBNA	16		16	none	none	none	80	algae, dried mud on plants
A31	2.0	Mix 1	4 each		16	none	none	none	20	browning, algae, biofouling
A32	2.0	Mix 2	4 each		16	none	none	none	20	browning, lots of algae, biofouling
ADDITIONAL NOTES:										
1:00 pm flock of geese calling somewhere upstream.										

Duwamish Floating Wetlands - Waste Management Site								Recorder: James Lee, CS Olympic		
Plant Monitoring Field Datasheet								Measurer: CS Olympic, James Lee		
Date:	6/20/2		Weather:	Sunny, 75% cloud cover.			Key:	few = 1-3, some = <50%, most = >		
						Plants Field Notes				
Wetland Biofilter		Species	Total # Originally Planted (# of holes)	# plants planted in 2019	# plants planted in 2020	Broadleaf Volunteers? (note: none, few, some, most, all)	Grazing? (note: none, few, some, most, all)	Flowers? / Seeds? (note: none, few, some, most, all)	Percent Cover (use reference diagram)	Vegetation Notes (e.g. mushrooms, health, biofouling, algae/wrack, driftwood, etc.)
B2	1.0	SCHTAB	41	41		few	none	some	-50, M; 9.8%	
B5	1.0	BOLMAR	46	46		few	none	none	1-5, C	algae, esp. in degraded area
B8	1.0	SCHACU	34	34		none	none	some	11-25, C	
B13	1.0	SCHAME	39	39		none	none	most	51-75, C	
B33	2.0	SCIMIR	16		16	none	none	none	25, C; 30.2%	
B34	2.0	ELEPAL	16		16	none	none	few	11-25, C	lots of algae
B35	2.0	CXLYNG	16		16	none	none	none	1-5, D	
B36	2.0	CXOBNA	16		16	none	none	none	76-100, C	
B37	2.0	Mix 1	4 each		16	none	none	none	26-50, M	
B38	2.0	Mix 2	4 each		16	none	none	none	51-75, M	
B39	2.0	SCIMIR	16		16	none	none	none	26-50, C	trash
B40	2.0	ELEPAL	16		16	none	none	few	51-75, C	woody debris
B41	2.0	CXLYNG	16		16	none	none	none	76-100, C	lots of algae
B42	2.0	CXOBNA	16		16	none	none	none	26-50, C	
B43	2.0	Mix 1	4 each		16	none	none	none	6-10, C	
B44	2.0	Mix 2	4 each		16	none	none	none	1-5, D	woody debris, trash
ADDITIONAL NOTES:										
3:50pm 12 starlings passed overhead										

Duwamish Floating Wetlands - Waste Management Site										
Plant Monitoring Field Datasheet						Recorder: James Lee, CS Olympic				
Date:	7/4/20		Weather: Cloudy.			Measurer: CS Olympic, James Lee				
						Key: few = 1-3, some = <50%, most = >				
						Plants Field Notes				
Wetland Biofilter		Species	Total # Originally Planted (# of holes)	# plants planted in 2019	# plants planted in 2020	Broadleaf Volunteers? (note: none, few, some, most, all)	Grazing? (note: none, few, some, most, all)	Flowers? / Seeds? (note: none, few, some, most, all)	Percent Cover (use reference diagram)	Vegetation Notes (e.g. mushrooms, health, biofouling, algae/wrack, driftwood, etc.)
B2	1.0	SCHTAB	41	41		none	none	some	15	browning
B5	1.0	BOLMAR	46	46		none	none	none	< 1	
B8	1.0	SCHACU	34	34		none	none	some	40	browning
B13	1.0	SCHAME	39	39		none	none	some	50	browning
B33	2.0	SCIMIR	16		16	none	none	none	25	browning, algae
B34	2.0	ELEPAL	16		16	none	none	some	33	browning, algae
B35	2.0	CXLYNG	16		16	none	none	none	0	plants floating due to loss of subs
B36	2.0	CXOBNA	16		16	none	none	none	50	browning, algae
B37	2.0	Mix 1	4 each		16	none	none	none	40	browning, algae
B38	2.0	Mix 2	4 each		16	none	none	none	25	browning, algae
B39	2.0	SCIMIR	16		16	none	none	none	30	browning, trash in cage
B40	2.0	ELEPAL	16		16	none	none	some	20	browning, woody debris, algae
B41	2.0	CXLYNG	16		16	none	few	none	70	browning, woody debris, algae
B42	2.0	CXOBNA	16		16	none	none	none	50	browning, woody debris
B43	2.0	Mix 1	4 each		16	none	none	none	20	browning, algae
B44	2.0	Mix 2	4 each		16	none	none	none	10	browning, woody debris, trash
ADDITIONAL NOTES:										
9:30 am Geese swimming downstream.										
10:00 am Birds resting on wooden piling by dock.										

Duwamish Floating Wetlands - Waste Management Site						Recorder:		CS		
Plant Monitoring Field Datasheet						Measurer:		James Lee		
Date:	7/18/2		Weather:	Sunny, cloudless, but windy.		Key:		few = 1-3, some = <50%, most = >		
						Plants Field Notes				
Wetland Biofilter		Species	Total # Originally Planted (# of holes)	# plants planted in 2019	# plants planted in 2020	Broadleaf Volunteers? (note: none, few, some, most, all)	Grazing? (note: none, few, some, most, all)	Flowers? / Seeds? (note: none, few, some, most, all)	Percent Cover (use reference diagram)	Vegetation Notes (e.g. mushrooms, health, biofouling, algae/wrack, driftwood, etc.)
B2	1.0	SCHTAB	41	41		none	none	some	40	browning
B5	1.0	BOLMAR	46	46		none	none	none	< 1	
B8	1.0	SCHACU	34	34		none	none	some	50	browning, some dead
B13	1.0	SCHAME	39	39		none	none	some	50	browning, some dead
B33	2.0	SCIMIR	16		16	none	none	none	25	browning, algae
B34	2.0	ELEPAL	16		16	none	none	few	< 33	browning, algae, plants flat/subm
B35	2.0	CXLYNG	16		16	none	none	none	0	plants floating due to loss of subs
B36	2.0	CXOBNA	16		16	none	none	none	5	almost totally brown/dead, algae
B37	2.0	Mix 1	4 each		16	none	none	none	25	browning, algae
B38	2.0	Mix 2	4 each		16	none	none	none	25	browning, algae
B39	2.0	SCIMIR	16		16	none	none	none	33	browning, woody debris, trash
B40	2.0	ELEPAL	16		16	none	none	none	10	browning
B41	2.0	CXLYNG	16		16	none	few	none	66	browning, woody debris
B42	2.0	CXOBNA	16		16	none	none	none	66	browning
B43	2.0	Mix 1	4 each		16	none	none	none	33	browning, algae
B44	2.0	Mix 2	4 each		16	none	none	none	5	browning, seaweed, woody debris
ADDITIONAL NOTES:										
2:00 pm: Terns observed circling and calling.										

