Topics Related to Restoration of the Edmonds Marsh

Project Reports
Ecological Restoration
ESCI 470, Fall 2016

Report No. 17-01 January 2017

Western Washington University

Sustainable Communities Partnership

About SCP

Western's SCP program focuses the energy and ideas of faculty and students upon the issues that cities face as our society transitions to a more sustainable future. SCP partners with one community each academic year, facilitating a program in which many Western courses complete service-learning projects that address problems identified by the partner.

Sustainable Communities Partnership

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SCP Partner for Academic Year 2016 - 2017: The City of Edmonds, WA

SCP is proud to partner with the City of Edmonds, Washington, during the program's inaugural year. Eleven courses at Western will tackle ten projects identified in collaboration with city staff.

Acknowledgment

The Association of Washington Cities (AWC) has provided invaluable assistance during the launch of the SCP program. AWC provided seed funding, guidance regarding program design, help with promotion of the program, and advice regarding selection of the inaugural partner.

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PREFACE

The fall 2016 Ecological Restoration course (ESCI 470) worked on topics related to restoration of the Edmonds Marsh. Students in the course were organized into five teams, with each team concentrating on a distinct aspect of the marsh, as prearranged between the instructors and Edmonds officials. Edmonds staff visited campus on September 29 and provided a detailed briefing to the students. The students performed field work in Edmonds in October, wrote project reports, and presented findings on December 1 in Bellingham. Three teams then presented findings in Edmonds on January 13, 2017. The five project reports are collected in this document.

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EDMONDS MARSH COMMUNITY ENGAGEMENT BOARDWALK PROJECT

Jade Flores, Matt Stevenson & Meghan Schilling

Introduction and Background

The Edmonds Marsh provides both ecological and social functions. Wetlands are one of the most ecologically important habitats on Earth (Mitsch & Gosselink, 2007). Saltwater marshes in particular serve as vital nurseries for fish and crustacean species that utilize marshes as places of protection from predators during crucial life stages (Boesch, 1984). Tidal marshes also serve as carbon sinks, reportedly storing more carbon than peatlands (Chmura et al., 2003). The Edmonds Marsh receives many visitors each day, mostly to observe the diversity of wildlife that depends on the marsh as crucial habitat. This unique ecosystem is one of the only remaining saltwater marshes along the south Salish Sea, as there are no other salt marshes between Everett and Tacoma. The Edmonds Marsh hosts more than 90 species of resident and migratory birds over the course of a year, according to "Birds of Edmonds, Washington: A Complete Checklist" (City of Edmonds, n.d.). The marsh has the potential to provide habitat to a wide array of aquatic species, including salmon (which are absent today, due to poor connectivity between the marsh and Puget Sound). The marsh also plays an integral role as urban green space for the community of Edmonds.

The Edmonds Marsh is a 23-acre category II wetland and originally occupied almost 40 acres along the Edmonds waterfront. Wetlands classification is based on specific criteria involving the ability of the wetland to improve water quality, maintain hydrologic functions, and provide habitat of a certain quality or standard (Hruby, 2014). A category I wetland provides the maximum amount of ecosystem services possible, based on its type and location. Being classified as category II means that the Edmonds Marsh has the ability to provide more ecosystem services than it currently does. While presently home to many avian species, such as the Great Blue Heron, the marsh historically was a highly valuable habitat for juvenile salmonids to transition between fresh and saltwater. However, with Willow Creek conveyed to Puget Sound via a culvert, and with associated tidal gates closed for over half of each year, salmonids have an extremely low chance of ever entering the marsh. In addition, the closing of tidal gates has caused an expansion of cattail habitat and recession of the mud flats, the latter supporting a greater biodiversity than the former. The marsh has lost the ability to be a dynamic ecosystem, creating a static habitat highly vulnerable to ecosystem disturbances.

The City of Edmonds currently maintains a 350-meter boardwalk adjacent to the marsh. The boardwalk is located on the north edge of the marsh and is a combination of asphalt and wood construction. It supports different community uses, including photography, walking, education, and wildlife observation. The results of a community survey show that among these uses, it is wildlife observation that draws the most people to the current boardwalk. Expanding the boardwalk has the potential to connect the marsh to southern and eastern areas within Edmonds, including neighborhoods and an Edmonds City Park. Greater connectivity has the potential to expand community access to and use of the marsh. As National Geographic Society photographer Thomas Peschat said, "You can't have something and become a champion for it if you don't know it exists" (Mission Blue II). The ability to access this unique habitat through a boardwalk may cause a larger and broader cross-section of the community to become "champions" for the Edmonds Marsh.

Activities in the Marsh

Currently, several service groups and the City of Edmonds pursue restoration and educational activities at the marsh. Among the organizations represented are the Willow Creek Hatchery, the Wildlife Habitat and Native Plant Demonstration Garden, City of Edmonds Parks and Recreation, EarthCorps, City of Edmonds Discovery Program, Students Saving Salmon, and Pilchuck Audubon/Birdwatchers. Willow Creek Hatchery plays an integral role within the community, as well as being an important stakeholder in marsh-related issues. The hatchery is managed by approximately 20 volunteers, who conduct two community outreach projects a year for the City of Edmonds. A sportsman enhancement program is conducted at the marina saltwater net pen, where 30,000 Coho are released for sport fisherman each summer. The hatchery also conducts an education program, taking around 80,000 Coho eggs, raising them, and releasing them in small creeks qualified as suitable habitat for juvenile salmon. While the fish are being raised in the hatchery, five local elementary schools (and a handful of middle schools) learn about the salmon species, their life cycle, and their habitat needs. The Wildlife Habitat and Native Plant Demonstration Garden is a Community Wildlife Habitat certified since 2010 by the National Wildlife Federation. The garden provides information and education regarding plant species, pollinators, rain gardens, and how to improve sustainability in home gardens and overall habitat in the City of Edmonds. Partnerships between the Demonstration Garden, City of Edmonds Parks and Recreation, and EarthCorp organize and participate in regular marsh restoration work. The City of Edmonds Discovery Program works mostly with school-aged children, utilizing the marsh as an environmental education site. Students Saving Salmon is a club from Edmonds Woodway High School that monitors water quality monthly in the streams that feed into Edmonds Marsh. Pilchuck Audubon regularly uses the marsh as a site for wildlife observation, as it is the first stop on the Great Washington State Bird Trail Cascade Loop. The Edmonds Marsh also functions as a stop on the annual three-day Puget Sound Bird Fest.

Framework, Goals, and Objectives

The framework for this research project measures ecological restoration as the product of stakeholder success, ecological success, and learning success, as portrayed in Figure 1 (Palmer et al., 2005). The main goal of our Community Engagement Boardwalk Project was to recommend a design for a proposed boardwalk expansion in the Edmonds Marsh that balances both ecocentric and anthropocentric methodologies (Thompson & Barton, 1994). The strategy we pursued included 1) clearly identifying the needs and objectives of each stakeholder group, 2) designing a simple prototype with the information gathered from the stakeholder groups, 3) gathering feedback on the prototype from the community, and 4) making a final recommendation to the City of Edmonds. Our objectives in designing the boardwalk were to increase community health, mitigate the impact on the marsh's habitat, ensure the project matched the community's needs, emphasize educational opportunities, and minimize human social impact, such as vandalism and non-designated trails. Though the majority of the Edmonds community supports a boardwalk, it is imperative that the boardwalk design and construction also take into consideration the fragile and unique nature of the saltwater marsh habitat.

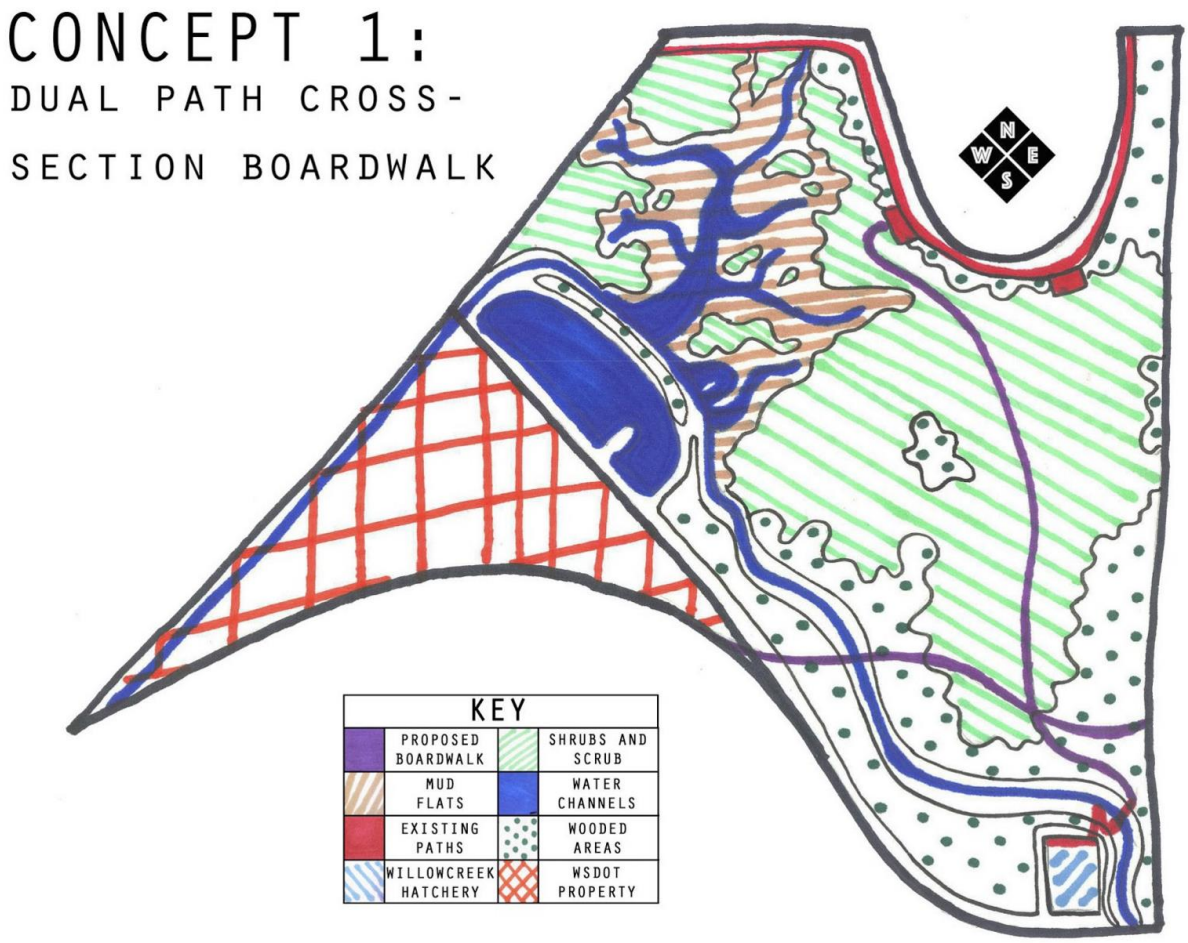
Figure 1. (Palmer et al. 2005) The most effective restoration projects lie at the intersection of the three primary axes of success. This study focuses on the five attributes of ecological success, but recognizes that overall restoration success has two additional axes. Stakeholder success reflects human satisfaction with restoration outcome, whereas learning success reflects advances in scientific knowledge and management practices that will benefit future restoration action.

Methods

This project included several stages of primary data collection in the Edmonds community. Through key informants, several stakeholder groups were identified and approached for input. In-depth interviews were conducted with representatives from each stakeholder group to understand the needs and desires of each group in relation to the Boardwalk Project**.** Participants in the in-depth interviews included: Willow Creek Hatchery, City of Edmonds Sustainability and Discovery Program, City of Edmonds Parks and Recreation, City of Edmonds Arts Council, Thrive City youth program, Students Saving Salmon high school education, Edmonds Wildlife Habitat Native Plant Demonstration Garden, Pilchuck Audubon/Birdwatchers, marsh photographers, Save Our Marsh, EarthCorps, and Edmonds Bicycle Group. For each of these organizations, at least one representative was asked for their general thoughts on the installation of a boardwalk, what characteristics they would like to see in a boardwalk, and their concerns for the potential project, specifically, but not exclusively, in terms of pet accessibility and trail use. A separate in-person session was held with the youth from Thrive City, to gain perspectives from the youth demographic. By participating in the process and learning more about the state of the marsh, the teens from Thrive City were able to bring forward concerns that had yet to be addressed by other stakeholders.

