Sweetgrass Living Shorelines:

2021 and 2022 Monitoring Report

GREEN FUTURES RESEARCH + DESIGN LAB

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ROSE FOUNDATION for COMMUNITIES and the ENVIRONMENT

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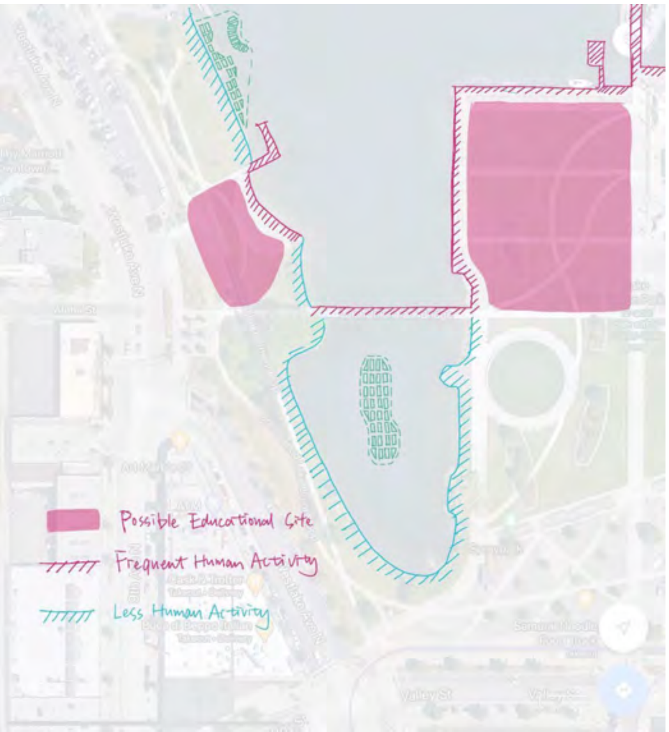
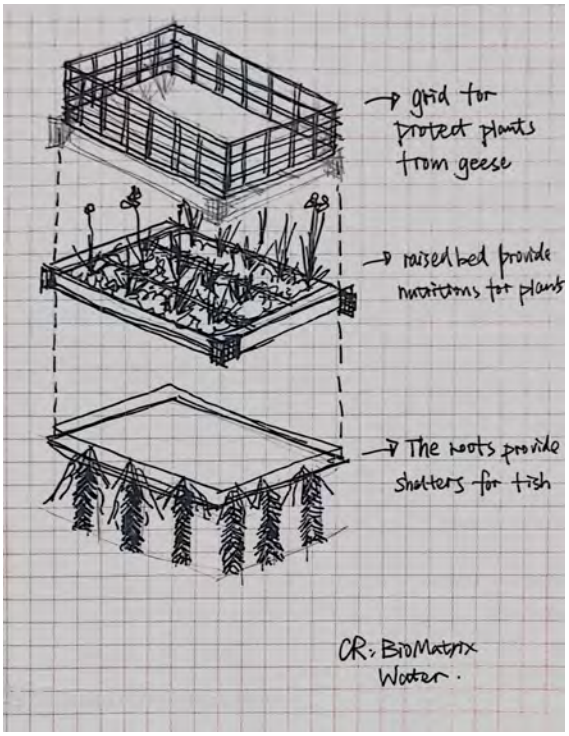
EXECUTIVE SUMMARY

This report summarizes the results of the 2020 - 2022 Sweetgrass Shoreline Restoration Project research and community science program that investigated the role that Constructed Floating Wetlands (CFWs) and other Living Shoreline designs could play in creating freshwater habitat in urbanized areas, especially for outmigrating juvenile salmon in the Lake Washington Basin. 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.

The goal of the Sweetgrass Shoreline Restoration Project was to determine if constructed floating wetlands and living shorelines using freshwater native wetland species 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 on viability of varying CFW design prototypes, including durability, flotation, plant growth, possible water quality improvement and juvenile salmon interactions with the CFWs. The social objectives of the program were to encourage collaboration between indigenous youth, community scientists, community organizations and local government and to connect the community back to important resources that play vital roles in their wellbeing.

In 2020 an Urban Shorelines Working Group (USWG) was formed consisting of researchers, professionals, decision-makers, and stakeholders. After meetings and charrette style information gathering sessions with the USWG, two project sites were located. In 2021, an interdisciplinary team designed, constructed and deployed 16 floating CFWs consisting of versions 2.0, 3.0 and 4.0, to the North and South fender wall of the East side of the Fremont Cut. At South Lake Union (SLU), designs focused on permanent biodegradable prototypes that looked to extend the shoreline and create a healthier salmon habitat. Designs looked for ways to promote plant growth and create better substrate options. Additionally, shoreline designs needed to consider the lake's reverse hydrologic pattern with higher water levels in the summer and 2'-3' lower levels in the winter.





At the end of year 2021 and into 2022 CFW versions 2.0 and 4.0 were completely removed from the Fremont locations due to structural failure. Both direct and reflected wave energy from motorized watercraft created a chronically turbulent hydrodynamic environment that separated the substrate and prevented wetland macrophytes from successfully rooting. . The 4.0 units were a submerged unit and became too heavy to maintain flotation. The 4.0 units were transported by boat to the SLU location where they could sit at the shoreline, while the 2.0 units were replaced with a newer design, 4.1 CFW units. The new 4.1 units were lighter and more buoyant, making them better suited to stand up against all of the water action. These units were later modified to use pipe for flotation, transforming them into a “4.2” version.

The CFWs and the Living Shorelines were monitored at two field study sites from the spring to summer periods of 2021 and 2022. The Fremont location included the North and South fender walls at the Eastside of the Fremont Cut. The SLU location was on the West shoreline due North of the pedestrian bridge.

Fremont Location

Plant Research

Eight different species of wetland plants were chosen to grow on our floating wetlands. 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. Four metrics were used to determine plant health from June 2021 to July 2021 and April 2022 to July 2022. These metrics were plant height, percent foliage cover, mortality, and number of blooms. The monitoring of plants were to answer two questions:

- Do our floating substrates support viable growth and survival of wetland plants in the Lake Washington Ship Canal?
- 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?

Results showed several species that are well-adapted for survival in CFWS at the Fremont location. *Deschampsia cespitosa*, *Carex obnupta*, and *Sidalcea hendersonii* had the best results for the conditions at Fremont. S*cirpus microcarpus*, *Carex stipata*, *Eleocharis palustris*, *Schoenoplectus americanus*, and *Sidalcea hendersonii* are next best suited for Fremont's conditions. The performance of *Schoenoplectus acutus, Scirpus cyperinus,* and *Sisyrinchium idahoense* performed the worst and would suggest that plants are not well suited for CFWs. It is important to note the plant data collection portion of this project had several limitations. The performance of the species tested depended on the quality of starts received from the nursery. A second limitation is the integrity of the units. During the project, several units started to fall apart due to wake action. A final limitation is the inconsistency of subjective data collection from collector to collector. This is most relevant in the percent cover data collection. One person may perceive a certain unit to have a specific percent cover value and another person might determine a different value.

Water Quality Research

Water quality monitoring occurred at the Fremont location, near the shorelines along the north and south sides of the canal. Monitoring focused on parameters specific to juvenile salmon survival: water temperature, dissolved oxygen levels (DO), and salinity. Questions that were to be answered based on the monitoring were:

- Do the floating wetlands improve, or at least not interfere with, water quality conditions critical to juvenile salmon survival (temperature, DO, salinity)?
- Do the floating wetlands remove any of the following contaminants from the water: arsenic (As), barium (Ba), chromium (Cr), copper (Cu), manganese (Mn), molybdenum (Mo), nickel (Ni), lead (Pb), zinc (Zn), and carbon (C)?

Two PME MinDOTs were deployed in May 2021 for continuous monitoring for temperature and DO, and a YSI EXO2 sonde was used for spot monitoring during site visits several times each month in May, June, and July. The sonde was calibrated for DO and salinity on site the days it was used. The MiniDOTs were deployed approximately 0.5 m beneath the surface on the north side of the canal: one as a control at the east end of the fender wall and the other attached beneath a floating wetland located in the middle of the deployment. The MiniDOTs were programmed to record DO and water temperature at 10 minute intervals throughout the duration of floating wetland deployment, ending in late July. Unfortunately the miniDOT attached to the floating wetland was never retrieved; its disappearance a mystery. Sonde readings were taken on both sides of the canal: a control and underneath a floating wetland on the south side and a control and underneath a floating wetland on the north.

Water temperatures for juvenile salmon throughout the sampling period ranged from 12- to 22-degrees Celsius from early May to late July (Figure 3.2.2). Dissolved oxygen levels also were favorable, ranging from 12.5 to 9.5 mg/L from early May to late July (Figure 3.2.4).

Puget Sound's salinity typically is 22 ppt and freshwater is 0 to 0.1 ppt (King County, 2018). The Chittenden Locks' usage frequency peaks in the summer months, leading to saltwater intrusion into Lake Union and the Ship Canal; however, the intrusion is minimal, measuring between 0.5 and 1.5 ppt (King County, 2018). Our data gathered in the ship canal at any depth did not reflect salinity levels higher than 0.05 psu (the equivalent to ppt), perhaps due to an unseasonably rainy June, resulting in higher than normal freshwater outflow through the ship canal deep into the summer.

Each of the materials tested indicated a significant uptake of Zn compared to its control, especially Substrate 1 and woodstraw, and all but Substrate 2 showed modest uptakes of Cu (Figure 3.2.7). Curiously, none of the materials showed detectable or only trace levels of Pb uptake, and the two substrate controls had more Pb levels (42.9 and 44 µg/g) than their counterparts deployed in the field. Both substrates, which contained 10 percent biochar and 60 percent woodstraw each, took in significantly more carbon than the 100-percent woodstraw sample, suggesting these substrates could play an additional role in carbon sequestration.

Fish Research

The Sweetgrass Project assessed the benefits the CFW units could provide for out-migrating juvenile salmonids in the Lake Washington Ship Canal. The project used weekly GoPro video sampling to assess differences in juvenile salmonid and other fish presence and behavior at our floating wetland units and living shoreline units 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. Questions fish monitoring looked to answer were:

- Do juvenile salmonids use floating wetland structures more than the control or as much as at nearby reference sites?
- Do predatory fish species use the floating wetlands as shelter or hunting territory?

After two years of extensive research to determine whether the units would be beneficial to juvenile salmon, we had no confirmed sightings of salmonid species. This is especially concerning in light of the ever decreasing number of salmon we know spawn in the Lake Washington watershed. It is possible that the lack of salmon could be attributed to the specific location of the units. The area has high amounts of boat traffic as well as little shore habitat. We hypothesize that instead of lingering in the canal, juvenile salmon prefer to travel their way further downstream, and may be doing so at night.

South Lake Union

At South Lake Union (SLU), designs focused on ways to extend the shoreline and non-traditional restoration methods for creating healthier shorelines and salmon habitat. Designs looked for ways to promote plant growth and create better substrate options. Additionally, designs needed to consider a reverse hydrologic pattern with higher water levels in the summer and 2’-3’ lower levels in the winter. We explored ways to promote healthy shorelines that could survive the water level changes and stay at the shoreline edge. Lastly, we tried to make the SLU prototypes biodegradable. One anecdotal comment offered with the Duwamish project and while making the Fremont prototypes was how much plastic and unnatural materials we were using. A goal with this site was to be biodegradable and see how it might eventually become part of the shoreline. Out-migrating juvenile salmon are known to stick to the edges; our ultimate goal is to create healthier shoreline for the salmon.

For future living shorelines, visual optics are essential to tell the story of how living shorelines are supporting out-migrating juvenile salmon. These attempts were keen to use biodegradable materials and shoreline elements that are not harmful to the environment, but they attracted a lot of other animals and didn’t hold together as we had hoped. Further research in biodegradable materials would be beneficial to expand the material options that we had. Additionally, stronger netting is needed to protect the plants from geese predation. The browse seen on these plants was significant and caused extensive replanting. Lastly, it would be interesting to see these living shorelines extended further into the water to create a larger patch of living shoreline and be more beneficial to salmon as well as stronger plant survival.

Plant Research

Plant monitoring at the SLU location looked to answer the following questions:

- Do our substrates support viable growth and survival of wetland plants in South Lake Union?
- Which species of plants perform better on living shoreline units, if performance is defined at each field site as plant growth (established height and percent cover), successful phenological cycle, and mortality rate?

Mortality, height, percent cover, and number of blooms were recorded for each species at South Lake Union in 2021 and 2022. In 2021, all species had mild survival success with the exception of Schoenoplectus acutus. However, in 2022, *Schoenoplectus acutus* was much more successful with a survival rate of 93%. *Sagittaria latifolia* (43%-58%) and *Carex stipata* (27%-33%) did similarly well in both seasons. *Scirpus microcarpus* did not do well in 2022. The species tested at South Lake Union all proved moderately successful. Though it took Schoenoplectus acutus one year to establish itself, it was well-suited for the South Lake Union conditions after a year.

Community Engagement

The project looked to include as much community participation it could. It is important to note that the Sweetgrass Shoreline Restoration Project occurred during the COVID Pandemic. Commitment from outside groups and individuals became an issue with safety and general reluctance in participating with the project. Recruiting for community scientists generally consisted of outreach that was done with outside Indigenous communities and organizations through email correspondence and flyers. Many community members were involved throughout the entirety of the project. Students for the University of Washington helped take notes during the USWG meetings as well as provided needed labor to help produce prototypes for the project to be used for the project, so at a time where there were not many internship opportunities due to the COVID Pandemic they were able to gain valuable work experience. The Puget Sound Keeper Alliance helped with trash that accumulated around the study areas. The project had Indigenous youth engagement and a Sweetgrass Arts celebration that provided local Indigenous Artists the opportunity to share in meaningful ways what salmon meant to them.

Summary

In this Sweetgrass Living Shorelines study, we designed, built, implemented, and monitored five different versions of floating wetlands and living shorelines in freshwater conditions. These floating wetlands increased ecosystem services by improving water quality and aquatic habitat to benefit a variety of aquatic species. This research monitored the prototype design, plant health, water quality benefits, and fish use to better understand the impact they have in the ecosystem. The research also engaged community in meaningful ways throughout the project.

The project demonstrated that floating wetlands can be designed and implemented to retrofit urban shorelines in freshwater locations . Through continuous monitoring and adaptive management the designs were tested and modified in an ongoing improvement process. During field deployment, we learned that turbulence from wave action and wildlife browse compromised the structural integrity and plant communities of the unit. Wave turbulence also degraded and destroyed anchoring systems, indicating that wake protection should be incorporated into the design, and consideration for anchoring units is critical for unit survival.

Encapsulating the substrate in nonwoven polyester geotextile and attaching pontoon floats prevented the substrate from being pushed out of the units by boat wakes. For the 5.0 units, more research needs to be done on biodegradable substrate options that would not get destroyed by geese, ducks, or beavers. The visual optics of the 5.0 and 6.0 units were positive with being biodegradable, but they did not stay intact due to boat wakes. Furthermore, better boat protection should be incorporated into the 3.0, 4.0, and 4.1 designs. The units were behind a fender wall, but still took considerable hits from the boat wakes in an active transportation channel. Because these CFWs are meant to be in areas where traditional restoration is not feasible (i.e. navigable channels), designing boat wake protection into them would be beneficial. Lastly, when anchoring the units to the fender wall, they were more restricted when boat wakes came. By securing them with a bottom anchor, the unit could maintain flexibility without it hitting the fender wall during boat wakes. Future siting of CFW's would benefit from a hydrodynamic modeling of wave action. An existing hydrodynamic model of Lake Washington (https://www.eemodelingsystem.com/efdc-insider-blog/lake-washington-real-time-model) could potentially be calibrated to a finer resolution to identify shorelines with lower wave action where floating wetlands could be sited.

The prototypes showed positive results in plant health and water quality. The plant health showed healthiest results for *Sidalcea hendersonii, Carex obnupta,* and *Deschampsia cespitosa* at Fremont. Having healthy initial plugs and planting them right away is critical to plant health. The plant longevity and/or consistency of the plants that did not perform as well (*Scirpus cyperinus* and *Sisyrinchium idahoense*) is likely due to not being planted soon enough after arriving from the nursery. A colder winter and spring did not help the plants last or take as anticipated. For water quality, the colder seasons were beneficial to having cooler water temperatures and higher DO levels in year 2. DO levels under the CFWs were not of concern even while temperatures peaked in mid to late July, and there were no appreciable changes in summer water temperatures between the control and the floating wetlands. Additionally, the substrate and plants showed an intake of copper and zinc, both which are harmful to salmon. There were increases in carbon and nitrogen for most of the tests. This shows that the units are collecting contaminants present in the water, potentially reducing greenhouse gasses in the atmosphere and helping to create cleaner ecosystems. From these results, we have learned lessons about floating wetland and living shoreline designs to use in the future and how they could benefit our local urban ecosystems.

RESEARCH REPORT

1.0 Introduction

Past urban development has created hard shorelines that have had a large impact on current plant and fish life. The goal of the Sweetgrass Shoreline Restoration Project was to create a built environment that protects and sustains natural ecosystems. The UW's Green Futures Lab proposed to test the restoration possibilities of urbanized nearshore emergent wetland habitats to improve water quality and provide salmon habitat by integrating science, planning, and stakeholder participation. A principal initial objective was to reestablish Ka'qsxW or sweetgrass (common three-square bulrush) and thule (giant bulrush). Bulrush improves water quality, provides salmon habitat, prevents shoreline erosion, and is an ecological and cultural keystone species. In addition to sweetgrass, the project looked to include other wetland species that would have the same effect, and tested various means of supporting these species in challenging urbanized conditions critical to juvenile salmon out-migration. The project engaged researchers, professionals, decision-makers, and stakeholders to collaborate in project planning, design, installation, monitoring and assessment. Project outcomes included demonstration sites to show how urbanized nearshore emergent habitats can be restored to enhance water quality, habitat functions, and shoreline resiliency.

Project research investigated innovative design treatments for retrofitting hardened shorelines by rapidly establishing emergent wetland vegetation through the use of constructed floating wetlands and vegetated coir logs. Designs included the use of materials such as oyster shells, activated charcoal (aka biochar), mycelium-bonded substrates (aka Mycoboard), Wood Straw, and Coir-encapsulated pillows.

Partnerships

The Sweetgrass Shoreline Restoration Project partnered with EarthCorps, United Indians of All Tribes Foundation, Seattle Parks Department, Na'ah Illahee Foundation, Lake Washington Rowing Club and Puget Sound Keepers Alliance. A parallel Sweetgrass Arts project additionally partnered with the Fremont Arts Council.

EarthCorps

The nonprofit organization EarthCorps became a key partner, as they and their young adult trainees were instrumental in constructing, installing and removing the constructed floating wetlands when the project was completed..

Urban Shoreline Working Group

At the start of the Sweetgrass Shoreline Restoration Project, an Urban Shoreline Working Group (USWG) was formed that consisted of scientists, designers, government staff, regulators and civil society experts who were actively implementing or interested in implementing nearshore restoration and enhancement projects. Priority was given to individuals and organizations working in Watershed Resource Inventory

Area (WRIA) 8. The USWG was led by the Sweetgrass team to help coordinate the group's work and sustain opportunities for learning.

The USWG provided shared experiences, expertise, and lessons learned, as well as identified opportunities for targeted technical assistance and/or peer exchange. At open meetings the USWG came to consensus on priority areas of engagement. Participants were expected to actively collaborate through in-person and virtual sessions. With the onset of the COVID pandemic, virtual meetings became the norm.

The working group was essential because shoreline restoration and enhancement involves complex, technical, and regulatory issues. The buy-in of the USWG generated multiple perspectives which facilitated implementation. The commitment of this group was invaluable in achieving the project outcomes.

The USWG met a total of six times, with the last meeting being in person.

Site Selection

During our first Urban Shoreline Working Group (USWG) meeting questions were proposed regarding WRIA 8 current issues related to juvenile salmon survival, what interventions were needed and where they were needed. Our USWG came up with 40 plus locations within WRIA 8 that could be possible sites for interventions.

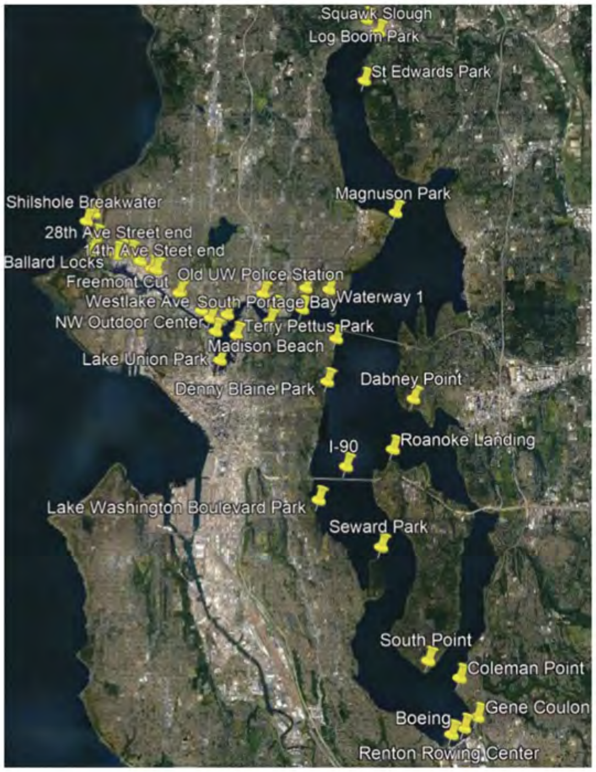


Figure 1.1 Initial site considerations

Our Sweetgrass Shoreline Restoration Project Team whittled down the selection sites to six locations: Fremont Bridge, Gene Coulon Park, South Lake Union, Gasworks Park, Shilshole Marina and the Marine side of Ballard Locks, for further discussion with the USWG. The USWG members were assembled into six groups that proposed site-specific interventions for one of the selected sites.

Study Sites: Fremont Bridge and South Lake Union

The Sweetgrass Team further assessed each of the six sites, after which the Fremont Bridge and South Lake Union sites were selected for the research trials. Sites were chosen based on intervention type, proximity to the University of Washington, others' current research conducted on salmon behavior within the Lake Washington Basin, public visibility, and ease of obtaining permits and permissions to conduct the interventions. Public education was a goal of the project; with both locations being publicly visible we would be able to place signage in key areas. Research indicated that both sites chosen had proximate juvenile salmon activity.

Figure 1.2 Entry to Lake Washington Ship Canal

Figure 1.3 South Lake Union site

Constructed floating wetlands were to be placed to the North and the South of fender walls located at the entry to the Lake Washington Ship Canal. See Figure 1.2. Coir interventions were to be placed to the northwest of the pedestrian bridge located at South Lake Union Park, adjacent to the planned carving house of the United Indians of All Tribes Foundation. See Figure 1.3.

Permits

Many permits were needed to conduct research at both sites. The Sweetgrass Shoreline Restoration Project was an outright research project, so some of the permits required by the City of Seattle did not apply. The state permits that were required for the research were a Hydraulic Project Approval (HPA) permit, which was filed through the Washington Department of Fish and Wildlife (WDFW), and a Joint Aquatic Resources Permit Application (JARPA) was completed through Washington Department of Natural Resources (WDNR) for both sites. For the City of Seattle, a shoreline exemption permit was completed for both locations through the Seattle Department of Construction and Inspections (SDCI). An exemption was requested because there was no actual construction being done, this was a research project, and the floating wetlands were only to be temporary. If this project was not temporary, additional permits would have been needed as well as if this project incorporated “staking” or anchoring that disturbed soil. A Right-of-Way permit was required for the Fremont location through the Seattle Department of Transportation (SDOT) because the waterway behind the fender walls was technically a right of way. Permissions were also obtained from the group that owned the building at the North Fremont location for the use of signage and community engagement, since they are the owners of that section of the Burke-Gilman trail. Permission was received from the Lake Washington Rowing Club to use their public launch to store our row boat to monitor the Fremont location and to store our boat equipment in their shell house. Permission from Seattle Parks and United Indians of All Tribes Foundation were granted to use the South Lake Union Location. Permit drawings are found in Appendix C and D.

2.0 Constructed Floating Wetlands Design – Fremont Bridge

Design Objectives

In the Fremont Bridge location, we sought to build on lessons learned from the Duwamish Floating Wetland designs and to develop additional out-migrating juvenile salmon habitat in freshwater. Having plants along the edge of the constructed floating wetland (CFW) was important to create a soft edge for the salmon habitat. It also allowed for increased potential for the invertebrate food sources on the plants to reach the fish. We aimed to generate a unit size that was moveable and buildable with person power. This led us to examine smaller units and determine how we could link them together either at the shoreline or in the water. In the past, putting CFWs behind docks helped prevent large erosion from boat wakes. Docks are generally close to the shorelines where juvenile salmon tend to swim, and often located in deep water next to inhospitable steepened, urbanized shorelines. At the Fremont location, fender walls (aka protection piers), were similarly thought to provide some erosion protection for the floating wetlands, while supplying attachment within the constricted migration corridor. We were interested in emergent and submergent design options. With the emergent version, could the plants provide food and dappled shade, and root biofilms increase water quality factors related to salmon health and survival? In the submergent version, could the submerged plants provide refuge and the substrate and plant biofilms help to ameliorate water quality? With these design goals in mind, we created two initial prototypes to test at Fremont Bridge.

The prototypes were built in partnership with EarthCorps, UW landscape architecture students, and local Indigenous youth/adults. EarthCorps was hired through a grant from the Puget Soundkeeper Alliance and the Rose Foundation for Communities and the Environment Foundation to help build, install, and remove the units. UW landscape architecture students volunteered to help test the prototype design. They were provided food and drinks for volunteering. Local Indigenous youth and adults were paid to help with the construction and installation. Additionally, the Port of Seattle provided time and materials in the installation. Local volunteers/fishermen helped captain the boats and support the repair work that was done. Lastly, the research team was involved in the step-by-step field process to deploy the units.

2021 Designs and Lessons Learned

2021 Design - 2.0 Units

After having some success with plant growth in the “2.0” floating wetland units on the Duwamish River (particularly in Tukwila in 2020), we salvaged the best units and repurposed them to create a new 2.0 unit at Fremont Bridge. Each 2.0 unit was approximately a 2-foot cube with 1-foot of substrate and 1-foot of geese protection. The substrate was woodstraw packed around 12 blocks of pumice (from Featherock, Inc.). The pumice block served as the flotation material for the 2.0 units. There were four plants used in the 2020 trials – *Eleocharis palustris* (common spike-rush), *Carex obnupta* (slough sedge), *Scirpus microcarpus* (smallfruit bulrush), and *Carex Lyngbyei* (Lyngbye’s sedge). Common spike-rush, slough sedge, and smallfruit bulrush had the most intact units that could be reused or rehabilitated. We also had a number of smaller units that were created at the end of the 2020 year with *Schoenoplectus pungens/americanus* (sweetgrass).

These units were removed from the Duwamish in August of 2020 and placed in the raceways of the old hatchery on the University of Washington campus where CFW construction was occurring. The units required some repair to be re-usable at Fremont. In many units, the pumice was replaced with fresh blocks due to erosion of the block. New woodstraw was added and packed into the units low on woodstraw. Some units were replanted all together or were filled as needed to have consistent numbers of plants/plugs in each unit.

To create larger units, one common spike-rush cube, one slough sedge cube, one smallfruited bulrush cube, and one sweetgrass cube were melded together to create a 2-foot by 8-foot unit, see figure 2.1. Each cube was given a 2-foot wood plank on the inside of the tensar with bolts to attach to a larger unit. An 8-foot wood 1x4 was used on the outside to bolt to and connect the cubes. The two units on the end had an additional wood plank added on the inside and outside of the cube to attach eye-bolts. Once the units were combined and in the water, ¼” steel braided cable was used to wrap around the pilings and connect to each of the eye-bolts. The cable was connected to the eye-bolts using s-beaners and shackles to hold the unit to the piling without drilling into the piling. There were restrictions on touching or changing the pilings as well as allowing the unit to adjust its elevation to water level changes.

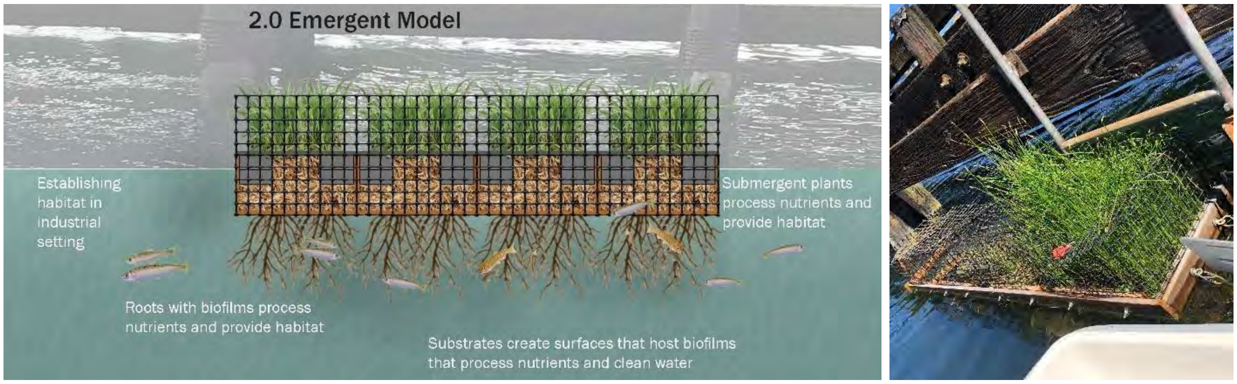


Figure 2.1: Emergent Model 2.0 that reuses 2.0 cubes from the Duwamish Floating Wetlands Project.

2021 Design - 3.0/4.0 Units

New prototypes were developed to bring emergent and submergent units together. The emergent units (3.0s) were designed at a 24”x40” size with extra flotation properties. The submergent units (4.0s) were designed at a 24”x 36” size and were intended to be 2’ below the water level. A full prototype consisted of two 3.0 units held together with a 10-foot 1x4 on each side and the 4.0 submerged unit hanging below the water between the two units.

For the 3.0 units, two prototypes were tested during the first year at Fremont; all units had a Tensar exterior shell that was 24”x40”x8”. The first prototype used an excelsior coir blanket as the inside liner to help hold the woodstraw in. The flotation component for this prototype was a 4” PVC pipe with caps glued onto both ends to make it airtight. Each unit had 2 pipes on each side with woodstraw packed in the middle as the substrate. The second prototype for the 3.0 units, see figure 2.2, used a woven geotextile fabric as the inside liner to prevent the substrate from erosion. The woodstraw was packed on the bottom and topped with a 4” polylactic acid (PLA) infused mycoboard from Ecovative. This provided both substrate assistance in the mycoboard and flotation support from the PLA. Each prototype was constructed and attached with another unit of the same kind to make the full prototype. Wood surrounded each of the units to give the unit structure, prevent erosion, and provide connecting points. The outside of the units had eye-bolts and were attached to the pilings similar to the 2.0 units. The inside also had eye-bolts which the 4.0 unit could attach to.

The 3.0 units in freshwater were testing new planting species – *Sidalcea hendersonii* (Henderson’s checkermallow), *Deschampsia cespitosa* (tufted hairgrass), *Carex stipata* (awl-fruited Sedge), and *Sisyrinchium idahoense* (Idaho blue eyed grass). Each unit only had one type of plant in it, but each plant was tested in both of the 3.0 prototypes.

The 3.0 units were also protected from geese. Each unit had bamboo rods attached to the base wood and tensar wrapped around the top of the unit, where the plants were growing, to prevent the unit from bird predation. The bamboo was woven through the tensar to connect the netting to the bamboo. To create more stability at the top, the tensar was zip-tied together at the top to prevent geese from entering the netting.

The 4.0 unit was slightly smaller with less weight and to see if we could get plants to grow. Since these were submergent units, we removed the flotation piece from them and focused on a substrate that would sink, but not be too heavy that it sank the full prototype. Two substrates were tested in these units. The original mixes were labeled as mix 1 (10% biochar, 40% woodstraw, 25% pumice, and 25% sand) and mix 2 (10% biochar, 40% woodstraw, 40% oyster shells, and 10% sand). They were first tested and weighed with small units (12”x6”x6”). As we increased their size to the full 24”x36”x6”, they got too heavy. We ended up adding more woodstraw to the units to decrease weight and increase volume. The final percentages of mixes were as follows: mix 1 – 60% woodstraw, 15% pumice, 15% sand, and 10% biochar; and mix 2 – 60% woodstraw, 20% oyster shells, 10% sand, and 10% biochar. Each of these mixes were wrapped in woven geotextile and had an outer shell of tensar to prevent substrate from escaping. Wood planks were attached to all four sides and the two ends had eye-bolt attachments. The eye-bolts were chained to the inner eyebolts of the 3.0 units to create a 4.0 unit that hung between the 3.0 units.

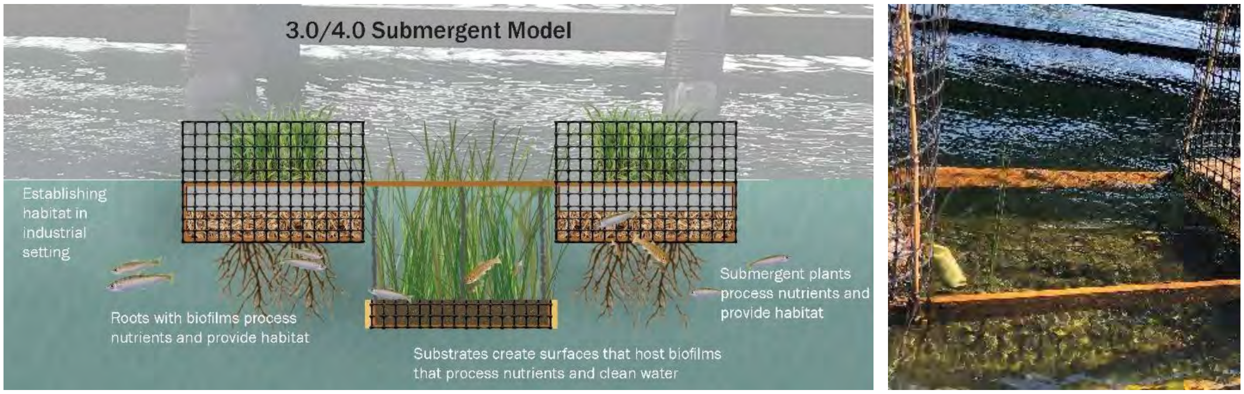


Figure 2.2: Emergent (3.0) and submergent (4.0) models shown with mycoboard in the diagram and pvc pipe flotation in the field image

2021 Lessons Learned

As the 2.0 and 3.0/4.0 units were prototypes installed at Fremont, we learned several design lessons. First, the 4.0 units placed too much weight on the 3.0/4.0 prototype. The full units began to sink because of the weight of the submergent units. Second, the fender wall didn't block boat wakes. The docks had a consistent solid barrier, whereas the fender walls had breaks that let considerable boat wakes through. As a result, the units were jostled around more than we anticipated. The coir blanket also didn't hold in the substrate during these boat wakes and the substate for the plants to grow into was lost. The pipe with the coir blanket started to pop through and move around further jostling the woodstraw out of the unit. The geotextile fabric held the substrate in significantly better. In the 2.0 units, the substrate wasn't held in by anything other than tensar. As a result, much of the woodstraw that wasn't interconnected to the plant roots was lost. The pumice became waterlogged. The units began to slowly sink and didn't retain its original flotation properties. Lastly, the 2.0 units went from estuary conditions to freshwater conditions. The units that originally came from Tukwila (freshwater) survived better than those that came from the Waste Management (partial saltwater) location. Considering these lessons learned, we modified our design for the end of the season and for the next summer.