Duwamish Floating Wetlands - Tukwila Site								Recorder:		James Lee, DDCSP	
Plant Monitoring Field Datasheet								Measurer:		DDCSP, James Lee	
Date:	6/27/2		Weather:	Cloudy, bursts of heavy rain.					Key:	few = 1-3, some = <50%, most = >	
						Plants Field Notes					
Wetland Biofilter		Species	Total # Originally Planted (# of holes)	# plants planted in 2019	# plants planted in 2020	Broadleaf Volunteers? (note: none, few, some, most, all)	Grazing? (note: none, few, some, most, all)	Flowers? / Seeds? (note: none, few, some, most, all)	Percent Cover (use reference diagram)	Vegetation Notes (e.g. mushrooms, health, biofouling, algae/wrack, driftwood, etc.)	
C15	1.0	SCHTAB	39	39		some	none	none	10, D		
C4	1.0	BOLMAR	41	41		none	none	none	0	totally empty - no plants!	
C9	1.0	SCHACU	46	46		some	none	some	60, D		
C14	1.0	SCHAME	42	42		some	none	few	6-10, D		
C45	2.0	SCIMIR	16		16	few	none	none	76-80, C	duckweed, grass-type volunteer	
C46	2.0	ELEPAL	16		16	some	none	some	51-75, D	duckweed	
C47	2.0	CXLYNG	16		16	some	none	none	26-50, C	duckweed	
C48	2.0	CXOBNA	16		16	none	none	none	51-75, C	duckweed	
C49	2.0	Mix 1	4 each		16	none	none	none	60, C		
C50	2.0	Mix 2	4 each		16	few	none	none	51-75, C		
C51	2.0	SCIMIR	16		16	none	none	none	80, C		
C52	2.0	ELEPAL	16		16	few	none	some	40, D		
C53	2.0	CXLYNG	16		16	few	none	none	51-75, C		
C54	2.0	CXOBNA	16		16	few	none	none	60, C	duckweed	
C55	2.0	Mix 1	4 each		16	none	none	none	60, C	biofouling	
C56	2.0	Mix 2	4 each		16	some	none	none	51-75, C		
ADDITIONAL NOTES:											

Duwamish Floating Wetlands - Tukwila Site									Recorder: Bradey Bononcini	
Plant Monitoring Field Datasheet									Measurer: James Lee	
Date:	7/11/2		Weather:	Partly cloudy.				Key:		few = 1-3, some = <50%, most = >
					Plants Field Notes					
Wetland Biofilter		Species	Total # Originally Planted (# of holes)	# plants planted in 2019	# plants planted in 2020	Broadleaf Volunteers? (note: none, few, some, most, all)	Grazing? (note: none, few, some, most, all)	Flowers? / Seeds? (note: none, few, some, most, all)	Percent Cover (use reference diagram)	Vegetation Notes (e.g. mushrooms, health, biofouling, algae/wrack, driftwood, etc.)
C15	1.0	SCHTAB	39	39		some	some	none	10	duckweed, plants trapped in cage
C4	1.0	BOLMAR	41	41		none	none	none	0	duckweed
C9	1.0	SCHACU	46	46		none	few	most	60	duckweed
C14	1.0	SCHAME	42	42		many	few	most	5	duckweed, plants trapped in cage
C45	2.0	SCIMIR	16		16	few, big	none	none	90	duckweed, grass, scum
C46	2.0	ELEPAL	16		16	few	none	some	60	duckweed, woody debris
C47	2.0	CXLYNG	16		16	none	none	none	70	
C48	2.0	CXOBNA	16		16	none	none	none	80	browning
C49	2.0	Mix 1	4 each		16	none	none	none	75	duckweed
C50	2.0	Mix 2	4 each		16	none	none	none	75	grass
C51	2.0	SCIMIR	16		16	none	none	none	90	algae
C52	2.0	ELEPAL	16		16	none	none	some	60	
C53	2.0	CXLYNG	16		16	none	none	none	80	large grass, algae
C54	2.0	CXOBNA	16		16	few	none	none	80	yellowing, duckweed
C55	2.0	Mix 1	4 each		16	none	none	none	80	duckweed, algae, bent plants
C56	2.0	Mix 2	4 each		16	few, big	few	few	70	duckweed, bent plants
ADDITIONAL NOTES:										
11:20 Sun came out after clouds fully separated.					12:04 Plane flew overhead.			12:45 Another plane.		
11:46 Truck drove by.					12:10 Geese observed downstream.					

Duwamish Floating Wetlands - Tukwila Site									Recorder:	Bradey Bononcini	
Plant Monitoring Field Datasheet									Measurer:	James Lee	
Date:	7/11/2		Weather:	Partly cloudy.				Key:	few = 1-3, some = <50%, most = >		
					Plants Field Notes						
Wetland Biofilter		Species	Total # Originally Planted (# of holes)	# plants planted in 2019	# plants planted in 2020	Broadleaf Volunteers? (note: none, few, some, most, all)	Grazing? (note: none, few, some, most, all)	Flowers? / Seeds? (note: none, few, some, most, all)	Percent Cover (use reference diagram)	Vegetation Notes (e.g. mushrooms, health, biofouling, algae/wrack, driftwood, etc.)	
C15	1.0	SCHTAB	39	39		some	some	none	25	duckweed, grass, plants trapped in	
C4	1.0	BOLMAR	41	41		none	none	none	0	duckweed	
C9	1.0	SCHACU	46	46		few	few	most	80	duckweed, grass, plants trapped in	
C14	1.0	SCHAME	42	42		few, big	few	most	5	duckweed, plants trapped in cage	
C45	2.0	SCIMIR	16		16	none	few	none	80	duckweed, grass	
C46	2.0	ELEPAL	16		16	none	none	some	50		
C47	2.0	CXLYNG	16		16	none	none	none	70		
C48	2.0	CXOBNA	16		16	none	none	none	70	plants are desiccating	
C49	2.0	Mix 1	4 each		16	none	none	none	85	duckweed, grass	
C50	2.0	Mix 2	4 each		16	none	none	none	90	grass	
C51	2.0	SCIMIR	16		16	none	none	none	100		
C52	2.0	ELEPAL	16		16	none	none	some	80		
C53	2.0	CXLYNG	16		16	few, big	none	none	75	large grass	
C54	2.0	CXOBNA	16		16	few	none	none	80	duckweed, yellowing	
C55	2.0	Mix 1	4 each		16	none	none	few E	85	duckweed, bent plants	
C56	2.0	Mix 2	4 each		16	few, big	few	few E	75	duckweed, bent plants	
ADDITIONAL NOTES:											
2 pm Cabbage butterfly flew around the biobarge.											