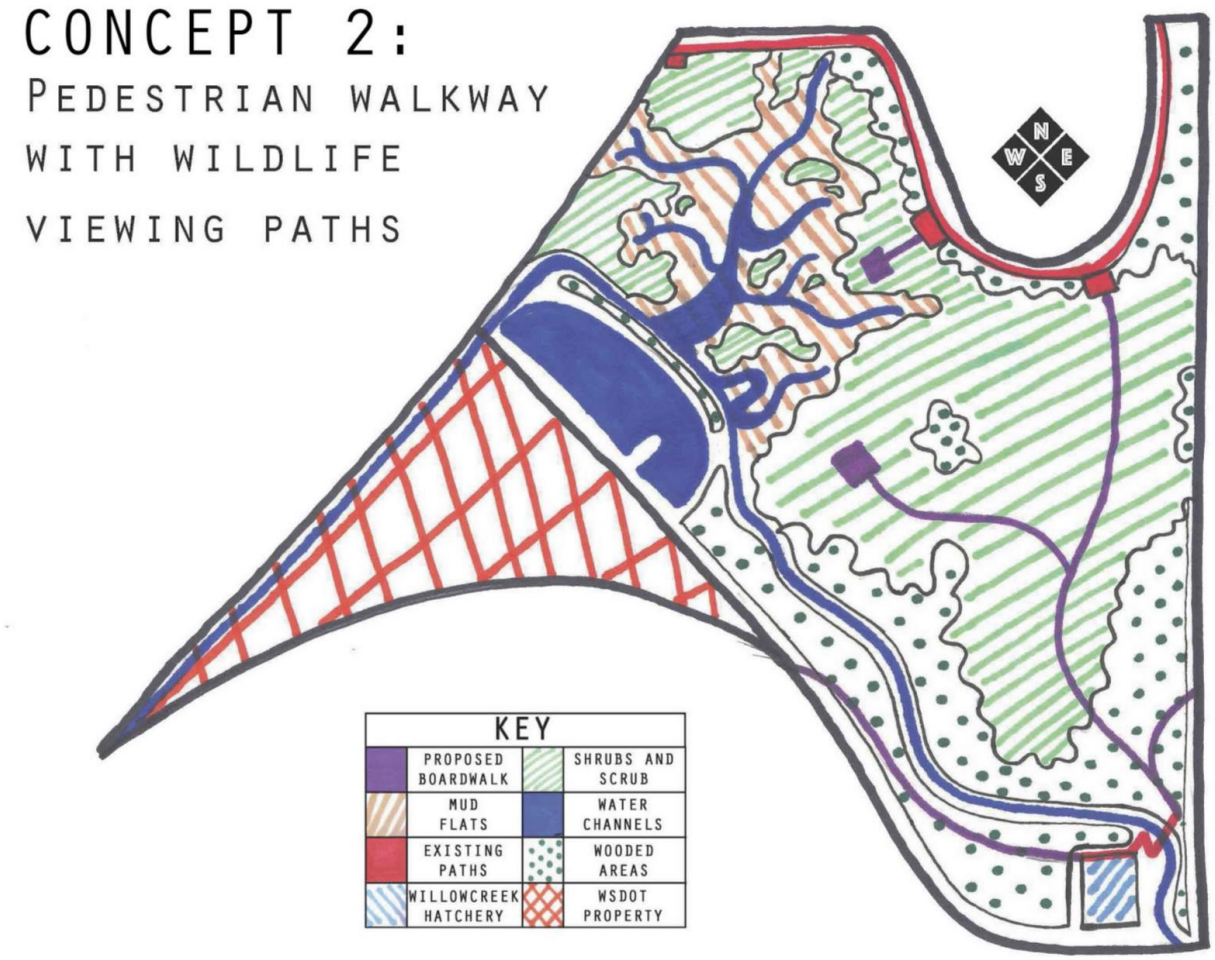
In conducting background research for the project, the Yesler Swamp in Seattle was used as a successful comparative case study. Using information gathered from the in-depth interviews, three prototype concept maps for the boardwalk were designed (see below), with the intention of meeting as many stakeholder groups' needs as possible. The three concepts were then released in the form of a general survey for community feedback. The survey asked participants to evaluate each design concept on a 10-point scale, with 1 being very unenthusiastic and 10 being very enthusiastic. Participants were also asked questions about current and future uses of the boardwalk, including whether dogs and/or bikes should be allowed. The survey was circulated online for 10 days with a sample pool including the in-depth interview stakeholder groups, the in-depth interview stakeholder constituents, the City of Edmonds social media page, the Friends of the Edmonds Marsh social media page, and the Puget Sound Bird Fest in Edmonds social media page. After receiving and reviewing the survey responses, the boardwalk proposal was modified to best reflect the community feedback, and final recommendations were developed.

Three Concepts

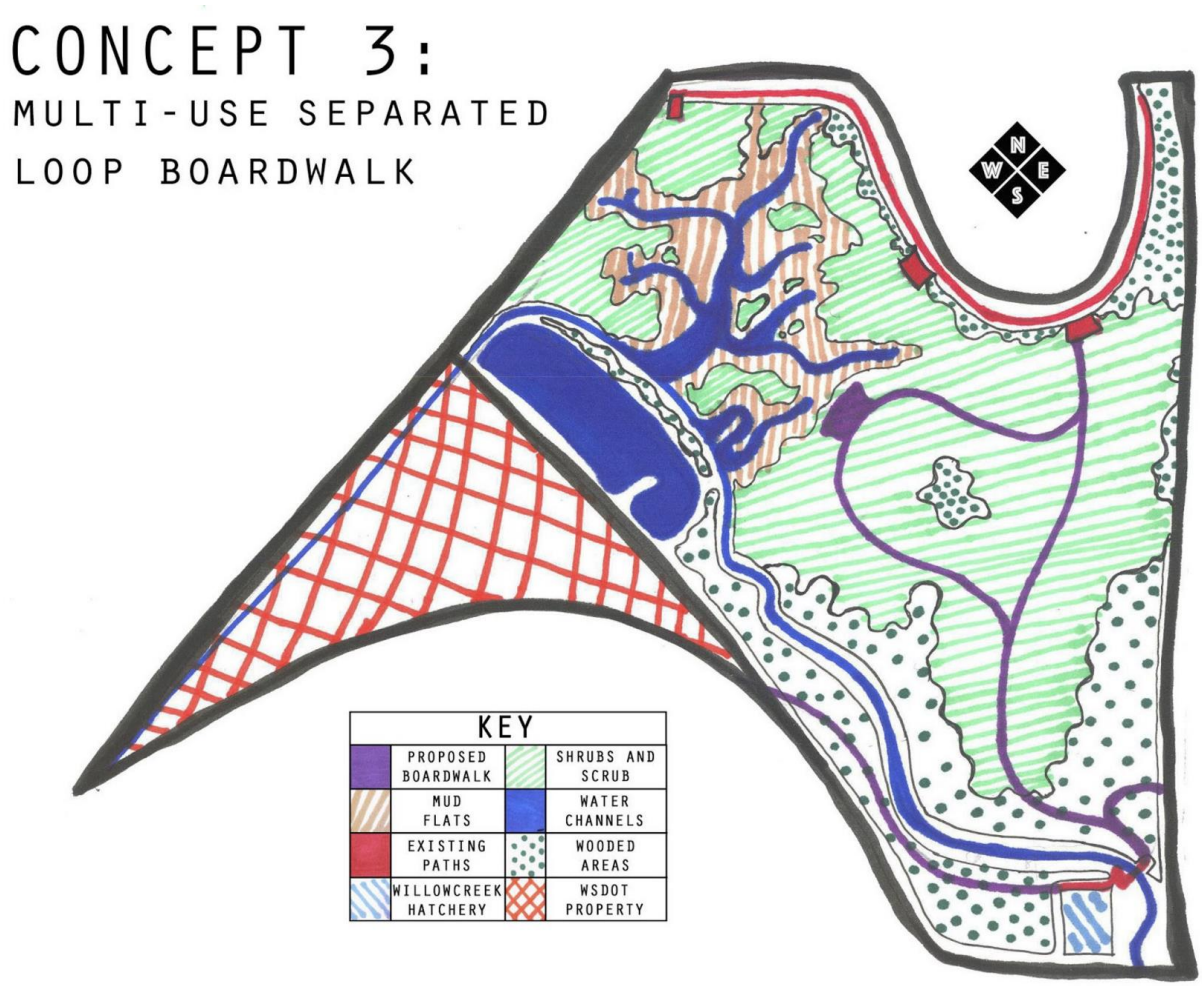


Concept 1. Existing boardwalk in red, proposed boardwalk in purple. This concept has two new segments of boardwalk intersecting in the southeast corner of the marsh. Making use of the existing Boy Scouts bridge, one segment connects the Willow Creek Hatchery to an existing boardwalk viewing platform opposite the tennis courts. The other segment connects the SR 104 crosswalk (which accesses the City Park) to residential areas south of the marsh, along an alignment that implies the need for a new bridge spanning Willow Creek.

This concept provides a north-south thoroughfare for foot traffic and provides some increased accessibility for viewing wildlife in the eastern margin of the marsh, but does not approach the western side, where a majority of the avian species of concern spend time. There is opportunity for lookout platforms and educational signage, but the concept excludes any access for pets or bicycles.



Concept 2. Existing boardwalk in red, proposed boardwalk in purple. This concept includes a primary segment that connects the residential areas south of the marsh to the Willow Creek Hatchery (staying to the south of Willow Creek), crosses the Boy Scouts bridge, and then heads north to the easternmost existing viewing platform, traversing the eastern edge of the marsh. It also includes three spur segments: one accessing the SR 104 crosswalk, one accessing the heart of the marsh, and one extending south from the existing viewing platform opposite the tennis courts. This concept would increase accessibility for viewing wildlife in the eastern margin of the marsh, as well as the interior. This concept has the potential to support pet and bicycle use on the main path but restrict them to that path only, leaving the spur trail exclusively for wildlife viewing. The spur trail provides the opportunity to view wildlife in the heart of the marsh and would feature educational signage and viewing platforms.



Concept 3. Existing boardwalk in red, proposed boardwalk in purple. Similar to Concept 2, this concept includes a primary segment that connects the residential areas south of the marsh to the Willow Creek Hatchery (staying to the south of Willow Creek), crosses the Boy Scouts bridge, and then heads north to the easternmost existing viewing platform, traversing the eastern edge of the marsh. It also includes a spur to the SR 104 crosswalk, as well as a segment that loops west into the heart of the marsh, tied into the primary segment at each end. Gates would exist at both ends of the loop. This concept has the potential to incorporate a mixed-use trail system, where the "thoroughfare" trail would include use for pet owners and/or bikes, and the western loop would be limited to walking and wildlife observation.

Results

From the community's perspective, the main goals of expanding the boardwalk are to improve access for wildlife observation, environmental education, and aesthetic appreciation of a unique estuarine habitat. Concerns about the boardwalk include the potential impact to native flora and fauna, and the introduction of collateral social impacts, such as litter and noise. A certain amount of dissonance exists between ecocentric and anthropocentric goals for the marsh. Users of the Edmonds Marsh take pride in having such a unique saltwater ecosystem in their community, and clearly there is a strong desire to protect and preserve the marsh. At the same time, increased access into the marsh and opportunities to view diverse wildlife are the main community desires for the boardwalk. Certain recreational uses of the boardwalk, specifically dog and bicycle accessibility, seem relatively undesired, based on the data we collected.

In-depth Interviews

All 12 key stakeholder representatives who were interviewed supported the addition of a boardwalk in the Edmonds Marsh. Uses of the marsh included education, wildlife observation and photography, restoration work, and the potential to increase community health, sustainability, and safety. The general consensus was in favor of a perimeter route and a low impact build-out of the boardwalk, minimizing disruption to the marsh ecosystem. One of the main concerns of stakeholders was the impact of a boardwalk on the marsh environment. Stakeholders stated concerns about having a boardwalk in the mudflat (regarded as the most sensitive area of the marsh), the implied intrusion of an extensive boardwalk, limiting habitat connectivity by encircling the marsh, and the timing of boardwalk construction (avoiding nesting season). At the same time, there was also a strong desire for increased accessibility to the marsh. Stakeholders also expressed specific preferences and needs regarding the boardwalk installation, including educational access, interpretive signage, an elevated walkway, and best practices for materials and installation processes. Among the potential problems that stakeholders identified for the boardwalk installation were a complex permitting process, buffer restrictions, side effects from dredging Shellabarger Creek, and side effects from daylighting Willow Creek.