2021 Design – 4.1 Units

During late summer 2021, we considered the lessons above and created a 4.1 prototype to test/install before the year ended. Instead of trying to remake the 2.0 units that failed, we developed a 4.1 emergent version that used the same species as a replacement. The 4.1 units were the same size as the 4.0 submergents and used the same sized template, 24”x36”x6”. Tensar was the outside material, and it was lined with geotextile fabric or excelsior coir blanket. The initial flotation material was pumice blocks. The pumice was semi-attached to the sides of the units with wraps of tensar. The middle of the unit was packed with woodstraw. Wood surrounded all four to help support the structure. The ends of each unit were installed with eye-bolts. See figure 2.3.

Each unit had two species planted, one on each half of the unit. The same plants used in the 2.0 units were used here. *Eleocharis palustris* (common spike-rush) and *Carex Lyngbyei* (Lyngbye's sedge) were paired on one unit. *Scirpus microcarpus* (smallfruit bulrush) and *Schoenoplectus pungens/americanus* (sweetgrass) were paired together.

To create a full prototype, two of the units were chained together so that all four of the species were represented in the prototype. Each prototype had eye-bolts on the ends with cable to wrap around the pilings.

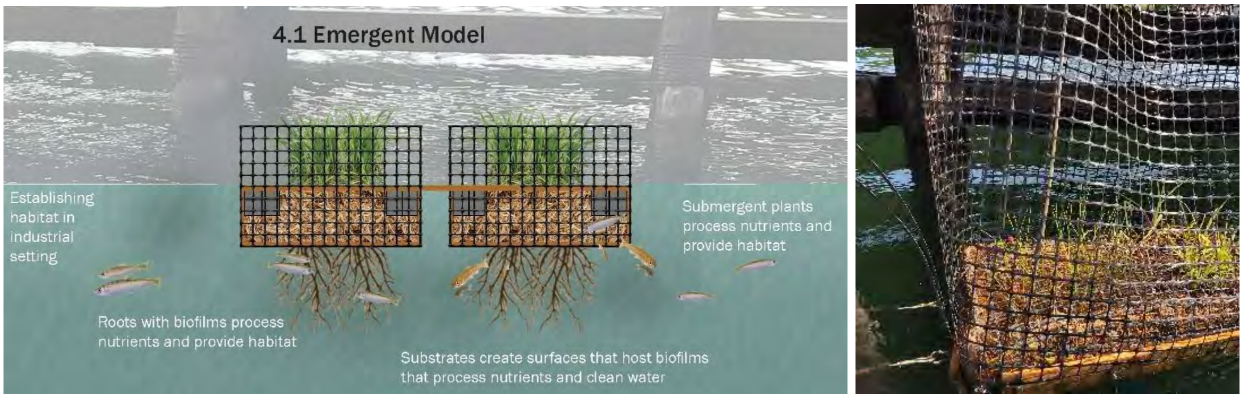


Figure 2.3: Emergent 4.1 model with pumice flotation

2022 Design Revisions and Results

2022 Design – 4.2 Units (late spring)

As the 4.1 units were initially in the water, the pumice became waterlogged and the units began to sink. New 4.2 units were created with a similar process but used 2” and 3” PVC pipe with air caps as flotation. Due to the movement that we saw from the pipe on the original 3.0 units, the pipe in the 4.2 units were zip-tied to the edges so that they couldn’t jostle out the woodstraw. The geotextile fabric was also the only fabric used as a liner to hold the substrate in. If the units were still doing well and were not rebuilt but still sinking, pipes were added to the outside of the 4.1 units to increase flotation properties.

2022 Design – 3.1 Units

With the 3.0/4.0 units sinking and substate eroding, changes were made for 2022. The 4.0 units were removed to South Lake Union (SLU) leaving only the 3.0 emergent units at the Fremont Bridge. The rest of the 3.0 units that used the biodegradable excelsior coir blanket needed to be rebuilt since the substrate was no longer intact. Those units were rebuilt as 3.1 units.

The 3.1 unit has Tensar to hold everything together in a 24”x40”x8” frame. The tensar is lined with a geotextile fabric. For flotation, 3” or 4” ABS pipe with glued caps for airtight flotation is zip-tied to the sides of the unit. Woodstraw is packed into the unit for substrate. Each side of the unit has wood planks to support the structure and provide additional flotation. Two units are connected with 10-foot 2x4 wood pieces.

The units were protected from geese using a lighter deer netting instead of tensar. The lighter geese netting protects the units without adding undue weight. It also created less visual block of the plants.

For year 2, units were replanted as needed with *Sidalcea hendersonii* (Henderson’s checkermallow), *Deschampsia cespitosa* (tufted hairgrass), *Carex stipata* (awl-fruited Sedge), and S*cirpus cyperinus* (woolgrass). For more information on the plant health, see the plant research section.

2022 Lessons Learned

After learning from the 2021 prototypes, we proposed adjustments for 2022. During the research season, we observed the units and continued to learn how the CFW designs performed and what we could do to improve them. First, the PVC tubes worked well for flotation in comparison to anything else we had tried, but they must be tied to the structure to prevent it from moving around. Additionally, the tubes we used were expensive. We have continued to look for and find less expensive tubes, but have not installed them to test since we already had the PVC materials bought. Second, the excelsior coir blanket had a loose weave/fabric and is biodegradable. The geotextile fabric is significantly better at holding the material together. It is a black fabric, so the visual optics look more constructed than natural. While we prefer it to look more natural, first and foremost, it needs to hold the substrate together. Third, the deer netting used in 2022 to keep the geese out is more flexible and easier to see through and to take measurements through. The lighter deer netting still did well at keeping the geese away. Fourth, wood on all four sides of the units were helpful structurally, but also added extra flotation and erosion prevention for the unit. Lastly, in comparing the tensar to the gabion metal used in the Duwamish project, the tensar is easier to use. That said, it is still stiff and hard to manipulate and often still scrapes skin and catches fingers.

Design Discussion

Through the design trial and iteration process, there were key ideas that were learned for future projects. The Duwamish Floating Wetlands told us the importance of having a wave block, so the units were places behind the fender walls. However, the fender walls did not provide a solid mass in the water to prevent wakes from coming through, so all boat movement through the Lake Washington Ship Canal rocked all the CFWs, inflicting considerable damage to some of the units. Better wake research and site selection criteria needs to be considered in future sites. We started by attaching the units on both sides to the pilings. While that helped keep the units in place, it also created more restrictions for the units to be able to move with the wakes. Future models should try attaching on one side of the unit only or using ground weights to hold the unit in place to have more flexibility. Lastly, the unit sizes were critical in this trial. Having 24”x40” units held together with chain or wood allowed them to float up and down more easily with the boat wakes. The chain provided more independence for the units, while the wood allowed more structure and flotation. Both allowed for light to get in and flexibility in moving. Future design iterations need to consider lessons learned about design strategy as well as location selections.

Full cut sheets for all designs can be found in Appendix E.

3.0 Floating Wetlands Research and Monitoring - Fremont

3.1 Plants

Introduction

Eight different species of wetland plants were chosen to grow on our floating wetlands. 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.

Four metrics were used to determine plant health from June 2021 to July 2021 and April 2022 to July 2022. These metrics were plant height, percent foliage cover, mortality, and number of blooms.

Research questions for Plant Monitoring

- Do our floating substrates support viable growth and survival of wetland plants in the Lake Washington Ship Canal?
- 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?

Plants Scheme

1. Plants used on 3.0 units
    a. DESCAE-*Deschampsia cespitosa* - Tufted hairgrass
    b. SISIDA-Sisyrinchium idahoense - Blue-eyed Grass (2021)/SCICYP-Scirpus *cyperinus* - Woolgrass(2022)
    c. SIDHEN-*Sidalcea hendersonii* - Henderson's Checkerbloom
    d. CXSTIP-*Carex stipata* - Sawbeak Sedge
2. Plants used on 2.0 units
    a. ELEPAL-*Eleocharis palustris* - Common Spikerush
    b. CXOBNU-*Carex obnupta* - Slough Sedge
    c. SCIMIC-*Scirpus microcarpus* - Small Fruited Bulrush
    d. SCHAME-*Schoenoplectus americanus* - Sweetgrass
3. Plants used on 4.0 units
    a. SCHACU-*Schoenoplectus acutus* - Hardstem bulrush

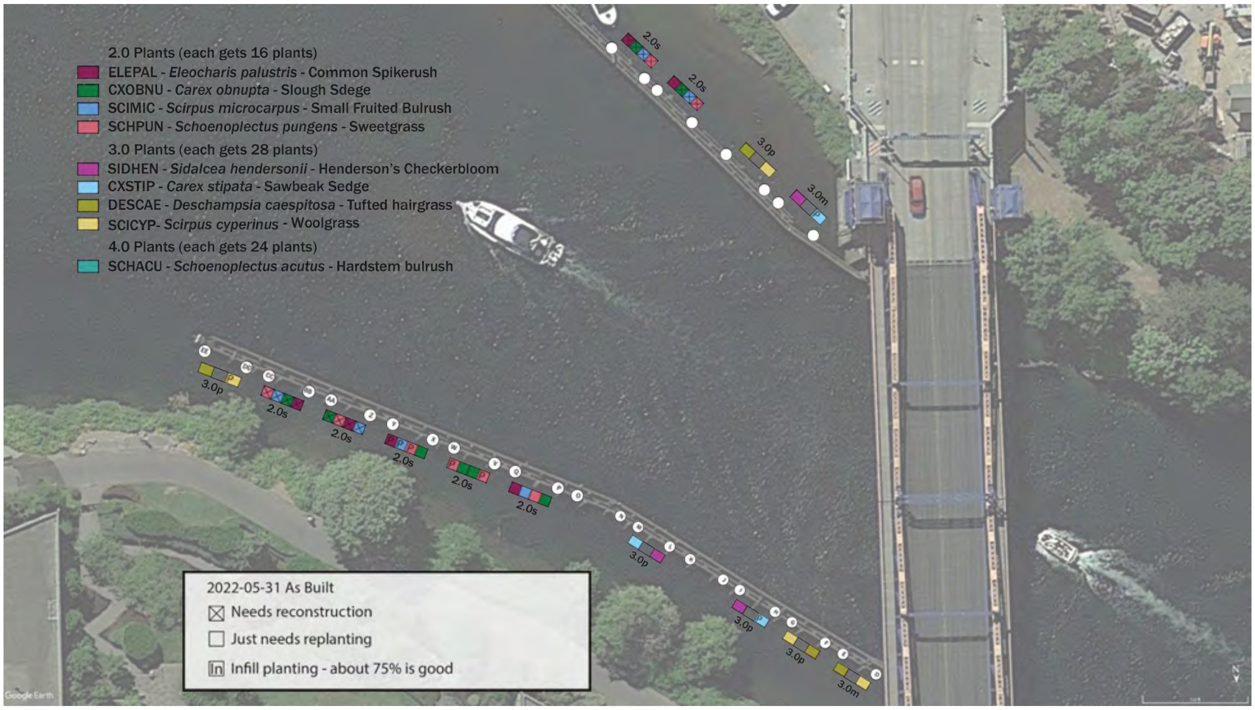


Figure 3.1.1: Planting plan and location of units for the data collection period starting 2022-05-31.

Materials and Methods

Collection Periods

Data was collected during the spring/summer of 2021 and 2022. The units were planted at the beginning of the 2021 period. After the first year, there were several units that needed replanting. This replanting occurred halfway through the 2022 data collection. Thus, the data analysis is divided into three populations; 2021 (all data collected in 2021), Early 2022 (all data collected from plants that were alive at the beginning of the 2022 period leftover from 2021), and Late 2022 (all data collected from plants installed in the summer of 2022). The 2021 period started June 11, 2021 and ended July 30, 2021, lasting 50 days. Replanting was done in fall 2021 to infill species and replace the SISIDA with SCICYP. The Early 2022 period started April 6, 2022 and ended June 21, 2022, lasting 102 days. Due to poor plant health, infill planting was done in late June to improve plant growth. The Late 2022 period started June 24, 2022 and ended July 21, 2022, lasting only 27 days. Data collection was conducted in the same protocol during all collection periods.

Plant Height

Throughout the data collection period, the height of the tallest plant in each unit was measured to the nearest cm. Measurements were taken every two weeks in the spring and every week in the summer when plant growth was occurring more rapidly. Plant height monitoring 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 the percentage of ground (rounded to the nearest 5%) covered by vegetation were taken in the field and standardized according to the research lead's best judgment.

Figure 3.1.2: Community scientist Sloane Palmer demonstrates collecting plant height data at Fremont floating units.

Total Mortality

Total mortality is a straightforward metric to record, 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. To analyze, the numbers counted in the final monitoring session are compared to the number of individuals initially planted.

Blooms

Floral inflorescences were counted per unit as another indicator of plant health. It is difficult to perform analysis with this data because there is little literature discussing the average number of inflorescences for the species we tested.

Naturalist Notes

Additionally, starting in 2022 any field observations that fell outside the other metrics being collected were recorded in a naturalist notebook. An emphasis was placed on any bird activity in order to determine interaction between the units and predator species.

Figure 3.1.3: Inflorescence of *Sidalcea hendersonii* (Checkers mallow).

Data Analysis

Statistical analysis was performed to determine whether any of the observed differences in our plant performance metrics were significant. A one-way ANOVA model was fitted and assessed to see if there was any significant correlation between plant performance and our species. The results were then visualized through a Tukey plot.

Results

Mortality/Survival

Mean survival percentage for each species was calculated for each data collection period. See Figure 3.1.4-3.1.6 for the mean percentages. *Deschampsia cespitosa* had one of the highest survival rates across two, in 2021 and early 2022. The Late 2022 population did not perform as well but it is speculated that this is due to the quality of plugs received from the nursery. *Carex obnupta* was another species with excellent performance having all populations at survival rates between 50% and 80%. *Scirpus* *microcarpus*, *Carex stipata*, *Eleocharis palustris*, *Schoenoplectus americanus*, and *Sidalcea hendersonii* performed moderately well with survival rates between 90% and 40% but only in one of the collection periods. *Schoenoplectus acutus, Scirpus cyperinus,* and *Sisyrinchium idahoense* all had very low or nonexistent survival when at Fremont. These species were also only sampled in one season.

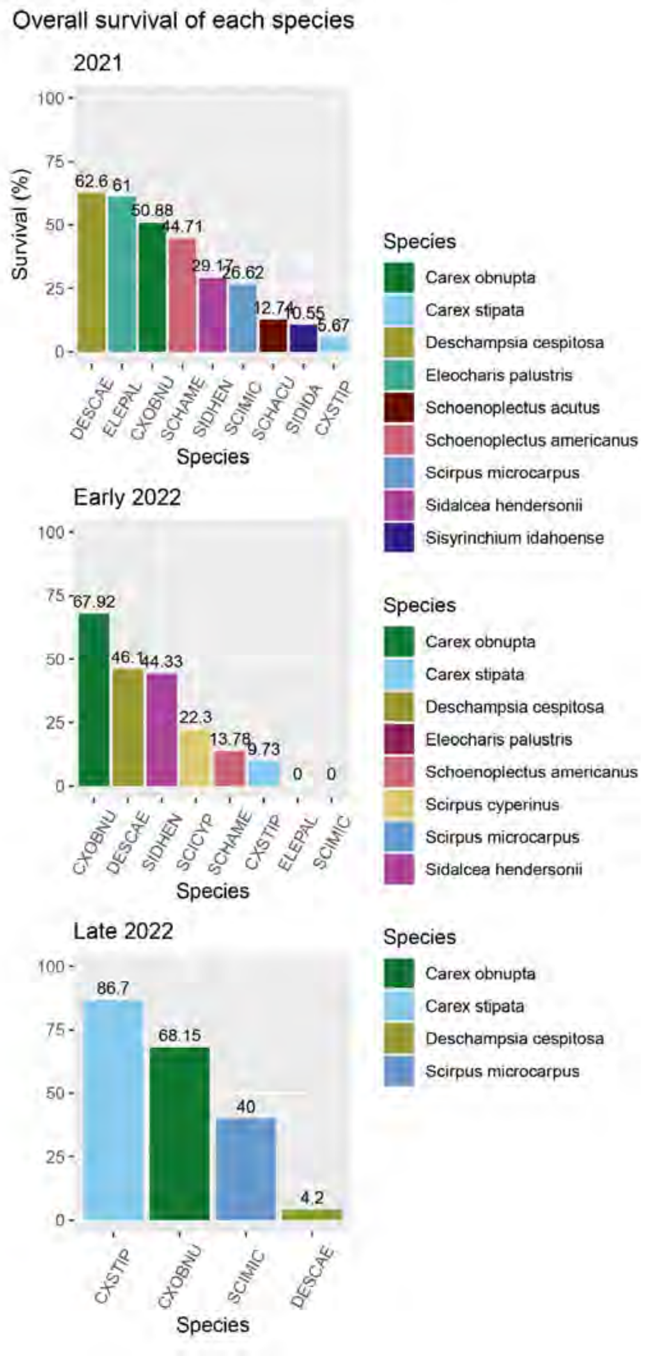


Figure 3.1.4: Figure summarizes the mean percentage of individuals that survived at the end of the data collection for each species at Fremont. Populations were separated by the 2021 sample period, early 2022, and late 2022 after 3 of the units were replanted on 6/24/22. Note that there are two bars for *Carex obnupta* in “Late 2022” because there the species was planted in both a 3.0 model and 4.1 model.

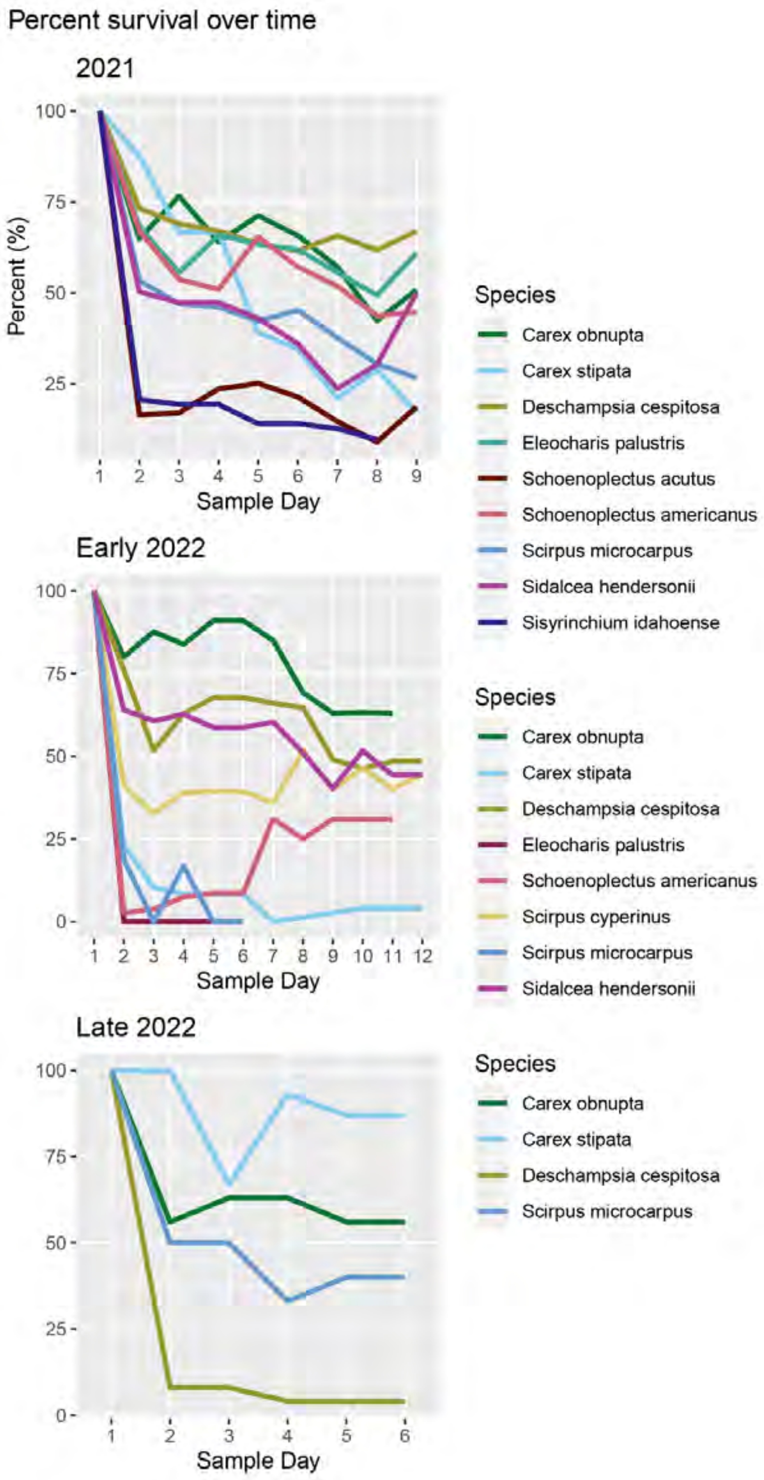


Figure 3.1.5: Figure summarizes the mean percentage of individuals that survived for each species over time at Fremont. Populations were separated by the 2021 sample period, early 2022, and late 2022 after 3 of the units were replanted on 6/24/22.

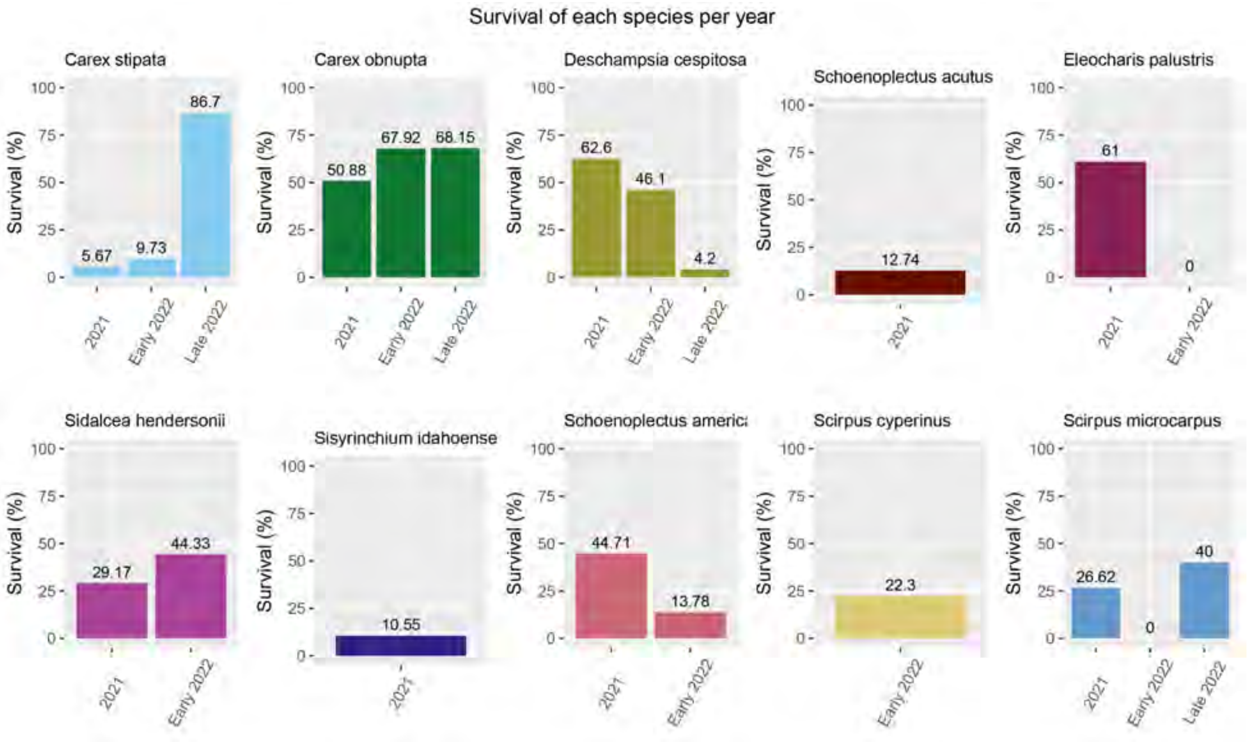


Figure 3.1.6: Figure summarizes the mean of the percentage of individuals that survived at the end of the data collection separated out by each species at Fremont. Populations were separated by the 2021 sample period, early 2022, and late 2022 after 3 of the units were replanted on 6/24/22.

Percent Cover

Percent cover is another helpful metric in determining the performance of each species. Refer to figures 3.1.7-3.1.9 for mean percentages of percent cover. Most of the percent cover data confirms the performance results determined by the survival data. Similar to survival results, *Deschampsia cespitosa* had the highest percent cover at the end of two collection periods but suffered in Late 2022 due to the poor quality of starts received from the nursery. *Carex obnupta* percent cover results also reflected the survival results demonstrating higher percent cover data than other species. *Carex stipata* and *Eleocharis palustris* demonstrated percent cover in the 20%-50% range though only in one season as they generally did not survive the exceptionally cold winter. Other than these few species, however, the data shows low percent cover results for the rest of the species and does not precisely mirror the survival percentage data. This may indicate that percentage of survival alone is not an adequate indicator of performance. It is also important to note the significant variance in percent cover across time for percent cover (Figure 6). The data was sometimes collected by different individuals from week to week and it is possible that this could result in inconsistent percent cover data reporting.

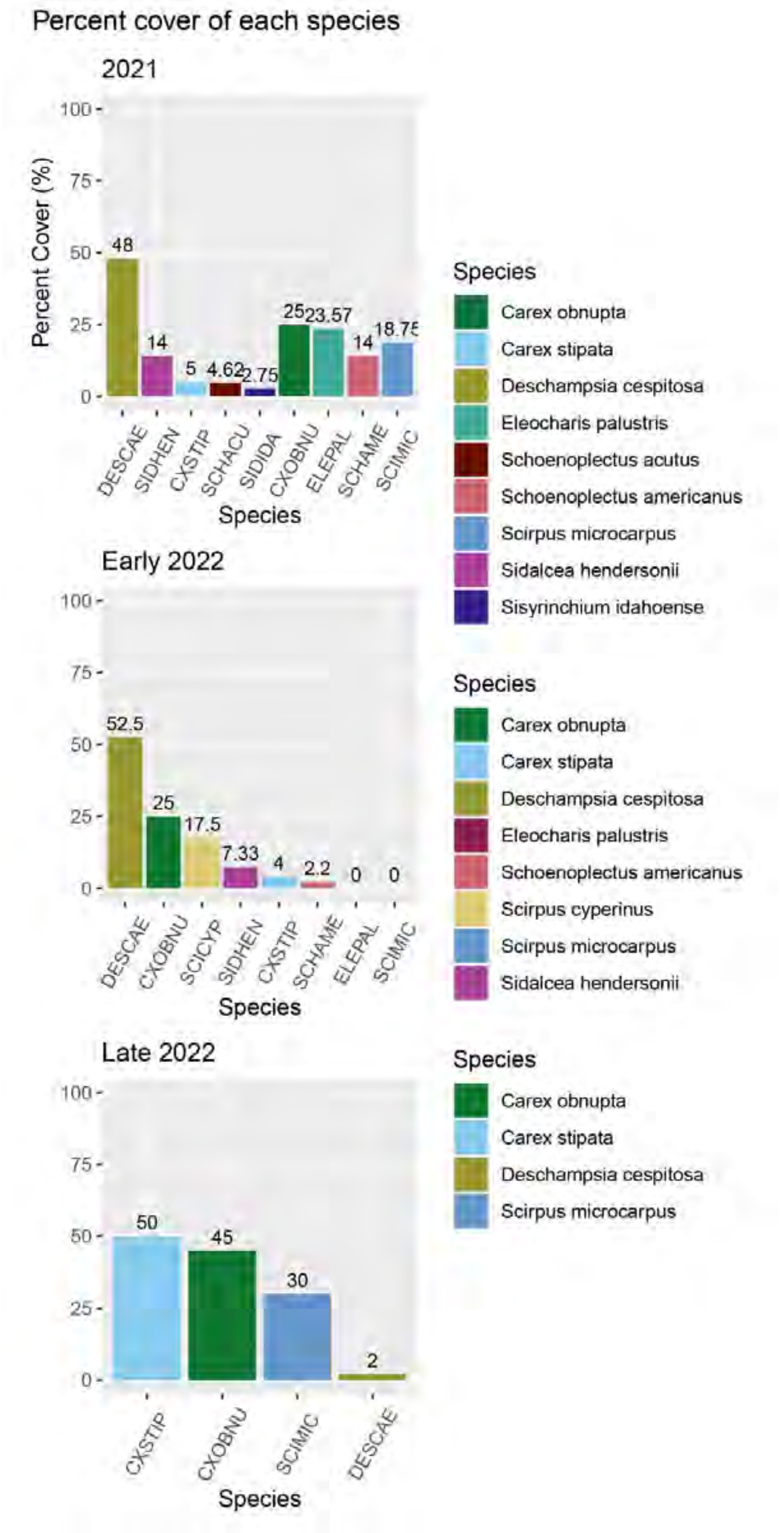


Figure 3.1.7: This figure summarizes the mean of the percent cover of each population at the end of the data collection at Fremont. Populations were separated by the 2021 sample period, early 2022, and late 2022 after 3 of the units were replanted on 6/24/22.

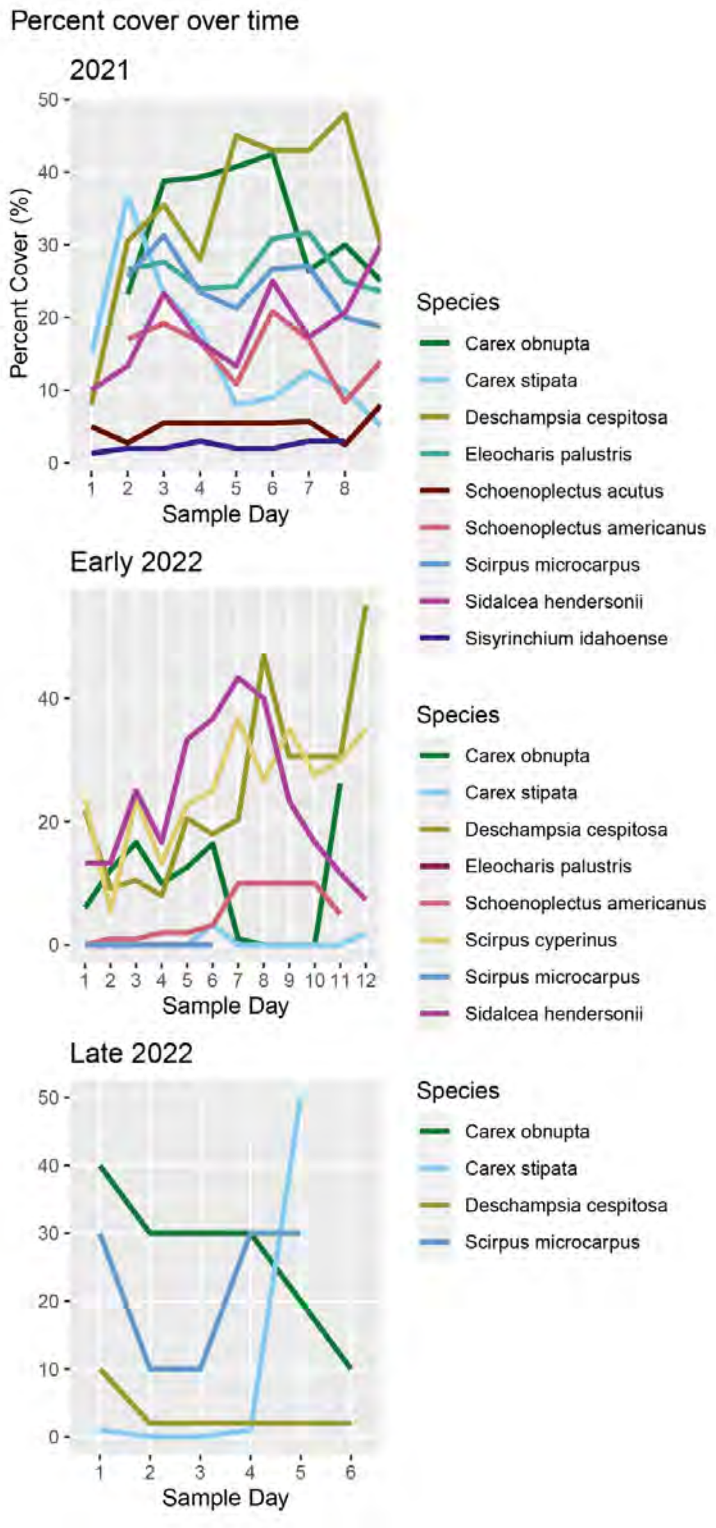


Figure 3.1.8: This figure summarizes the mean of percent cover of vegetation for each species over time at Fremont. Populations were separated by the 2021 sample period, early 2022, and late 2022 after 3 of the units were replanted on 6/24/22.