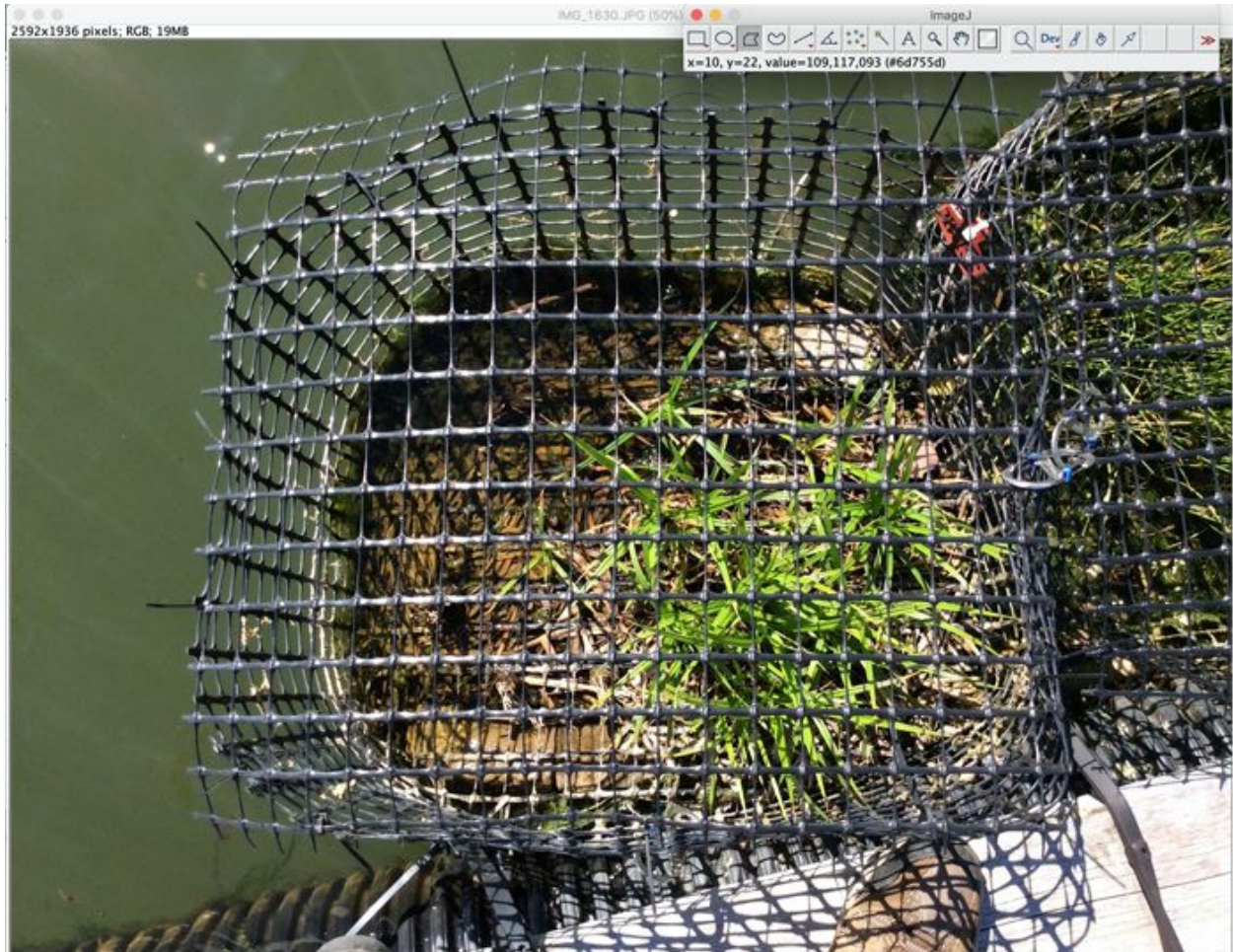
Duwamish Floating Wetlands - Tukwila Site					Recorder:	James Lee, DDCSP					
Plant Monitoring Field Datasheet					Measurer:	DDCSP, James Lee					
Date:	6/27/2		Weather:	Cloudy, light showers.		Key:	few = 1-3, some = <50%, most = >				
					Plants Field Notes						
Wetland Biofilter		Species	Total # Originally Planted (# of holes)	# plants planted in 2019	# plants planted in 2020	Broadleaf Volunteers? (note: none, few, some, most, all)	Grazing? (note: none, few, some, most, all)	Flowers? / Seeds? (note: none, few, some, most, all)	Percent Cover (use reference diagram)	Vegetation Notes (e.g. mushrooms, health, biofouling, algae/wrack, driftwood, etc.)	
D18	1.0	SCHTAB	41	41		some	all	none	6-10, D	moss, biofouling	
D6	1.0	BOLMAR	46	46		few	few	none	0-5, D		
D10	1.0	SCHACU	47	47		some	none	some	11-25, D	moss	
D16	1.0	SCHAME	42	42		few	none	some	6-10, D	trampling, muskrat nest!!!	
D57	2.0	SCIMIR	16		16	none	none	none	80-90, C	duckweed	
D58	2.0	ELEPAL	16		16	few	none	none	26-50, D	duckweed	
D59	2.0	CXLYNG	16		16	few	none	none	26-50, C	duckweed	
D60	2.0	CXOBNA	16		16	none	none	none	60-70, C	duckweed	
D61	2.0	Mix 1	4 each		16	none	none	none	30, C	duckweed	
D62	2.0	Mix 2	4 each		16	few	none	none	60, C	duckweed	
D63	2.0	SCIMIR	16		16	few	none	none	80-90, C	4 or 5 plants are yellowing; 2 large	
D64	2.0	ELEPAL	16		16	none	none	few	26-50, D		
D65	2.0	CXLYNG	16		16	few	none	none	60, C	1 plant is yellowing	
D66	2.0	CXOBNA	16		16	none	none	none	60, C		
D67	2.0	Mix 1	4 each		16	none	none	none	70, C		
D68	2.0	Mix 2	4 each		16	none	none	none	40, C	algae	
ADDITIONAL NOTES:											
2:20 pm Mom mallard and 5 juveniles came onshore close to the Biobarges.											
2:22 pm Green heron observed.											