Dogs and bikes on the boardwalk are concerns for many stakeholders. Only one interviewee advocated slightly for dog access, while two others were neutral. The remaining nine stakeholders interviewed felt dogs should be excluded from the boardwalk. The City of Edmonds Park Department does have an existing policy regarding dogs, and a dog-specific off-leash park exists less than half a mile from the marsh. As a counterpoint, it was argued that allowing dogs would more than likely increase pedestrian use, especially with a thoroughfare trail system. Stakeholder concerns regarding dogs included the safety issue posed for children visiting the marsh, the potential disruption to resident and migrant bird populations, noise, excrement, disease introduction, and concern about a disregard by dog owners for rules imposed on dogs, even if signs exist. Support by some stakeholders for dog access increased slightly with the introduction of a mixed-use trail option that would give separation for wildlife observation. Bike access was not specifically asked about in initial stakeholder interviews, but the subject was brought up by interviewees when discussing disruptions imposed upon wildlife observation. As follow-up, we contacted the Edmonds Bicycle Group as an additional stakeholder group. Exclusion from the boardwalk was not an issue for the Edmonds Bicycle Group, as the group does advocate for pedestrian use. The idea of a mixed use trail was intriguing to the Bicycle Group. If bikes were allowed, reduced speed limits and an increased width of the boardwalk are suggested.

Human impact on the Edmonds Marsh remains a concern for most stakeholders. Instances of vandalism and theft have occurred at the Willow Creek Hatchery, but the Hatchery stakeholder voiced enthusiasm for the boardwalk and suggested it could lead to a decrease in unwanted activities. Concerns surrounding human impact include litter, pollution, social trails, camping, vandalism, and noise. The Parks Department, however, is not concerned about people inadvertently dispersing invasive species into the marsh. In fact, the feedback received from the Parks Department is that the increased accessibility to the marsh provided by the boardwalk would make it easier to carry out restoration activities, such as invasive species monitoring and removal.

Survey Responses

We received a total of 41 survey responses from the Edmonds community, though not all respondents answered every question in the survey instrument. Overall, 63 percent of respondents were highly interested in the installation of a boardwalk, citing an array of boardwalk uses that include education, exercise, photography, ecological restoration, and wildlife observation (Figure 6).

Concept 1 Feedback

Concept 1 received mixed community feedback in the survey, with an average score of 5.2 on a scale of 1 to 10 (Figure 2). One survey respondent commented, "One of my reasons for preferring Concept 1 is that it seems to leave more area in the interior of the marsh undisturbed. I am very enthusiastic about an expanded boardwalk, but DO NOT want the boardwalk to distract from the health of the marsh or the privacy that might be a draw for nesting birds." In total, 16.7 percent of respondents preferred this concept over the others (Figure 5). One contrasting viewpoint was provided by a respondent who said "For study, education, and viewing purposes, Concept 1 offers limited appeal since it skirts most of the marsh."

Concept 2 Feedback

This concept received varied community feedback in the survey, but overall had more positive reactions than Concept 1. "For education, study, and viewing purposes, this is a much better concept, since it offers better views of the interior of the marsh, plus a viewing platform," claims one respondent. The enthusiasm scale scored 6.2 (Figure 3), and 33 percent of respondents preferred this concept over the others (Figure 5). One respondent suggests, "(Moving) viewing platforms back a little so people do not disturb wildlife," which shows that despite higher levels of enthusiasm, there is still concern about environmental impacts with this concept.

Concept 3 Feedback

Concept 3 was the most preferred boardwalk option, with 43.3 percent choosing it over the other two concepts (Figure 5). A closer look at survey responses, however, reveals relatively polarized community views on Concept 3 (Figure 4). One respondent said "I very strongly feel that Concept 3 puts human needs over what is best for the marsh and its wildlife," while another states, "This concept is my most favorite one. It offers good views of the marsh, good study and education opportunities, and limits access to undesirable elements (pets & bikes) that would undoubtedly cause some harm." Overall the enthusiasm score for Concept 3 averaged 5.3, which was lower than Concept 2, reflecting the mix of strongly negative as well as positive viewpoints.

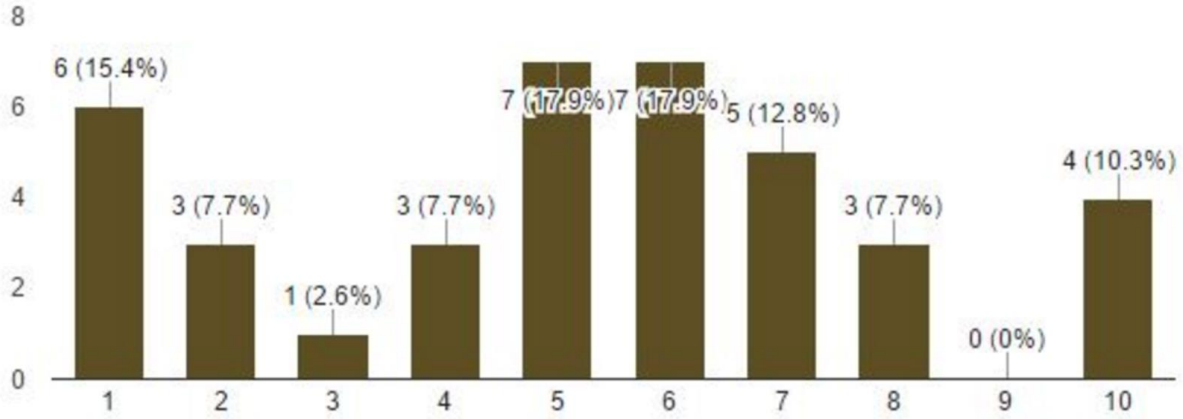


Figure 2. Concept 1 online survey results. X-axis indicates level of enthusiasm about the concept (1 = unenthusiastic, 10 = very enthusiastic), Y-axis shows the number of people who indicated a given level of enthusiasm. 39 responses. Data gathered from November 17 to 27, 2016.

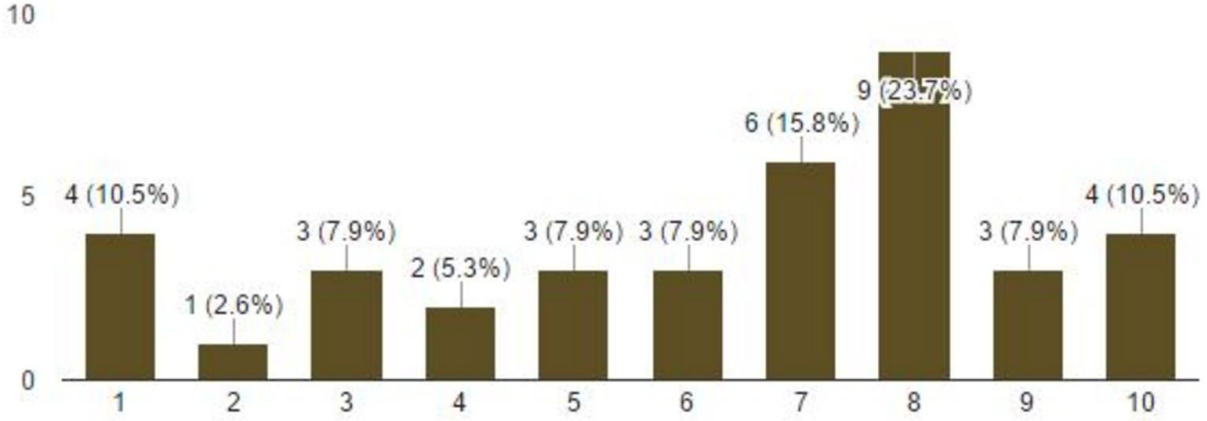


Figure 3. Concept 2 online survey results. X-axis indicates level of enthusiasm about the concept (1 = unenthusiastic, 10 = very enthusiastic), Y-axis shows the number of people who indicated a given level of enthusiasm. 38 responses. Data gathered from November 17 to 27, 2016.

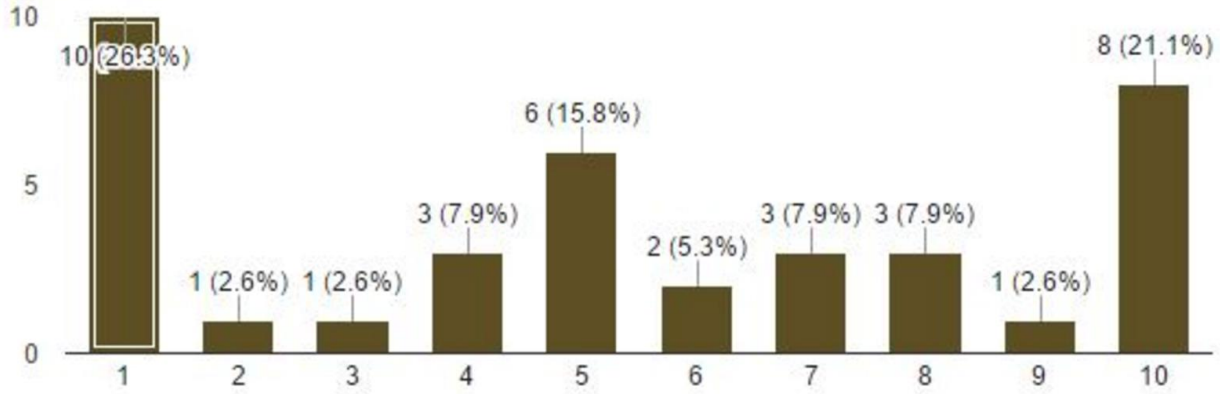


Figure 4. Concept 3 online survey results. X-axis indicates level of enthusiasm about the concept (1 = unenthusiastic, 10 = very enthusiastic), Y-axis shows the number of people who indicated a given level of enthusiasm. 38 responses. Data gathered from November 17 to 27, 2016.

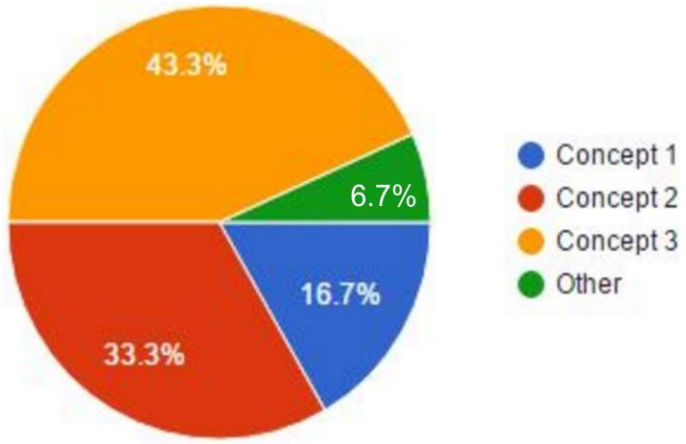


Figure 5. Overall concept preference. 38 responses. Data gathered from November 17 to 27, 2016.