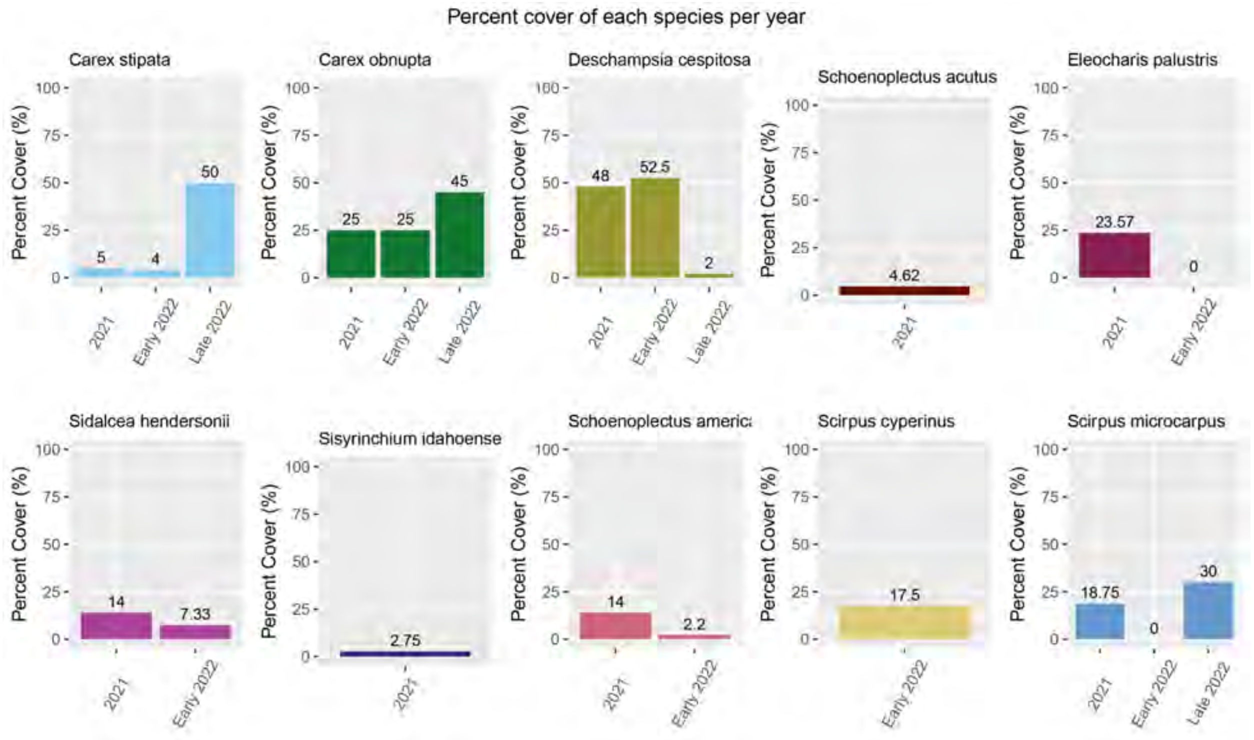


Figure 3.1.9: Figure summarizes the mean of percent cover of vegetation at the end of the data collection separated out by each species at Fremont. Populations were separated by the 2021 sample period, early 2022, and late 2022 after 3 of the units were replanted on 6/24/22.

Plant Height

Figures 3.1.10 through 3.1.12 and Table 3.1.1 summarize the plant height data. The percent of average height was calculated by taking the average height of each species on the last day of data collection and comparing it to the King County or USDA average expected height. *Sidalcea hendersonii*, *Deschampsia cespitosa* (excluding Late 2022 data), *Sisyrinchium idahoense,* and *Schoenoplectus acutus* performed well with the average height percent ranging from 50% to 116%. All species in the 2021 season performed well (reaching over 50% of their average height) while in Early 2022 and Late 2022 there were two species that reached over 40% of their height but the rest of the species were farther off from reaching their full height. In Late 2022, it is possible that this can be attributed to the shortened growing period in comparison to the others.

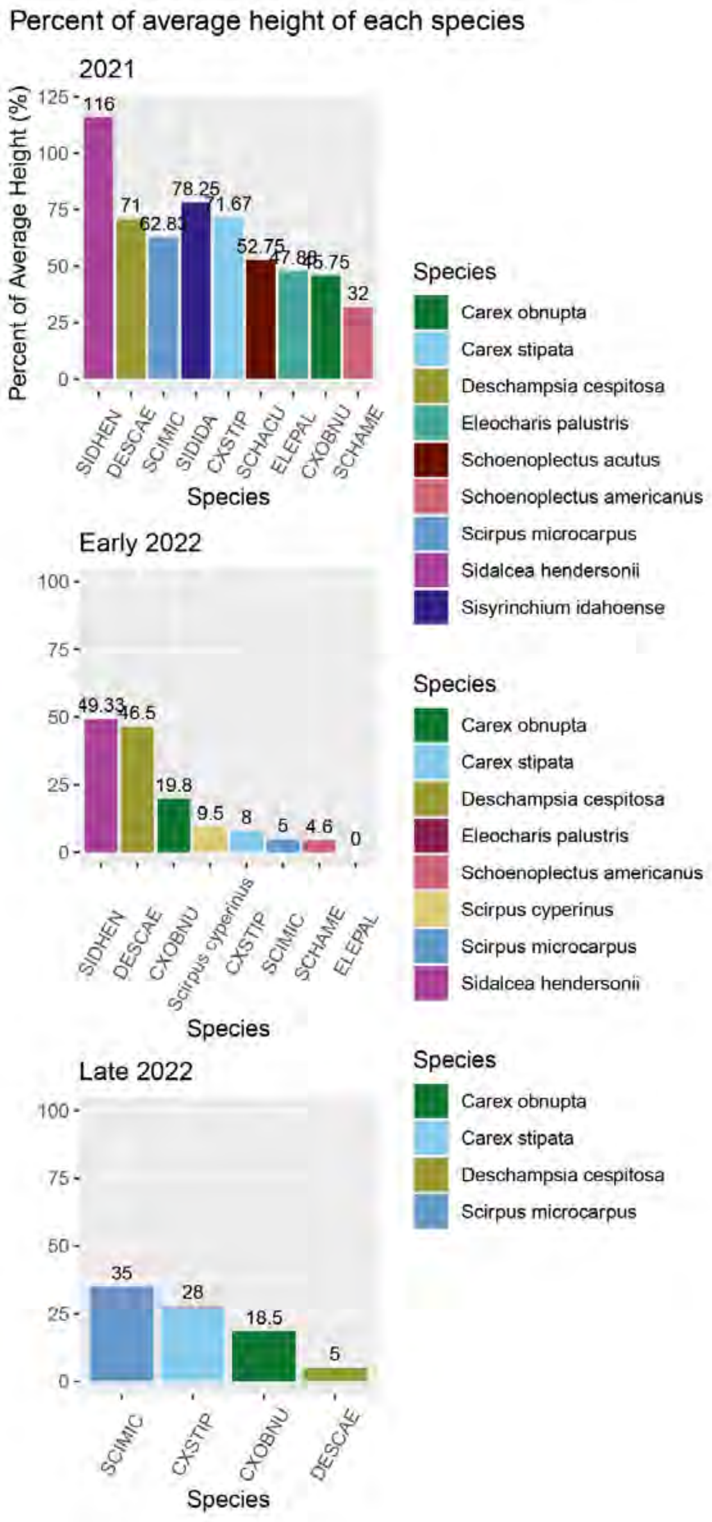


Figure 3.1.10: Figure summarizes the mean of the percentage of height compared to the national average of each species at the end of the data collection at Fremont. Populations were separated by the 2021 sample period, early 2022, and late 2022 after 3 of the units were replanted on 6/27/22.

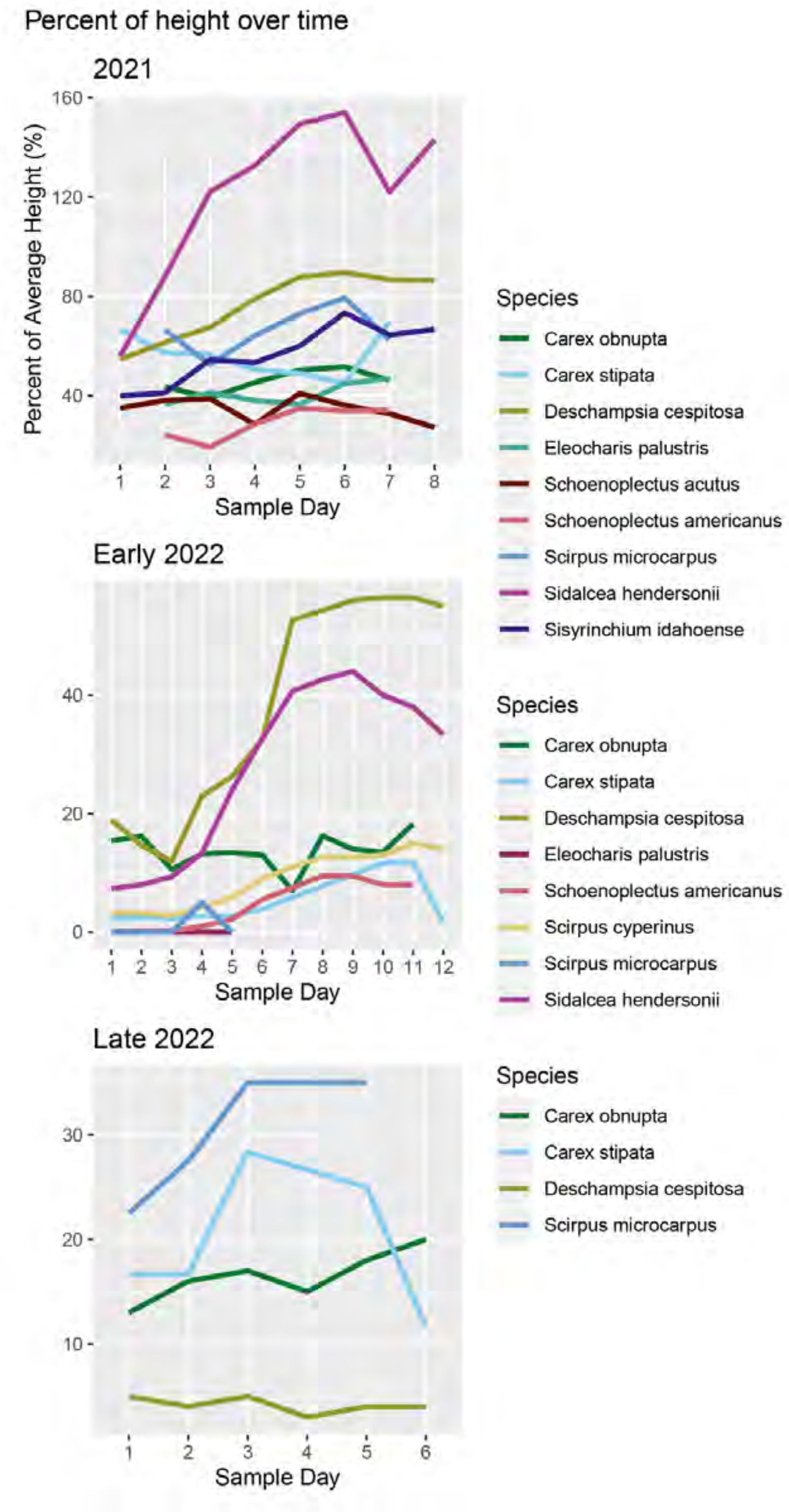


Figure 3.1.11: This figure summarizes the mean of the percentage of height compared to the national average of each species over time at Fremont. Populations were separated by the 2021 sample period, early 2022, and late 2022 after 3 of the units were replanted on 6/24/22.

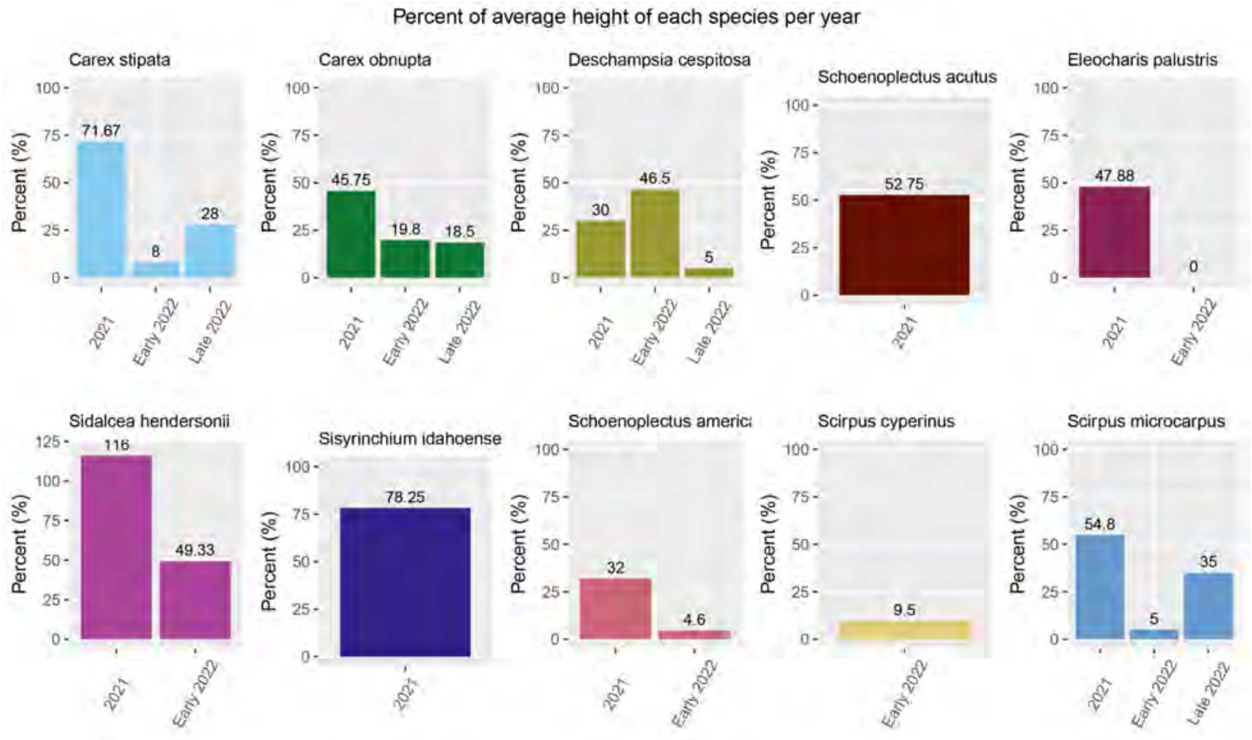


Figure 3.1.12: Figure summarizes the mean of the percentage of height compared to the national average of each species at Fremont. Populations were separated by the 2021 sample period, early 2022, and late 2022 after 3 of the units were replanted on 6/24/22.

Table 3.1.1: Plant height comparisons to published average heights at Fremont.

Observation Time Period	Species	Average height (cm) on final day of observation	Average height in cm per USDA/King County	Percent of full growth
Early 2022	*Carex obnupta**	19.8	100	19.8%
Late 2022	*Carex obnupta*	18.5	100	18.5%
2021	*Carex stipata*	46.5	60	77.5%
Early 2022	*Carex stipata*	4.7	60	7.8%
Late 2022	*Carex stipata*	17.0	60	28.3%
2021	*Deschampsia cespitosa*	89.7	100	89.7%
Early 2022	*Deschampsia cespitosa*	46.5	100	46.5%
Late 2022	*Deschampsia cespitosa***	5.0	100	5.0%
Early 2022	*Eleocharis palustris**	0	120	0.0%
2021	*Schoenoplectus acutus*	99.8	200	49.9%
Early 2022	*Schoenoplectus americanus**	8.6	200	4.3%
Early 2022	*Scirpus cyperinus*	14.3	150	9.5%
Early 2022	*Scirpus microcarpus**	2.0	40	5.0%
Late 2022	*Scirpus microcarpus*	14.0	40	35.0%
2021	*Sidalcea hendersonii*	80.0	50	160.0%
Early 2022	*Sidalcea hendersonii*	23.5	50	47.0%
2021	*Sisyrinchium idahoense***	25.3	30	84.4%

*There was concern that *Carex obnupta*, *Eleocharis palustris*, and *Schoenoplectus acutus*, and *Scirpus microcarpus* were grown in units that had become compromised due to complete loss of substrate or the unit itself was coming apart and that this might affect the growth performance.

**The *Deschampsia cespitosa* (late 2022) and *Sisyrinchium idahoense* (2021) were partially dead at installation.

Blooms

The number of blooms per species was recorded as another metric of overall plant health. The only species that produced blooms were *Sidalcea hendersonii*, *Carex stipata*, *Sisyrinchium idahoense*, *Deschampsia cespitosa*, and *Carex obnupta*. *Sidalcea hendersonii* produced the most blooms in both periods it was tested. *Deschampsia cespitosa* produced blooms in both 2021 and Early 2022, though not Late 2022 likely due to the poor quality of starts as well as the shorter growing period.

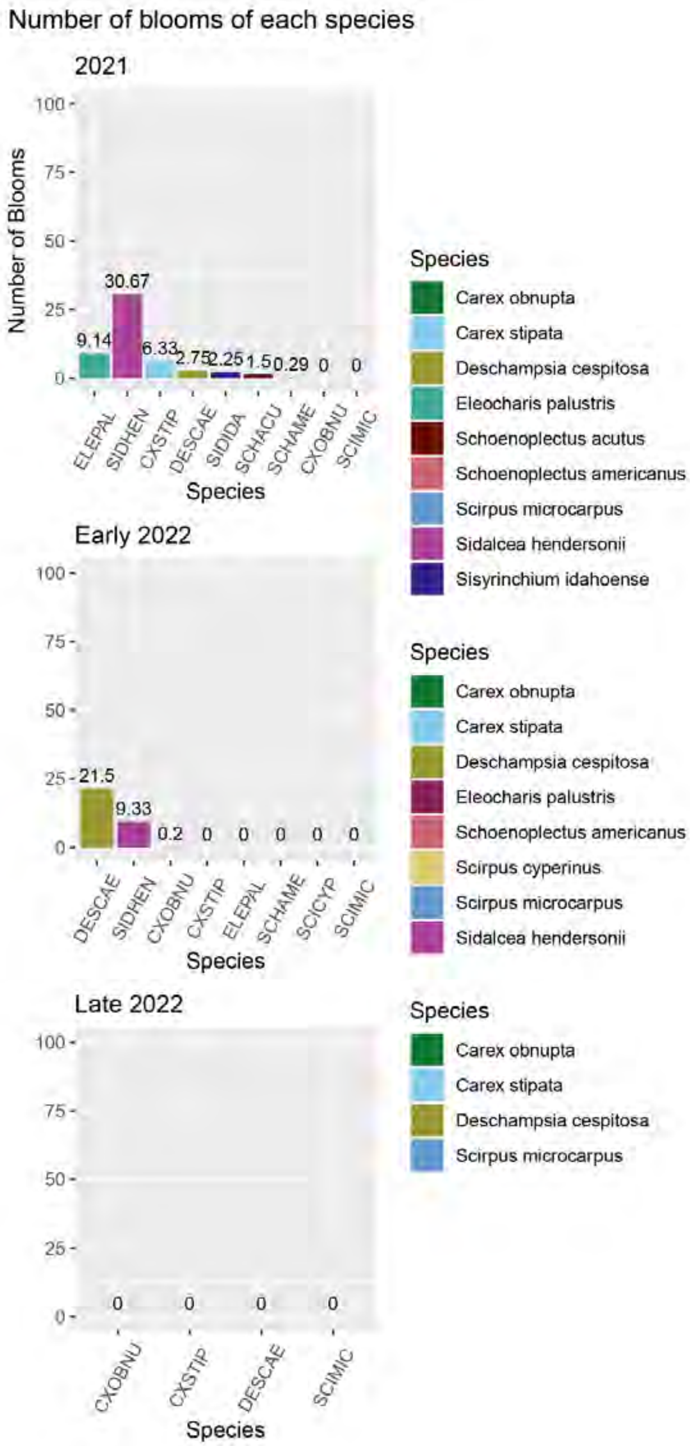


Figure 3.1.13: Figure summarizes the mean of the number of blooms at peak bloom production for each species at Fremont. Due to the fact that several species had started to decline in bloom production by the end of the collection period, we used the day with the most blooms for analysis rather than the last day of data collection. Populations were separated by the 2021 sample period, early 2022, and late 2022 after 3 of the units were replanted on 6/24/22. In both seasons, *Sidalcea hendersonii* and *Deschampsia cespitosa* had the highest number of blooms recorded. *Carex stipata* and *Sisyrinchium idahoense* also produced inflorescences.

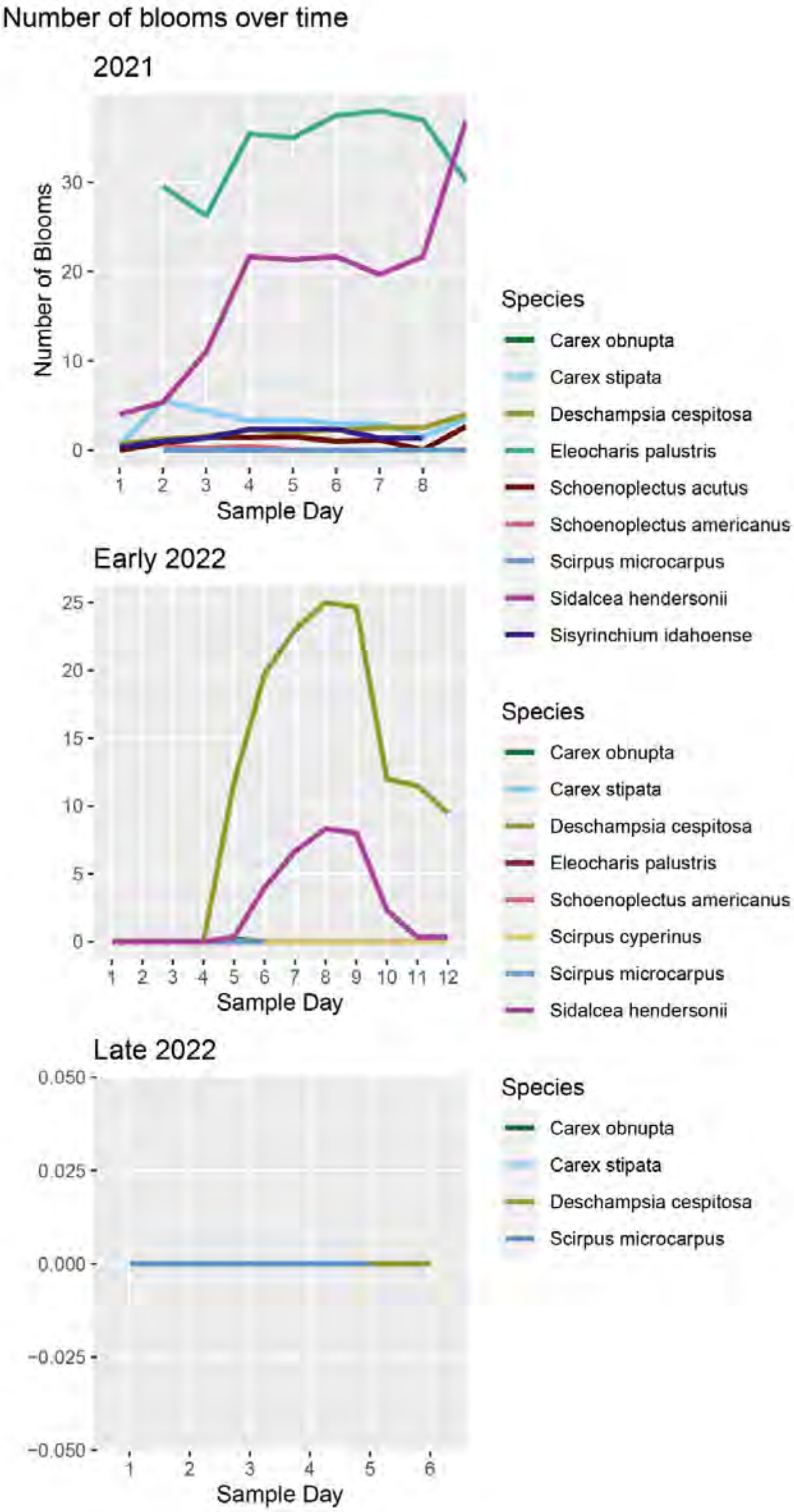


Figure 3.1.14: This figure summarizes the mean number of blooms for each species over time at Fremont. Populations were separated by the 2021 sample period, early 2022, and late 2022 after 3 of the units were replanted on 6/24/22.

Statistical Analysis

Table 3.1.2 and Figure 3.1.15 summarize the statistical analysis conducted for plant performance. After performing a one-way ANOVA for the percent of survival across all species, the resulting p-value is 0.0068. This would suggest that there is a statistically significant difference between the means of the data. In order to visualize the difference, a Tukey plot was produced. The Tukey plot compares each individual mean to the other means of the dataset. *Carex obnupta* was statistically different from *Schoenoplectus acutus* and *Scirpus microcarpus*. Referring to Figures 1-3 this would make sense since *Carex obnupta* had the highest survival rate and *Schoenoplectus acutus* and *Scirpus microcarpus* had the lowest. This comparison simply tells us *Carex obnupta* greatly outperformed other species.

Table 3.1.2: Statistical tests of average survival percentage between all the plant species at Fremont (one-way ANOVA, significant if less than 0.05).

Species	P-Value
All plant species	0.0068

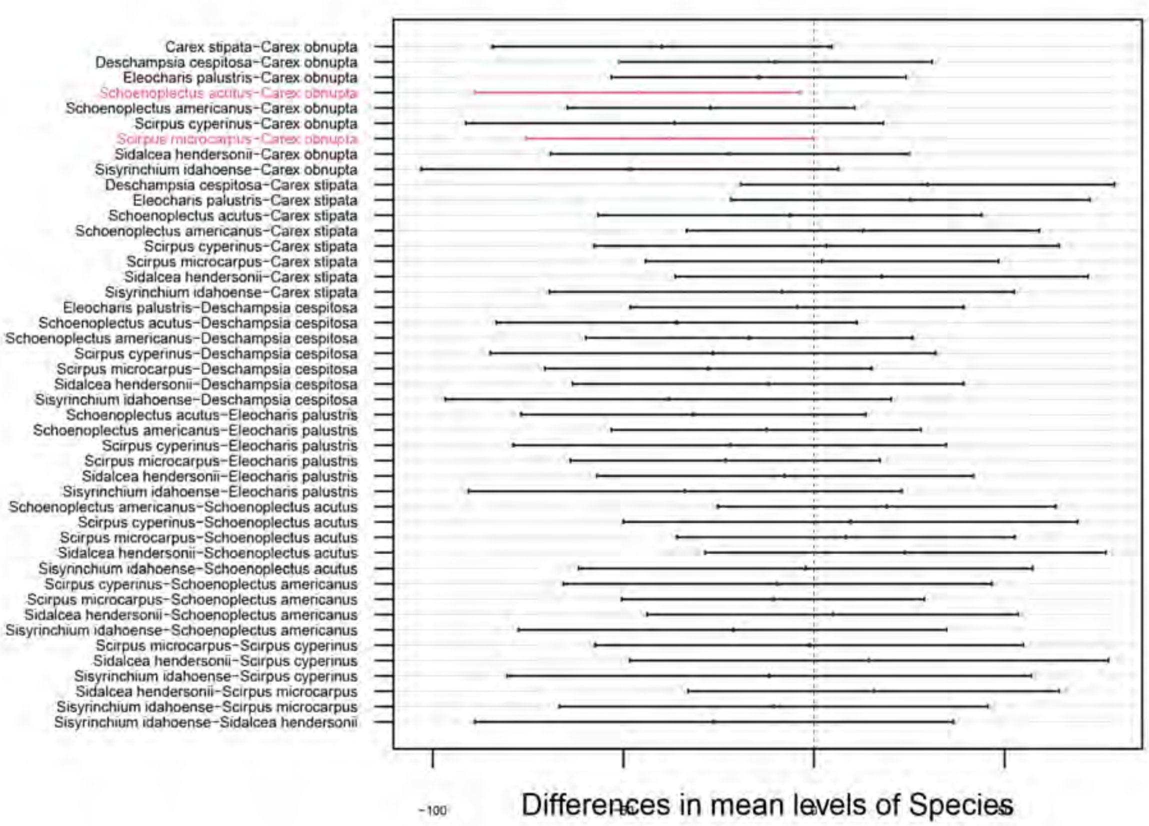


Figure 3.1.15: This figure summarizes the results of the ANOVA test comparing the variance of the mean percentage of survival of each species to overall data at Fremont. The comparisons that fall closer to the centerline have less significant differences. Comparisons that are farther to the left or right have more difference. Species highlighted in red are statistically significant.

Naturalist Notes

Table 3.1.3: This table shows any field observations and the dates they were recorded on.

Date	Observation
4/6/22	● shell seen on wetland at Fremont, presumably left by a bird.
5/13/22	● shells seen on wetland at Fremont
5/27/22	● blue heron fishing from shore directly adjacent to units at Fremont North
6/16/22	● blue heron fishing from shore at Fremont north
6/17/22	● blue heron fishing from shore at Fremont north
6/24/22	● blue heron fishing from shore at Fremont north ● mother duck and duckling eating algae from units on North Fremont
6/26/22	● dragonflies seen along shore line
7/11/22	● beaver seen at 10 pm while snorkeling. Lodge seems to be directly on shore adjacent to North units
7/15/22	● dragonflies hanging out on multiple units at Fremont
7/21/22	● dragonflies seen at wetlands units at Fremont

Discussion

All in all, we determined several species that are well-adapted for survival in floating wetland units at the Lake Washington ship canal location. *Deschampsia cespitosa*, *Carex obnupta*, and *Sidalcea hendersonii* are all strongly suited for these conditions as demonstrated by our performance result. S*cirpus microcarpus*, *Carex stipata*, *Eleocharis palustris*, *Schoenoplectus americanus*, and *Sidalcea hendersonii* are next best suited for Fremont's conditions. The performance of *Schoenoplectus acutus, Scirpus cyperinus,* and *Sisyrinchium idahoense* would suggest these species are not well-suited for floating wetland units in the Lake Washington ship canal.

Limitations

The plant data collection portion of this project had several limitations. The performance of the species tested depended on the quality of starts received from the nursery. In a few circumstances, the species arrived at UW nearly dead or in very poor health. A second limitation is the integrity of the units. Several of the units started to fall apart due to wake action. This meant that the species they held suffered as a result. Because of this it is difficult to determine whether some of the species underperformed due to the fact that their growth conditions or because of some other factors. A final limitation is the inconsistency of subjective data collection from collector to collector. This is most relevant in the percent cover data collection. One person may perceive a certain unit to have a specific percent cover value and another person might determine a wildly different value.

3.2 Water Quality

Introduction

The ship canal is bordered by a mixture of residential, commercial, and industrial development, including a small amount of undeveloped land. The shoreline contains very little natural vegetation and is dominated by docks, houseboats and bulkheads. Water bodies in WRIA 8, including Lake Union, receive stormwater from their contributing urbanized watersheds, as well as combined sewer overflows. Hence, regional urban development stormwater runoff containing toxins harmful to marine life is the largest source of contaminants in Puget Sound (source).

The Hiram M. Chittenden Locks in Salmon Bay at the west end of the canal regulate the water level of Lake Union and Lake Washington to about 6.7 m above the U.S. Army Corps of Engineers (USACE) datum for the locks from May through August and about 6.1 m the rest of the year (Lake Union/Ship Canal Water Quality Report, 2018). King County in 2017 highlighted three significant concerns for Lake Union and the Ship Canal:

1. Elevated water temperatures and low DO during the summer;
2. Elevated levels of polychlorinated biphenyls (PCBs) and phthalates in surface waters; and,
3. Widespread sediment contamination.

The metals identified as the most widespread contaminants were nickel, arsenic, mercury, silver, lead, copper, and chromium (King County, 2017).

Seattle Public Utilities and King County Wastewater Treatment Division are leading the Ship Canal Water Quality Project, which includes an underground storage tunnel expected to significantly reduce the amount of polluted stormwater and sewage that flows into the Lake Washington Ship Canal, Salmon Bay, and Lake Union from Seattle's combined sewer system.

Figure 3.2.1: The project locations of the Ship Canal Water Quality Project. (Image: Seattle Public Utilities and King County)

The floating wetlands were designed to enhance juvenile salmon habitat in the human-constructed ship canal between Lake Washington and Puget Sound. Water quality monitoring was specific to the deployment near the Fremont Bridge, near the shorelines along the north and south sides of the canal. Monitoring focused on parameters specific to juvenile salmon survival: water temperature, dissolved oxygen levels (DO), and salinity.

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, salinity)?
- Do the floating wetlands remove any of the following contaminants from the water: arsenic (As), barium (Ba), chromium (Cr), copper (Cu), manganese (Mn), molybdenum (Mo), nickel (Ni), lead (Pb), zinc (Zn), and carbon (C)?

Materials and methods

As in past years, measurements focused on water temperature, DO, salinity, and metals uptake. Two PME minDOTs were deployed in May for continuous monitoring for temperature and DO, and a YSI EXO2 sonde was used for spot monitoring during site visits several times each month in May, June, and July. The sonde was calibrated for DO and salinity on site the days it was used.

Both MiniDOTs were deployed approximately 0.5 m beneath the surface on the north side of the canal: one as a control at the east end of the fender wall and the other attached beneath a floating wetland located in the middle of the deployment. The MiniDOTs were programmed to record DO and water temperature at 10 minute intervals throughout the duration of floating wetland deployment, ending in late July. Unfortunately the miniDOT attached to the floating wetland was never retrieved; its disappearance a mystery.

Sonde readings were taken on both sides of the canal: a control and underneath a floating wetland on the south side and a control and underneath a floating wetland on the north on the following dates: May 1, 8, 22, June 6,19,30, and July 10, 15 and 21, in 2022.

To understand if stratification was developing in the ship canal, the sonde also was deployed to a depth of approximately 8 m along a north-south transect across the canal on May 1, 8, 22, June 6 and 19. The team also conducted a 30-minute east-west ~8 m deployment in the middle of the canal May 22 and June 6 from the east end of the fender wall to just west of the Fremont Bridge (Table 3.2.1).

Table 3.2.1: Data from the two east-west transects at approximately 8 m.

	Depth (m)	Duration (mm:ss)	DO	Temp	Salinity (PSU)
22-May	7.9	11:30	10.48	12.96	0.05
6-Jun	7.5	24:10	9.86	14.90	0.05

For the metals analysis, samples were extracted from the substrate [of which wetlands?] and sent to the UW Soil Analytics Lab for analysis.

Results

Water temperatures were favorable for juvenile salmon throughout the sampling period, barely reaching lethal levels in mid to late July (Table 3.2.2). At the deepest part of the ship canal the water temperature usually was 2 degrees Celsius cooler than at the surface. There was no statistically significant difference in water temperature between the control sites and just beneath the floating wetlands (Table 3.2.2).

Table 3.2.2: Water temperatures (degrees Celsius) for each sampling date in the middle of the ship canal (MC) at depths of 8- to 9 m; beneath a floating wetland along the south fenderwall (SFW); the control site along the south fenderwall (SC); beneath a floating wetland along the north fenderwall (NFW); and the control site along the north fenderwall (NC). N/A represents data not collected at that location.

	MC(8-9 m)	SFW	SC	NFW	NC
1-May	10.70	12.65	12.40	12.73	12.62
8-May	11.52	12.11	12.11	12.05	12.16
22-May	12.98	13.63	13.64	14.44	14.89
6-Jun	15.13	16.42	16.53	16.57	16.72
19-Jun	16.17	16.26	16.28	16.30	16.30
30-Jun	N/A	N/A	19.33	19.43	19.33
10-Jul	N/A	N/A	N/A	21.00	21.22
15-Jul	19.86	N/A	N/A	22.31	21.88
21-Jul	20.95	N/A	N/A	22.47	22.43

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

The ship canal water temperature rose gradually between May 1 and July 21, but did not approach the 22 degrees Celsius lethal level for juvenile salmon until July 15 and July 21. (Figure 3.2.2).