Duwamish Floating Wetlands - Tukwila Site								Recorder:		Bradey Bononcini
Plant Monitoring Field Datasheet								Measurer:		James Lee
Date:	7/11/2		Weather:	Partly cloudy.				Key:		few = 1-3, some = <50%, most = >
						Plants Field Notes				
Wetland Biofilter		Species	Total # Originally Planted (# of holes)	# plants planted in 2019	# plants planted in 2020	Broadleaf Volunteers? (note: none, few, some, most, all)	Grazing? (note: none, few, some, most, all)	Flowers? / Seeds? (note: none, few, some, most, all)	Percent Cover (use reference diagram)	Vegetation Notes (e.g. mushrooms, health, biofouling, algae/wrack, driftwood, etc.)
D18	1.0	SCHTAB	41	41		some	all	none	10	duckweed, moss, grass
D6	1.0	BOLMAR	46	46		few	few	few	5	duckweed
D10	1.0	SCHACU	47	47		few	none	some	40	duckweed, moss, plants trapped in
D16	1.0	SCHAME	42	42		none	none	most	15	duckweed, nest
D57	2.0	SCIMIR	16		16	none	none	none	100	bent leaves
D58	2.0	ELEPAL	16		16	few	none	few	60	duckweed
D59	2.0	CXLYNG	16		16	few	none	none	30	duckweed, scum
D60	2.0	CXOBNA	16		16	none	none	none	70	duckweed, scum
D61	2.0	Mix 1	4 each		16	none	few	none	60	duckweed
D62	2.0	Mix 2	4 each		16	none	none	few E	70	duckweed
D63	2.0	SCIMIR	16		16	few, big	none	none	100	browning, plants trapped in cage
D64	2.0	ELEPAL	16		16	none	none	some	75	
D65	2.0	CXLYNG	16		16	none	none	none	60	yellowing, grass
D66	2.0	CXOBNA	16		16	none	none	none	75	one plant significantly taller
D67	2.0	Mix 1	4 each		16	few	none	none	75	
D68	2.0	Mix 2	4 each		16	none	none	none	50	1 large SCHTAB or SCHACU
ADDITIONAL NOTES:										
Lots of scum (diatoms?) in the water.					12:12 Another helicopter flew overhead.					
11:33 Two helicopters flew overhead.					12:15 Geese flew by, honking.					

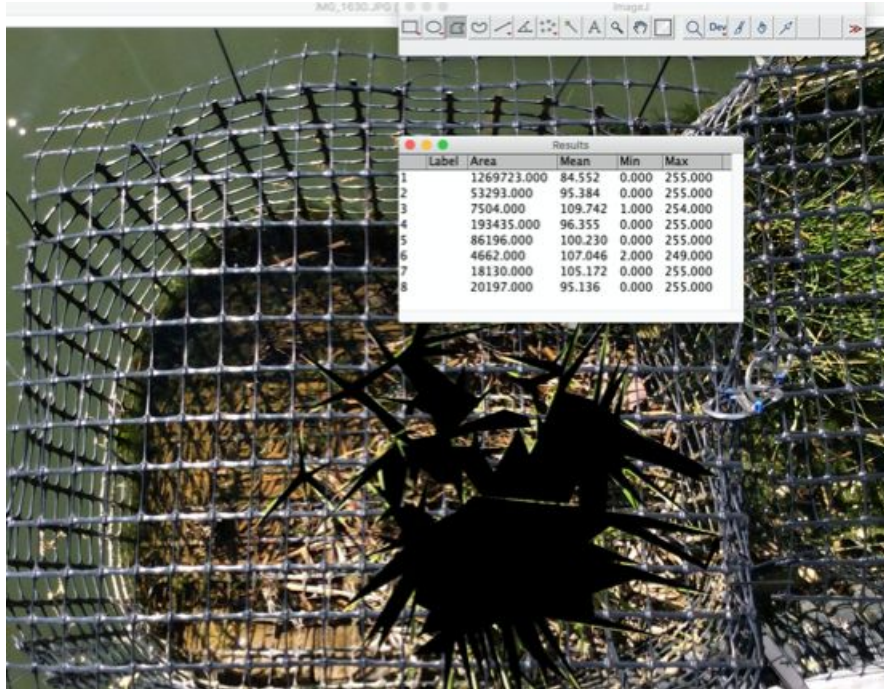
Duwamish Floating Wetlands - Tukwila Site						Recorder:		James Lee			
Plant Monitoring Field Datasheet						Measurer:		CS			
Date:		7/25/2		Weather:		Sunny, cloudless, light breezes.			Key:		few = 1-3, some = <50%, most = >
						Plants Field Notes					
Wetland Biofilter		Species	Total # Originally Planted (# of holes)	# plants planted in 2019	# plants planted in 2020	Broadleaf Volunteers? (note: none, few, some, most, all)	Grazing? (note: none, few, some, most, all)	Flowers? / Seeds? (note: none, few, some, most, all)	Percent Cover (use reference diagram)	Vegetation Notes (e.g. mushrooms, health, biofouling, algae/wrack, driftwood, etc.)	
D18	1.0	SCHTAB	41	41		few	all	none	10	duckweed, moss, grass	
D6	1.0	BOLMAR	46	46		none	none	none	0	plants submerged, duckweed, algae	
D10	1.0	SCHACU	47	47		none	few	some	40	duckweed, moss, plants trapped in	
D16	1.0	SCHAME	42	42		none	none	most	15	duckweed, nest	
D57	2.0	SCIMIR	16		16	none	few	none	100	bent leaves	
D58	2.0	ELEPAL	16		16	few	none	few	50	duckweed	
D59	2.0	CXLYNG	16		16	few	some	none	50	duckweed	
D60	2.0	CXOBNA	16		16	none	few	none	70	duckweed	
D61	2.0	Mix 1	4 each		16	none	few	none	65	duckweed	
D62	2.0	Mix 2	4 each		16	none	none	few E	60	yellowing, duckweed	
D63	2.0	SCIMIR	16		16	few, big, vine-l	few	none	100	browning, plants trapped in cage	
D64	2.0	ELEPAL	16		16	few	none	some	85	duckweed	
D65	2.0	CXLYNG	16		16	few	none	none	80	yellowing, duckweed, lots of grass	
D66	2.0	CXOBNA	16		16	none	none	none	90	duckweed, algae	
D67	2.0	Mix 1	4 each		16	few	none	none	95	duckweed	
D68	2.0	Mix 2	4 each		16	none	none	none	80	1 large SCHTAB or SCHACU, duckv	
ADDITIONAL NOTES:											
3:30 pm Person went into the river with an inner tube by the underpass and floated downstream.											
4:12 pm Two black and white birds. Doesn't seem to be terns, dark back, white face, dark ring around neck.											