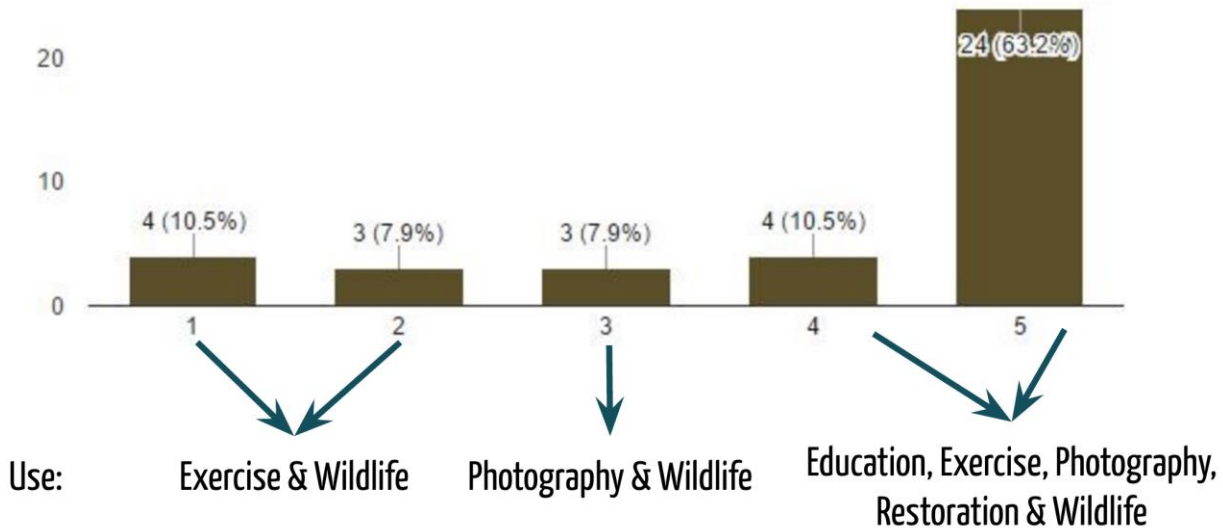


Figure 6. Level of interest in future activities. X-axis indicates level of interest in boardwalk expansion (1 = uninterested, 5 = very interested), Y-axis shows the number of people who indicated a given level of interest. 38 responses. Data gathered from November 17 to 27, 2016.

Additional Survey Feedback

It's worth noting that 6.7 percent of 38 participants rejected all three concepts, preferring that another alternative be provided (Figure 5). Respondents cited a variety of reasons for preferring an alternate. One said the boardwalk should, "[Go] only around the edge, not through the middle of the marsh. That is clearly bad for wildlife." Another said "A boardwalk through the very thick cattail section of the marsh is simply a waste of money. There is nothing to see in there except red-winged blackbirds and swallows in summer. The avian action is in the saltwater western section of the marsh. It would be an incredible waste of money (and Edmonds has little to spend on this) to invest in such an extensive boardwalk in an area that won't yield much for birders or photographers."

In response to a separate question, survey respondents noted that they expect future uses of an expanded boardwalk to be more diverse than current uses of the existing boardwalk. Wildlife observation accounted for 50 percent of the current boardwalk activities cited by respondents, but decreased to 33.3 percent when respondents listed the future activities they anticipated on an expanded boardwalk (Figures 7, 8).

Overall, the survey results showed that nearly two-thirds of respondents favor an expanded boardwalk in the Edmonds Marsh. Concept 2 scored highest in enthusiasm (Figure 3), while Concept 3 scored the highest in head-to-head preference comparisons (Figure 5). A minority of respondents (6.7 percent) did not like any of the three concepts, or selected "other" in the survey (Figure 5). Respondents currently use the existing boardwalk primarily for wildlife viewing (Figure 7). For an expanded boardwalk, the types of use are likely to diversify (Figure 8). With respect to bicycle use on the boardwalk, a wide majority (76.3 percent) favor a complete prohibition. Similarly, the survey showed that 77.5 percent of participants favor the prohibition of pets.

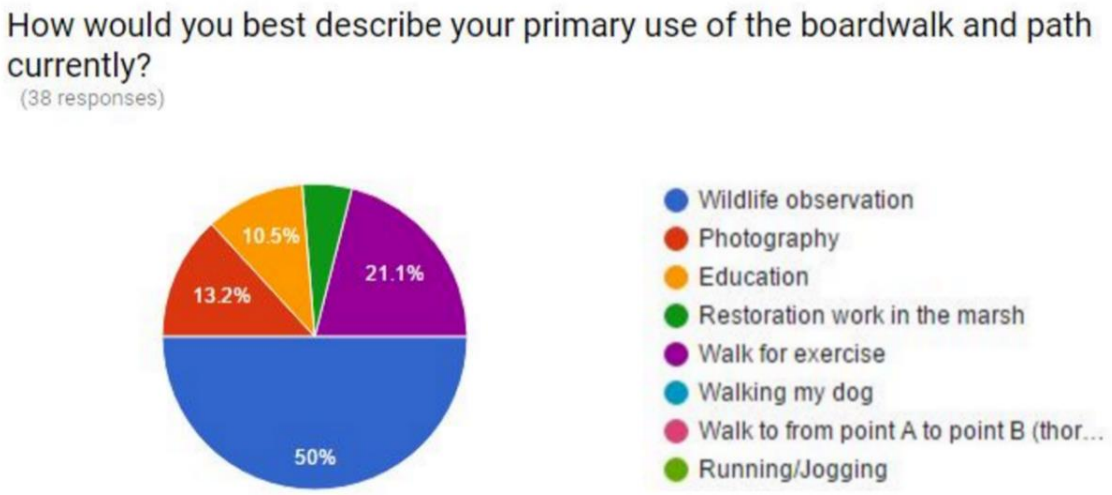


Figure 7. Current boardwalk use. 38 responses. Data gathered from November 17 to 27, 2016.

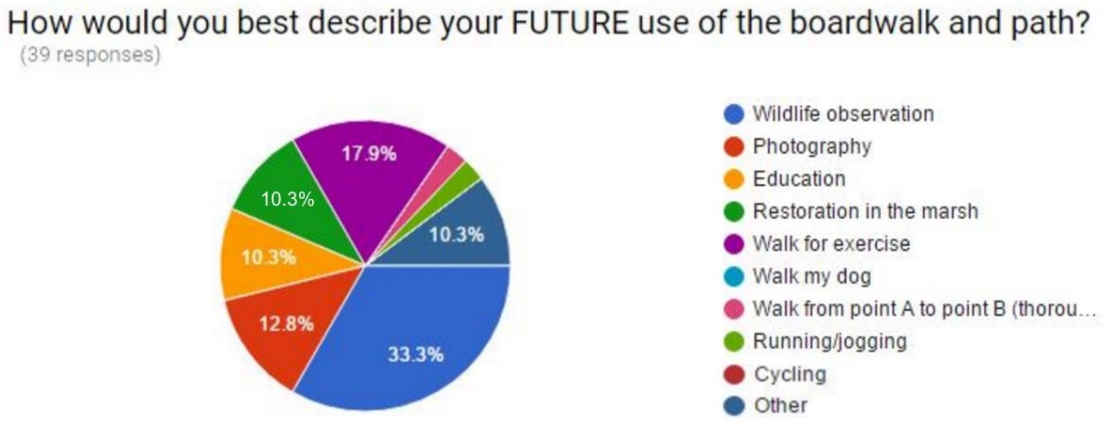


Figure 8. Potential use of expanded boardwalk. 39 responses. Data gathered from November 17 to 27, 2016.

Clearly, there is a deep desire for marsh protection with the implementation of a boardwalk project. As one survey participant states, "My answers are neutral. I love the idea of more trails in the marsh area BUT do not have enough science background to know how additional people in the marsh would impact wildlife. People have more places to be; wildlife need some areas reserved for them."

Discussion and Recommendations

After analyzing the data regarding the three concepts, we conclude that Concept 2 best meets the majority of community needs, while mitigating community concerns over the environmental impacts of an expanded boardwalk in the marsh. Community support for Concept 2 comes with the adamant desire to protect the marsh ecosystem as well as maximize the safety of people on the boardwalk. Our recommendation is that dogs and bikes not be allowed on the boardwalk. In order to prohibit dogs and bikes, the City of Edmonds could explore the idea of gated entrances on both ends of the boardwalk. We also recommend implementing a litter management plan using best practices in litter management. Multiple techniques to achieve reduction of litter include implementing annual or biannual volunteer clean-up days, trash cans, hotlines to request services for trash clean up, and clearly visible educational signage. The addition of benches along the boardwalk appears to match projected future uses and meets the majority of the community desires.

We recommend that the boardwalk be accessible to those of all abilities, including wheelchairs. Railing could include divots, or absence of railings altogether in some sections, for wildlife scopes and professional cameras. Interpretive signage is important for educational purposes, though not in line-of-sight of wildlife observation. Safety is another concern. Currently, a sidewalk exists along the busy SR 104. The Edmonds City Park sits directly east of the marsh, connected via a well-marked crosswalk. Boardwalk access to the Edmonds City Park would provide a safer and more pleasant north-south alternative to the SR 104 sidewalk. Ample parking also exists at Edmonds City Park, allowing for ease of access to the marsh for recreational use and marsh restoration work parties, since parking in Harbor Square is under private ownership and a less viable option.

In Washington State, Edmonds Marsh holds a category II wetland rating. The construction of the boardwalk within the marsh would be subject to a required 3:1 ratio for wetland restoration or creation, or a 16:1 ratio for wetland enhancement projects (Table 1). The wetland mitigation credit system would need to be assessed for planning and implementation of the boardwalk.

Community education and transparency will serve the process well, especially considering the ample concerns we received from stakeholder and community responses with regards to marsh protection and best practices. Clearly, a deep desire for marsh protection exists side by side with enthusiasm for an expanded boardwalk.

Category I and II wetlands over 100 square feet in total size or of any size with the characteristics described in subsection 25.09.160.B.1.c above	100 feet 110 feet for moderate level habitat function 200 feet for high level of habitat function
Category III wetlands over 100 square feet in total size or of any size with the characteristics described in subsection 25.09.160.B.1.c above	60 feet 85 feet for moderate or greater level habitat function
Category IV wetlands 1000 square feet or more in total size or of any size with the characteristics described in subsection 25.09.160.B.1.c above	50 feet
Category IV wetlands under 1000 square feet in total size that do not have the characteristics described in subsection 25.09.160.B.1.c above	No buffer. Use mitigation under subsection 25.09.160.C.3.

Table 2. Assigned wetland buffer widths, based upon wetland rating (SMC 25.09.160)*
**SMC buffers are based upon the 2004 Washington State Wetland Rating System. The City of Seattle has not updated their code to reflect the updated 2014 Rating System.*

	Restoration or Creation Ratios	Enhancement Ratios
Category I	6:1	16:1
Category II	3:1	16:1
Category III	2:1	8:1
Category IV	1.5:1	6:1

Table 3. Assigned wetland mitigation ratios based upon wetland rating (SMC 25.09.160)

Table 1. Wetland mitigation standards used in constructing the Yesler Boardwalk, Seattle, WA.

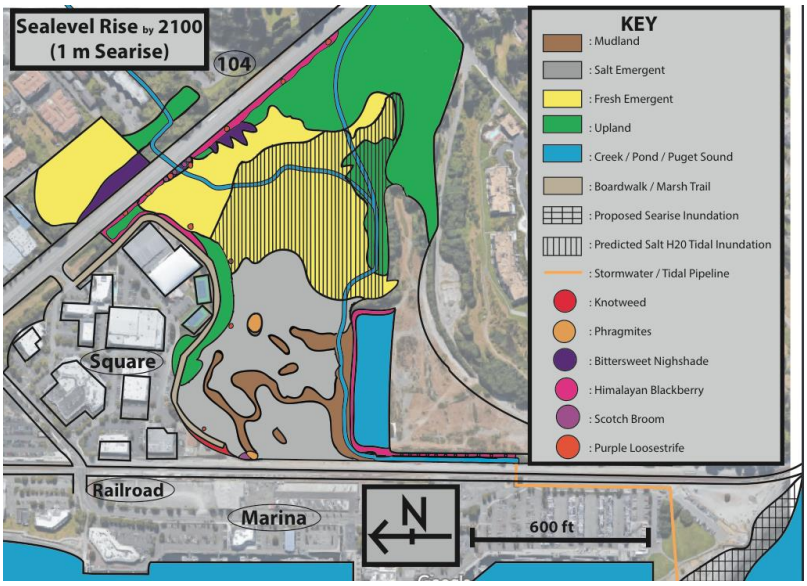


Figure 9. Total impact of 1 meter of sea level rise within the marsh. Vertical stripes on the map indicate the level of seawater inundation and yellow indicates freshwater emergent areas. This is Figure 2 within the revegetation chapter.