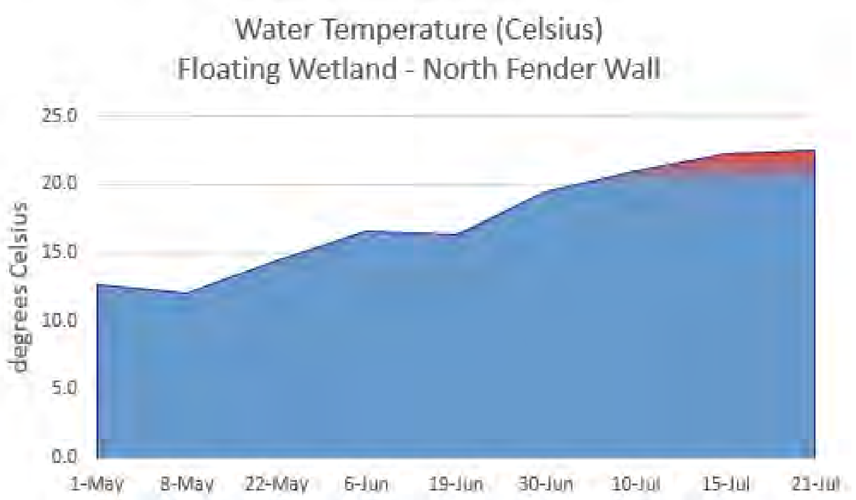


Figure 3.2.2: Water temperature measurements taken with the sonde beneath a floating wetland along the north fender wall. Red indicates lethal temperatures of 22 degrees Celsius and higher.

With successful retrieval of the miniDOT at the control location on the north fender wall, we were able to compare its data with the data spot-checked with the sonde (Figure 3.2.3).

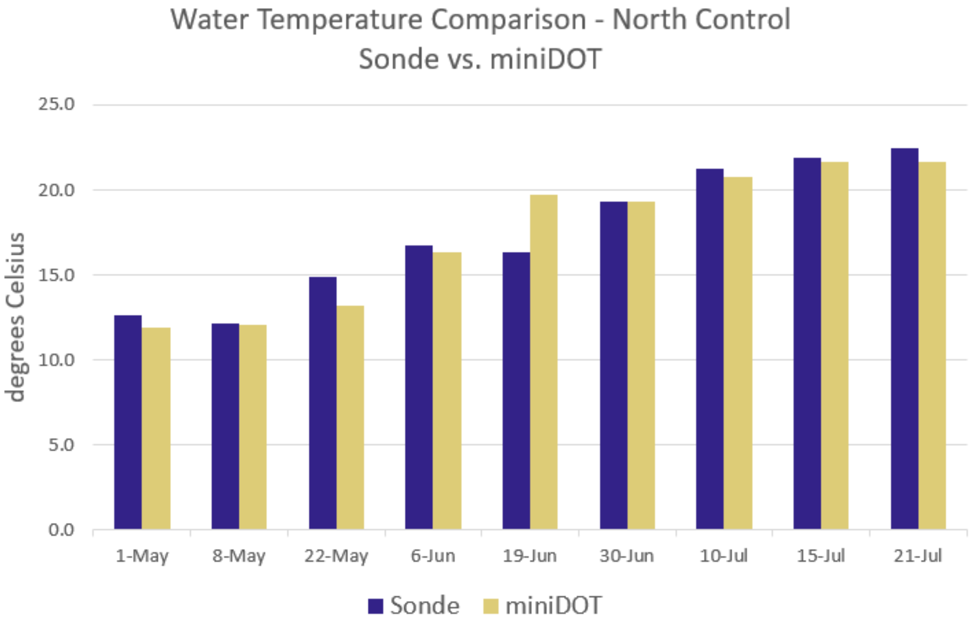


Figure 3.2.3: Water temperature (Celsius) comparisons between the sonde and miniDOT at the control location at the north fender wall.

The miniDOT collected data at 10-minute intervals, so six consecutive data points were averaged in the 30 minutes before and after the 2-minute spot check using the sonde. Differences were slight, with outlying larger differences perhaps resulting from high wake activity generated by frequent boat traffic.

Salinity

Salinity levels were consistently low and similar throughout the sampling period (Table x3.2.3). There was no difference between the floating wetlands or control sites. Also, unlike estuarine salinity profiles, there was no intrusion of salinity or salt wedges; salinity was consistent regardless of depth.

Table 3.2.3: Salinity levels (psu) for each sampling date in the middle of the ship canal (MC) at depths of 8- to 9 m; beneath a floating wetland along the south fenderwall (SFW); the control site along the south fenderwall (SC); beneath a floating wetland along the north fenderwall (NFW); and the control site along the north fenderwall (NC). N/A represents data not collected at that location.

	MC(8-9 m)	SFW	SC	NFW	NC
1-May	0.10	0.10	0.10	0.10	0.10
8-May	0.05	0.05	0.05	0.05	0.05
22-May	0.05	0.05	0.05	0.05	0.05
6-Jun	0.05	0.05	0.05	0.05	0.05
19-Jun	0.05	0.05	0.05	0.05	0.05
30-Jun	N/A	N/A	0.05	0.05	0.05
10-Jul	N/A	N/A	N/A	0.05	0.05
15-Jul	0.05	N/A	N/A	0.05	0.05
21-Jul	0.05	N/A	N/A	0.05	0.05

Dissolved Oxygen

The DO levels throughout the sampling period with the sonde at the Fremont location (May 1 to July 21) were ideal for juvenile salmon, ranging from 9.13 mg/L to 12.50 mg/L (Table 3.2.4).

Table 3.2.4: DO values for each sampling date in the middle of the ship canal (MC) at depths of 8- to 9 m; beneath a floating wetland along the south fenderwall (SFW); the control site along the south fenderwall (SC); beneath a floating wetland along the north fenderwall (NFW); and the control site along the north fenderwall (NC). N/A represents data not collected at that location.

	MC(8-9 m)	SFW	SC	NFW	NC
1-May	11.80	12.35	12.46	12.47	12.50
8-May	11.08	10.95	10.95	10.94	10.97
22-May	10.49	10.65	10.62	10.76	10.63
6-Jun	10.00	10.31	10.35	10.37	10.43
19-Jun	9.51	9.62	9.62	9.61	9.61
30-Jun	N/A	N/A	9.95	9.93	9.91
10-Jul	N/A	N/A	N/A	10.05	10.04
15-Jul	8.40	N/A	N/A	9.28	9.49
21-Jul	9.13	N/A	N/A	9.17	9.38

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).

The DO levels between the floating wetlands and the control sites were not statistically significant, varying slightly and in some instances identical (Table x). Similarly, DO levels did not differ significantly between the floating wetlands sampled along the north fender wall and the south fender wall (Figure 3.2.4).

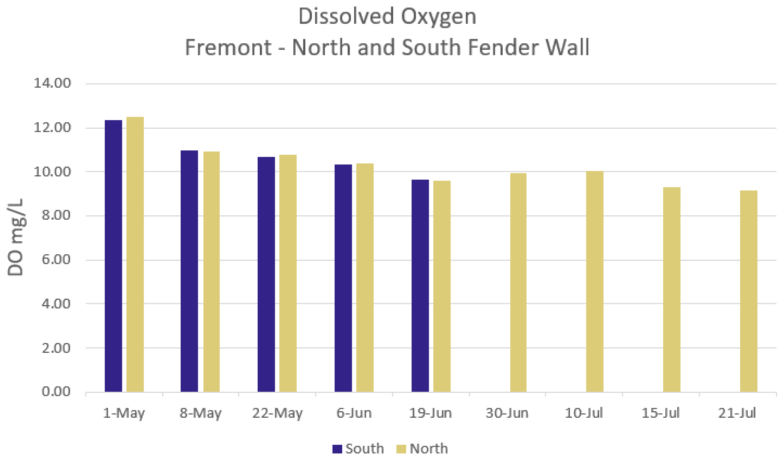


Figure 3.2.4: Dissolved oxygen levels taken with the sonde beneath a floating wetland along the south fender wall (blue) and one along the north fender wall (gold). June 19 was the last time data was gathered along the south fender wall.

Data also was collected at the deepest part of the ship canal, where DO levels were consistently favorable for juvenile salmon, in the event the fish selectively out migrate at depth (Figure 3.2.5).

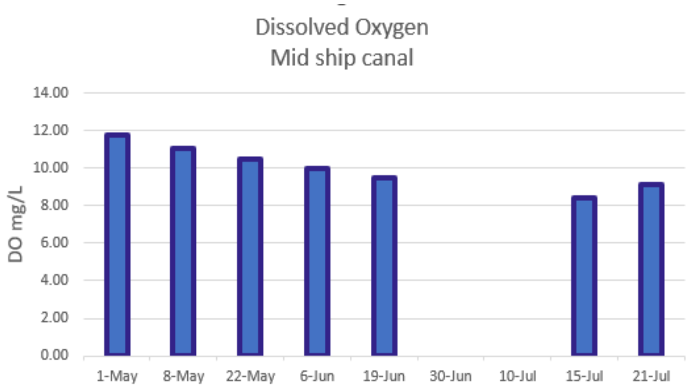


Figure 3.2.5: DO levels at 8- to 9 m in the middle of the ship canal. Data not collected June 30 or July 10.

With successful retrieval of the miniDOT at the control location on the north fender wall, we were able to compare its data with the data spot-checked with the sonde (Figure 3.2.6).

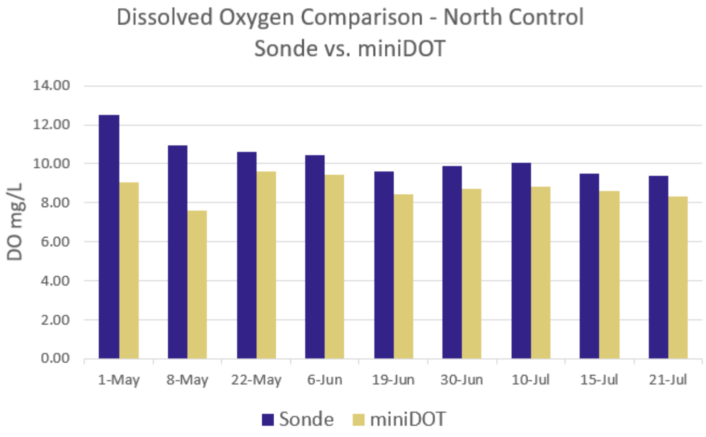


Figure 3.2.6: DO comparisons between the sonde and miniDOT at the control location at the north fender wall.

The miniDOT collected data at 10-minute intervals, so for comparison six consecutive data points were averaged in the 30 minutes before and after the 2-minute spot check made using the sonde. Given the large difference early in the deployment and a relatively consistent difference May 22 and later, it's likely the miniDOT's DO sensor is partly faulty, providing lower readings than the sonde, which was calibrated moments before deployment on each of the days researchers were in the field collecting data. If the miniDOT's calibration cannot be verified or its sensors replaced it may be time to retire the unit.

Heavy Metals, Nitrogen, Carbon

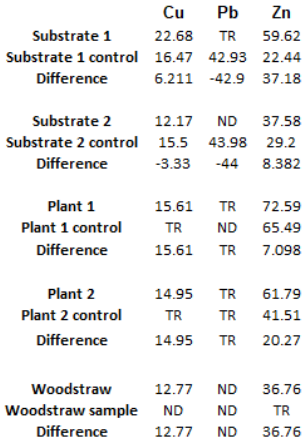
A total of 10 plant and substrate samples were tested for metal intake, carbon percentage (an indication of primary production), and nitrogen percentage, 5 of which were controls. Of the 5 samples extracted from the floating wetlands, one was woodstraw, two were substrate, and two were from plants. Both substrate samples were first deployed in the Fremont location (2021) and then relocated to South Lake Union for 2022 (the 4.0 design). Substrate 1 was 60 percent woodstraw, 20 percent oyster shells, 10 percent sand, and 10 percent biochar. Substrate 2 was 60 percent woodstraw, 15 percent pumice, 15 percent sand, and 10 percent biochar.

The two plant samples were different species: Plant 1 was *Schoenoplectus acutus* and Plant 2 was *Carex obnupta*. The woodstraw sample came from the Fremont location.

The metals test was performed for the following elements: aluminum (Al), arsenic (As), boron (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).

Among the metals, four are considered to be harmful to juvenile salmon: Cd, Cu, Pb, and Zn. No Cd was detected in any of the samples. Test results for the other harmful metals are in Table 3.2.5.

Table 3.2.5: Metal intake results of the 5 samples compared with their control samples (values in µg/g). "TR" refers to only traces of the metal were detected, and "ND" indicates no detection of the metal.



	Cu	Pb	Zn
Substrate 1	22.68	TR	59.62
Substrate 1 control	16.47	42.93	22.44
Difference	6.211	-42.9	37.18
Substrate 2	12.17	ND	37.58
Substrate 2 control	15.5	43.98	29.2
Difference	-3.33	-44	8.382
Plant 1	15.61	TR	72.59
Plant 1 control	TR	ND	65.49
Difference	15.61	TR	7.098
Plant 2	14.95	TR	61.79
Plant 2 control	TR	TR	41.51
Difference	14.95	TR	20.27
Woodstraw	12.77	ND	36.76
Woodstraw sample	ND	ND	TR
Difference	12.77	ND	36.76

The largest impact on metal uptake from both substrate and plants was in zinc, with update of Zn highest in plants, woodstraw, and the substrates. And the Plants and woodstraw were more effective than the substrates in taking up Cu. Both substrates appeared to lose Pb, though the control substrates may have actually acquired Pb during holding. None of the experimental samples took up significant levels of Pb.

For biomass, samples were taken from substrates and woodstraw and one plant for each species, air dried, and then dried in an oven for a couple days, 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. The samples were measured for carbon percentage and nitrogen percentage (Table 3.2.6).

Table 3.2.6: Carbon and nitrogen increase/decrease (µg/g) by material, compared to the controls.

	Carbon	**Nitrogen**
Substrate 1	44.9	0.49
Substrate 1 control	14.6	0.033
Difference	30.3	0.457
Substrate 2	47.7	0.41
Substrate 2 control	9.74	0.025
Difference	37.96	0.385
Plant 1	38.7	0.84
Plant 1 control	0.55	0.003
Difference	38.15	0.837
Plant 2	41.7	1.38
Plant 2 control	57.8	1.45
Difference	-16.1	-0.07
Woodstraw	45.6	0.53
Woodstraw control	45.3	0.153
Difference	0.3	0.377

Nitrogen uptake was strongest in Plant 1 and the two substrate samples, and carbon was highest in all but Plant 2 and woodstraw. The carbon uptake was particularly high in the substrates and Plant 1 relative to their controls, which suggests there is additional benefit of carbon sequestration.

Metals, Nutrients and Carbon

Each of the materials tested indicated a significant uptake of Zn compared to its control, especially Substrate 1 and woodstraw, and all but Substrate 2 showed modest uptakes of Cu (Figure 3.2.7). Curiously, none of the materials showed detectable or only trace levels of Pb uptake, and the two substrate controls had significantly more Pb levels (42.9 and 44 µg/g) than their counterparts deployed in the field.

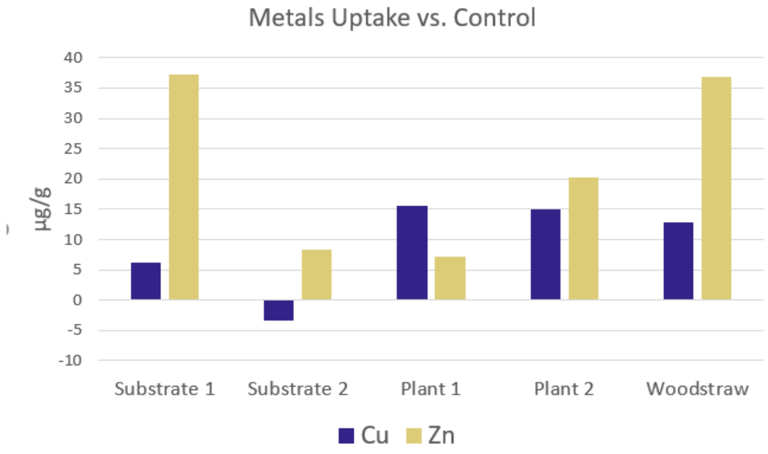


Figure 3.2.7: Metals uptake for Cu (purple) and Zn (gold) compared to their controls (µg/g).

Both substrates and Plant 1 showed significant levels of carbon uptake compared to their controls, but woodstraw alone barely had an impact, and Plant 2 had less carbon compared to its control (Figure 3.2.8).

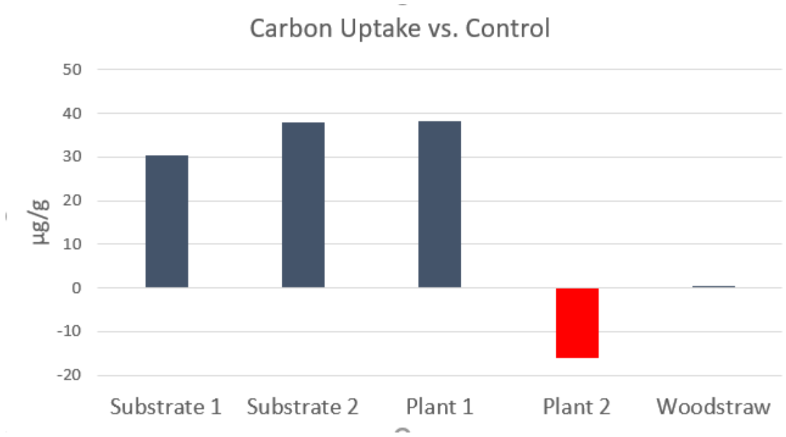


Figure 3.2.8: Carbon uptake for each sample compared to its control (µg/g).

It could be notable both substrates, which contained 10 percent biochar and 60 percent woodstraw each, took in significantly more carbon than the 100-percent woodstraw sample. Biochar is applied in various sectors in part as a carbon sink, but also can be used in water and soil remediation to remove pollutants, including the heavy metals considered harmful to juvenile salmon: Zn, Pb, and Cd (Osman et al, 2022).

Discussion

By mid June and through August, Lake Union is thermally stratified, with surface temperatures approximately 5 degrees Celsius warmer than the bottom (King County, 2018). From May through September, water temperatures in Lake Union and the Ship Canal track similarly, ranging from the low teens in May to peaking in the low 20s degrees Celsius in September. While floating wetlands could potentially cool water temperatures and could therefore aid in juvenile salmon survival, we saw no appreciable difference between adjacent control sites compared to beneath the experimental floating wetland units. However, with the amount of water flowing through the Ship Canal, it could be expected that there would not be enough residence time, or enough coverage to shade the water, to influence water temperature.

Dissolved oxygen in Lake Union's surface waters typically peaks at approximately 12 mg/L in the spring, and as thermal stratification takes hold in June DO decreases with depth. By late June or early July, the DO within the lower layer declines to below the method detection limit (0.5 mg/L) (King County, 2018). Even in late July we did not record DO levels below 8 mg/L at the deepest part of the ship canal by the Fremont Bridge. As there was no difference in DO levels between the floating wetland and control sites, it can be concluded that the experimental units had no adverse effect upon DO.

Puget Sound's salinity typically is 22 ppt and freshwater is 0 to 0.1 ppt (King County, 2018). The Chittenden Locks' usage frequency peaks in the summer months, leading to saltwater intrusion into Lake Union and the Ship Canal; however, the intrusion is minimal, measuring between 0.5 and 1.5 ppt (King County, 2018). Our data gathered in the ship canal at any depth did not reflect salinity levels higher than 0.05 psu (the equivalent to ppt), perhaps due to an unseasonably rainy June, resulting in higher than normal freshwater outflow through the ship canal deep into the summer.

Regarding the substrate and plant samples, all except Substrate 2 successfully removed Cu from the water, with the plants and woodstraw taking up 15 percent more compared to their controls. And Zn uptake was more impressive in all samples, with Substrate 1 and woodstraw taking up approximately 36 percent more compared to their controls. Also, the high carbon uptake of the substrates and Plant 1 suggest these have added value in carbon sequestration efforts to mitigate climate change.

3.3 Fish

Introduction

Research Questions for Fish Monitoring:

- Do juvenile salmonids use floating wetland structures more than the control or as much as at nearby reference sites?
- Do predatory fish species use the floating wetlands as shelter or hunting territory?

One of the main goals of the Sweetgrass Project was to assess the benefits our constructed floating wetland units could provide for out-migrating juvenile salmonids and other fish species in the Lake Washington Ship Canal. 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 GoPro video sampling to assess differences in juvenile salmonid and other fish presence and behavior at our floating wetland units and living shoreline units 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.

Materials and Methods

Go Pros

The team deployed 5 GoPro video cameras weekly under one floating wetland at each site for 1 hour intervals from May 27th 2021 to July 27th 2022. The experimental cameras were deployed on the end of a selfie stick, attached to a mount on the fender wall, extending approximately 1 foot below water pointing perpendicular to the unit and facing upstream.

The control cameras were deployed on the end of a selfie stick, attached to a mount secured on the fender wall, extending approximately 1 foot below water pointing upstream. During the hour of footage collection, a GoPro camera was suspended from a rowboat and pointed along the shoreline. The footage was reviewed at a later point in time for fish presence and behavior. In the second year of research, a GoPro was attached to a Sonde Water Sensor and lowered to the bottom of the channel in order to determine fish presence at an additional reference point. Cameras were also deployed to capture fish activity during four snorkel sampling events in 2021 and 2022.

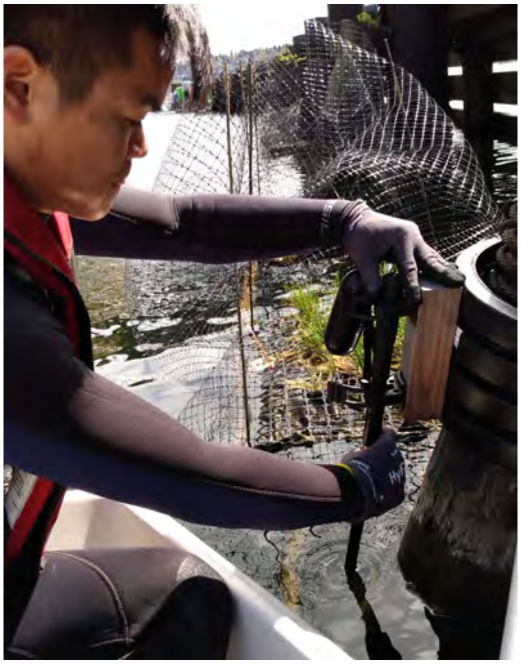


Figure 3.3.1: Adam Nguyen deploys a Go Pro camera connected to a selfie-stick beneath a floating wetland. (Photo: George Thomas Jr.)

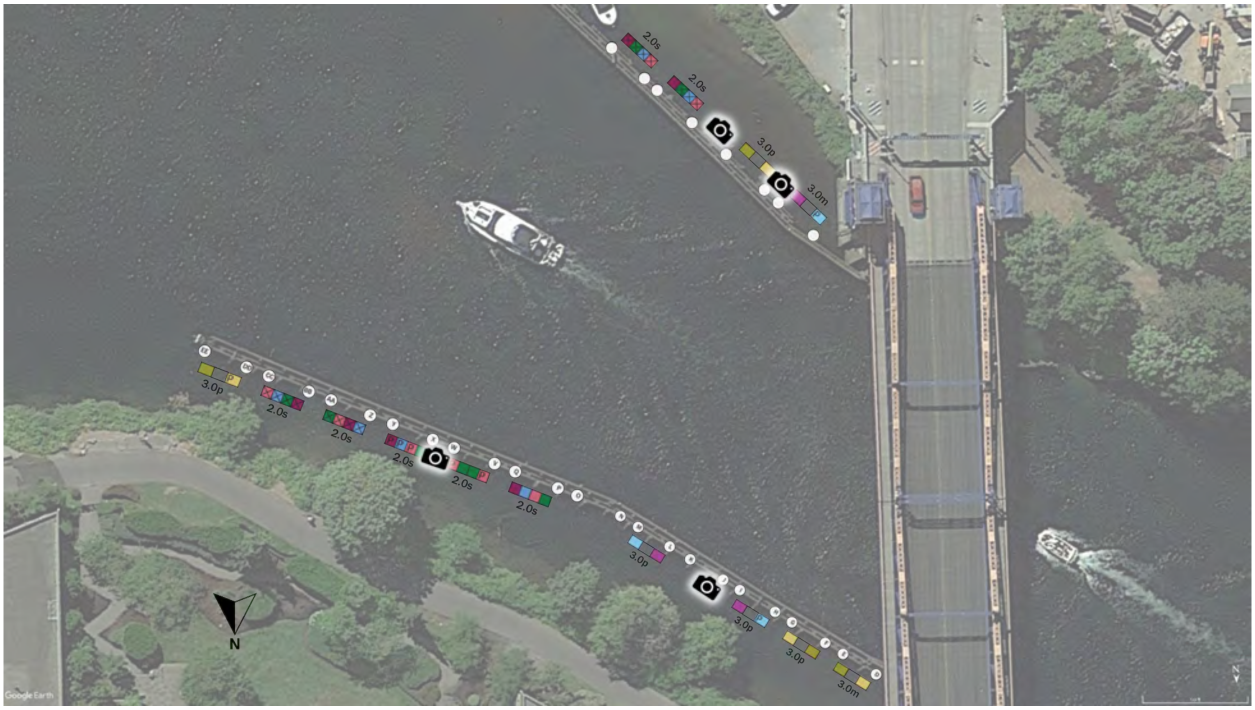


Figure 3.3.2: Shows the locations of the cameras deployed at Fremont. There were 4 cameras attached at the fender wall, 2 control and 2 at units. Another camera was attached to the Sonde and suspended to the bottom of the channel and also moved along the shorelines.

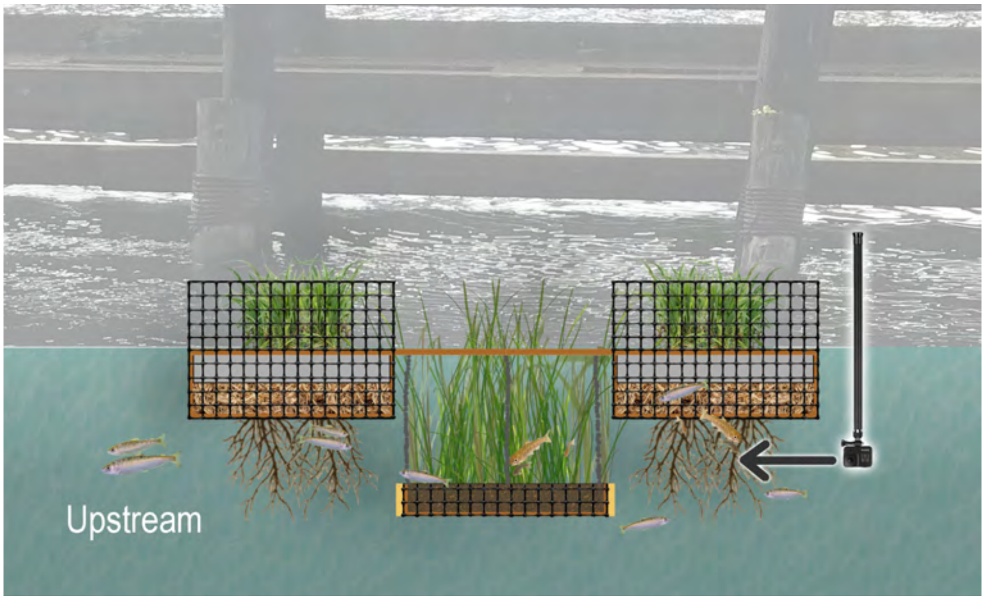


Figure 3.3.3: This figure demonstrates how the GoPros were installed for fish monitoring. The camera was attached on the fender wall and extended approximately 1 foot below the water, facing upstream and towards the unit.

Results

The GoPro footage fish monitoring yielded fish sightings at all control, unit, and reference sites. In 2022, the North Fremont units had the most sightings out of the other units and the controls. There were more fish sightings in 2022 at the North location compared to the south. In 2021, however, there were more fish sightings at the South Fremont units. A possible explanation for this is because the south units were moved to the north side on 6/24/22. If the south units had remained on the south side for the entire duration of the summer, it is possible that there would have been more, or at least a similar amount of sightings, as the North side. The overall most sightings were seen at the shoreline in 2022. Despite suggestions that there may be fish, especially salmon, in the center of the channel we did not observe any fish there.

Table 3.3.1: Summary of fish sightings by site and variable type in 2021 and 2022 at Fremont.

Site	Variable	Number of Fish seen in 2021	Number of Fish seen in 2022	Total
Fremont North	Control	2	12	14
Fremont North	Unit	25	60	85
Fremont South	Control	2	10	12
Fremont South	Unit	43	3	46
Shoreline	Reference	8	80	88
Center Channel	Reference	0	0	0

In both years of GoPro fish observation, we observed no salmonids. We identified Pumpkinseed fish, Largemouth Bass, Smallmouth Bass, Perch, and Sticklebacks. The majority of our observations consisted of Pumpkinseed fish, Largemouth Bass, and Sticklebacks. In 2021, the majority of fish sightings were recorded at the wetland units. In 2022, the majority of the sightings were still recorded at the North unit, however, the shoreline also had a significant number of sightings.

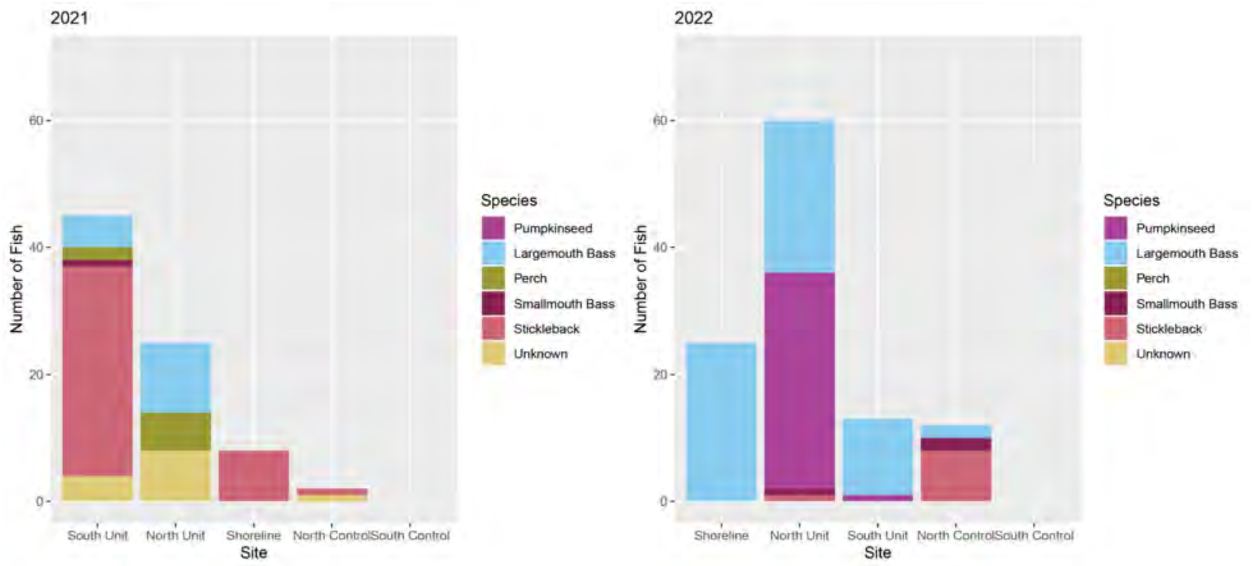


Figure 3.3.4: Total number of fish separated by species seen at each site in both study years at Fremont.

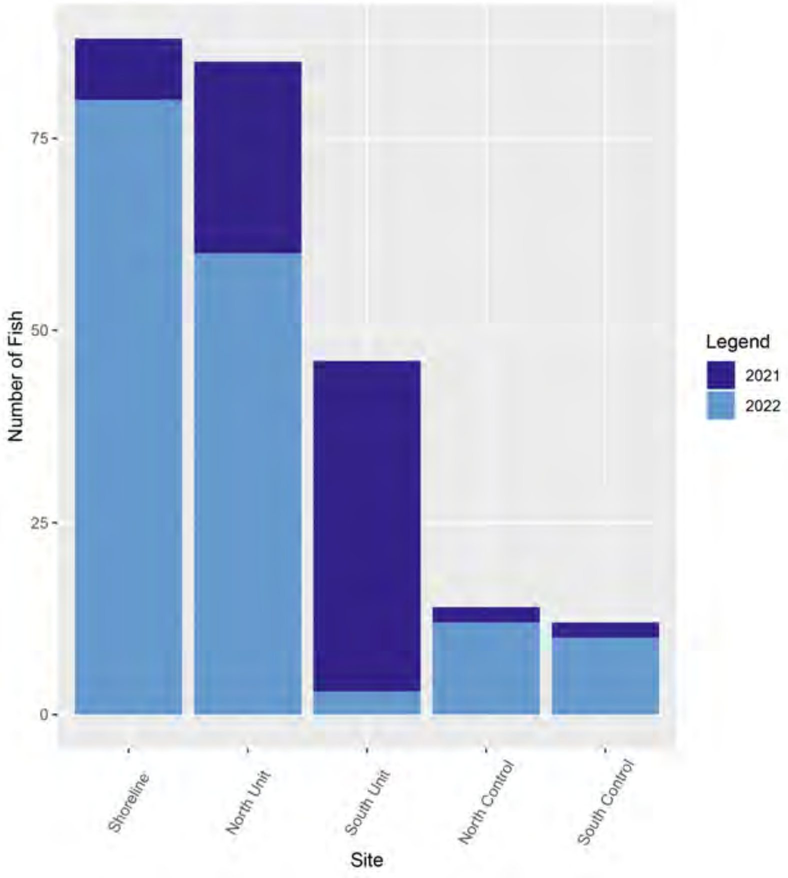


Figure 3.3.5: Total fish sightings by site and variable type at Fremont. The majority of fish sightings were recorded at the shoreline, the north unit, and the south unit.