Appendix C – ImageJ Software Analysis for Foliage Cover

The free image analysis software **ImageJ** was downloaded from the National Institutes of Health’s website and used to process “top-down photos” taken of wetland biofilters at the Tukwila Dock site:



The polygon tool was used to create polygons that correspond to the shapes of the plants themselves. ImageJ calculated the area of these polygons to determine the total area in the image covered by foliage. The total area in the image taken up by the WBF substrate was also calculated:



By dividing the total area of the plants by the area of the WBF substrate, a percentage value was calculated for foliage cover. These values were compared to visual estimates recorded in the field to “ground truth” and standardize all assessments for which there was both field data and ImageJ data. Photos taken on field days where visual estimates were recorded were then used to standardize visual estimates of foliage cover for photos taken on days where no visual estimates were available:

	A	B	C	D	E	F	G	H
1			Area					
2	1		1269723	<- WBF Area				
3	2		53293					
4	3		7504					
5	4		193435					
6	5		86196					
7	6		4662					
8	7		18130					
9	8		20197					
10			383417	<- Plant Cover Area				
11								
12			30.2	<- Percent Cover				
13								
14								
15								
16								
17								

Appendix D – A Guide to Our Wetland Sedge Research Species

Duwamish Floating Wetlands Project

A Brief Reference Guide for Plants

Abbreviations

- WBF 1.0 - Wetland Biofilter, Built in 2019
- WBF 2.0 - Wetland Biofilter, Built in 2020
- Plant Species Used on WBF 1.0:
 - BOLMAR - *Bolboschoenus maritimus*
 - SCHACU - *Schoenoplectus acutus*
 - SCHAME - *Schoenoplectus americanus*
 - SCHTAB - *Schoenoplectus tabernaemontani*
- Plant Species Used on WBF 2.0:
 - CXLYNG - *Carex lyngbyei*
 - CXOBNA - *Carex obnupta*
 - ELEPAL - *Eleocharis palustris*
 - SCIMIC - *Scirpus microcarpus*

Introduction¹

We have eight different species of wetland plants growing on our floating Biobarges (listed above under “Abbreviations”). All of these plants are perennials, so they don’t die off in the winter. Instead, they go dormant and begin putting out new growth the next spring.

All eight species are in the family Cyperaceae, the family of plants that are called sedges. Sedges are graminoid plants. Graminoids are any plant with a grass-like shape and appearance, but sedges in particular are not true grasses. True grasses are in the family Poaceae.

Sedges differ from rushes and true grasses in that their stems almost always have triangular cross-sections. For sedge plants, leaves are spirally arranged in threes, whereas grasses have alternating leaves.

All eight species of plants are native to the area. Many have been used and continue to be used by Indigenous nations, including Salish peoples for various purposes, from food, to basketry, hatmaking, mats, and more.

A quick note about some terms used in this guide: **Habit** is the characteristic form in which a given species of plant grows. An **inflorescence** is the complete flowering head of a plant, which could include stems and other parts besides the cluster of flowers itself.

Rhizomes are thick, underground stems by which many sedges spread and send out new roots and shoots that are genetically identical to the parent plant. This is known as rhizomatous spreading or clonal propagation.

Spreading through rhizomes allows our plants create large colonies quickly, which is great for restoration projects where the aim is to use plants to stabilize a soft shoreline and protect it from erosion.

¹ eFloras.org – Cyperaceae

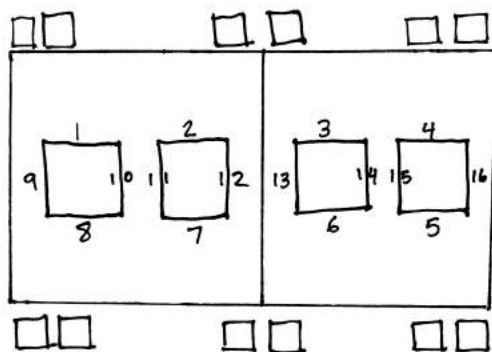
Research Questions

1. At what rates do our plants (a) survive and (b) grow in our new locations?
2. Which species of plants perform better on floating wetlands, if performance is defined as plant growth (height and percent cover) and mortality rate, at each location?
3. What is the impact of a second year on growth of the plants in the WBF 1.0s?
4. Does a mix of plants perform better than “monocultures”, if performance is defined as plant growth (height and percent cover) and mortality rate?
5. Are there site-specific differences in plant and species performance between the lower estuary site (Waste Management) and the lower river site (Shumate dock, Tukwila)? How does plant performance relate to the conditions at each of these sites?

Materials and Methods

Configuration:

- Four biobarges, two at each study site.
- Each biobarge contains four WBFs 1.0 in the center, and 12 WBFs 2.0 (six each along the longer sides of the biobarge; see **Fig. 1**, below).
- **Figure 1.** *Biobarge WBF Configuration.* Four WBF 1.0s are aligned in the middle; twelve WBF 2.0s are arranged along the edges (ignore number markings).