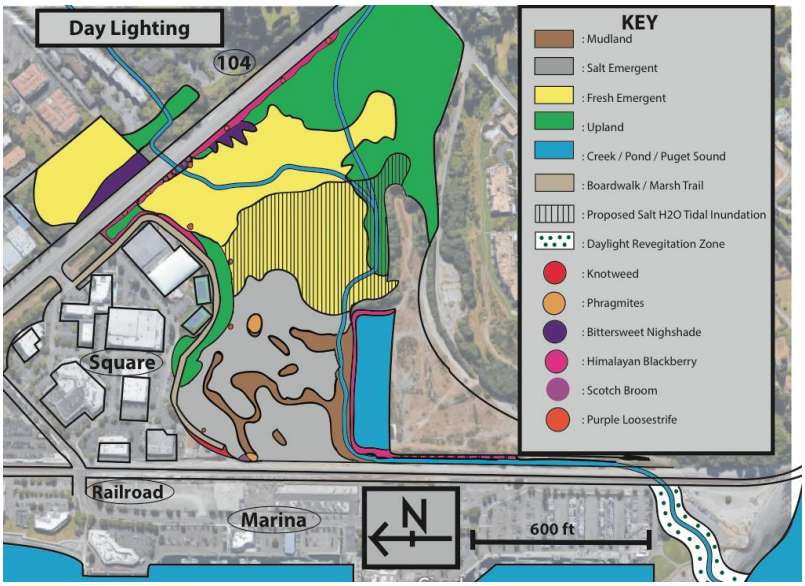


Figure 10. Total impact on marsh inundation associated with Willow Creek daylighting. Vertical stripes on the map indicate the level of seawater inundation and yellow indicates freshwater emergent areas. This is Figure 4 within the revegetation chapter.

Regarding Daylighting and Sea Level Rise

Looking forward, two dynamic processes that will affect the conditions of the Edmonds Marsh are the daylighting project for Willow Creek and the long-term effects of sea level rise (Figures 9, 10), each of which could result in changes to seawater influx. With our boardwalk design concepts, we took into account potential future saltwater inflows, which will clearly affect boardwalk placement and proximity to critical habitat. A main concern from community survey respondents was the opportunity to access views of the marsh mudflats for wildlife observation. Please refer to further research in the Willow Creek Daylighting and Sea Level Rise chapters for more information regarding saltwater inundation.

Research Improvements

In light of our survey- and interview-based research, our team has recommendations for further research on the boardwalk proposal. The data we collected on future uses suggest that an expanded boardwalk will increase diversity of uses for the marsh, and the total number of community members utilizing the new boardwalk would likely increase (Figure 8). One way to improve our study would be to gather a wider range of survey participants. Our survey was only open for response for 10 days, and only publicized through stakeholder contacts and social media. Releasing the survey for a longer period of time would increase the representativeness of community input. Additionally, when reviewing the survey results, we had difficulty interpreting community responses that selected "other," since respondents did not have the opportunity in the survey to expand on what "other" means. Lastly, we highly recommend soliciting feedback from regional tribal constituents. Unfortunately, time constraints prevented our interviewing Todd Zacky at Tulalip.

Plan for Assessment

For measuring the success of an expanded boardwalk at the Edmonds Marsh, we recommend using an assessment framework that balances stakeholder success, ecological success, and learning success, as conceptualized in Figure 1 (Palmer et al., 2005), and that also distinguishes between ecocentric and anthropocentric values. The assessment plan should include measurements correlated to the objectives of the proposed boardwalk. The objectives that our research team has identified include: increasing community health, mitigating the boardwalk's environmental impact, matching the project with the community's needs, enhancing educational opportunities, and minimizing adverse human-caused impacts, such as vandalism and non-designated trails. To assess community health, walkability and accessibility are variables that could be measured. To monitor the environmental impacts of the expanded boardwalk, citizen scientists using bird watching mobile apps, such as eBird and iNaturalist, could help track any increase or decline in bird populations or bird species richness in the marsh, both before and after boardwalk installation (Cornell Lab of Ornithology, 2016) (INaturalist, n.d.). Educational opportunities could be measured by the installation of interpretive signage and the number of educational programs implemented on an annual basis. Monitoring adverse human impacts could involve measuring the amount of litter removed, the extent of social trails, the number of work parties required, or the number of calls to a litter hotline. Whichever measurements are chosen, a plan for assessment will help meet the project objectives for the Edmonds Marsh Boardwalk.

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HARBOR SQUARE STORMWATER MANAGEMENT

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Introduction

Urbanization and Stormwater

In order to understand the effects of urbanization on hydrology in a watershed, one only needs to examine the hydrology of the Edmonds Marsh or a (relatively) nearby equivalent. The primary hydrologic function of the marsh is to slow water flow (Galster et al. 2006). Currently, the generally impermeable nature of the Harbor Square property results in rapid runoff which quickly overwhelms the existing stormwater system, resulting in increased flooding at Harbor Square and discharge of urban runoff with constituent pollutants to Edmonds Marsh. The effects of urbanization increase as a function of the percentage of watershed area covered by impervious surfaces. At 10 percent imperviousness, flood frequencies may be significantly increased and water quality may be significantly decreased in receiving waterbodies (Klein 1979, Booth and Jackson 1997, Schiff and Benoit 2007). At 25 percent imperviousness, receiving waterbodies may be considered degraded (Matlock and Morgan, 2011). In cases like Harbor Square where 75 to 100 percent of surfaces are impermeable, the intensity of runoff ensures that downstream bodies of water (in this case the Edmonds Marsh) may be considered seriously degraded (Figure 1).

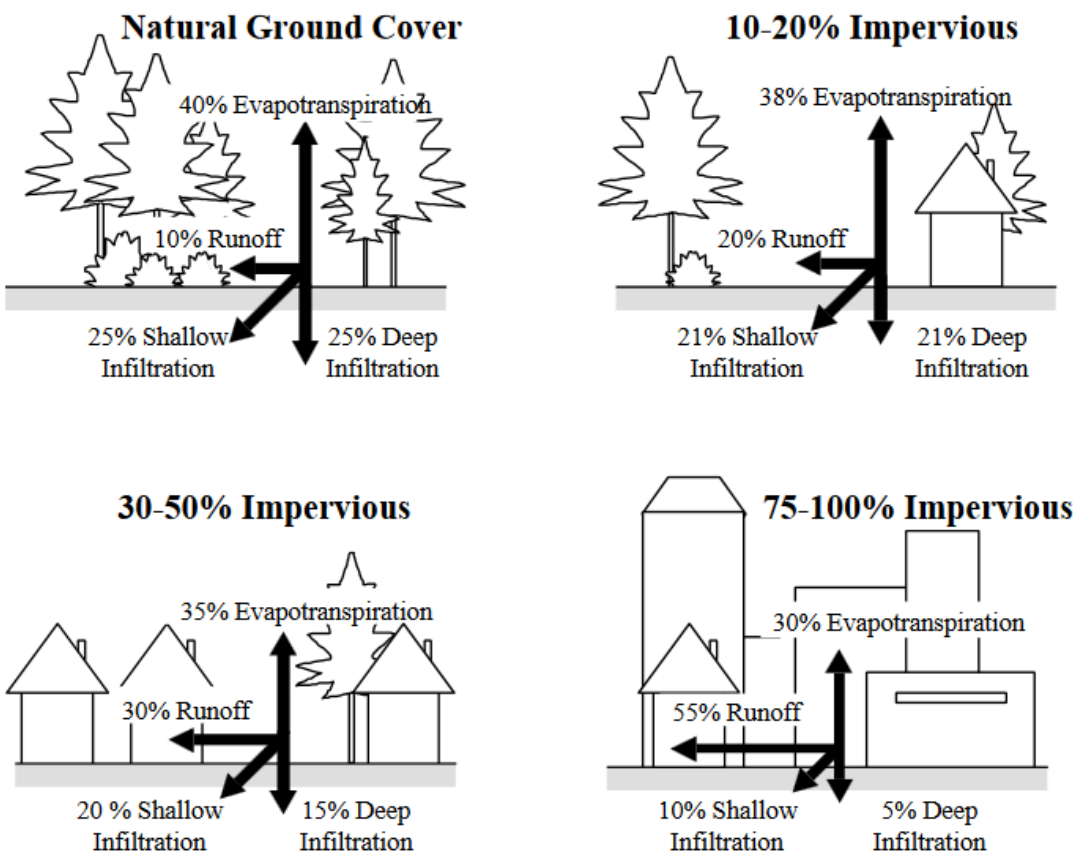

Figure 1. Effects of imperviousness on runoff and infiltration. Arnold and Gibbons, 1996.

Not only does the inadequate stormwater infiltration and retention capacity of the property result in significant flooding, it promotes poor water quality which has the potential to cause harmful effects to wildlife using the marsh. A study of urban runoff done in Washington State found an annual total suspended solids load of 107 kilograms per hectare per year, phosphorus load of 0.63 kilograms per hectare per year, and zinc load of 0.43 kilograms per hectare per year (Reinelt and Hornes, 1995). Other particularly harmful contaminants include hydrocarbons, readily soluble salts, and acid-generating compounds which alter pH, most commonly sulfur oxides and nitrogen oxides (Göbel et al., 2007). Thus, given the high percentage of impermeable surface in Harbor Square and its situation adjacent to the fragile Edmonds Marsh, there is reason for concern regarding the pollutant load entering the aquatic ecosystem. If the percentage of impermeable surface can be reduced, the resulting increased retention time and infiltration capacity could not only dampen the peak rate of flow, thereby reducing flooding of the surrounding areas, but also serve to improve the quality of stormwater draining into the marsh.

The increased runoff associated with impermeable surfaces tends to increase sedimentation in stormwater draining to the marsh, as well. Greater sediment loads increase the turbidity of the water (a condition of greater opacity/lesser transparency), which tends to result in increased water temperature due to increased absorption of shortwave (solar) radiation and consequently greater emission of longwave (infrared/thermal) radiation (Fondriest 2014). Increased water temperature will in turn decrease the amount of dissolved oxygen in the water, because the solubility of oxygen in water declines with increasing temperature. Native salmonid fish depend on water that is clean, clear, cold, and well oxygenated, and for these reasons an urbanized watershed tends to reduce the quality of salmonid habitat it contains.

Harbor Square

Harbor Square is a commercial property located immediately adjacent to and draining into the Edmonds Marsh. It is owned by the Port of Edmonds and contains several buildings which house tenants including a hotel, dental offices, a restaurant, and an exercise club, among others. During fall and winter, major flooding occurs on the property due to the combined effects of high tides and heavy and prolonged precipitation events. The tidal component to the flooding serves to complicate matters, and there doesn't seem to be an obvious method of mitigating this problem, other than opening or closing the tide gate adjacent to the marina. An additional wrinkle rears its head in the form of relatively narrow culverts through which the tides are conveyed into and out of the marsh. The narrow bore induces a pronounced lag between the occurrence of high and low tide outside and inside the marsh. At this point, the vast majority of surfaces within the Harbor Square complex are impermeable; parking lots and roofs made mostly of asphalt and the attendant flooding issues are a predictable consequence of urbanization in a watershed.

The ecological impacts from flooding due to impermeable surfaces include the discharge of large quantities of pollutants into the marsh, and ultimately the Salish Sea, as well as implications regarding community health. The economic impacts of flooding include loss of commerce when businesses are inaccessible, in addition to property damage. Between 1990 and 2013, the combined cost of physical damage and reduced patronage to Harbor Square business owners is estimated to be $783,500 (Conner 2016). Not including ecological or water quality management costs, the average annual cost of this recurring flooding is $34,000.

Objectives of this Report

The objectives of this report are to provide recommendations to the City of Edmonds for (1) improving stormwater management at Harbor Square using retrofittable solutions (as opposed to total site redevelopment), (2) making stormwater management strategies appealing and beneficial to business owners, property owners, and the community in general, and (3) monitoring and assessing the effectiveness of stormwater management strategies. We will assess the benefits of possible solutions and the ways in which implementation of these solutions will affect the community, with the ultimate goal being to find a strategy that will provide maximum benefit for the stakeholders.

Low Impact Development

Definitions and Overview

Low Impact Development (LID) is a relatively new urban design technique applicable to stormwater management, with widely recognized capabilities to improve the water quality of runoff (Clar, 2015). Methods can range from minor additions to major installations, and include permeable pavement, bioswales, green roofs, and rain gardens. LID takes into account the needs of the ecosystem while simultaneously decreasing the cost of wastewater management and decreasing the frequency, intensity and severity of flooding. We recommend application of LID at Harbor Square because these solutions focus on environmental conservation and use or mimicry of onsite natural features and processes, without necessitating complete redevelopment.