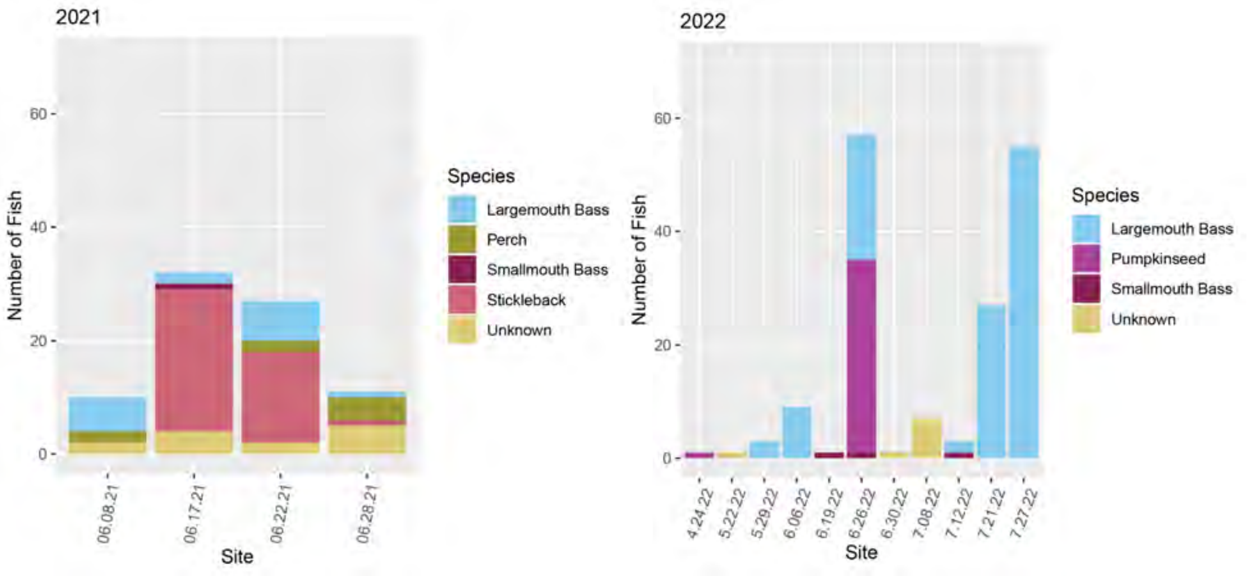


Figure 3.3.6: Figure summarizes the fish species seen over time. Each bar represents a different date in which fish data was collected.

There was some speculation throughout this study that the units would increase the opportunity for predator fish to prey on juvenile salmon. We observed perch and bass which are predator species of juvenile salmon. Figure 6 visually shows the use of the units separated by predator and non-predator fish.

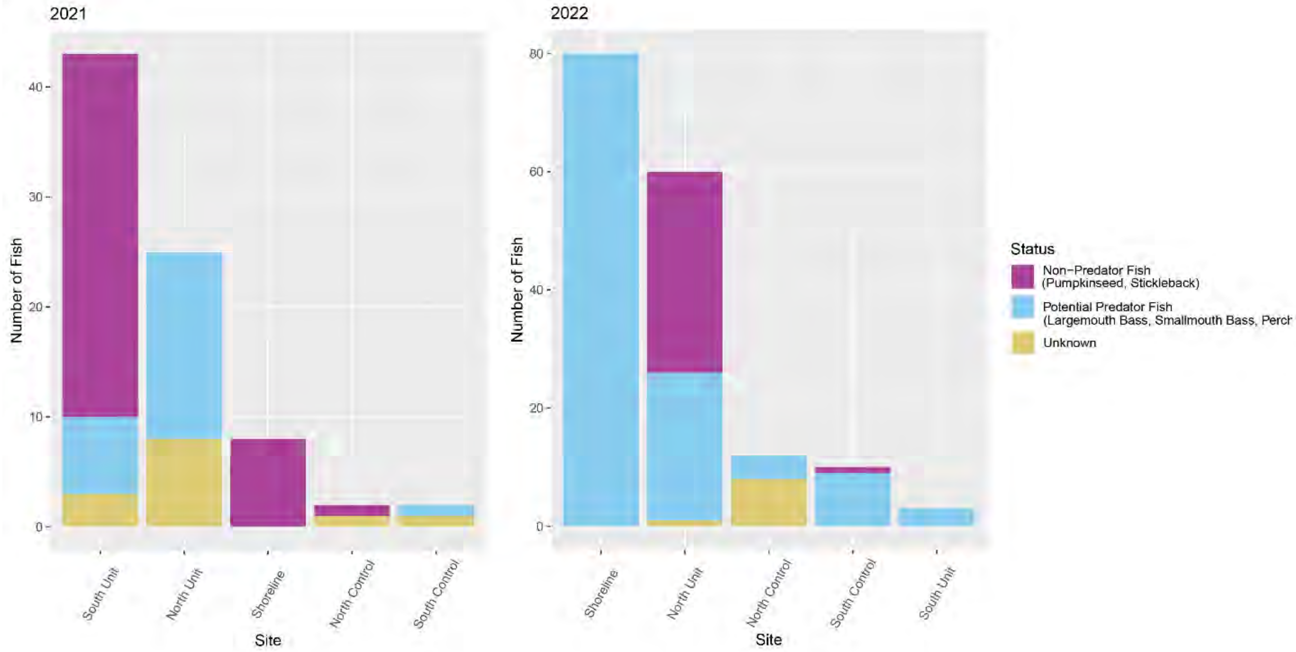


Figure 3.3.7: Figure summarizes possible predator (bass and perch) and non-predator fish observed at each site in both study years.

Table 3.3.2: Statistical tests on average number of fish sightings between Units, Control and Reference sites at Fremont (ANOVA level, significant if less than 0.05)

Fish	P-value
All fish species	3.85E-06
Possible Predator fish only	1.21E-15

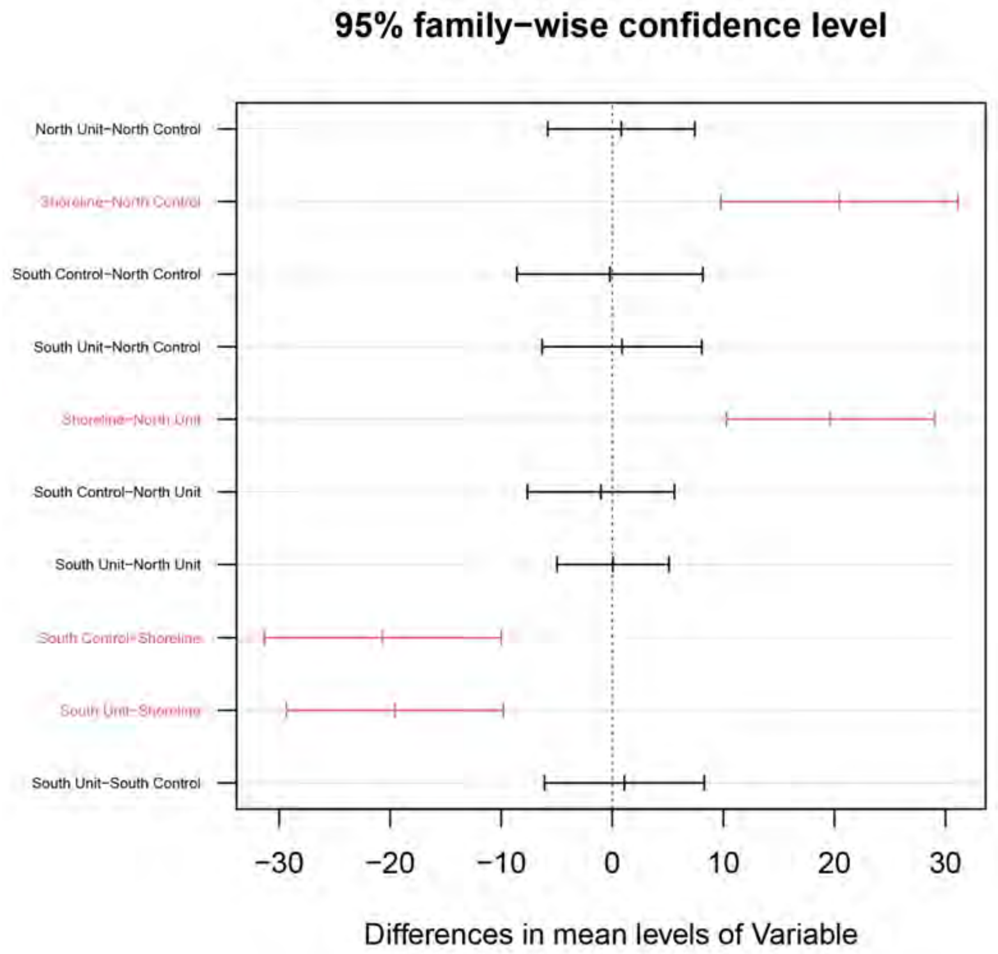


Figure 3.3.8: Statistical analysis of fish (all species) presence between units, controls, and reference site at Fremont.

Table 3.3.2 and Figure 3.3.8 summarize the statistical analysis conducted for fish sightings. After performing a one-way ANOVA for the percent of survival across the controls and units, the resulting p-value is 3.85×10^{-6}. This would suggest that there is a statistically significant difference between the means of the data. In order to visualize the difference, a Tukey plot was produced. The Tukey plot compares each individual means to the other means of the dataset. When compared to all controls and units, the shoreline was statistically different from nearly every other mean. This is consistent with the rest of the data. These results would suggest that there is no preference for fish to use the units over the control, but rather they prefer shore habitat over deeper water.

Discussion

After two years of extensive research to determine whether the units would be beneficial to juvenile salmon, we had zero confirmed sightings despite utilizing the same strategies that were successful in 2020 to record salmon at the Duwamish floating wetlands. This is especially concerning in light of the ever decreasing number of salmon we know spawn in the Lake Washington watershed. It is possible that the lack of salmon could be attributed to the specific location of the units. The area has high amounts of boat traffic as well as little shore habitat. We hypothesize that instead of lingering in the canal, juvenile salmon prefer to travel their way further downstream, and may be traveling at night.

4.0 Living Shorelines Design – South Lake Union

Design Objectives

At South Lake Union (SLU), designs focused on ways to extend the shoreline and non-traditional restoration methods for creating healthier shorelines and salmon habitat. Designs looked for ways to promote plant growth and create better substrate options. Additionally, designs needed to consider a reverse hydrologic pattern with higher water levels in the summer and 2’-3’ lower levels in the winter. We explored ways to promote healthy shorelines that could survive the water level changes and stay at the shoreline edge. Lastly, we tried to make the SLU prototypes biodegradable. One anecdotal comment offered with the Duwamish and while making the Fremont prototypes was how much plastic and unnatural materials we were using. A goal with this site was to be biodegradable and see how it might eventually become part of the shoreline. Out-migrating juvenile salmon are known to stick to the edges; our ultimate goal is to create healthier shoreline for the salmon.

2021 Designs and Lessons Learned

2021 Design – 5.0 Living Shoreline

The 5.0 prototype is connected to the shoreline at one end, while the other end floats and is movable with the water level, see figure 4.1. The unit is “pillow”-like and sewn together. The unit consists of a coir fabric to hold everything together. Stuffed inside of the fabric on one side was three pumice bricks for partial flotation along with woodstraw as a substrate. The unit was then sewn together and wrapped in an additional excelsior coir blanket. The extra blanket added another level of protection if the first coir fabric ripped. The excelsior coir blanket also had grommets sewn in on the end opposite the pumice. The grommets helped attach the units to the shoreline at one end and allowed them to float with the water on the other end.

These units tested five different species, two in each unit, considering the water levels that they are planted in. *Scirpus microcarpus* (smallfruit bulrush), *Juncus ensifolius* (three stamened rush), *Schoenoplectus pungens/americanus* (sweetgrass), and *Sagittaria latifolia* (Wapato/broadleaf arrowhead) were alternated on the upper halves of the units. These halves would get less water than the lower halves. *Carex stipata* (awl-fruited Sedge), *Schoenoplectus pungens/americanus* (sweetgrass), and *Juncus ensifolius* (three stamened rush) were alternated on the lower half of the units.

The units were installed in the same area of SLU. Around that area of the 5.0 prototypes, wood stakes were set up and tensar was attached to them to create a barrier from geese and ducks.

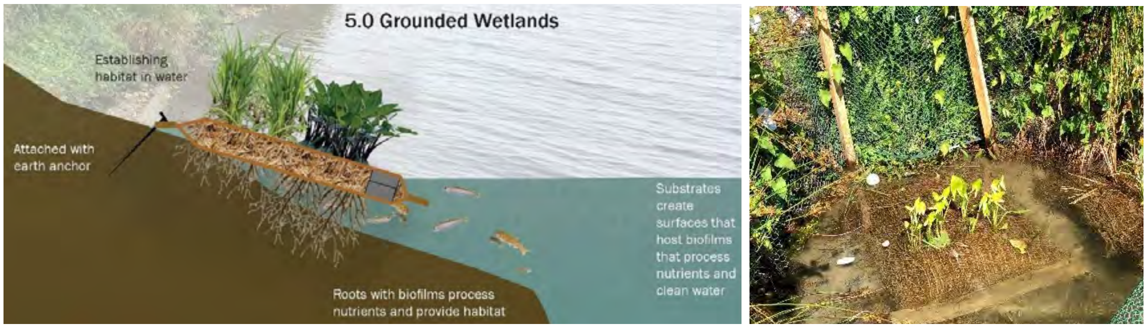


Figure 4.1: Pillow-like 5.0 wetland that moves with the water level

2021 Design – Living Shoreline 6.0

The other living shoreline prototype worked to add substrate to the existing shoreline. Three 20-foot coir logs were lined up to follow the shoreline. Coir logs, typically used for erosion control, were used for adding shoreline. They were staked into the shoreline with wood stakes to create a tight raised shoreline that is 20' x 3', see figure 4.2. One zone was placed to the south of the 5.0 prototypes and one zone was placed to the north.

The same five plants – *Scirpus microcarpus* (smallfruit bulrush), *Juncus ensifolius* (three stamened rush), *Schoenoplectus pungens/americanus* (sweetgrass), *Carex stipata* (awl-fruited Sedge), and *Sagittaria latifolia* (Wapato/broadleaf arrowhead) – were planted with the 6.0 structures. Two planting styles were tested in each zone. In one half of the zone, the plants were placed between the coir logs. In the other half, they were planted into the coir log. Tensar was added to wood stakes to keep geese and ducks off of these plants.

Figure 4.2: Modular 6.0 wetlands made from coir logs as a living shoreline extension

2021 Lessons Learned

The biggest concern with the living shorelines plantings at SLU is the geese browse. There are large groups of geese and ducks that live in that area of the lake. There was significant browse seen in the first year and the protection from geese needs additional work. A beaver that lives in the area went after the woodstraw that was in the pillow. In doing that, the pillow started to disintegrate as it was torn apart. Being biodegradable, the beaver was able to break through the outside coir blanket and get to the woodstraw quickly. The beaver didn't go after the coir and that worked well for planting. Lastly, when the 6.0 plants were planted between the coir logs, they quickly rooted or attached themselves to one of the logs. Therefore, planting them directly into the log would be easier and help them to become established more quickly. By planting in between the coir logs, the plant has to work harder to find a rooting source. There wasn't enough water at that shoreline elevation to allow the plants to grow hydroponically. Therefore, the coir provided a substrate and water source for the plants.

2022 Design Revisions and Results

2022 Design – 4.0 Units from Fremont

When the 4.0 units were too heavy and sinking at the Fremont bridge location, the submergent units were detached, replanted, and brought to SLU. In this water condition, they could sit at the bottom of Lake Union. 6” to 2.5’ of water remained above the units depending on the season. The plants were able to pop through the water and hold biofilms that would be beneficial for fish. The 4.0 units were clustered together, creating a new lake floor, and surrounded with deer netting to reduce geese and duck browse.

Full cut sheets for designs are found in Appendix E.

Figure 4.3: 4.0 Units growing at South Lake Union. Surrounded by new prototypes and Canada geese.

Design Discussion

For future living shorelines, visual optics are essential to tell the story of how living shorelines are supporting out-migrating juvenile salmon. These attempts were keen to use biodegradable materials and shoreline elements that are not harmful to the environment, but they attracted a lot of other animals and didn’t hold together as we had hoped. Further research in biodegradable materials would be beneficial to expand the material options that we had. Additionally, stronger netting is needed to protect the plants from geese predation. The browse seen on these plants was significant and caused extensive replanting. Lastly, it would be interesting to see these living shorelines extended further into the water to create a larger patch of living shoreline and be more beneficial to salmon as well as stronger plant survival.

5.0 Living Shoreline Research and Monitoring - South Lake Union

5.1 Plants

Introduction

Research Questions for Plant Monitoring:

- Do our substrates support viable growth and survival of wetland plants in South Lake Union?
- Which species of plants perform better on living shoreline units, if performance is defined at each field site as plant growth (established height and percent cover), successful phenological cycle, and mortality rate?

Plant Scheme

1. SCIMIC-*Scirpus microcarpus*
2. CXSTIP-*Carex stipata*
3. JUNENS-*Juncus ensifolius*
4. SCHPUN-*Schoenoplectus pungens*
5. SAGLAT-*Sagittaria latifolia*

Materials and Methods

Plant Height

Throughout the data collection period, the height of the tallest plant in each unit was measured to the nearest cm. Measurements were taken every two weeks in the spring and every week in the summer when plant growth was occurring more rapidly. Plant height monitoring 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.

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.

Blooms

Floral inflorescences were counted per plant as another indicator of plant health. It is difficult to perform analysis with this data because there is little literature discussing the average number of inflorescences for the species we tested. Additionally, not all plants typically produce an inflorescence.

Naturalist Notes

Additionally, any field observations that fell outside the other metrics being collected were recorded in a naturalist notebook.

Results

Mortality/Survival

Mortality, height, percent cover, and number of blooms were recorded for each species at South Lake Union in 2021 and 2022. In 2021, all species had mild survival success with the exception of Schoenoplectus acutus. However, in 2022, *Schoenoplectus acutus* was much more successful with a survival rate of 93%. *Sagittaria latifolia* (43%-58%) and *Carex stipata* (27%-33%) did similarly well in both seasons. *Scirpus microcarpus* did not do well in 2022.

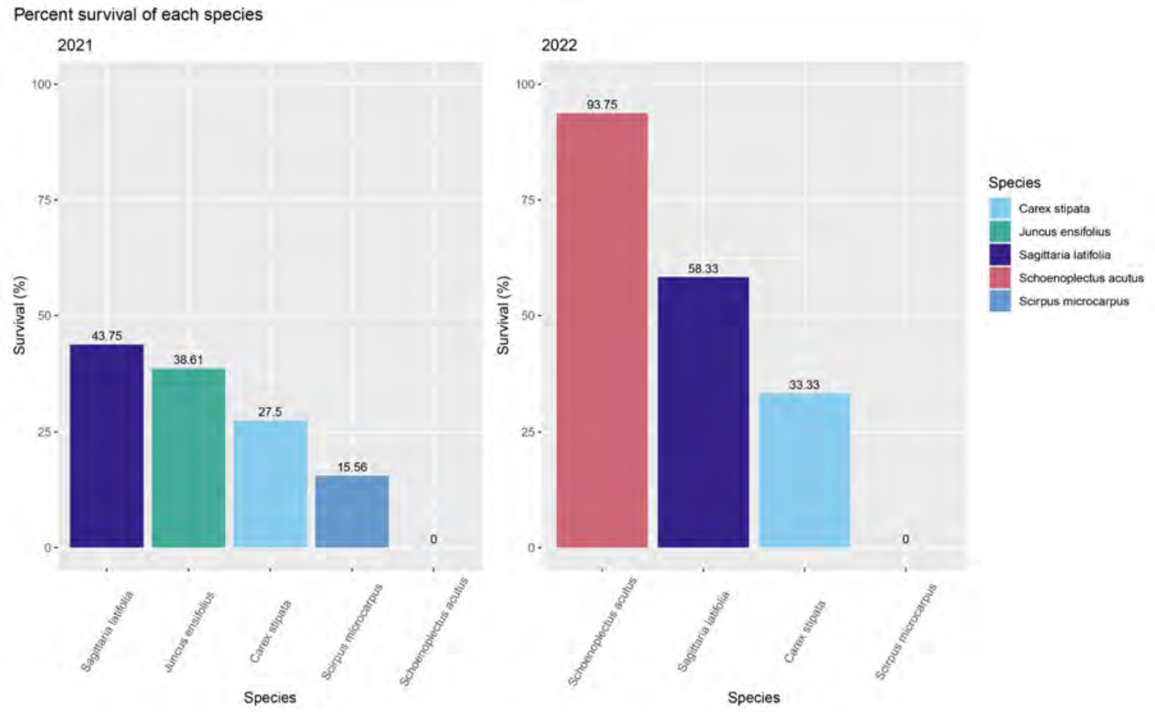


Figure 5.1.1: Figure summarizes the mean percentage of individuals that survived at the end of the data collection for each species at South Lake Union. Populations were separated by the 2021 and 2022 sample periods.

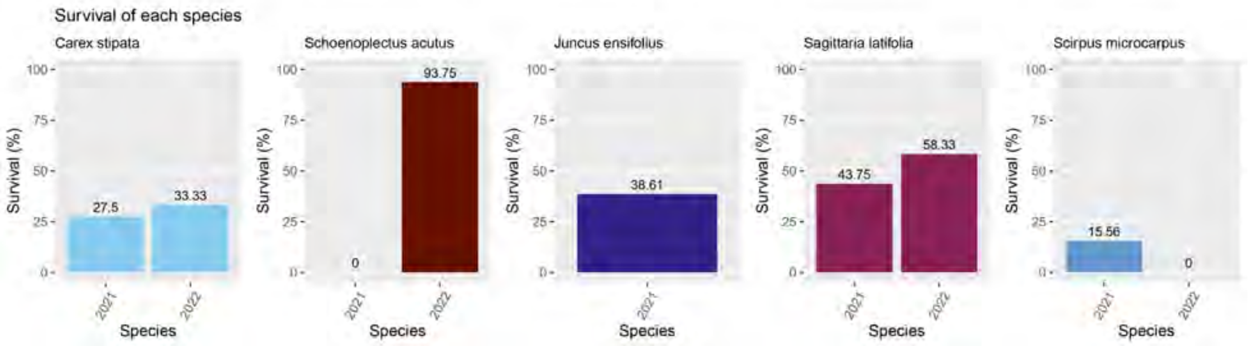


Figure 5.1.2: Figure summarizes the mean of the percentage of survival of each species at South Lake Union.

Height

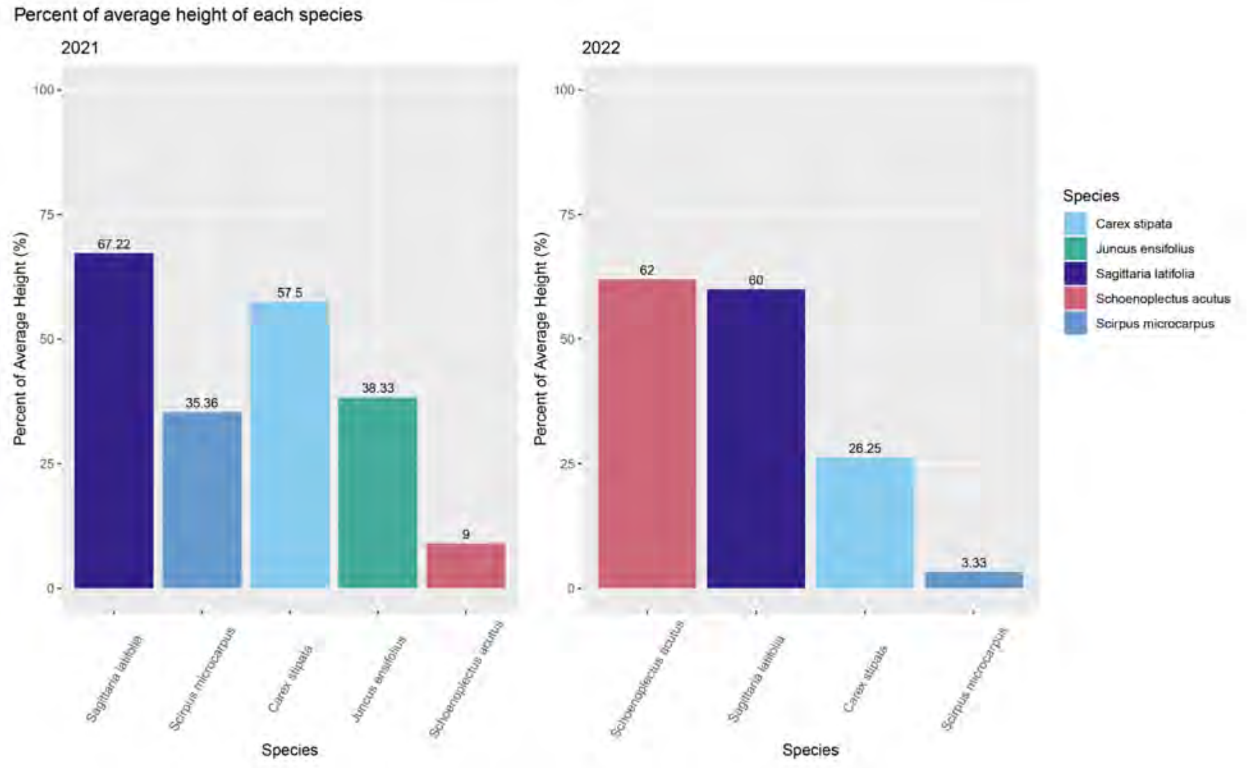


Figure 5.1.3: Figure summarizes the mean of the percentage of height compared to the national average of each species at the end of the data collection at South Lake Union. Populations were separated by the 2021 and 2022 sample periods.

Table 5.1.1: Plant height comparisons to published average heights at South Lake Union.

Collection Period	Species	MaxHeight	AverageHeight	HeightPercent
2021	Carex stipata	37.0	60.0	61.7
2022	Carex stipata	15.8	60.0	26.3
2021	Juncus ensifolius	23.0	60.0	38.3
2021	Sagittaria latifolia	24.4	30.0	81.3
2022	Sagittaria latifolia	18.0	30.0	60.0
2021	Schoenoplectus pungens	9.0	100.0	9.0
2022	Schoenoplectus pungens	62.0	100.0	62.0
2021	Scirpus microcarpus	23.4	40.0	58.6
2022	Scirpus microcarpus	1.3	40.0	3.3

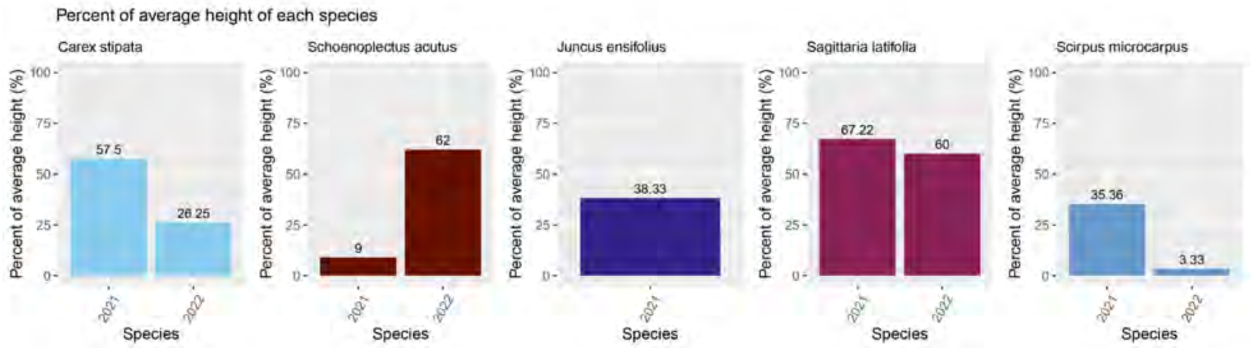


Figure 5.1.4: Figure summarizes the mean of the percentage of height compared to the national average of each species at South Lake Union.

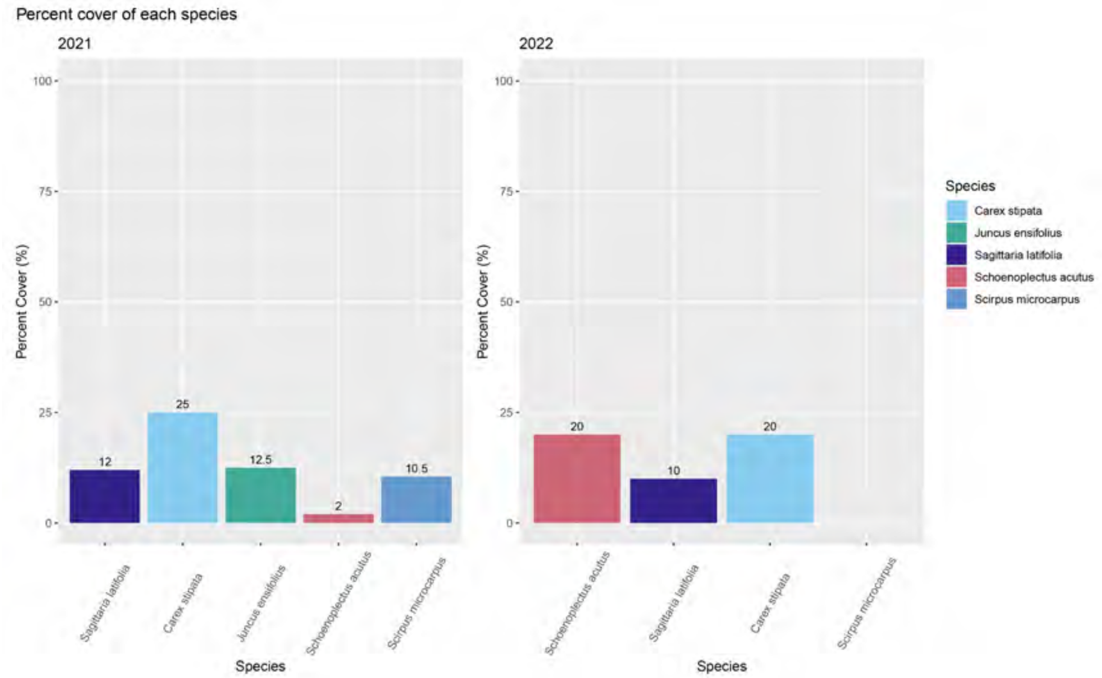


Figure 5.1.5: This figure summarizes the mean of the percent cover of each population at the end of the data collection at South Lake Union. Populations were separated by the 2021 and 2022 sample periods.

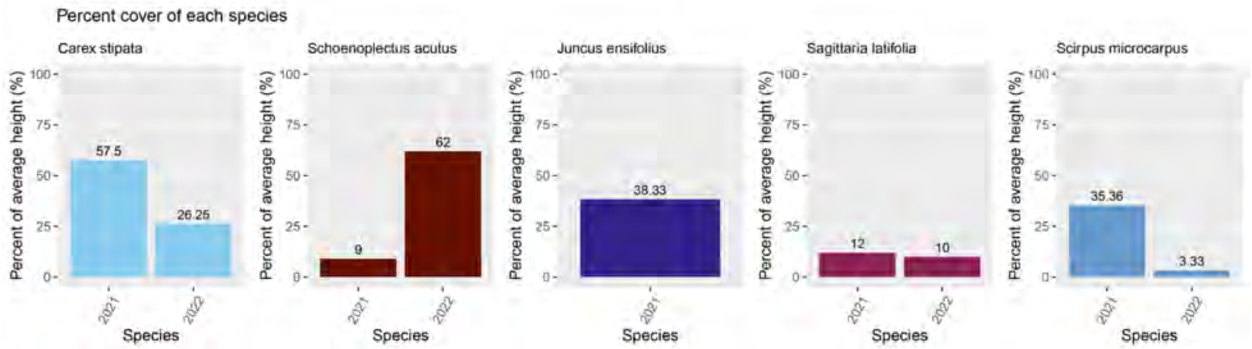


Figure 5.1.6: Figure summarizes the mean of the percent cover of each species at South Lake Union.

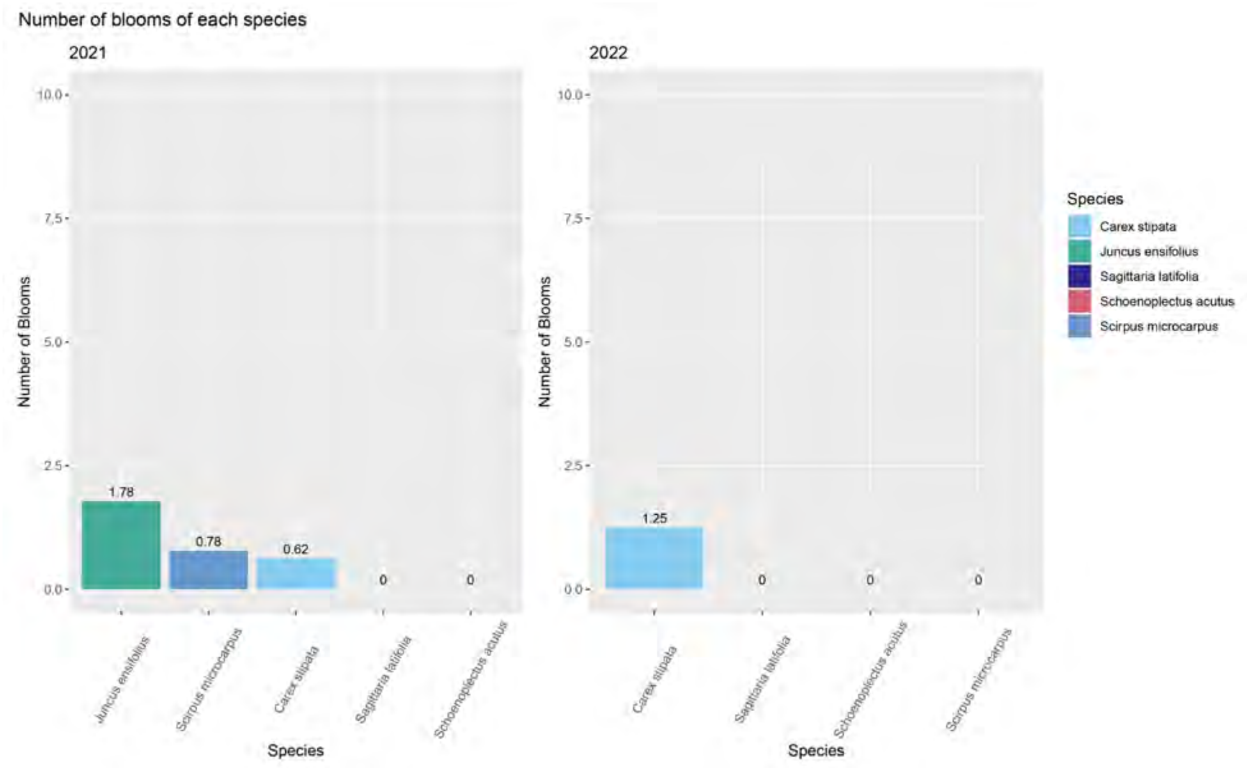


Figure 5.1.7: Figure summarizes the mean of the number of blooms at peak bloom production for each species at South Lake Union. Due to the fact that several species had started to decline in bloom production by the end of the collection period, the day with the most blooms was used for analysis rather than the last day of data collection.