Planting Scheme:

- Each WBF 1.0 contains single-species plantings of BOLMAR, SCHACU, SCHAME, or SHTAB.
- Each WBF 1.0 has received infill plantings of the corresponding species used during the 2019 iteration of the project to recover losses from mortality.
- Each WBF 2.0 has received single-species plantings ($n = 16$) of CXLYNG, CXOBNA, ELEPAL, or SCIMIC, OR a mix of all four ($n = 4 \times 4 = 16$).
- WBFs 2.0 with single-species plantings of CXOBNA will also have a removal plug installed for invertebrate analysis.
- Along the longer side of each biobarge will be six WBFs 2.0 (for a total of twelve): one for each single-species planting, and two with a mixed-species planting.

Carex lyngbyei (CXLYNG)²³⁴⁵

Common name: Lyngbye's sedge.

Growth: Height ranges from 25–130 cm. Rhizomatous spreading.

Inflorescence: Spike-like growths on long, nodding stalks.

Ecology: Common sedge of Pacific coastal salt marshes. Generally one of the first species to colonize tidal mud flats. Found in brackish marshes and or salt marshes (salinity of 0-20 ppt). Prefers silt over sand. Optimum elevation for growth is mean low high water or mean high high water.

Flowering time: April–July.

Carex obnupta (CXOBNA)⁶⁷⁸

Common name: Slough sedge.

Growth: Height ranges from 60–150 cm. Rhizomatous spreading.

Ecology: Grows in large beds or dense clumps making it good for erosion control and shoreline stabilization. Prefers fresh water but tolerates brackish and often saline coastal wetland areas.

Elevation: Found at under 1100 m.

Flowering time: April–July.

Eleocharis palustris (ELEPAL)⁹¹⁰¹¹¹²

Common name: Common spikerush.

Growth: Height ranges from 10–100 cm. Will continue to grow to keep heads above water.

Rhizomatous spreading. Does not produce fruit until at least 2 or 3 years old.

Stems: Oval in cross-section.

Habit: Reduced leaves, making the plants look leafless, like a bunch of stems.

Inflorescence: Solitary brown mass on the end of each stem.

Ecology: Dense root mass good for shore stabilization. Fixes nitrogen and makes it available to other plants! Grows better in single-species plantings than in mixed.

² [eFloras.org – Carex lyngbyei](#)

³ [Burke Herbarium – Carex lyngbyei](#)

⁴ [Native Plant Workbook – Carex lyngbyei](#) (2003)

⁵ [University of California Jepson Manual Treatment – Carex lyngbyei](#) (2015)

⁶ [Burke Herbarium – Carex obnupta](#)

⁷ [SevenOaks Native Nursery – Carex obnupta](#)

⁸ [University of California Jepson Manual Treatment – Carex obnupta](#) (2015)

⁹ [SevenOaks Native Nursery – Eleocharis palustris](#)

¹⁰ [eFloras.org – Eleocharis palustris](#)

¹¹ [Fire Effects Information System – Eleocharis palustris](#)

¹² Keddy, P., Fraser, L.H., Wisheu, I.C. (1998). [A comparative approach to examine competitive response of 48 wetland plant species](#). *Journal of Vegetative Science*, 9(6), 777-786. doi: 10.2307/3237043

***Scirpus microcarpus* (SCIMIR)¹³¹⁴¹⁵**

Common name: Smallfruit bulrush or paniced bulrush.

Growth: Height ranges from 70–160 cm. Rhizomatous spreading.

Stems: Triangular in cross-section.

Habit: Five to eleven flat, grass like leaves sprout from the base and along the stem.

Inflorescence: Panicle-like (panicles are loose, branching clusters of flowers).

Ecology: Spreads quickly via rhizomes, good for resisting shoreline erosion. Grows in marshes, wet meadows, streambanks, pond margins.

Elevation: Found at under 2900 m.

Flowering time: June–August.

2019 SPECIES

***Bolboschoenus maritimus* (BOLMAR)¹⁶¹⁷¹⁸¹⁹**

Common name: Cosmopolitan bulrush or alkali bulrush.

Growth: Height ranges from 50–150 cm. Rhizomatous spreading.

Stems: Triangular in cross-section.

Habit: Stems sheathed by serrated leaves. Leaf blades are flat or rolled in at the edges.

Inflorescence: Golden-brown clump at the tip, sitting atop horizontally growing blades.

Ecology: Prefers wet marshy flats, seasonal and permanent wetlands, pond margins and estuaries. Can survive in fresh and saline conditions, as well as total submersion and dry periods. Rhizomes control erosion by stabilizing soft substrates, and they also form a habitat for beneficial bacteria.

Elevation: Found at under 700 m.

Flowering time: June–September.

***Schoenoplectus acutus* (SCHACU)²⁰²¹²²**

Common name: Tule, hardstem bulrush.

Growth: Height ranges from 100–300 cm. Rhizomatous spreading.

Stems: Rounded and stout, especially at the base (over 1 cm thick toward the base).

Habit: Leaves are reduced to sheaths at the base of the stem so what you see is mostly the central stem.

¹³ [University of California Jepson Manual Treatment – *Scirpus microcarpus* \(1993\)](#)

¹⁴ [Burke Herbarium – *Scirpus microcarpus*](#)

¹⁵ [SevenOaks Native Nursery – *Scirpus microcarpus*](#)

¹⁶ [Burke Herbarium – *Bolboschoenus maritimus*](#)

¹⁷ [Go Botany – *Bolboschoenus maritimus*](#)

¹⁸ [PlantZAfrica – *Bolboschoenus maritimus*](#)

¹⁹ [eFloras.org – *Bolboschoenus maritimus*](#)

²⁰ [Fire Effects Information System – *Schoenoplectus acutus*](#)

²¹ [SevenOaks Native Nursery – *Schoenoplectus acutus*](#)

²² [Burke Herbarium – *Schoenoplectus acutus*](#)

Inflorescence: Umbel-like (umbels are short stalks radiating out from a common point like the spokes of an umbrella).

Ecology: Spreads quickly via rhizomes, creating dense colonies that provide streambank stabilization. Grows best in sites with saturated soil or standing water for most of the year. Can grow in fresh or brackish water.

Elevation: Found at under 2300 m.

Flowering time: May–July.

***Schoenoplectus americanus* (SCHAME)²³²⁴²⁵**

Common name: Chairmaker's bulrush.

Growth: Height ranges from 40–250 cm. Rhizomatous spreading.