A primary benefit of LID for Harbor Square is that complete redevelopment would be avoided. A September 2016 ruling by the City Council of Edmonds expanded the required buffer surrounding the Edmonds Marsh from 65 feet to 125 feet (Soergel, 2016). This means that any new development by the Port of Edmonds must, in effect, fit within a substantially smaller developable footprint because of areas lost to the new, enhanced buffer zone. While major renovations to Harbor Square will need to happen eventually, we propose a short term plan (20 to 40 years) of minor changes to increase permeable surfaces without redevelopment of the entire property. Keeping in mind that Harbor Square is an important business center in the area, we have a few recommendations to decrease urban runoff and flooding without negatively affecting the Port or the people of Edmonds.

Economic Costs and Benefits

Implementation of LID often proves to be an economic boon to communities which choose to do so. In many cases, LID has proven to be less expensive than traditional options. The economic benefit of these projects is estimated by accounting for increases in property value, reduced maintenance costs, and savings from eliminating pipes, manholes, and downstream water treatment requirements. Retrofitting Harbor Square to better manage its stormwater will yield additional economic benefits by increasing accessibility to the businesses during flood events and reducing the occurrence of property damage due to flooding.

One report from the U.S. Environmental Protection Agency (EPA, 2013) explores the economic costs and benefits of many kinds of LID infrastructure. The report found that permeable pavement in West Union, Iowa, resulted in lower long term costs than concrete pavement; an LID storm sewer system near Lake Como in Minnesota proved to be less expensive because it helped reduce nutrient discharge to the lake; and in Portland, Oregon, an eco-roof program had long-term benefits estimated at $400,000. Swales and permeable surfaces were some of the earliest forms of stormwater

management, and there are many examples of their successful implementation. Newer to the market are systems like portable, above ground rain gardens. These approaches may all produce the aforementioned benefits, can be used as an extension of existing infrastructure, and are relatively inexpensive (EPA, 2007).

Community Benefits

The installation of permeable pavement and rain gardens or bioswales in Harbor Square would be economically beneficial to the business interests therein, but tangential benefits would also accrue—the site would be aesthetically pleasing and would boost mental and physical health within the community. The benefits of green infrastructure within urban settings on public wellness were elucidated in a University of Washington study (Wolf, 2014). Wolf explains how "introducing nature" into an urban space contributes to socialization, active living, and healthy mental states, including reduced stress and anxiety. In Harbor Square, bioswales, tree box filters, and rain gardens would serve to introduce more "nature" onto the property. Sidewalk repairs would promote walking, providing people with more access to businesses and opportunity for exercise. With a senior center nearby, it is of particular interest that Wolf's (2014) study also indicates that, over a five-year period, tree lines and other natural features have played a role in longer lifespans. Flood mitigation derived from green infrastructure would allow for better accessibility to the marsh (i.e., access would be less frequently blocked), where the public visits for recreational purposes, which could serve to encourage socialization. Maintenance of rain gardens could offer a chance for the community to come together for teaching and horticulture practices, as well. In Harbor Square, the *employees* of the various businesses, an often overlooked group, would benefit from green infrastructure features. Employees with a view of nature are better able to attend to tasks, report fewer illnesses, and have higher job satisfaction (Wolf, 2014).

Another important benefit of rain gardens and permeable pavement for the employees, customers, businesses, and additional visitors of Harbor Square, is retention of adequate parking combined with concurrent reduction of flooding. The reduced flood severity/frequency would contribute to year-round accessibility and little to no net loss of parking capacity and/or commerce, a mutually advantageous condition for both customers *and* business owners. As well, birdwatchers and other visitors to the marsh use the Harbor Square parking lot. Consequently, flood reduction could enhance the beneficial uses of the restored marsh in addition to fostering a healthier community for the City of Edmonds at large.

Improved safety would also be an important benefit. With a combination of effective stormwater management methods, reduced flooding of the parking lot and nearby roads would result in safer driving conditions. The tendency to hydroplane will be reduced, and during periods of cold weather there will be less chance of ice on the roads, one of the most serious driving-related weather hazards in Washington. The implementation of rain gardens will act to promote safer walking surfaces as well. Our recommendations for south of the athletic center, near the sidewalk that abuts the marsh, would lead to reduced stormwater flow over the sidewalk and into the marsh. The walkway surface would be made less slippery, and thus safer to use, making the marsh and business center more accessible for the community.

Stormwater Management Recommendations

Leveling/Grading Drainage Improvements

Flooding and runoff pollution can be reduced simply by topographic (geomorphic) modification. The existing strip of vegetation along Dayton Street is about 2 to 3 feet above the surface of the parking lot (Figure R2). We recommend that this area be excavated to slightly beneath street grade so that stormwater runoff can be absorbed into the soil instead of gathering and flowing upon impervious pavement. Similarly, within the Harbor Square parking lot, some storm drain inlets are slightly above grade; elevated inlets cannot effectively capture water and are likely to contribute to flooding. We recommend leveling the existing drains, in particular the stormwater grate located on the south corner of the bookstore (Figure R3). In addition, adding curb-opening inlets on vegetated aisles between parking spaces could improve drainage. A perfect place for a curb-opening inlet is on the eastside parking lot of building 2, indicated in the map (Figure R1).

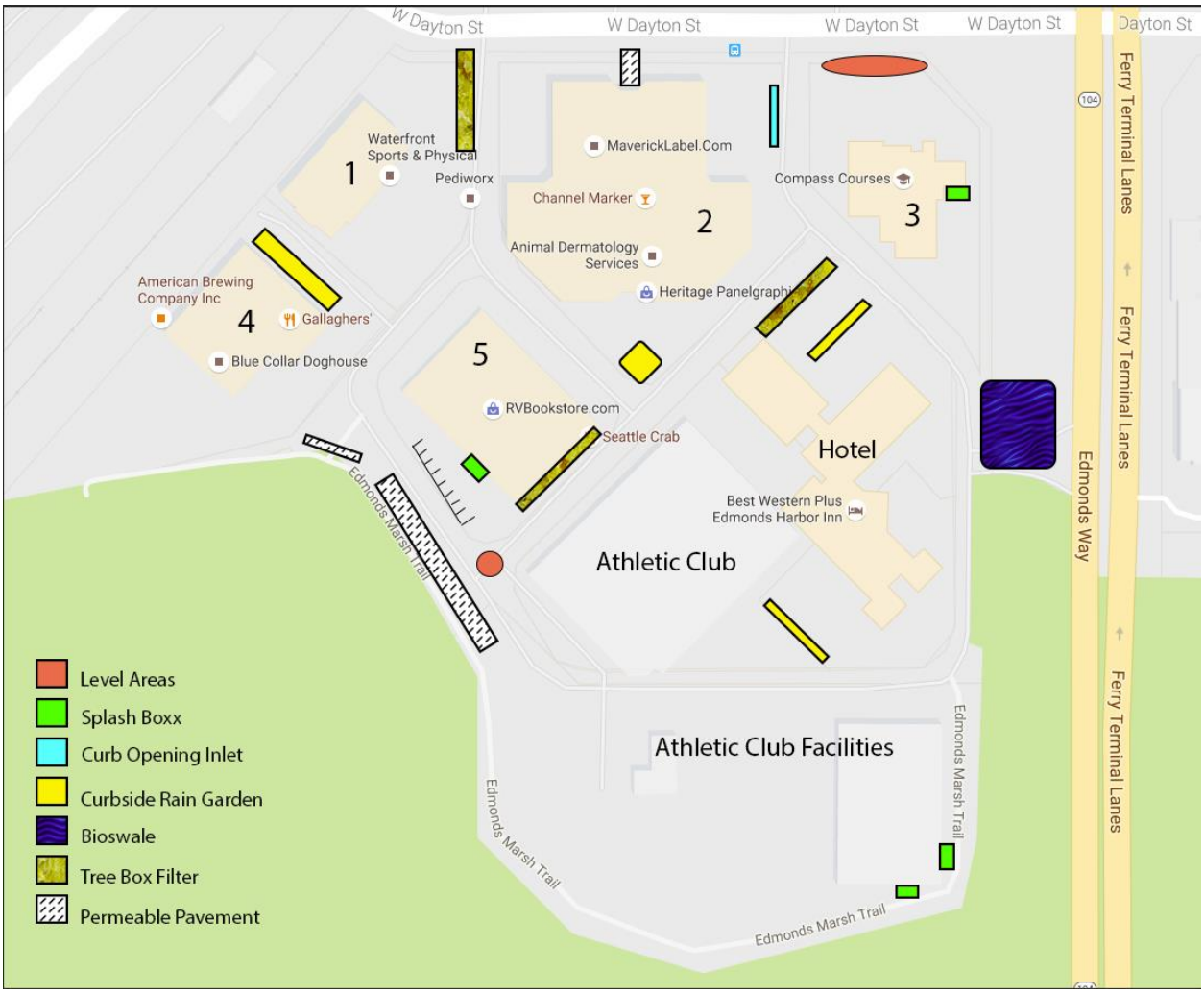

Figure R1. Recommendations for LID stormwater management.

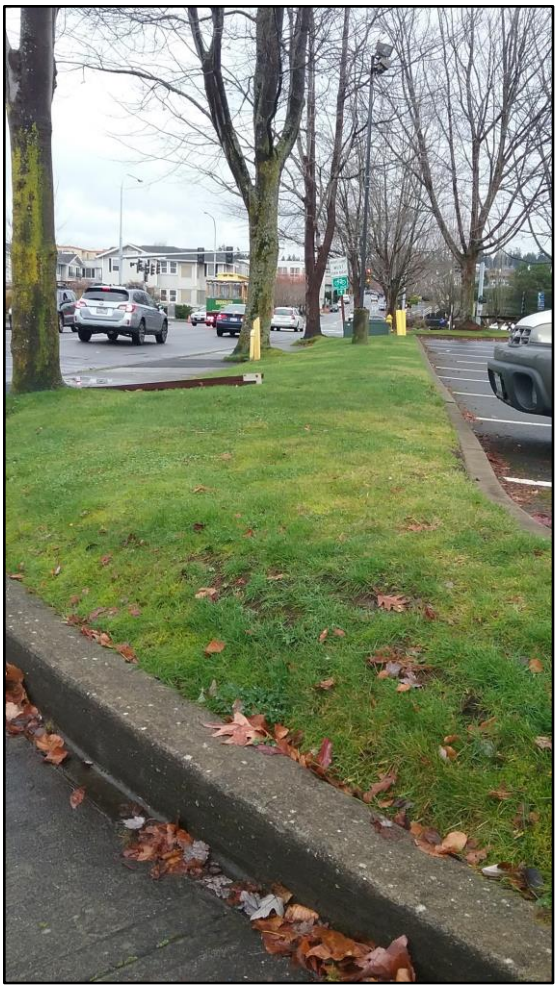

Figure R2. Mounded green space on Dayton Street north of hotel (photo courtesy Sara Schoeneman, 2016).

Figure R3. Grate on south corner of bookstore in Harbor Square (photo courtesy Sara Schoeneman, 2016).

Tree Box Filters

Existing tree-lined medians in the parking lot can be replaced with tree box filters that capture excess stormwater and filter it through tree root systems (below pavement) before entering the stormwater system (Figure R4). The drainage of these tree box filters would connect with the current stormwater piping, and minimal excavation would be required. The addition of tree box filters will have a combined advantage of slowing and filtering rainwater, increasing permeable surfaces, and completing a much needed renovation to the parking lot. There are some places in the mall, namely the west entrance off of Dayton Street, where existing tree roots have damaged the pavement (Figure R5).