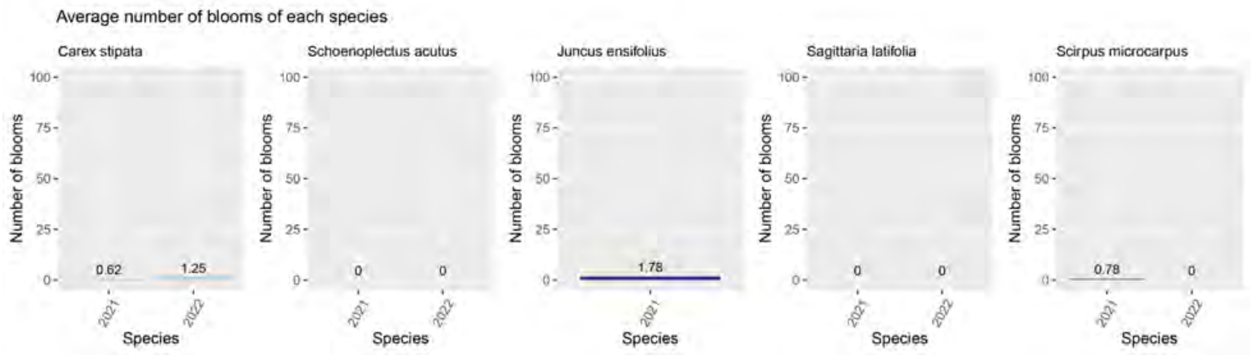


Figure 5.1.8: Figure summarizes the mean of the number of blooms of each species at South Lake Union.

Discussion

In summary, the species tested at South Lake Union all seemed to prove moderately successful. Though it took *Schoenoplectus acutus* one year to establish itself, it was well-suited for the South Lake Union conditions after a year.

5.2 Fish

Introduction & Materials and Methods

GoPro cameras were used to observe fish activity during two sampling events, one of which was a snorkel sampling event in July of 2022. Cameras were deployed once a week. An experimental camera was secured to the tensar netting around the unit on the west side and pointed in towards the plantings. A control camera was secured approximately 20 yards on the shoreline.

Results

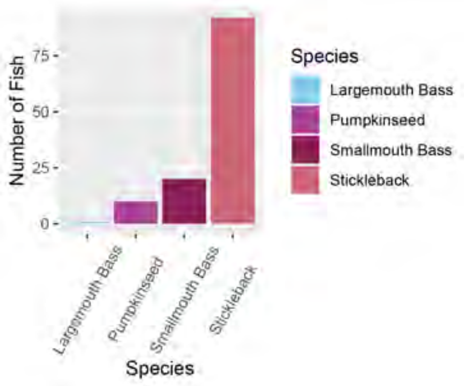


Figure 5.2.1: Figure summarizes the number of fish by species seen at the South Lake Union units.

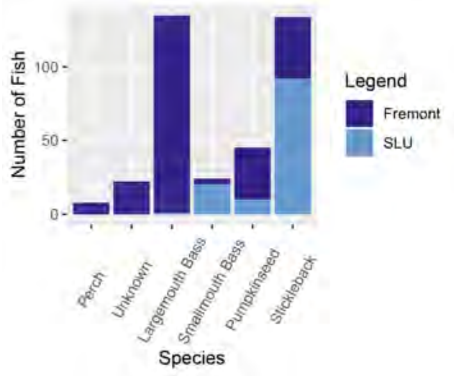


Figure 5.2.2: Figure compares the number of fish by species seen at the South Lake Union and Fremont.

While there were a variety of species observed at SLU, there were no confirmed sightings of juvenile salmon. The other observed species were Large-mouthed bass, Pumpkinseed, and Perch. These results reflect the fish results observed at Fremont.

Discussion

Similar to the Fremont floating wetland units, we had zero confirmed sightings of juvenile salmon. We thought maybe since we saw so few salmon at Fremont, that there would be a higher chance we would see them at SLU. It is possible that by the time we started collecting fish data it was too late in the summer and the fish had already passed through the area.

6.0 Community Engagement, Science Program, Education, and Outreach

Approach to Recruiting People

The Sweetgrass Shoreline Restoration Project occurred during the COVID Pandemic. Commitment from outside groups and individuals became an issue with safety and general reluctance in participating with the project. Recruiting for community scientists generally consisted of outreach that was done with outside Indigenous communities and organizations through email correspondence and flyers.

Figure 6.1: UW students assisting Jenn Engelke in constructing prototypes for the floating wetlands.

The project looked to include as many participants as it could. Many community members were involved throughout the entirety of the project. Students for the University of Washington helped take notes during the USWG meetings as well as provided needed labor to help produce prototypes for the project to be used for the project, so at a time where there were not many internship opportunities due to the COVID Pandemic they were able to gain valuable work experience. The Puget Sound Keeper Alliance helped with trash that accumulated around the study areas.

Community Scientists

As part of the weekly research monitoring and data collection, community scientists came out to the field each week with research team members. Each community scientist was paid to be in the field with us or earned class credit. Community scientists came with backgrounds in conservation, fisheries, and the environment and were able to contribute their own knowledge and expertise to the project as well as learned the research methods that we were using. Community scientists became essential team members with their contributions as well as for research safety. We required teams of at least two people to go out to the water so there was always a second person there if something were to happen. Community scientists were given Personal Flotation Devices as well as any other research equipment needed for that day.

The names of our community scientists were: Sloane Palmer, George Thomas Jr., Adam Nguyen, Kerry Acola and Nic Bartish.

Figure 6.2: Edwin repairing floating wetlands at the Fremont location

Steward

The past community steward was used from the Duwamish Floating Wetlands Project to help with construction and monitoring and repair of the floating wetlands. Edwin

Hernandez Rito oversaw monitoring both sites during the first year of deployment in regards to maintenance and/or repair. (Figure 6.2.)

Indigenous Recruit

The Sweetgrass team was able to get an Indigenous Steward named Joseph Aleck who helped to build and deploy the floating wetlands at both the Fremont and South Lake Union Sites. The picture below is Joseph assisting with the assembly of the constructed floating wetlands.

Figure 6.3: Joseph working with EarthCorps team members

Other Indigenous Youth Engagement

The Sweetgrass Team was able to take out a group of Latinx Youth from South Park to learn and view the constructed floating wetlands by boat. The youth were brought to the University of Washington where we talked about Natural Systems and the importance of new innovative interventions to help protect the current fragile ecosystem. Supplies were provided to allow the youth to participate in journaling and drawing of the Union Bay Natural Area. Later they were taken to where construction of the floating wetlands took place where they got to participate in the building of a unit. Food was provided during the day. Overall it was a great experience for the Latinx Youth and the Sweetgrass Team. Below is the Latinx Youth learning about the floating wetlands.

Figure 6.4: Youth seeing the construction zone

Hiring of a Steward, recruitment of Indigenous participants, and educational events for Indigenous and LatinX youth was made possible through a grant from the Puget Soundkeeper Alliance and the Rose Foundation for Communities and the Environment Foundation.

Sweetgrass Arts

Sweetgrass Arts was a successful attempt to look for creative ways to help tell the story of outmigrating juvenile salmon and reveal the possibilities for positive interventions in the urban environment through art in the landscape. We invited artists to submit designs that could be used at our Fremont location. The designs that the community artists were asked to produce consisted of banner art and writings that reflected the importance of salmon. Indigenous artists were commissioned to produce the art and poetry to be put on display to help bring attention to the project. Five artists were selected to produce banners, poetry, and stencil art to be used at the celebration of the project.

During the celebration the community was invited to participate in stencil painting on the Burke-Gilman Trail, and to talk with other community advocacy groups involved in similar urban environment preservation work. Food was provided along with live music from Rainy Dawg Radio affiliated with the University of Washington.

The Sweetgrass Arts project was supported through a grant from Seattle's Neighborhood Matching Fund.

Figure 6.5 The local community painting salmon with stencils on the Burke-Gilman Trail

Where the Floating Wetlands Went When the Research was Completed- They Live On!

The constructed floating wetlands that were used at the Fremont location were donated to the Port of Seattle and to United Indians of All Tribes Foundation. The units donated to the United Indians of All Tribes Foundation are located at the lower pond at Daybreak Star in Discovery Park where they will continue to grow culturally relevant plants that the youth and community will be able to harvest and learn about their cultural importance.

Recommendations for Future Programming

The COVID Pandemic did play a large role in community participation with the project. The University of Washington had strict guidelines on how many people participate at a given time. Also when groups did show interest in participating with the project, there was reluctance regarding safety. During the Pandemic Indigenous groups were beyond capacity and many events and youth engagement fell through. For future programming, starting as early as possible for community involvement would be ideal. Being able to provide transportation for youth was a large topic of discussion since many would need to be picked up and dropped off at different locations.

7.0 Conclusion

In this Sweetgrass Living Shorelines study, we designed, built, implemented, and monitored five different versions of floating wetlands and living shorelines in freshwater conditions. These prototypes contributed to adding salmon habitat back into the Lake Washington Ship Canal in hopes that it would benefit outmigrating juvenile salmon. This research monitored the prototype design, plant health, water quality benefits, and fish use to better understand the impact they have in the ecosystem. The research also engaged community in meaningful ways throughout the project.

The project demonstrated that floating wetlands can be designed and implemented in freshwater locations. The designs were tested and revised to continue to improve the results and design integrity. During the design process, we learned that units need to be securely held together to maintain the substrate, boat wake protection should be incorporated into the design, and consideration for anchoring units is critical for unit survival. By using a stronger geotextile around the units and securing the flotation to the units, less substrate was pushed out of the units from boat wakes. For the 5.0 units, more research needs to be done on biodegradable substrate options that would not get destroyed by geese, ducks, or beavers. The visual optics of the 5.0 and 6.0 units were positive with being biodegradable, but the 5.0 units did not stay intact due to predation by geese, ducks, and beavers. Furthermore, better durability should be incorporated into the 3.0, 4.0, and 4.1 designs, and/or given additional wake protection, when they are located in areas susceptible to wave action. The units were behind a fender wall, but still took considerable hits from the boat wakes in an active transportation channel. Locations due to boat wakes were also an issue in the Duwamish. Because these CFWs are meant to be in areas where traditional restoration is not feasible (i.e. navigable channels), designing boat wake protection into them is an important consideration. Lastly, when anchoring the units to the fender wall, they were more restricted when boat wakes came. By using a dropped anchor, units could maintain flexibility without hitting the fender wall during boat wakes. Locating on the leeward side of boat docks, rather than along boat transport lanes, could potentially provide such protection.

The prototypes showed positive results in plant health and water quality. The plant health showed healthiest results for *Sidalcea hendersonii, Carex obnupta,* and *Deschampsia cespitosa* at Fremont. Having healthy initial plugs and planting them right away is critical to plant health. The plant longevity and/or consistency of the plants that did not perform as well (*Scirpus cyperinus* and *Sisyrinchium idahoense*) is likely due to not being planted soon enough after arriving from the nursery. A colder winter and spring did not help the plants last or take as anticipated. For water quality, the cold spring and early summer season were beneficial to having cooler water temperatures and higher DO levels in year 2. The second year did not produce DO levels that were of concern while the temperature peaked in mid to late July. While the floating wetland prototypes had no significant impact on local water quality, the conditions were not lethal to outmigrating juvenile salmon. Additionally, the substrate and plants showed an intake of copper and zinc, both of which are harmful to salmon. There were increases in carbon and nitrogen in most of the substrate and plant analyses. This shows that the units are collecting contaminants present in the water and helping to create cleaner ecosystems. From these results, we have learned lessons about which plants to use in the future and how they could benefit the water quality in the area.

The prototypes were intended to improve outmigrating juvenile salmon habitat. Therefore, there is concern that we did not see salmon. We attempted to locate salmon at different locations in the Lake Washington Ship Canal, including at the units, the shoreline, and the base of the river, but were not successful. We have since learned of a new program through the Muckleshoot hatchery that is catching fish in Lake Washington or at the hatchery and transferring them directly through the locks. Therefore, the number of salmon is significantly reduced. It is still concerning that native salmonids were not found and the number of fish in the area was limited.

Lastly, this project demonstrated innovative transdisciplinary strategies for engaging the community and public. Our team included landscape architects, wetland biologists, environmentalists, fisheries biologists, and planners across the public and private sector. Through the USWG, we were able to bring together collaborators that are interested in how this could impact their own work in the future. Additionally, the community engagement targeted historically marginalized communities. Such individuals were critical parts of the team from the prototyping, building, implementing, and monitoring phases. Furthermore, all community participants were compensated for their work. Community became instrumental in the removal of the units with some prototypes continuing on at Daybreak Star and others being taken to the Port of Seattle.

This work has already been disseminated to the USWG (internal), Long Live the Kings, a round table at the Green Infrastructure Summit, and at an Association of Pacific Rim Universities webinar. We strive to continue publishing this work and hope to build upon it to further improve habitat for outmigrating juvenile salmon.

8.0 Acknowledgements

The authors of this report acknowledge that the project site runs through the ancestral lands of the Duwamish Indian Tribe and honor the Coast Salish peoples of this land, the land which touches the shared waters of all tribes and bands within the Duwamish, Puyallup, Suquamish, Tulalip and Muckleshoot nations. We understand that we are settler scientists and guests working in and profiting off our study in Coast Salish lands and that we have ongoing obligations to the Tribes.

We thank the King County Waterworks Grants, and Puget Soundkeeper Alliance and the Rose Foundation for Communities and the Environment Foundation Puget Sound Stewardship Fund, for funding our research and community work. King County Waterworks grants and programs, through the KC Waterworks staff and through Councilmember Jeanne Kohl-Welles provided the impetus and funds for USWG outreach, design and research related to the Sweetgrass Shoreline Restoration Project. The Puget Soundkeeper Alliance and the Rose Foundation for Communities and the Environment Foundation enabled our community engagement and partnership with Earthcorps; without the support of their leadership and crews the project would not have been possible. The Port of Seattle and Herrera Environmental furnished invaluable services which provided match for our grant funding, for which we are ever grateful.

We thank UW Soil Analytics Lab & Service Center, UW Departments of Landscape Architecture and Civil & Environmental Engineering, Schools of Aquatic & Fisheries Sciences, Marine & Environmental Affairs, and Environmental & Forest Science for equipment and research and analysis support.

We thank our community liaison, Edwin Alberto Hernandez Reto for connecting us with youth from the community and for his invaluable support in the field. Our gratitude goes to Nelson Salisbury's expert leadership at Earthcorps and the dedication of his crew for their important roles in constructing, deploying and decommissioning our floating wetland units. Furthermore, we would like to thank our community scientists, fabrication and research participants including: Joseph Aleck, Sloane Palmer, George Thomas Jr., Adam Nguyen, Justin Roberts, Kerry Accola and Nic Bartish. We are indebted to the members of the Urban Shores Working Group, who gave of their time to help us envision where and how this research could take place, and provided sage advice throughout the project. Our Green Futures Lab Team Emma Petersen, Daquan Proctor and Cami Freeman, and several dedicated Landscape Architecture students were instrumental throughout our Sweetgrass project processes.

SWEETGRASS TEAM

UW Green Futures Lab
Nancy Rottle, Principal Investigator, Director
Tim Lehman, Project and Outreach Coordinator
Jenn Engelke, Design and Research Lead
Meaghan O'Connor Lenth, Plants and Fish Monitoring
George Thomas Jr., Water Quality Monitoring

Bioemergent Solutions
Mason Bowles, Design and Technical Advisor

9.0 References

Osman, A.I., Fawzy, S., Farghali, M. et al. Biochar for agronomy, animal farming, anaerobic digestion, composting, water treatment, soil remediation, construction, energy storage, and carbon sequestration: a review. Environ Chem Lett 20, 2385–2485 (2022). https://doi.org/10.1007/s10311-022-01424-x

Appendix A

Biofilter Type	Number		Location (Between Piles…)	Species	Number of Plants Planted	Number of plants alive	Percent Cover	Tallest Plant Height	Number of Flowers	Notes of Plants
3.0	3-8	North	D & E	DESCAE	24					
4.0	4-8	North	D & E	SCHACU	24					
3.0	3-8	North	D & E	SISIDA	24					
3.0	3-7	North	F & G	SIDHEN	24					
4.0	4-7	North	F & G	SCHACU	24					
3.0	3-7	North	F & G	CXSTIP	24					
3.0	3-1	North	H & I	SIDHEN	24					
4.0	4-1	North	H & I	SCHACU	24					
3.0	3-1	North	H & I	CXSTIP	24					
3.0	3-6	North	J & K	DESCAE	24					
4.0	4-6	North	J & K	SCHACU	24					
3.0	3-6	North	J & K	SISIDA	24					
3.0	3-2	North	L & M	DESCAE	24					
4.0	4-2	North	L & M	SCHACU	24					
3.0	3-2	North	L & M	SISIDA	24					
3.0	3-3	North		SIDHEN	24					
4.0	4-3	North		SCHACU	24					
3.0	3-3	North		CXSTIP	24					

Biofilter Type	Number		Location (Between Piles…)	Species	Number of Plants Planted	Number of plants alive	Percent Cover	Tallest Plant Height	Number of Flowers	Notes
4.1	3	North	M & N	ELEPAL	16					
4.1	3	North	M & N	CXOBNU	16					
4.1	3	North	M & N	SCIMIC	16					
4.1	3	North	M & N	SCHPUN	16					
4.1	1	North	N & O	ELEPAL	16					
4.1	1	North	N & O	CXOBNU	16					
4.1	1	North	N & O	SCIMIC	16					
4.1	1	North	N & O	SCHPUN	16					
2.0	2-8	North	O & P	ELEPAL	16					
2.0	2-8	North	O & P	CXOBNU	16					
2.0	2-8	North	O & P	SCIMIC	16					
2.0	2-8	North	O & P	SCHPUN	16					
2.0	2-7	North	P & Q	ELEPAL	16					
2.0	2-7	North	P & Q	CXOBNU	16					
2.0	2-7	North	P & Q	SCIMIC	16					
2.0	2-7	North	P & Q	SCHACU	16					
2.0	2-3	North	Q & R	ELEPAL	16					
2.0	2-3	North	Q & R	CXOBNU	16					
2.0	2-3	North	Q & R	SCIMIC	16					
2.0	2-3	North	Q & R	SCHPUN	16					
4.1	2	North	R & S	ELEPAL	16					
4.1	2	North	R & S	CXOBNU	16					
4.1	2	North	R & S	SCIMIC	16					
4.1	2	North	R & S	SCHPUN	16					

Biofilter Type	Number		Location (Between Piles…)	Species	Number of Plants Planted	Number of plants alive	Percent Cover	Tallest Plant Height	Number of Flowers	Notes of Plants
3.0	3-5	South	furthest west	SIDHEN	24					
4.0	4-5	South	furthest west	SCHACU	24					
3.0	3-5	South	furthest west	CXSTIP	24					
3.0	3-4	South		DESCAE	24					
4.0	4-4	South		SCHACU	24					
3.0	3-4	South		SISIDA	24					
2.0	2-2	South		ELEPAL	16					
2.0	2-2	South		CXOBNU	16					
2.0	2-2	South		SCIMIC	16					
2.0	2-2	South		SCHPUN	16					
4.1	4	South	furthest east	ELEPAL	16					
4.1	4	South	furthest east	CXOBNU	16					
4.1	4	South	furthest east	SCIMIC	16					
4.1	4	South	furthest east	SCHPUN	16					

Biofilter Type	Number		Location	Species	Number of Plants Planted	Number of plants alive	Percent Cover	Tallest Plant Height	Number of Flowers	Notes of Plants
5.0		North	B-1	SCIMIC	8					
5.0		North	B-1	CXSTIP	8					
5.0		North	B-2	JUNENS	8					
5.0		North	B-2	SCHPUN	8					
5.0		North	B-3	SAGLAT	8					
5.0		North	B-3	CXSTIP	8					
5.0		North	B-4	JUNENS	8					
5.0		North	B-4	SCHPUN	8					
6.0		North	between the coir - lower	SAGLAT	5					
6.0		North	between the coir - lower	SCIMIC	5					
6.0		North	between the coir - lower	JUNENS	5					
6.0		North	between the coir - upper	SCHPUN	5					
6.0		North	between the coir - upper	CXSTIP	5					
6.0		North	lowest	SCIMIC	5					
6.0		North	lowest	JUNENS	5					
6.0		North	lowest	SAGLAT	5					
6.0		North	middle	SCIMIC	5					
6.0		North	middle	JUNENS	5					
6.0		North	middle	SAGLAT	5					
6.0		North	high	SCHPUN	5					
6.0		North	high	CXSTIP	5					

Biofilter Type	Number		Location	Species	Number of Plants Planted	Number of plants alive	Percent Cover	Tallest Plant Height	Number of Flowers	Notes
5.0		South	C-1	SCIMIC	8					
5.0		South	C-1	CXSTIP	8					
5.0		South	C-2	JUNENS	8					
5.0		South	C-2	SCHPUN	8					
5.0		South	C-3	SAGLAT	8					
5.0		South	C-3	CXSTIP	8					
5.0		South	C-4	SCIMIC	8					
5.0		South	C-4	SCHPUN	8					
6.0		South	between the coir - lower	SAGLAT	5					
6.0		South	between the coir - lower	SCIMIC	5					
6.0		South	between the coir - lower	JUNENS	5					
6.0		South	between the coir - upper	SCHPUN	5					
6.0		South	between the coir - upper	CXSTIP	5					
6.0		South	lowest	SCIMIC	5					
6.0		South	lowest	JUNENS	5					
6.0		South	lowest	SAGLAT	5					
6.0		South	middle	SCIMIC	5					
6.0		South	middle	JUNENS	5					
6.0		South	middle	SAGLAT	5					
6.0		South	high	SCHPUN	5					
6.0		South	high	CXSTIP	5					

Appendix B

Date	Site	Total Sightings per Visit	Prototype type		Video ID	Video Start time	Video End Time	Sighting number	School size	Total Fish per Date	sighting time	Type of Fish	Behavior	Location Within Frame	Other notes
06.08.21	Fremont Fremont North	9	2.0s	Unit	GH010002	around the 2 minute mark			1	1	in and out for 5 minutes	Perch	sitting on the other side of fender wall (inside ship canal)		

Appendix C

Sweetgrass Living Shorelines Restoration

GREEN FUTURES RESEARCH + DESIGN LAB

University of Washington
Green Futures Lab
242 Gould Hall, Box 355734
Seattle, WA 98195

March 17, 2021

Sheet Index:

- Cover Sheet
- L-100 Fremont Bridge Context
- L-101 Fremont Plan
- L-102 Fremont Sections

Team Members:

Principal Investigator: Nancy Rottle

Technical Lead: Mason Bowles

Contractor: Earth Corps

Community Outreach Lead: Tim Lehman

Research and Design Lead: Jenn Engelke

Project Manager: Emma Peterson

Client: King County Wastewater Treatment Division

Site Locations:

Water Location near Fremont Bridge (Parcel #182504HYDR)

Closest land parcels

North Side Fremont Bridge (Parcel #1973200385):

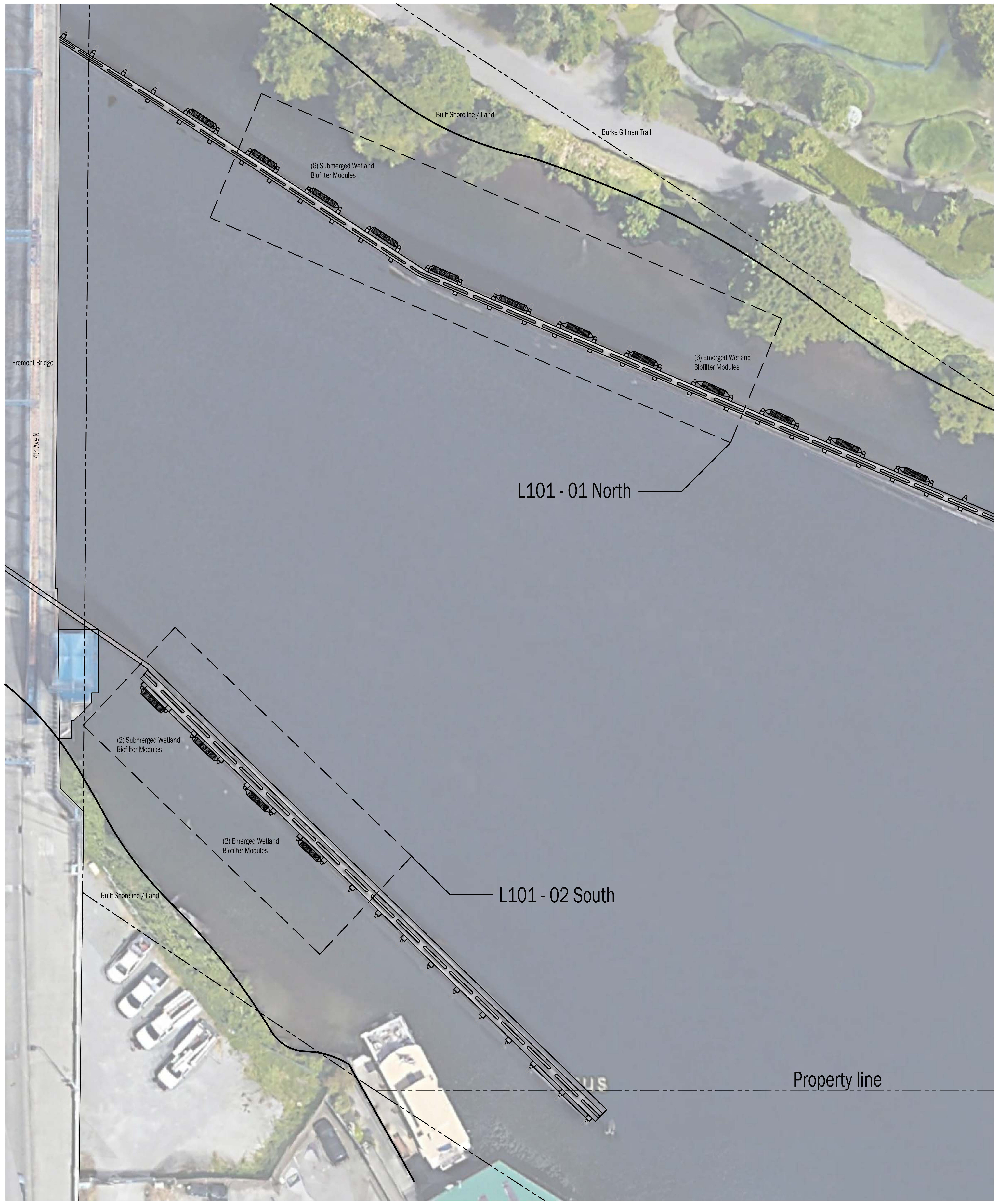
Fremont Lake Union Center - Adobe
801 N 34th St
Seattle, WA 98103
Legal Description: DENNY & HOYTS SUPL PLAT PORTION BLK 84 & LOTS 1 THRU 3 BLK 85 DENNY & HOYT'S SUPPLEMENTAL PLAT TO CITY OF SEATTLE & OF LOT 1 BLK 98 LAKE UNION SHORELANDS DAF: COMM AT INTERSECTION OF NLY PROLONGATION OF E LN OF W 7 FT SD BLK 84 & NLY MGN OF BURLINGTON NORTHERN INC'S SUMAS BRANCH R/W IN STR 18-25-4 TH S 77-28-32 E 194.84 FT ALG SD NLY MGN TH S 06-16-09 W 117.67 FT TH S 77-28-32 E 69.78 FT TH S 12-31-28 W 31.25 FT TH S 77-28-32 E 70.75 FT TH S 12-31-28 W 24.72 FT TH S 77-28-32 E 50.92 FT TH S 12-31-28 W 121.78 FT TO TPOB TH N 77-28-32 W 172.20 FT TH W 158.54 FT TO SD E LN OF W 7 FT OF BLK 84 & E MGN OF FREMONT AVE N TH S 00-09-34 W 192.81 FT ALG SD E MGN & ITS NLY PROLONGATION TO NELY MGN OF LAKE WASHINGTON SHIP CANAL AS CONDEMNED UNDER KING CO SCC NO 21942 TH S 56-49-54 E 452.56 FT ALG SD NELY MGN & SWLY LN SD BLK 98 TO MOST SLY CORNER SD BLK 98 TH N 63-49-55 E 106 FT ALG SELY LINE SD BLK 98 TO W LN OF E 50.71 FT SD LOT 1 BLK 98 & W MGN OF AURORA AVE N TH N 00-18-53 E 345.29 FT ALG SD W LN & MGN TH W 99.03 FT TO PT WHICH BEARS S 77-28-32 E FROM TPOB TH N 77-28-32 W 50.86 FT TO TPOB -AKA LOT B CITY OF SEATTLE LOT BOUNDARY ADJUSTMENT NO 9700157 REC NO 9706050452

Latitude: 47.64804, Longitude: -122.34853

South Side Fremont Bridge (Parcel #4088804375):

Fremont Bridge Marina
2940 Westlake Ave N.
Seattle, WA 98109
Legal Description: LAKE UNION SHORE LANDS ADD LOTS 1-2-3-4 OF BLK 97 OF SD PLAT TGW LOT 1 OF BLK 19 OF DAYS B F ELDORADO

Latitude: 47.6466, Longitude: -122.349



01 Fremont Bridge Plan Overall

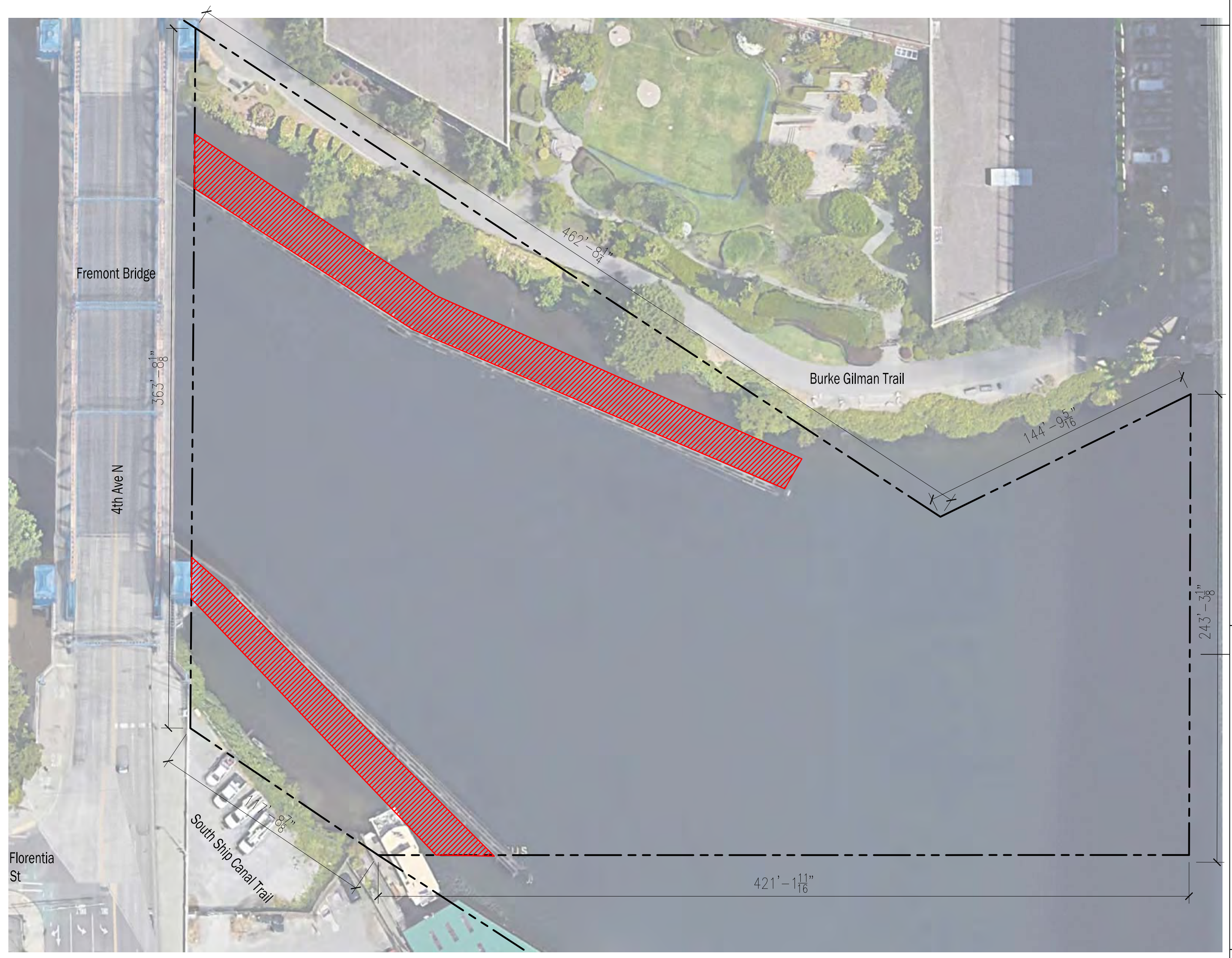
Scale: 1" = 20'

0 20' 40' North

Notes:

Water Parcel with no buildings on the site

Entrance to parcel from east side water enterance



▨ Location of Proposed Activity

02 Fremont Bridge Context

Scale: 1" = 60'

0 60' 120' North

GREEN FUTURES RESEARCH + DESIGN LAB

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242 Gould Hall, Box 355734
Seattle, WA 98195

Sweetgrass Living Shorelines Restoration

Fremont Bridge Fender Walls

Fremont Context

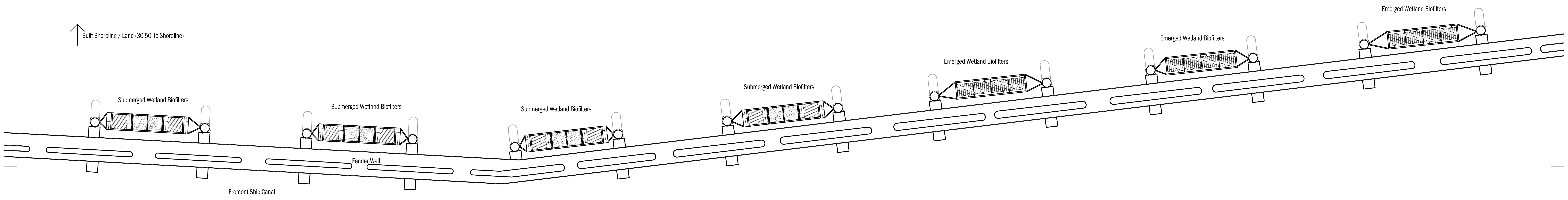
PROJECT NUMBER:	2020_01
DATE:	2021-03-06
DRAWN BY:	GFL
CHECKED BY:	GFL
FILENAME:	GFL_SWEETGRASS

L100

General Notes:

Location of fender wall is approximate, field verification needed.