Stems: Three concave sides to form a three-pointed star in cross-section.

Habit: One to three short leaves (10 cm at most) sprouting from the lower part of the stem.

Inflorescence: A single clump of 5 to 12 little spikes sprouting sideways near the stem's tip.

Ecology: Establishes best under salinities of 5-10 ppt, with the substrate submerged under 2 to 4 inches of water. Most abundant in brackish marshes. Rhizomatous spreading makes this plant useful in saltmarsh revegetation efforts. Model organism for studying saltmarsh ecology.

Elevation: Found at under 2200 m.

Flowering time: April–August.

***Schoenoplectus tabernaemontani* (SHTAB)²⁶²⁷²⁸**

Common name: Softstem bulrush or great bulrush.

Growth: Height ranges from 100–250 cm. Rhizomatous spreading.

Stems: Rounded in cross-section (three channels arranged in a triangle visible in the interior when cut).

Habit: Three to four leaves near the base of the stem.

Inflorescence: Umbel-like (umbels are short stalks radiating out from a common point like the spokes of an umbrella), arranged in open, drooping clusters.

Ecology: Used in wetland restoration because planted shoots can triple their biomass in one growing season. Used to reduce pollutant loads carried by stormwater runoff in urban wetlands.

Elevation: Found at under 2400 m.

Flowering time: June–August.

²³ [University of California Jepson Manual Treatment – *Schoenoplectus americanus*](#) (2012)

²⁴ [Fire Effects Information System – *Schoenoplectus americanus*](#)

²⁵ [Native Plants of North America – *Schoenoplectus americanus*](#)

²⁶ [Fire Effects Information System – *Schoenoplectus tabernaemontani*](#)

²⁷ [Burke Herbarium – *Schoenoplectus tabernaemontani*](#)

²⁸ [Minnesota Wildflowers – *Schoenoplectus tabernaemontani*](#)

Strategies for Identifying Our Eight Plant Species in the Field

Our Wetland Biofilters generally have tags that identify the sedge species that was planted in that Biofilter. But what about if you're looking at a Biofilter where multiple species are planted? Or maybe you want to learn how to use visual cues to identify our plants without looking at the tags. Here's a quick list of identification tips!

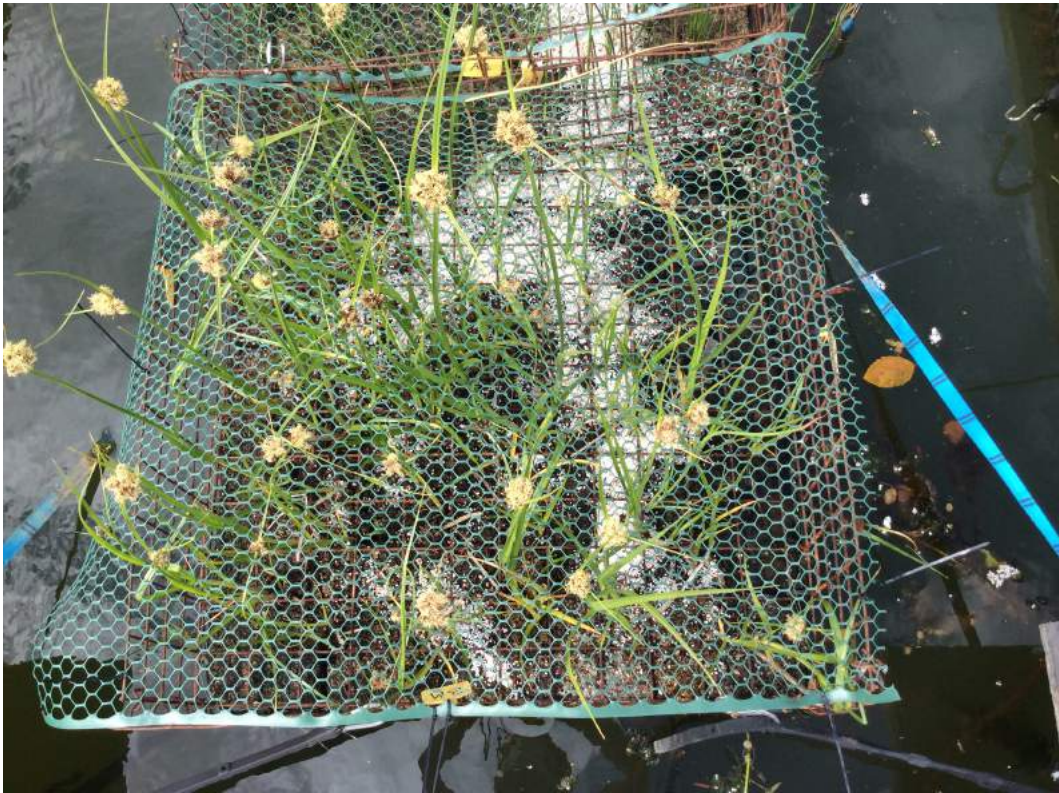
2020 SPECIES:

- ***Carex lyngbyei*** and ***Carex obnupta*** – Our two *Carex* species have a more cool-toned, bluer green color compared to *Scirpus microcarpus*, which has a more warm-toned, yellow green. It's very hard to distinguish between the two *Carex* species, but in general CXLYNG seems to be a slightly lighter green than CXOBNA. The CXLYNG plants are also generally taller than the CXOBNA plants at both of our field sites, but keep in mind that this could change if CXOBNA has a later growth spurt.
- ***Eleocharis palustris*** – Has very thin, deep green, needle-like shoots, reminiscent of pine needles.
- ***Scirpus microcarpus*** – Compared to our other 2020 species, SCIMIR has wider, fatter blades and a more warm-toned green color with more yellow in it.

2019 SPECIES:

- ***Bolboschoenus maritimus*** – The easiest way to identify this species is by its inflorescence. The BOLMAR inflorescence is a clump of rounded, golden-brown spikes at the tip of the stem, sitting atop horizontally growing blades. If there are no flowers, look for a three-sided, roughly triangular stem.
- ***Schoenoplectus acutus*** and ***Schoenoplectus tabernaemontani*** – These two *Schoenoplectus* species are easily confused with each other, as they have similar branched inflorescences and rounded stems. However, SCHACU has a slightly darker and warmer olive green color to its stem while SHTAB is a slightly lighter, cooler green. SHTAB also seems to have more a graceful, slender-looking inflorescence than SCHACU.
- ***Schoenoplectus americanus*** – This one is really easy to identify if you can get your hands on the stem. The stem has three deeply concave sides that would form a three-pointed star if you sliced the stem in cross-section. If you can't get close enough to feel the stems, look for an inflorescence that looks like a single clump of brown spikes attached to the side of the stem, near the tip.