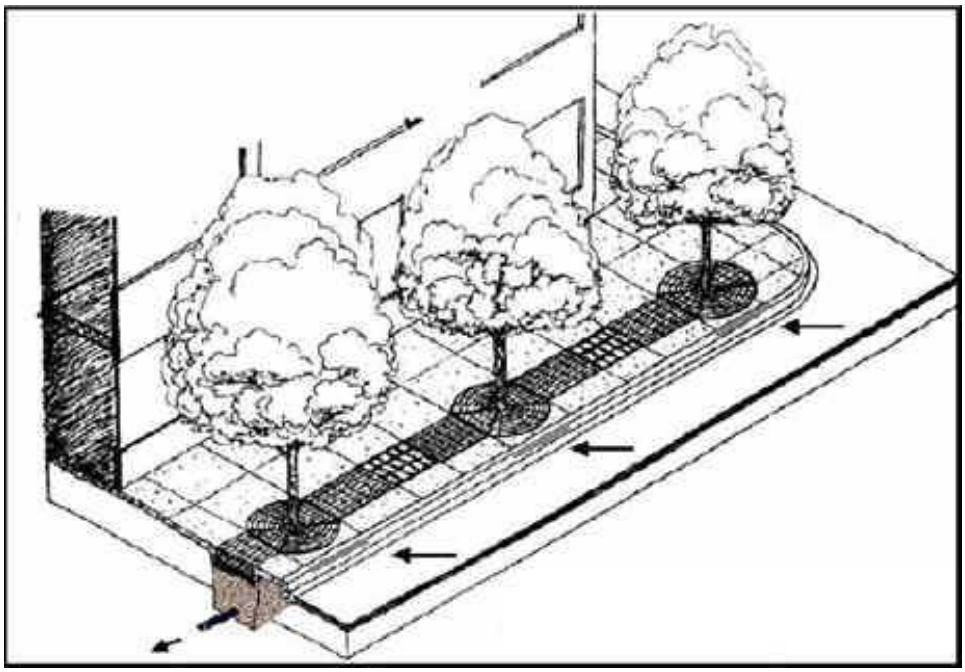

Figure R4. Tree box filter example (Low Impact Development Center, 2007).

Figure R5. Damage to existing walkway (photo courtesy of Robin Crandall, 2016).

There are three other sites where we recommend tree box filters. Two of the recommended areas already have vegetation: along the west side of building 5 and by the east parking lot of the Best Western (Figure R1). However, the existing vegetation is raised above pavement level and does not allow for slow drainage or infiltration from pavement runoff. Because there are already trees in these locations, retrofitting will not take parking spaces away from the business center and will only increase productivity of existing green areas. Our third proposal, though, is that a new island be sited behind building 5 (Figure R1). This would require restructuring the parking lot with potential benefits in the form of additional parking spaces and increased walkability and shade. Given the close proximity of the marsh, this tree box filter is of greater importance. Having more permeable surfaces near the marsh and within the buffer area will decrease flooding into the business district by acting as a hydrologic extension of the marsh.

With tree box filters covering just 5 percent of the catchment area, 91 percent of total suspended solids and 70 percent of soluble heavy metals might be removed, and runoff volume might be reduced by 40 percent at a hydraulic loading rate of no more than 1 meter per day (Geronimo et al. 2013). A 6-by-6-foot filter box per quarter-acre is the most cost effective and optimum for pollutant removal (Low Impact Development Center, 2007). Standard tree box filters in a catchment area of one-third of an acre cost $12,500 plus maintenance (Rector et al. 2013). Tree box filters serving larger areas would be more expensive due to increased installation and maintenance costs. If Harbor Square were to install tree box filters in the aforementioned locations, we estimate the cost of installation would be approximately $37,500. However, the larger catchment area would also increase the cost of maintenance.

Rain Gardens and Curbside Swales

In order to make use of the existing planters and vegetated islands in the parking lot of Harbor Square, we recommend the use of bioswales. A bioswale is designed to catch and hold stormwater runoff in a deep or long trench, constructed using layers of sediment and flood-tolerant plants. Bioswales modify topography in a hydrologically beneficial manner for stormwater treatment applications, while also providing improved habitat for local fauna. They function to mitigate the damaging effects of urban runoff by slowing flow and pollutant filtration, while also being visually appealing (Borst et al., 2008). Many of the currently vegetated areas do not effectively absorb stormwater runoff because of soil compaction and elevation. Minor renovations could be done to some of the existing green spaces to decrease the topographic prominence of the planters, install better drained soil, and revegetate with more drought/flood tolerant plants. Because Harbor Square has a high water table, there is less water holding capacity for green infrastructure. We recommend wide, shallow bioswales where appropriate. Where surface area is limited, we recommend curbside rain gardens that would channel water through a long strip, rather than hold it in a wide or deep pool (Figure R6).

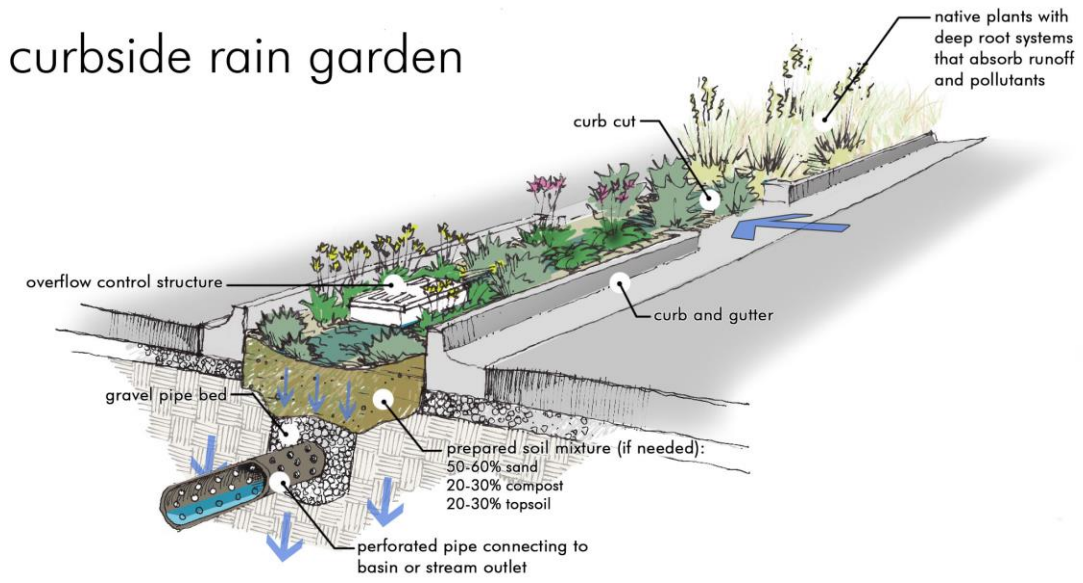

Figure R6. Example of curbside rain garden (Eagle Creek Watershed Alliance, 2016).

A curbside rain garden is an alternative form of bioswale that can occupy less surface area. It allows stormwater to run off the pavement through a gap in the raised curb, and then to filter through vegetation and several layers of sediment. For the most efficient use of space we recommend installing curbside rain gardens along the front of parking stalls. The map (Figure R1) details the specific locations where curbside rain gardens would be most effective. In all cases the rain gardens use very little surface area, but are highly effective in slowing stormwater runoff and decreasing pollutants entering the watershed.

Two locations are recommended for large bioswales: south of building 2, and at the east side of the square along SR 104 (Figure R1). The area by building 2 already has vegetation, but needs renovation. This location is also vital to stormwater management, because it is in the center of the site, where there are few storm drains. Flooding during storm events is likely caused by lack of drainage throughout the parking lot. Increasing the vegetated area would increase the permeable surface area substantially, which would serve to improve drainage. While a few parking spaces would be eliminated, the improved aesthetics could benefit quality of life (Barnhill & Smardon, 2012). At the current green space on the border of SR 104, the compacted soil can be replaced to allow for better drainage into the marsh through the drainage ditch and to alleviate flooding from Shellabarger Creek. The possibilities for this specific area are varied because of its large surface area and connectivity to the marsh. The south end of the current drainage ditch discharges to the marsh, and efforts could be made to restore ecological function of this historical marsh area.

In Portland, Oregon, a similar (but smaller scale) stormwater management project was recently completed. The city retrofitted the Oregon Museum of Science and Industry (OMSI) parking lot to help mitigate runoff into the adjacent Willamette River. Ten bioswales totaling almost 14,000 square feet were installed in the parking lot. These swales make up less than 7.5 percent of OMSI's property (parking lot and buildings) and permit infiltration of 3.9 million gallons of runoff every year (Larson, 2014). Between minimizing harmful impacts on the river and avoiding expensive maintenance of underground drainage systems, Portland estimates a savings of $78,000 over conventional management practices (Larson, 2014). Because of the climatic similarities between Portland and

Edmonds, the two sites are comparable; Portland averages 43.8 inches of rain annually, while Edmonds receives 36.2 inches on average (NOAA, 2016), with similar seasonality. At Harbor Square, a bioswale footprint of 7.5 percent equates to 33,000 square feet. Installing new swales costs between $3 and $10 per square foot (Larson, 2014), which would result in a minimum price of $99,000 at Harbor Square.

Mobile Rain Gardens

A novel technique we recommend is the installation of mobile rain gardens. This is a relatively new technology in which 8-by-12-foot roll-off containers, which can be relocated as needed, are used to mitigate the effects on stormwater hydrology caused by roofs. Each rain garden contains a layered aggregate composed of gravel at the base, followed by a large surface area of porous volcanic rock to absorb toxins, and lastly topsoil and mulch for plants. The container is then connected by a downspout to the existing gutter system, and the runoff is distributed to the rain garden via perforated pipe. There is an outlet orifice at the bottom of the container.

The manufacturer of these devices is Splash Boxx, a company based in the Puget Sound area and founded in 2012 (Figure R7). The containers are pre-engineered to accommodate storm water from a specific area of roof (Herrera Environmental Consultants, 2013). Splash Boxxes may also be connected in series to treat larger areas. The mobility of each unit, as well as the fact that no excavation is required, are each advantageous. With regard to excavation, the high water table at Harbor Square precludes digging to more than 2 feet below ground level. The mobile aspect of the Splash Boxx lets multiple businesses decide where to place it, and then move it at any time. It seems

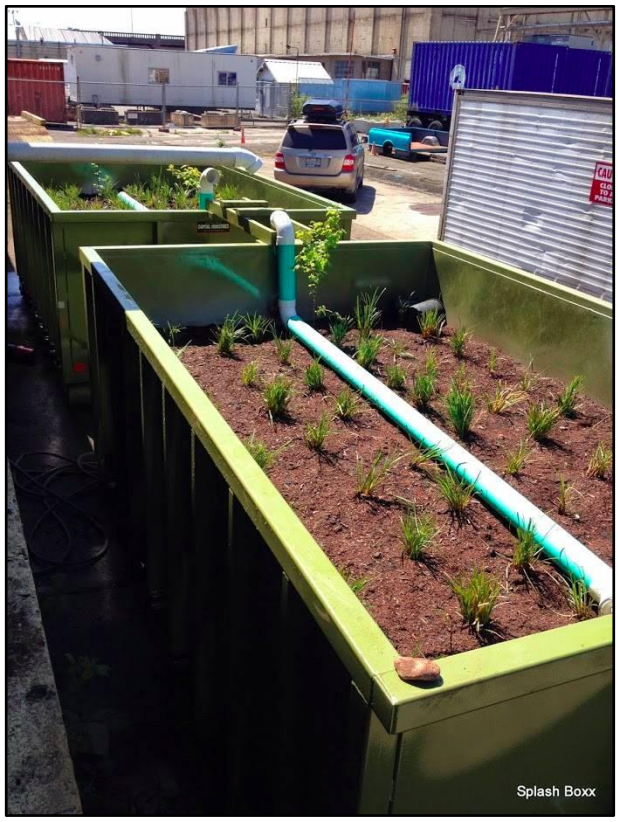

Figure R7. Splash Boxx rain garden (Kevin's Rain Gardens, 2014).

likely that a Splash Boxx would displace some parking adjacent to the building being served. This issue would best be resolved if tenants agreed to move the container(s) around the property on a schedule, so each tenant equally shares the burden of temporarily losing parking spots. Figure R1 includes potential locations for four Splash Boxx installations, but is only one of many possible configurations that tenants might pursue. Each Splash Boxx costs approximately $10,000, complete with piping, plants, media, and delivery to the site. They are expected to have a lifespan of 30 years with minimal maintenance, including checking inflows and outflows for obstructions, annual replenishment of mulch, and initial watering to ensure plant establishment (Herrera Environmental Consultants, 2013).