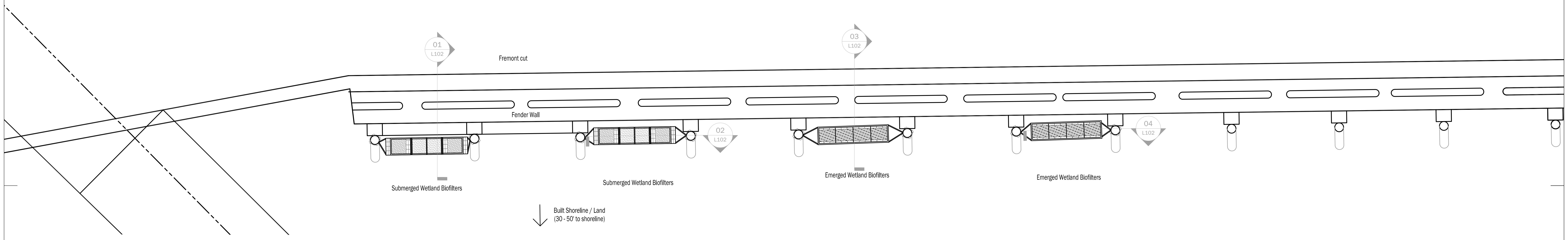
Property is a water property and does not have buildings on site.



01 Fremont Plan - North

Scale: 1" = 6'

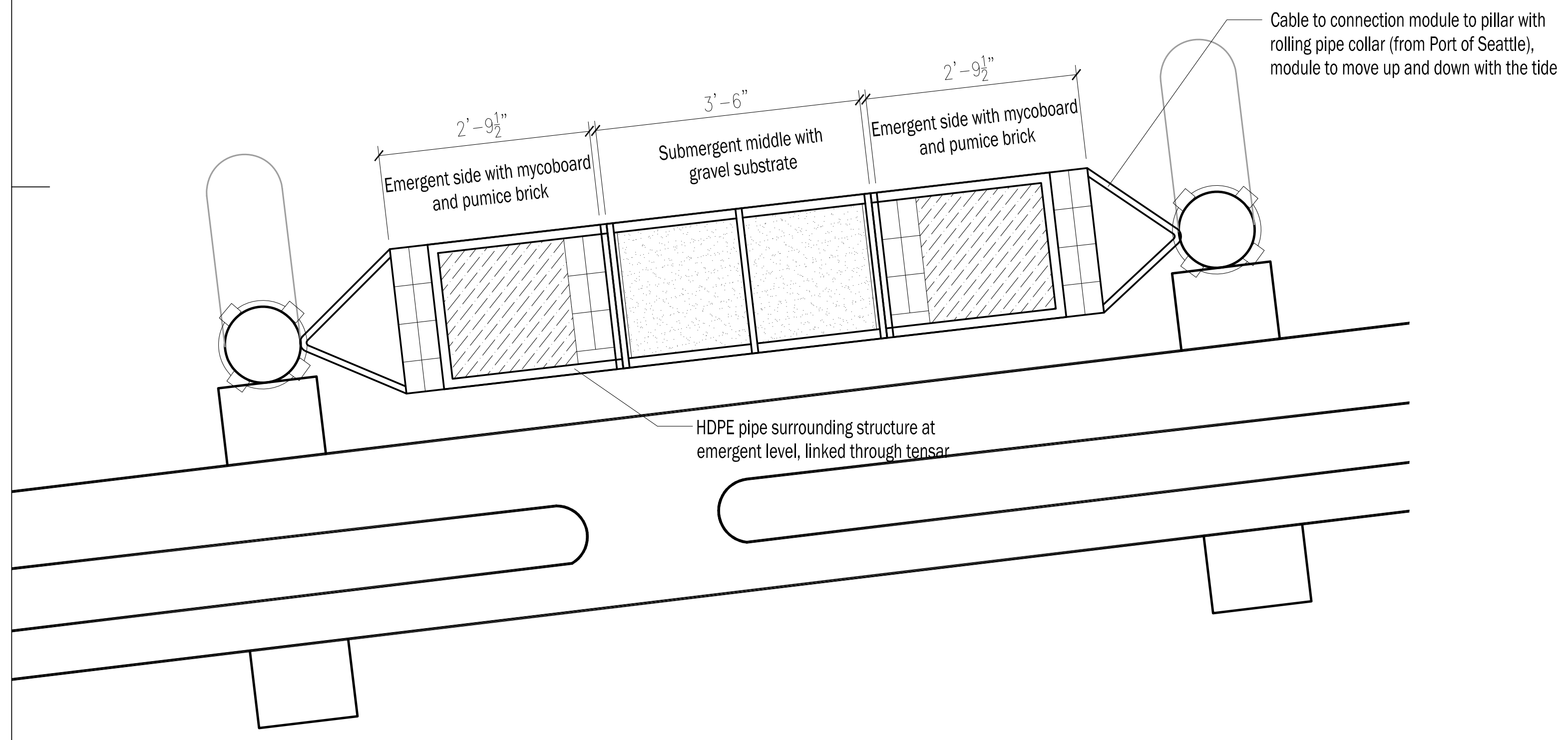
0 6' 12' North



02 Fremont Plan - South

Scale: 1" = 6'

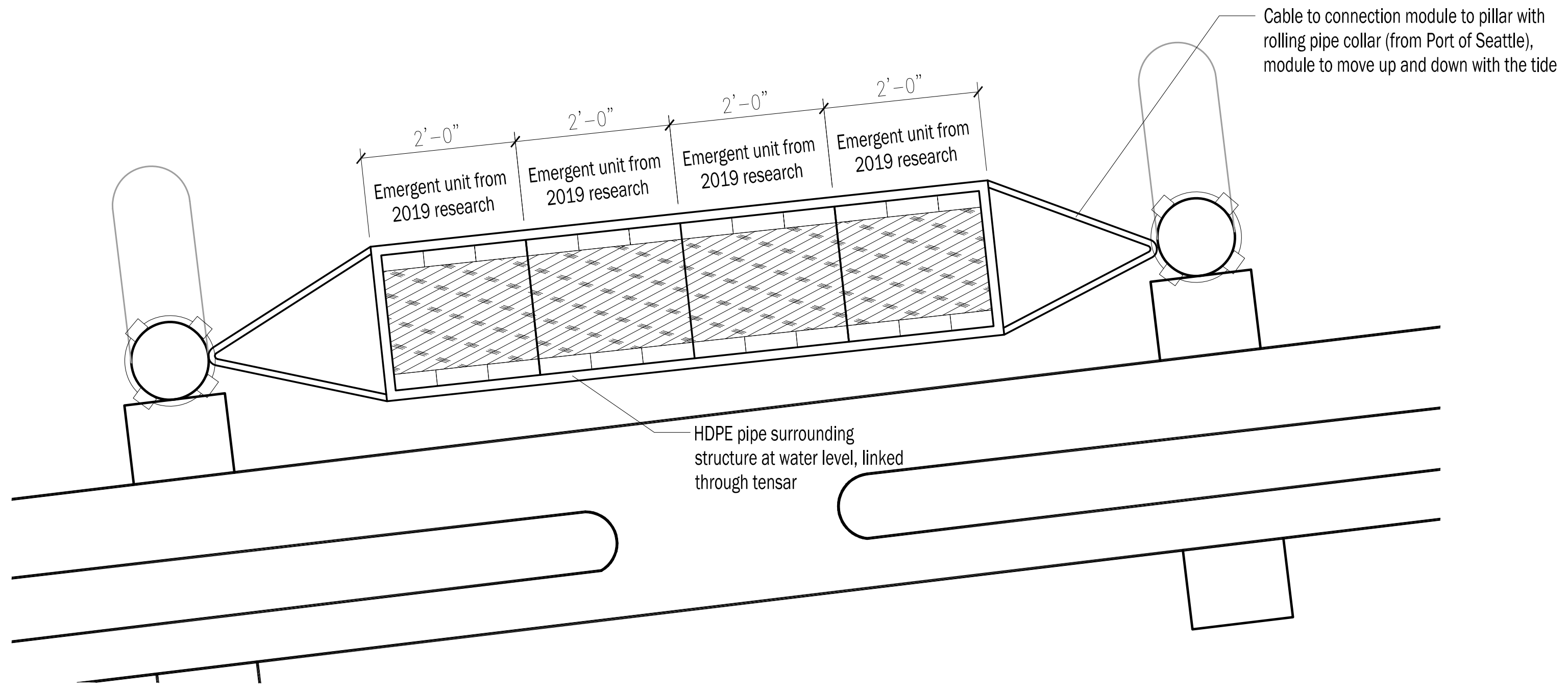
0 6' 12' North



03 Submerged Module

Scale: 1" = 2'

0 2' 4' North



04 Emergent Module

Scale: 1" = 2'

0 2' 4' North

GREEN FUTURES RESEARCH + DESIGN LAB

University of Washington
Green Futures Lab
242 Gould Hall, Box 355734
Seattle, WA 98195

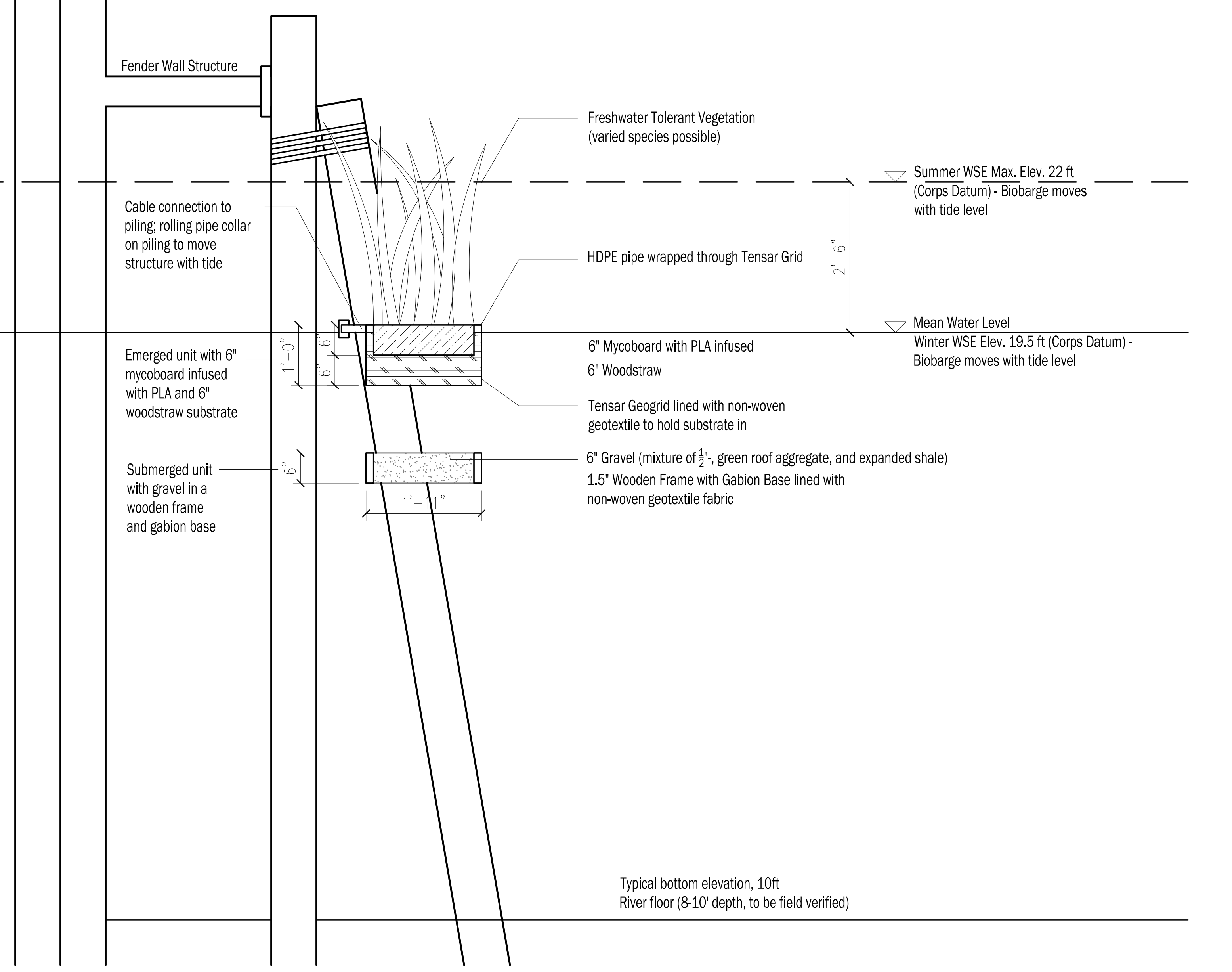
Sweetgrass Living Shorelines Restoration

Fremont Bridge Fender Walls

Plan View

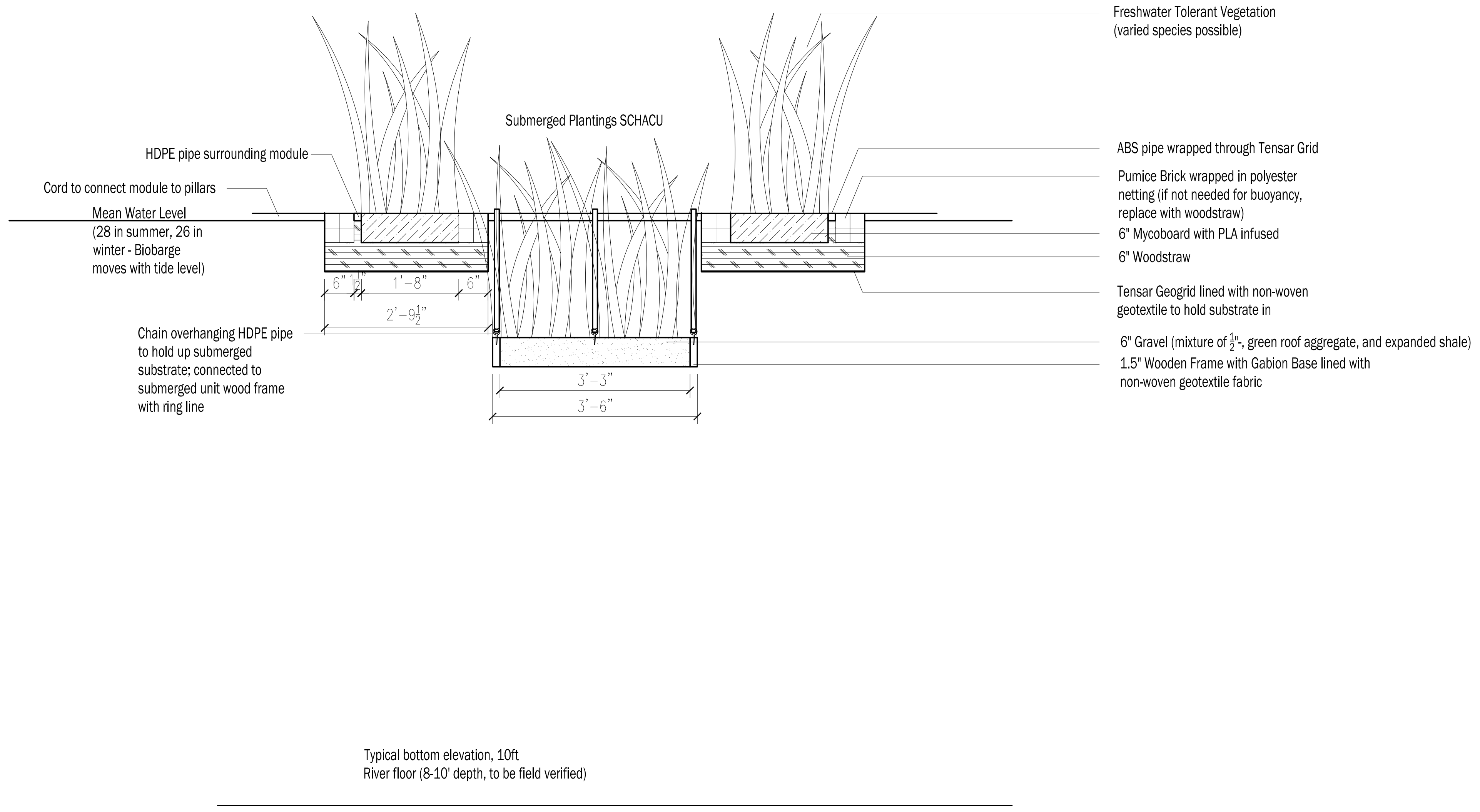
PROJECT NUMBER: 2020_01
DATE: 2021-03-06
DRAWN BY: GFL
CHECKED BY: GFL
FILENAME: GFL_SWEETGRASS

L101



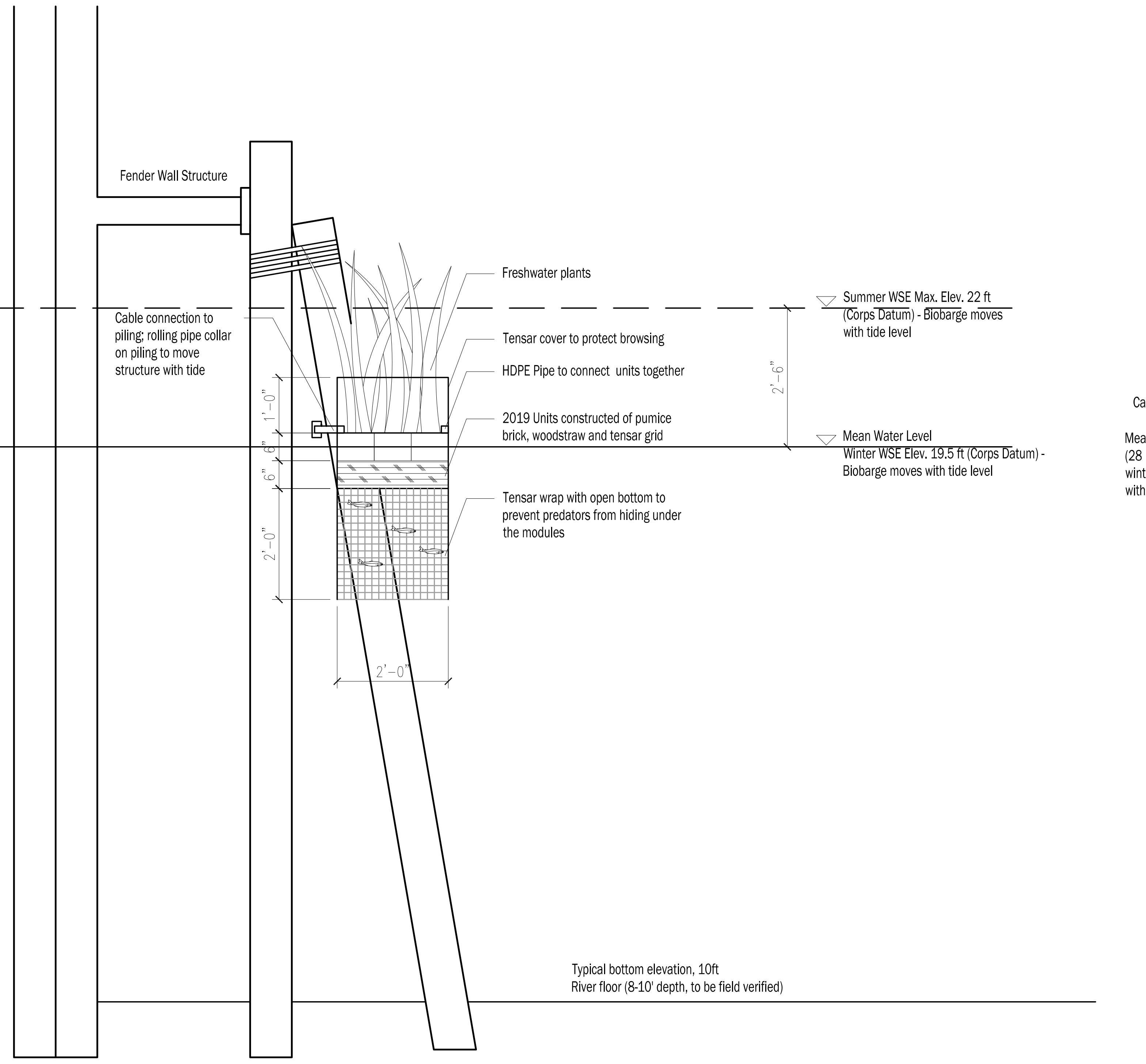
01 Submerged Wetland Biofilter: width

Scale: $\frac{1}{2}$" = 1' 0" (Horizontal and Vertical)



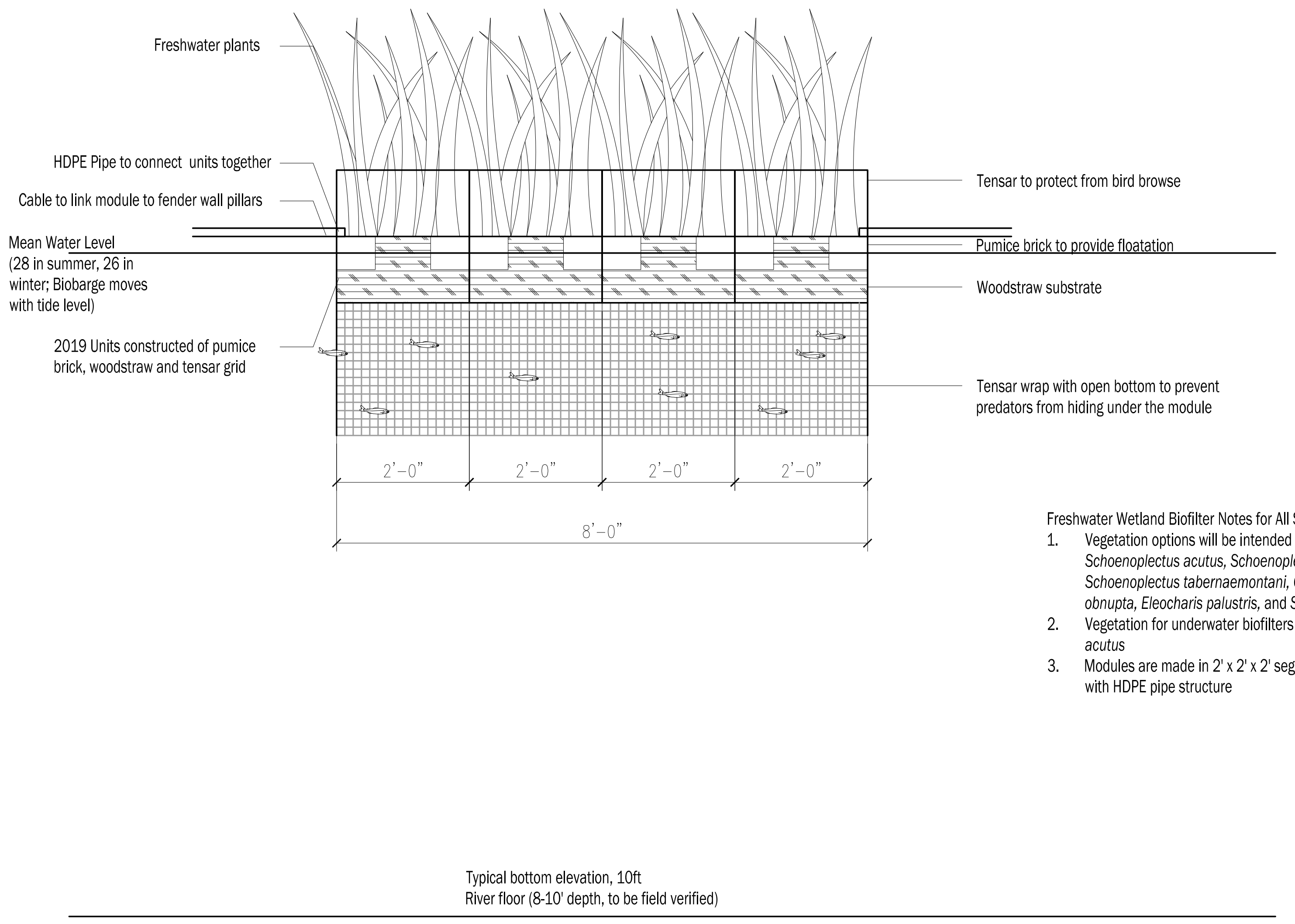
02 Submerged Wetland Biofilter: length

Scale: $\frac{1}{2}$" = 1' 0" (Horizontal and Vertical)



03 Emergent Wetland Biofilter: width

Scale: $\frac{1}{2}$" = 1' 0" (Horizontal and Vertical)

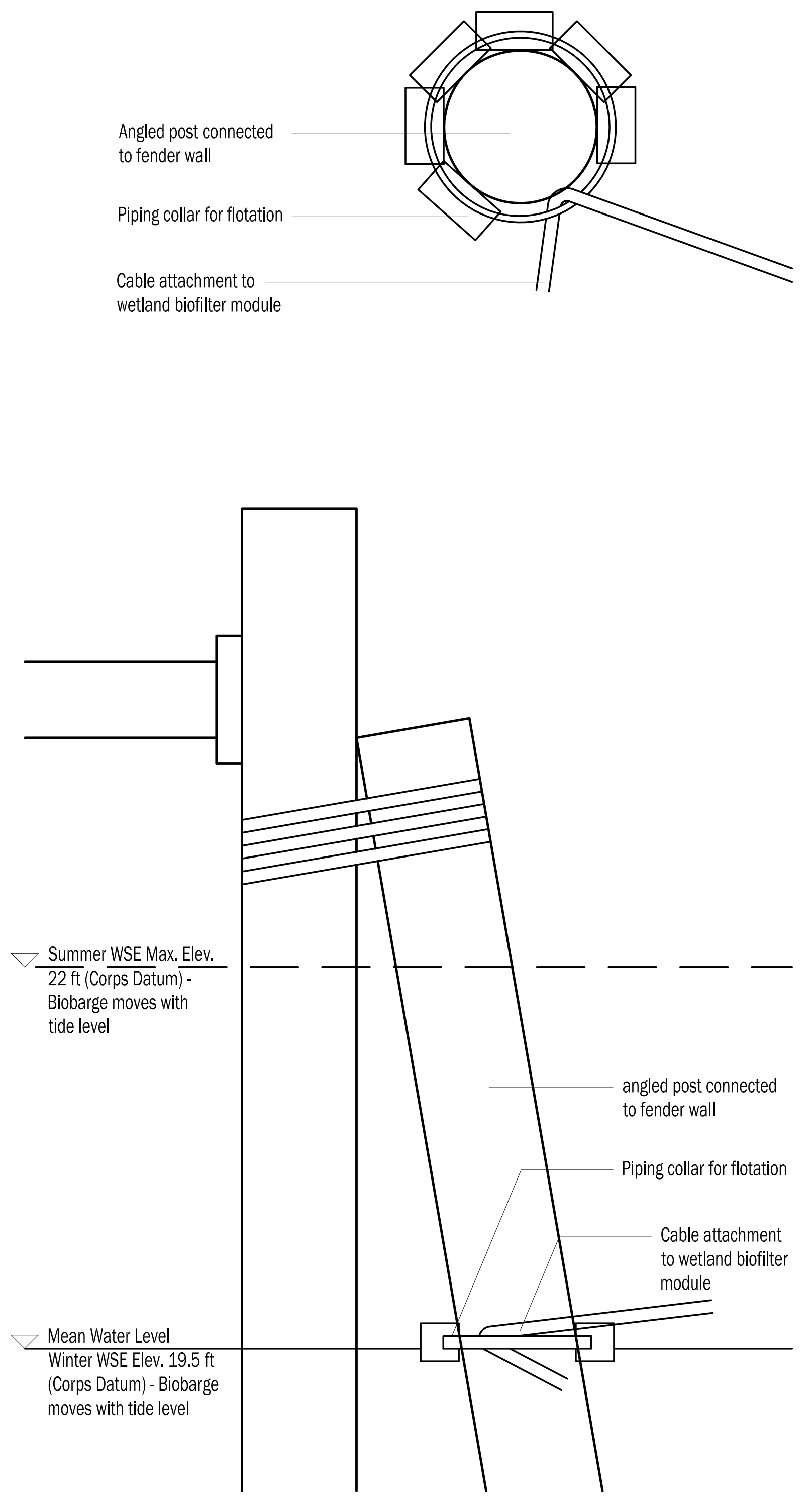


Freshwater Wetland Biofilter Notes for All Sections:

1. Vegetation options will be intended for fresh water and include *Schoenoplectus acutus, Schoenoplectus americanus, Schoenoplectus tabernaemontani, Carex lyngbyei, Carex obnupta, Eleocharis palustris,* and *Scirpus microcarpus*
2. Vegetation for underwater biofilters will be *Schoenoplectus acutus*
3. Modules are made in 2' x 2' x 2' segments combining together with HDPE pipe structure

04 Emergent Wetland Biofilter: length

Scale: $\frac{1}{2}$" = 1' 0" (Horizontal and Vertical)



Piling Collar rolls up and down the pilling with the tide. The piling collar is floation devices that are connected with a chain to form a circle around the piling. It is looped around the pilling for an attachment and not drilled into the piling. The rope that is attached to the module is linked through the chain and goes with the piling collar as the tide changes. (Device was used on Duwamish Floating Wetlands project in Summer 2019 and created by the Port of Seattle.)

05 Rolling Pipe Collar

Scale: 1" = 1'-0" (vertical and horizontal); pictures N.T.S.

GREEN FUTURES RESEARCH + DESIGN LAB

University of Washington
Green Futures Lab
242 Gould Hall, Box 355734
Seattle, WA 98195

Sweetgrass Living Shorelines Restoration

Fremont Bridge Fender Walls

Wetland Biofilter Sections

PROJECT NUMBER:	2020_01
DATE:	2021–03–06
DRAWN BY:	GFL
CHECKED BY:	GFL
FILENAME:	GFL_SWEETGRASS

L102

Appendix D

Sweetgrass Living
Shorelines Restoration

Team Members:

Principal Investigator: Nancy Rottle

Technical Lead: Mason Bowles

Contractor: Earth Corps

Community Outreach Lead: Tim Lehman

Research and Design Lead: Jenn Engelke

Project Manager: Emma Peterson

Client: King County Wastewater Treatment Division

University of Washington
Green Futures Lab
242 Gould Hall, Box 355734
Seattle, WA 98195

March 17, 2021

Sheet Index:

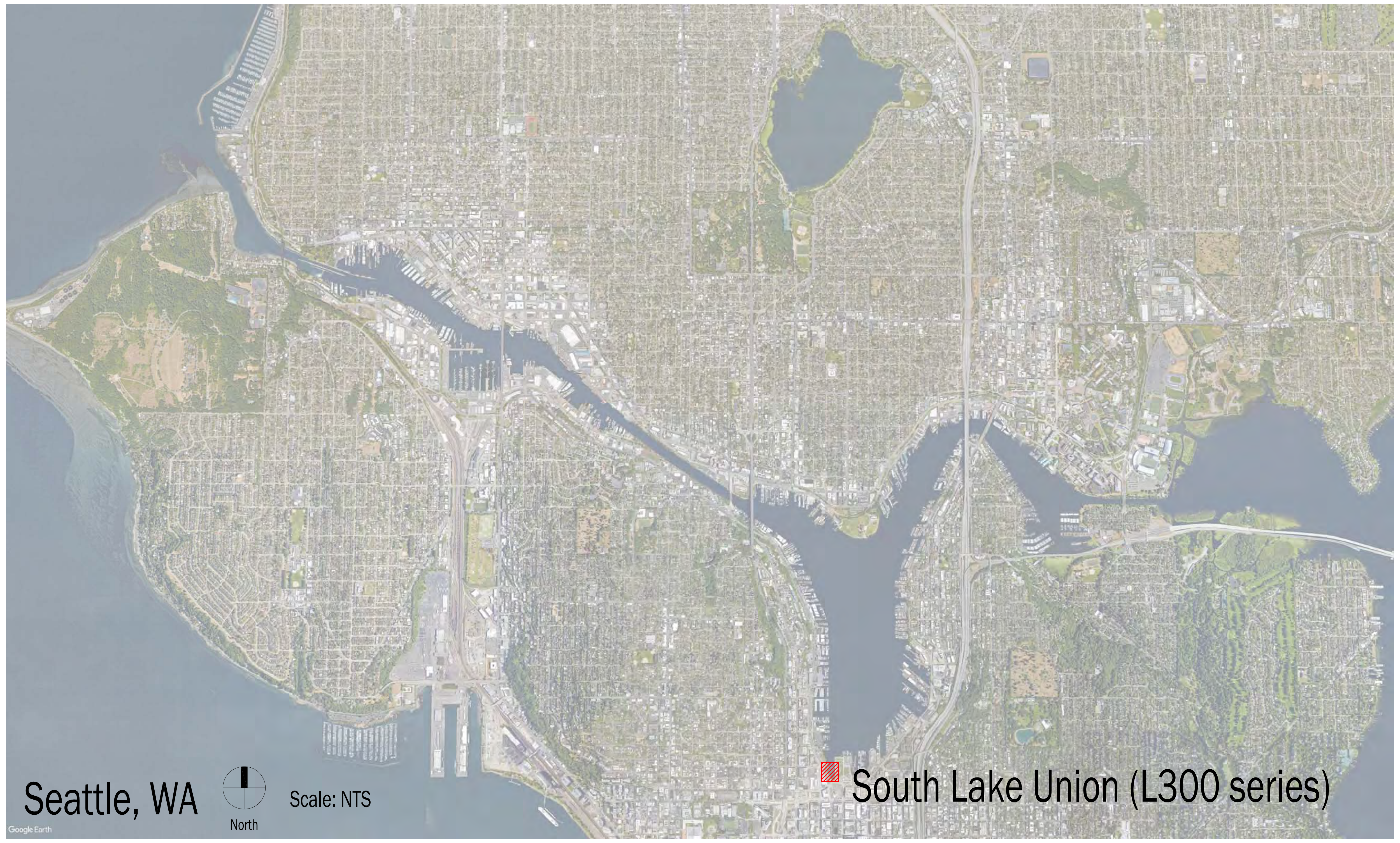
Site Locations:

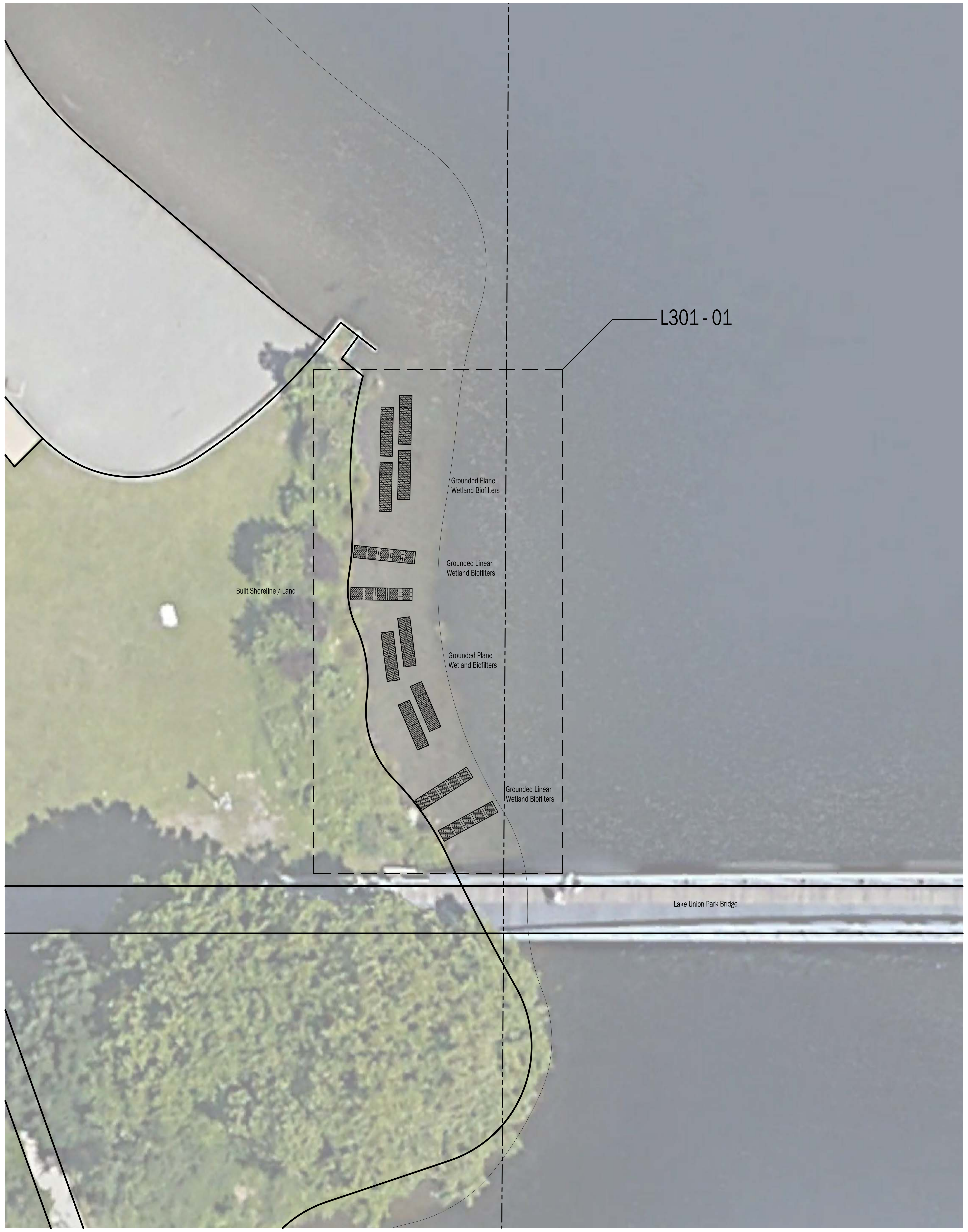
Water at South Lake Union Park (Parcel #302504HYDR):

CLOSEST STREET ADDRESS (Parcel #4088803600)
Seattle City of DPR
900 Westlake Ave N
Seattle, WA 98109

Latitude: 47.62754, Longitude: -122.33913

Parcel Description:: LAKE UNION SHORE LANDS ADD LOTS 1 THRU 4 BLK 83 LAKE UNION SHORE LANDS TGW PARCEL D CITY OF SEATTLE SHORT SUBD NO 9300160 REC NO 9309201850 (BEING LOTS 5 THRU 8 SAID BLK 83) TGW POR VAC RD ADJ PER SEATTLE ORDINANCE #124500





01 South Lake Union Plan Overall

Scale: 1" = 10'

0 10' 20' North

Notes:

Water Parcel with no buildings on the site
Park Parcel with no bildings on the site

▨ Location of Proposed Activity

02 South Lake Union Context

Scale: 1" = 40'

0 40' 80' North

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242 Gould Hall, Box 355734
Seattle, WA 98195

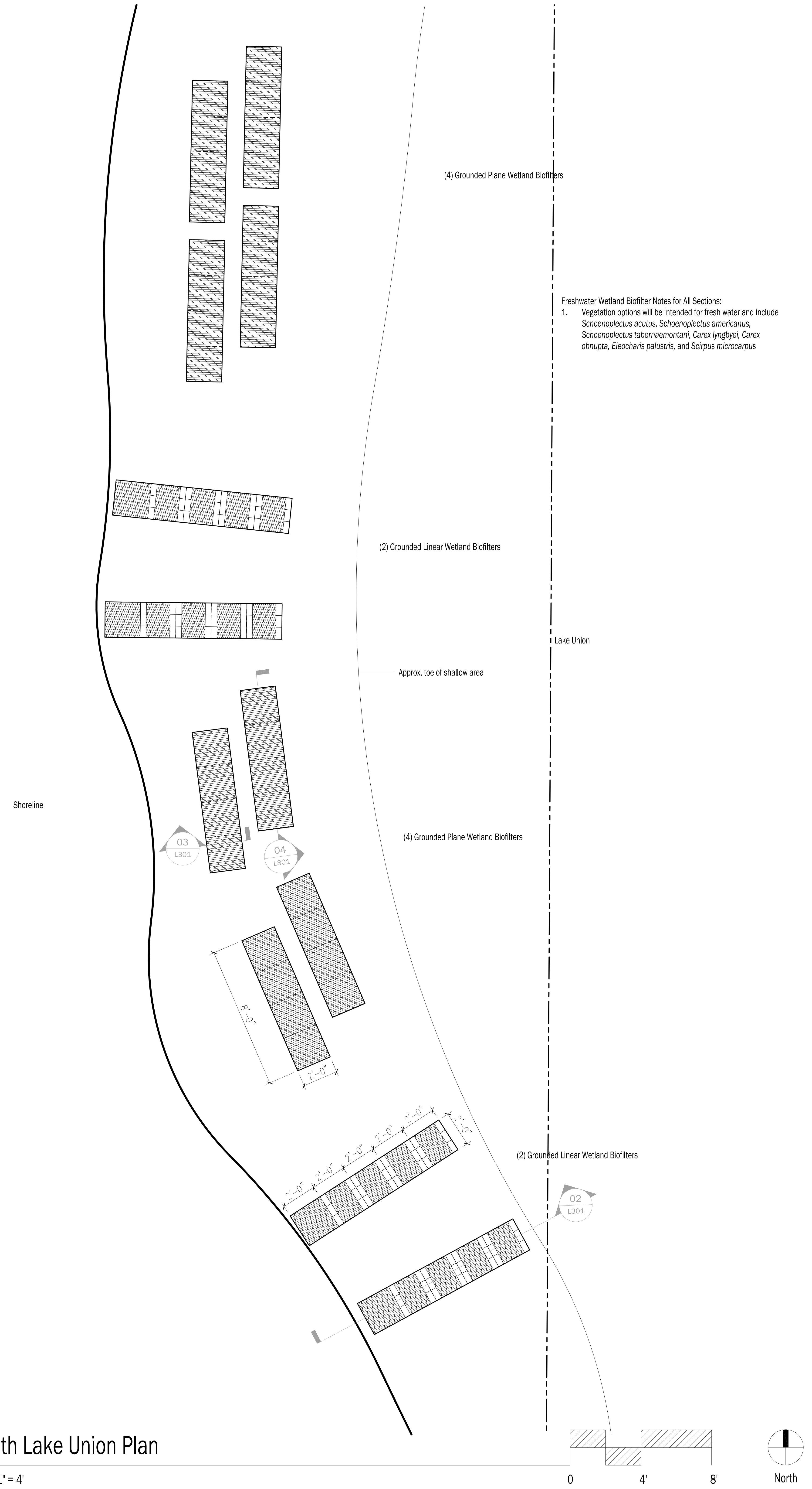
Sweetgrass Living Shorelines Restoration

South Lake Union Park

South Lake Union Context

PROJECT NUMBER:	2020_01
DATE:	2021-03-06
DRAWN BY:	GFL
CHECKED BY:	GFL
FILENAME:	GFL_SWEETGRASS

L300

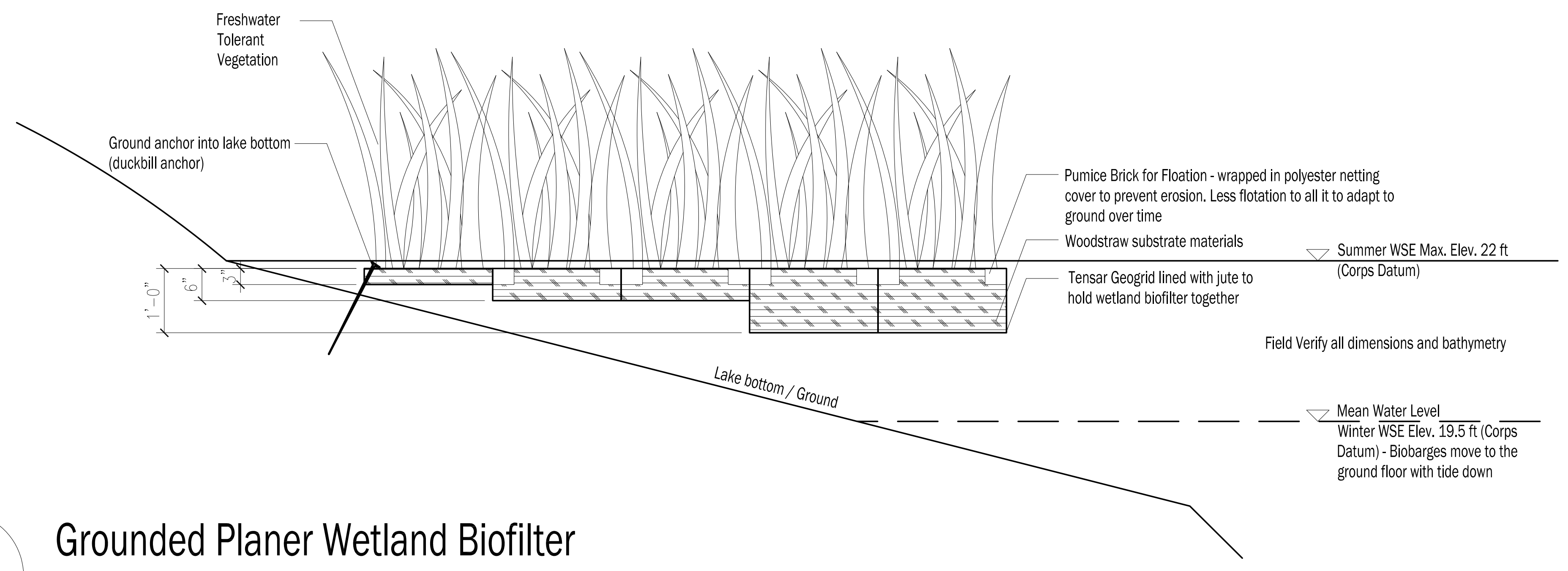


01 South Lake Union Plan

Scale: 1" = 4'

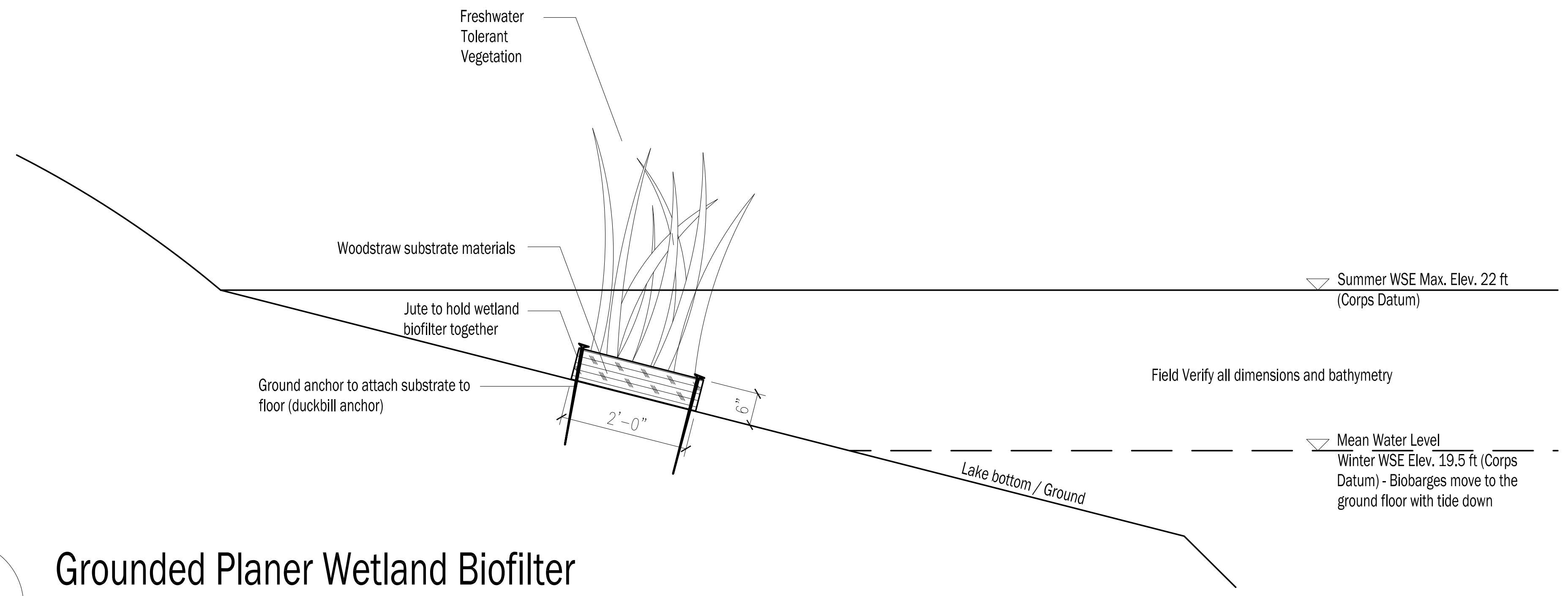
Freshwater Wetland Biofilter Notes for All Sections:

1. Vegetation options will be intended for fresh water and include *Schoenoplectus acutus, Schoenoplectus americanus, Schoenoplectus tabernaemontani, Carex lyngbyei, Carex obnupta, Eleocharis palustris,* and *Scirpus microcarpus*



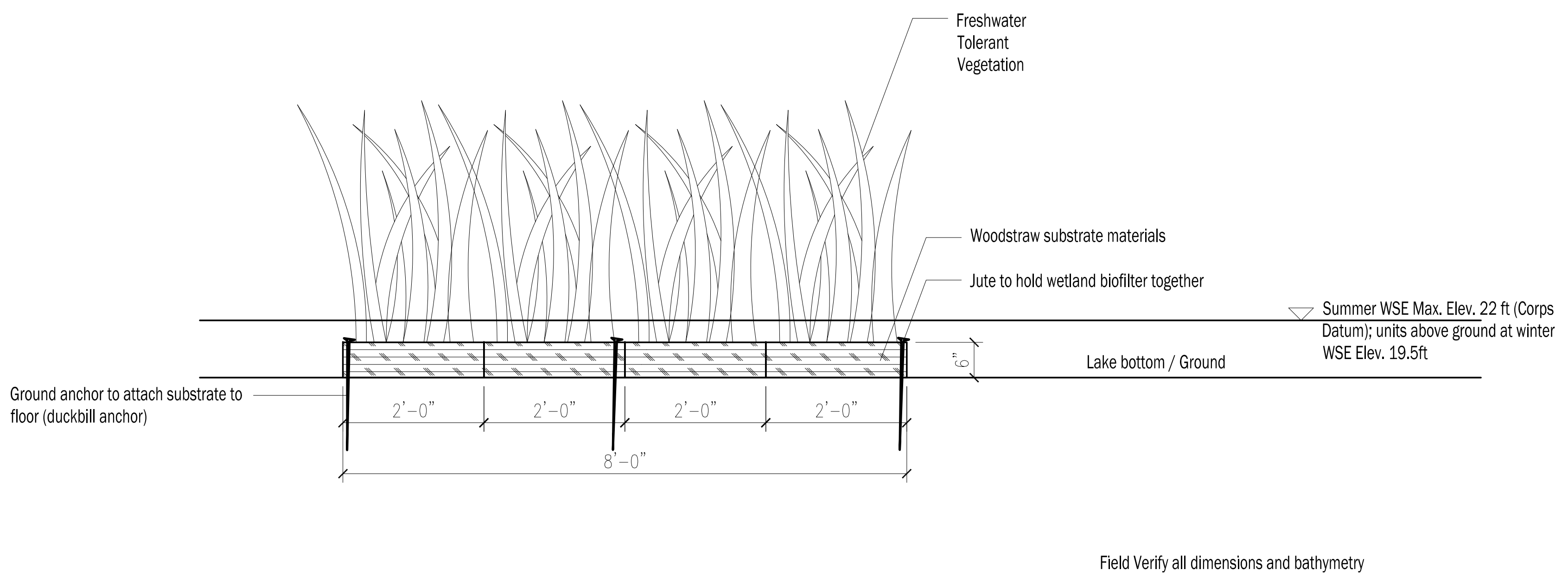
02 Grounded Planer Wetland Biofilter

Scale: $\frac{1}{2}$" = 1' (Horizontal and Vertical)



03 Grounded Planer Wetland Biofilter

Scale: $\frac{1}{2}$" = 1' (Horizontal and Vertical)



04 Grounded Planer Wetland Biofilter

Scale: $\frac{1}{2}$" = 1' (Horizontal and Vertical)

GREEN FUTURES RESEARCH + DESIGN LAB

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Green Futures Lab
242 Gould Hall, Box 355734
Seattle, WA 98195

Sweetgrass Living Shorelines Restoration

South Lake Union Park

Plan View and Sections

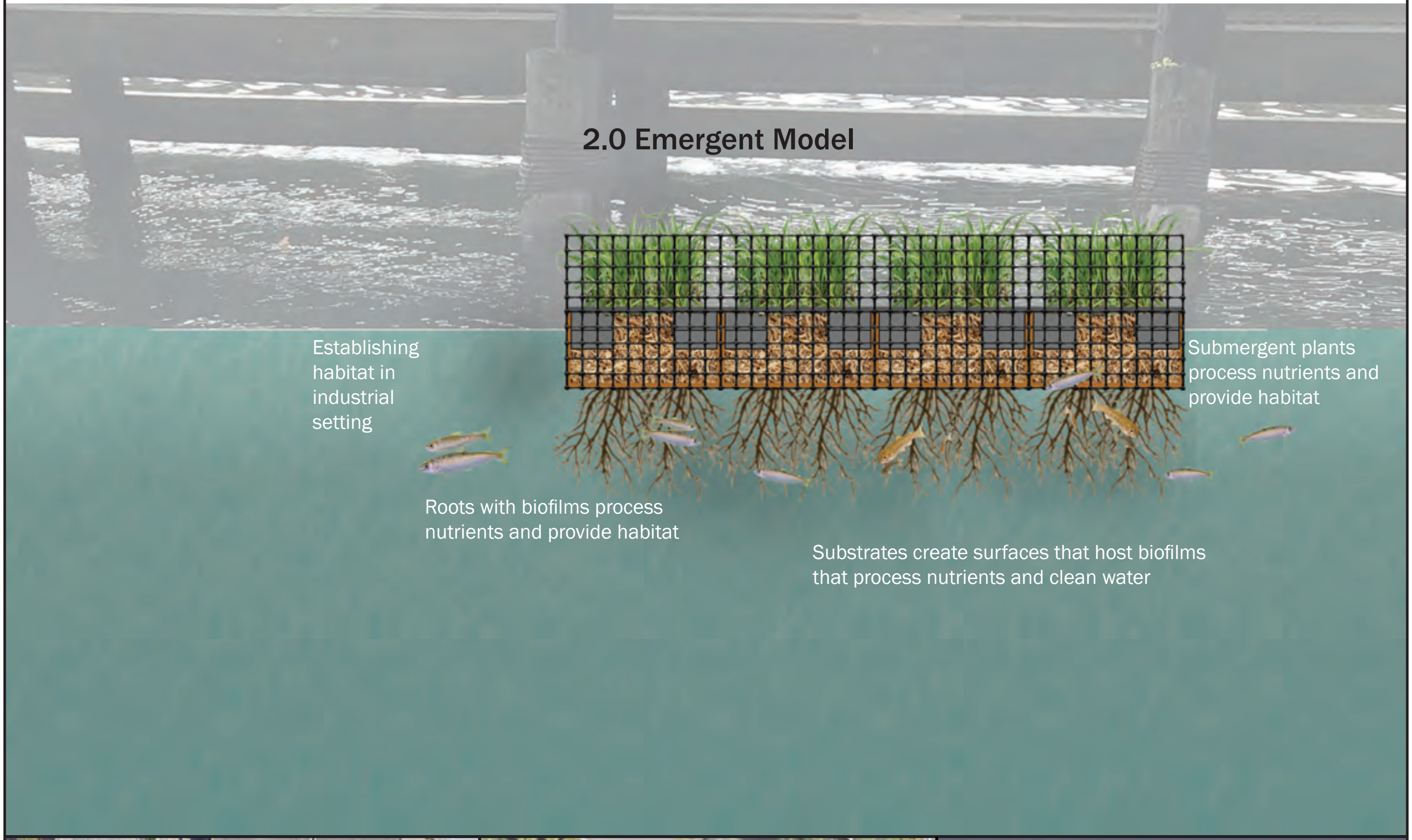
PROJECT NUMBER:	2020_01
DATE:	2021-03-06
DRAWN BY:	GFL
CHECKED BY:	GFL
FILENAME:	GFL_SWEETGRASS

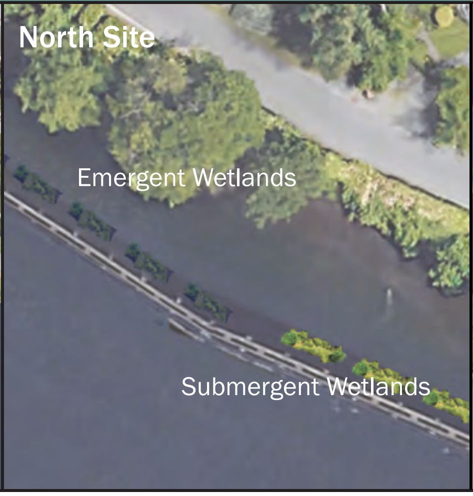
L301

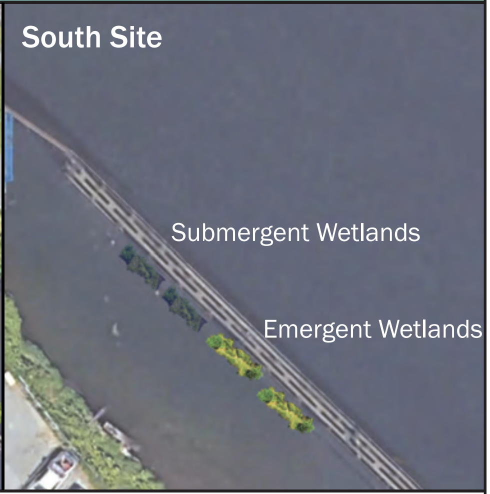
Appendix E

Fremont Bridge, Seattle, WA

Testing floating and submerged living shoreline habitats in annually-fluctuating Lake Union waters.







GREEN FUTURES RESEARCH + DESIGN LAB

Sweetgrass Shoreline Restoration Project

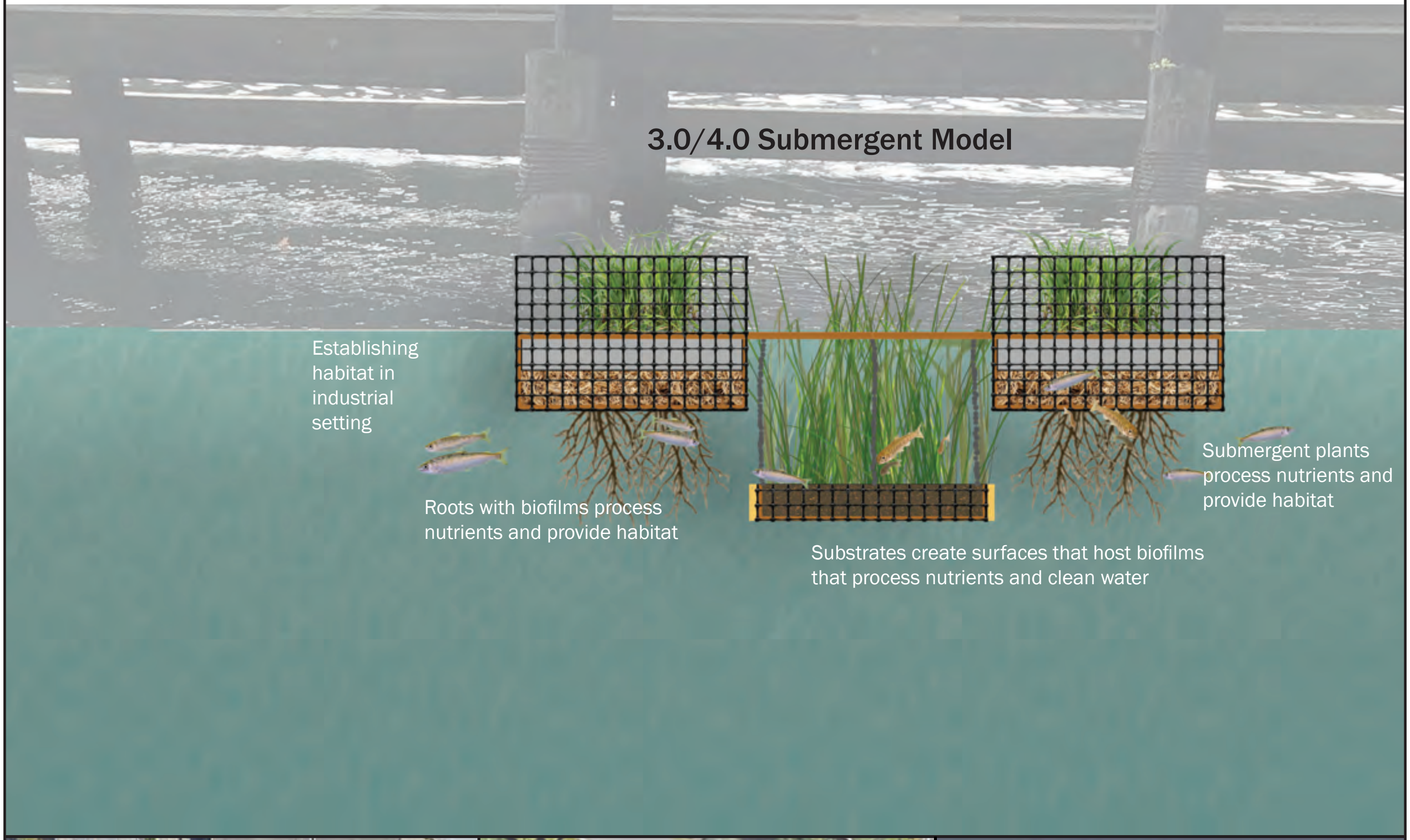
Fremont Bridge

Emergent Floating Wetlands

Date: June 27, 2021

Fremont Bridge, Seattle, WA

Testing floating and submerged living shoreline habitats in annually-fluctuating Lake Union waters.



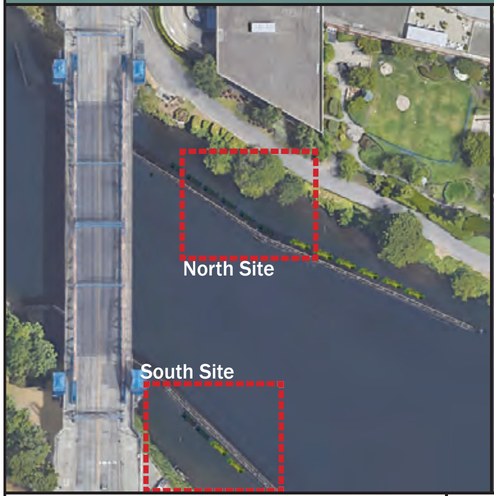
3.0/4.0 Submergent Model

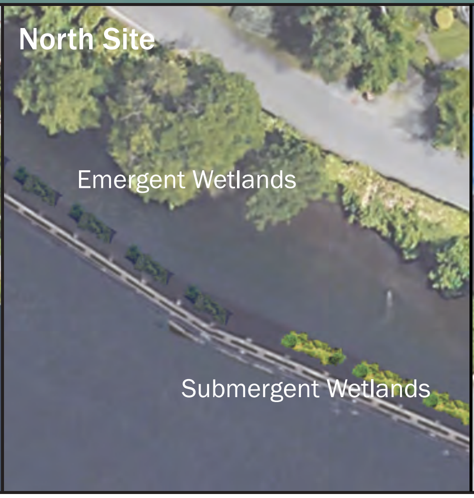
Establishing habitat in industrial setting

Roots with biofilms process nutrients and provide habitat

Substrates create surfaces that host biofilms that process nutrients and clean water

Submergent plants process nutrients and provide habitat





North Site

South Site

GREEN FUTURES RESEARCH + DESIGN LAB

Sweetgrass Shoreline Restoration Project

Fremont Bridge

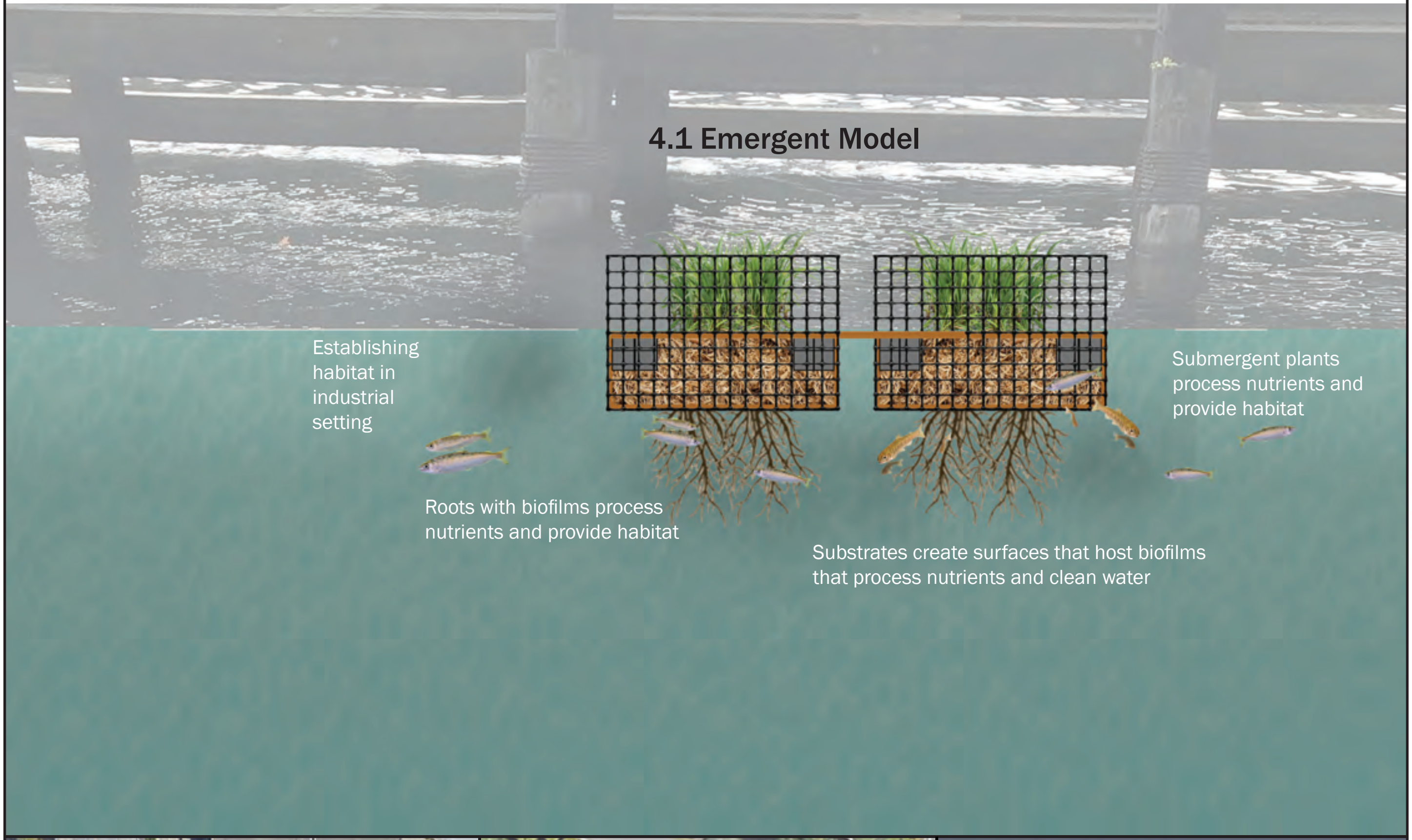
Emergent and Submergent Floating Wetlands

Date: June 27, 2021

Fremont Bridge, Seattle, WA

Testing floating and submerged living shoreline habitats in annually-fluctuating Lake Union waters.

4.1 Emergent Model

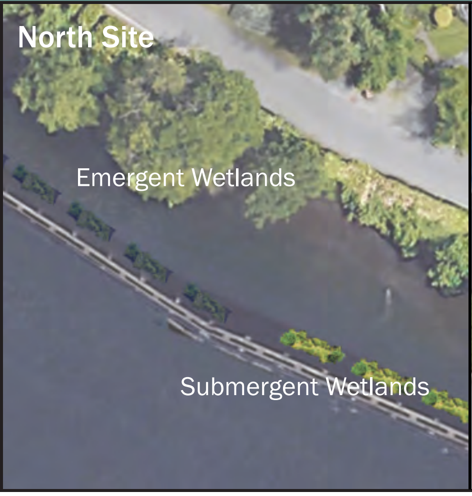


Establishing habitat in industrial setting

Roots with biofilms process nutrients and provide habitat

Substrates create surfaces that host biofilms that process nutrients and clean water

Submergent plants process nutrients and provide habitat



GREEN FUTURES RESEARCH + DESIGN LAB

Sweetgrass Shoreline Restoration Project

Fremont Bridge

Emergent Floating Wetlands

Date: June 27, 2021

South Lake Union, Seattle, WA

Testing floating and submerged living shoreline habitats in annually-fluctuating Lake Union waters.

GREEN FUTURES RESEARCH + DESIGN LAB

Sweetgrass Shoreline Restoration Project

South Lake Union Park

Grounded 5.0 Wetlands

Date: June 27, 2021

South Lake Union, Seattle, WA

Testing floating and submerged living shoreline habitats in annually-fluctuating Lake Union waters.

GREEN FUTURES RESEARCH + DESIGN LAB

Sweetgrass Shoreline Restoration Project

South Lake Union Park

Grounded 6.0 Wetlands

Date: June 27, 2021

Modular Materials

Materials used in the construction of the modular wetland biofilter.

Tensar
(outer shell held together with zip ties)

Pumice Brick
(with polyester netting cover)

Jute
(holds substrate together)

Wetland Plants
(emergent + submergent options)

Substrate Alternatives

Different options to consider for substrate. To be used individually or in combination.

Woodstraw

Biochar

Oyster Shells

Oyster Shells with Tensar Shell

Pumice Rock

Willow Branches

Mycoboard with Biofoam Infused

Washed Natural Round Gravel

GREEN FUTURES RESEARCH + DESIGN LAB

Sweetgrass Shoreline Restoration Project

Wetland Materials +
Substrate Options

Date: June 27, 2021