***Bolboschoenus maritimus* (BOLMAR)**



Carex lyngbyei (CXLYNG)



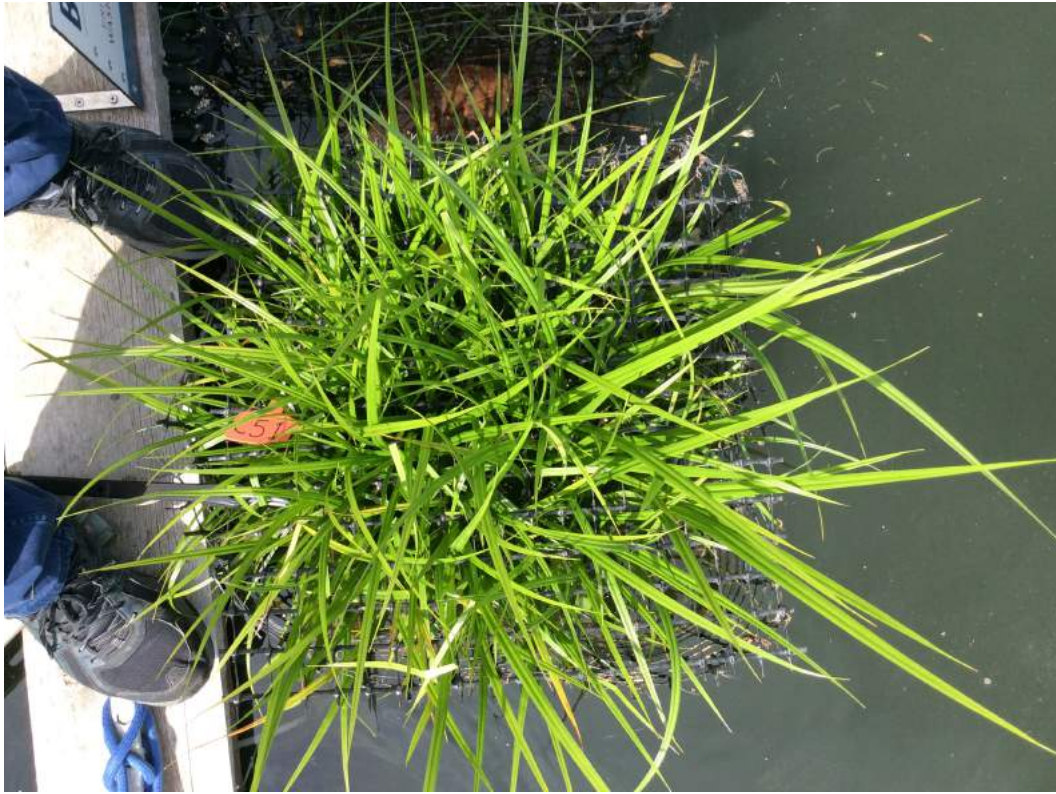
***Carex obnupta* (CXOBNA)**



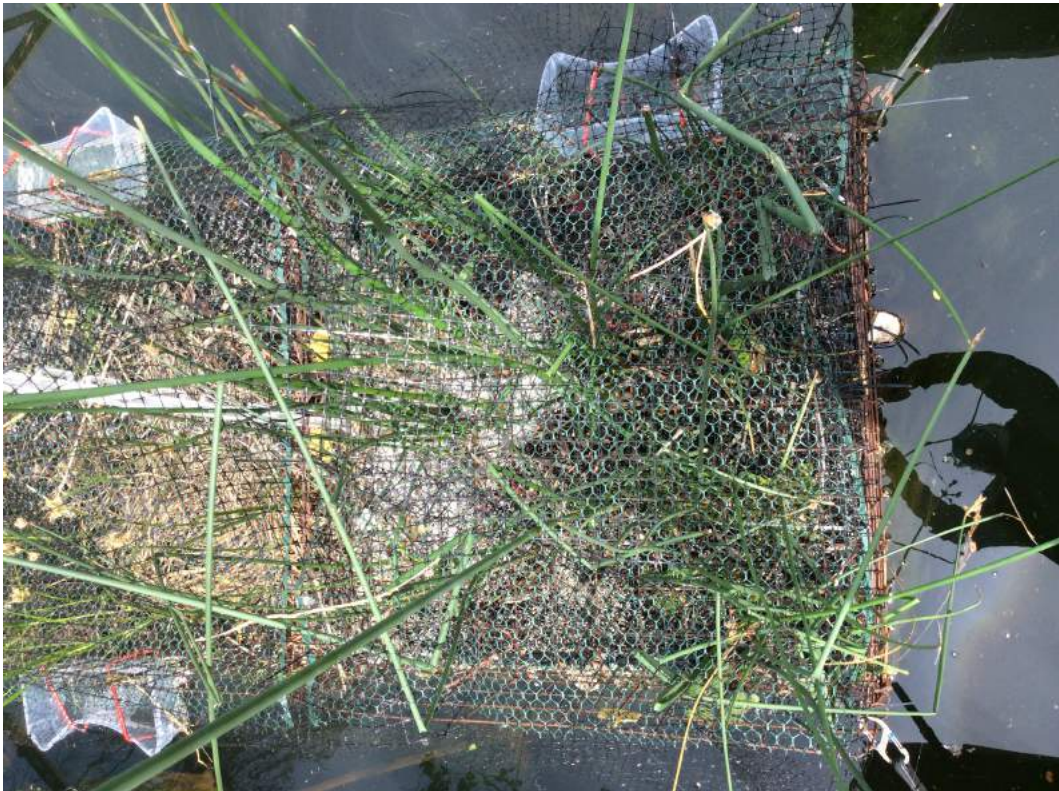
Eleocharis palustris (ELEPAL)



Scirpus microcarpus (SCIMIR)



Schoenoplectus acutus (SCHACU)



Schoenoplectus americanus (SCHAME)



***Schoenoplectus tabernaemontani* (SHTAB)**