Permeable Pavement

Reconstructing either the entire parking lot or portions thereof with permeable pavement could lead to a more natural hydrologic runoff scenario at Harbor Square, while also reducing flooding. This technology mimics the infiltration processes of natural soil by trapping pollutants and solids in granules comparable to soil particles (Green Building Alliance, 2016). Surveys have found the removal rate of suspended solids for permeable surfaces to range from 50 to 95 percent (Wright et. al. 2011; Gilbert & Clausen 2006; Ranchet 1995; Balades et al. 1992). Water that would otherwise flow unrestricted over impermeable surfaces is able to infiltrate more slowly, mimicking natural hydrology. There are several types of pervious surfaces that can be used: permeable clay bricks, interlocking concrete pavers, resin-bound paving, and porous concrete and asphalt (Table 1). A porous parking lot installation in Athens, Georgia, was studied and found to reduce runoff by 93 percent, compared to the previous asphalt (Dreelin et al., 2006). Although permeable surfaces have higher initial costs than conventional concrete or asphalt, in the long-run they require less maintenance (Terhell et al., 2015). In one study conducted over a 25-year span, dollar-cost benefits of permeable pavement installations were estimated to be $64,650 per half acre (Terhell et al., 2015). It should be recognized, however, that the shallow water table at Harbor Square limits subsurface water holding capacity, and may thus render permeable pavements less effective at promoting infiltration in comparison with installations at other sites.

Table 1. Cost estimates of various permeable surface materials (A Better City, 2016).

Pavement Type	**Cost**	**Service Life**
Clay brick pavers	$10-$12 per sq. ft.	20-40 years
Interlocking pavers	$2.50-$10 per sq. ft.	20-40 years
Resin-bound	$3-$12 per sq. ft.	5-10 years
Porous concrete	$2-$6.50 per sq. ft.	15-30 years
Porous asphalt	$0.50-$2.50 per sq. ft.	7-20 years

Although permeable pavements do not provide the aesthetic appeal or the same degree of pollutant filtration as planted areas, such pavements have many additional benefits. By allowing water to drain off the parking lot immediately, rather than forming puddles, the pavements can reduce the risk of hydroplaning, the presence of black ice, the formation of potholes caused by freeze-thaw cycles, and the need for salting/sanding.

Cost estimates for pervious pavement range from 50 cents to $10 and up per square foot (Table 1), not including the cost of installation or of removal of existing pavement. For material cost alone, we estimate that retrofitting 25 percent of the existing pavement at Harbor Square would cost at least $59,000. If resurfacing the entire parking lot is not economically feasible, we suggest priority be given to replacing the pavement immediately adjacent to the marsh, along the entrance to the boardwalk and walkways (Figures R1, R8 and R9). We consider these areas particularly important because replacing pavement next to the marsh would provide an additional buffer that could increase water quality and mitigate flooding, while porous walkways would likely be less slippery and thus safer.

Figure R8. Entrance to boardwalk from Harbor Square (photo courtesy Sara Schoeneman, 2016).

Figure R9. North-side walkway of building 2 (photo courtesy Sara Schoeneman, 2016).

Community Engagement Recommendations

Public Information and Education

Our primary community engagement goal is to get citizens of Edmonds on board and excited about proposed changes. We believe this process starts with education. In order to inform the community about stormwater management, we're proposing various community events, such as workshops and lectures. Events might be hosted by state or local environmental organizations and should aim to educate community members on hydrogeomorphology, wetlands ecology, and the associated pertinent effects on their day-to-day lives, as well as ways to combat deleterious effects, such as polluted runoff and flooding. Information from such events should also be made available electronically (e.g., on websites and through social media). Additionally, we recommend installation of informative signs/posters and tabling at various community events (e.g., concerts, film showings, markets, art shows). The advantage of involving community members in the early stages is that the city gets the opportunity to consider the needs of residents and visitors, and discuss ways the project could work toward a mutually beneficial end, both functionally and aesthetically.

Implementation of these proposals provides a unique opportunity to engage the community in improving the physical attractiveness of Harbor Square. This end could be furthered by staging work parties for community members to plant rain gardens, or construct tree box filters. Community members could also install art pieces (e.g., murals, sculptures) to complement new rain gardens and decorate Splash Boxxes. These projects would also provide opportunity for community members to volunteer their time and acquire a sense of pride of ownership. We also suggest outreach at local schools, including elementary through secondary. Reaching students is extremely valuable in creating new generations of active citizens who are informed about environmental issues and passionate about addressing them.

Incentive Programs

In order to assist the businesses of Harbor Square in dealing with flooding and stormwater management, we recommend the City of Edmonds create and apply an incentive/rebate program. Rain garden incentive programs are currently implemented throughout Western Washington. Cities like Seattle, Olympia, Everett, Port Angeles, Tacoma, and Bellingham all have some sort of rebate program which offers to pay percentages of project costs for building a rain garden. The purpose of these programs is to encourage home and business owners to take action in helping their community better manage urban stormwater and its associated pollutants.

The incentive program for Edmonds would be especially impactful for Harbor Square, as a tax deduction or refund would be more likely to encourage tenants and property owners to construct rain gardens. The reward to residents who choose to build rain gardens would depend upon Edmonds' budget, but the Lake Whatcom Incentive Program could serve as a model. Bellingham's program offers $1,000 to $6,000, based on the percentage of property improved using a rain garden. All necessary materials can be reimbursed up to 100 percent and labor costs up to 75 percent (City of Bellingham, 2015). Funding for this program has been provided by Whatcom County along with the Department of Ecology and Sustainable Connections. We recommend Edmonds create a website for such a program to inform the community about its details, such as how to construct and maintain a proper rain garden, how a rain garden works, and how much one costs.

Monitoring and Assessment Recommendations

Monitoring Plan for Runoff and Water Quality

A good assessment plan is needed to evaluate the performance of the modifications and should include a pre-project (i.e., baseline) evaluation as well as immediate and long-term post-completion monitoring. The assessment plan should be tailored to the specific objectives, locations and timelines of the project (Gulliver and Anderson, 2007).

Baseline monitoring is critically important, so much so that one year of pre-project data is worth 10 years of post-completion data (Roni and Quimby, 2015). Fortunately, we are in a position for Harbor Square to implement a pre-project assessment plan. Baseline monitoring for this specific project would have to account for restoration work already completed around the marsh. This would include all replanted vegetation and all invasive species that have been removed from the buffer zone separating the marsh from the parking area. Samples of stormwater from roof downspouts (particularly those targeted for installation of Splash Boxxes), as well as that entering the marsh, and potentially from within the marsh itself, should be collected and analyzed for metals, hydrocarbons and suspended solids. The data should include the main constituents found in urban runoff and compare that to mean concentrations found in Western Washington, as well as national water quality standards for aquatic life (Table 2). Turbidity and temperature of the water in the marsh should also be analyzed, as these parameters are among the most significant to the health of salmonids. Data on the intensity of the flooding and GIS mapping of flooded areas are also needed. Additionally, the percent coverage of permeable surfaces and impermeable surfaces of Harbor Square should be calculated.

Once the restoration design has been completed, post-project assessments can begin. This stage of the assessment should begin immediately following the completion of the project, and is a method used to confirm the project was finished according to the approved design and all the physical and fiscal design elements, and if not, why. While most of our monitoring would be focused on technical response variables (e.g., runoff volumes, water quality parameters), post-project assessments should also try to characterize the stakeholder's satisfaction with the project. All findings should be documented to guide adaptive management and inform the design of potential future stormwater management projects. The most effective restoration projects should also include some contribution to scientific knowledge, thus benefiting society as a whole (Palmer, et al., 2005).

To assure that stormwater management facilities function properly over time, visual inspections should be scheduled at least once per year (Gulliver and Anderson, 2007). Visual inspections include monitoring the integrity of the structures built for the project, health and mortality of plants inside the structures, and noting any additional, untreated problem areas. Considering the minimal effort and low cost required for visual inspection, it is recommended that visual inspection be used as an initial assessment tool. Quantitative information on performance of the design will require additional monitoring. Photographs should be taken as part of any visual inspection to document conditions of the facilities for future reference. Long-term monitoring can be expensive, but needs to be addressed to ensure the project meets its long-term objectives.

Table 2. Main constituents found in runoff entering Edmonds Marsh from Harbor Square, compared to mean concentrations (µg/L) found in Western Washington stormwater runoff and national water quality standards for aquatic life. *

	At Harbor Square	Western WA mean	National Criteria for Aquatic Life
Metals			
Arsenic	ND	2.2 - 2.6	150
Cadmium	ND	0.9 - 2.8	0.72
Chromium	ND	7.5 - 18.0	74
Copper	5.8	3.1 - 18.1	29
Iron	470	-	1000
Lead	ND	1.0 - 3.2	2.5
Mercury	ND	0.02	0.77
Zinc	58	13 - 134	120
PAH's			
Acenaphthalene	1.4	-	6.0
Benzo[a]anthracene	0.13	0.12	0.1
Benzo[a]pyrene	0.26	0.16	0.01
Chrysene	0.46	0.18	0.1
Fluoranthene	0.78	0.27	4
Fluorene	0.64	-	12
Indeno[1,2,3-cd]pyrene	0.23	0.15	-
Naphthalene	-	0.06	1
Phenanthrene	0.37	0.7	0.3
Pyrene	0.43	-	0.4

*Levels of contaminants entering the marsh from Harbor Square were determined by the Students Saving Salmon club at Edmonds Woodway High School. Western Washington mean averages found around the Puget Sound provided by Herrera Environmental Consultants (2007). National water quality criteria for aquatic life provided by Environmental Protection Act (EPA 2016). PAH = Polycyclic Aromatic Hydrocarbons; ND = Not Determined.

Use of Citizen Scientists and School Groups

To help minimize cost and promote community engagement, we recommend using students, interns and/or volunteer citizen scientists to help collect data. According to Cox et al. (2012), the quality of data collected by non-professional, citizen volunteers can be within the range of normal variability found in professional datasets. Citizen scientists could help with a majority of the visual inspections, as well as assist in any replanting necessary during long-term management of the structures built. School groups could also assist in the collection of water samples entering the marsh, and help provide up-to-date data.

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SEA LEVEL RISE AND THE EDMONDS MARSH: AN ISSUE BEYOND TRADITIONAL PLANNING HORIZONS

Raena Anderson, Anya Brown, Clay Finchen, Ben Menard

Overview & Best Known Science

The purpose of this report is to inform city officials and the public about the threats of sea level rise (SLR) to the Edmonds Marsh and the immediate surrounding area, and to provide recommendations for monitoring of and defenses against SLR. Sea level rise and the growing vulnerability of coastal communities and local ecosystems within those communities has sparked a frenzy of projections, data collections, and surveys. The National Oceanic and Atmospheric Administration (NOAA) predicts sea levels will rise 2.0 meters by 2100, putting much waterfront property in many major cities underwater (Parris *et al.* 2012). What are the key elements of SLR? How do communities determine their levels of vulnerability? What are the effects on local ecosystems, specifically on coastal salt marshes? Our research outlines the key elements of SLR, global projections, and environmental effects on salt marshes, specifically in relation to the Edmonds Marsh enhancement project. We will report salt marsh vulnerabilities and resilience, as well as potential solutions to the coming SLR within and surrounding Edmonds Marsh.

Best known science: Sea level rise

Sea level rise is caused by factors that are controlled by Earth's insolation and by the concentration of greenhouse gasses in the atmosphere. Earth's insolation normally changes on millennial scales; however, the concentration of greenhouse gasses (GHGs) in the atmosphere has been increasing rapidly since the late 1800s, causing climate change to become an issue within our lifetime (IPCC 2014). Currently, anthropogenic GHG emissions into the atmosphere are exceeding RCP8.5 scenarios (Horton *et al.* 2014; Kopp *et al.*2014). RCP8.5 is the climate change model that assumes no emissions reductions, or "business-as-usual" (IPCC 2014).

Rising sea levels are primarily, and most immediately, caused by the thermal expansion of water, followed by the increase in water volume attributable to the melting of ice sheets and inland glaciers (IPCC 2014). The oceans are absorbing over 90 percent of the increased atmospheric heat associated with emissions from human activity (Church *et al.* 2011). Like mercury in a thermometer, water expands as it warms, which is referred to as *thermal expansion*, and is the primary cause of rising sea levels. Melting glaciers and ice sheets also contribute to sea level rising at increasing rates (Meier *et al.* 2011). Since the late 1800s, tide gauges throughout the world have shown that global sea level has risen approximately 0.2 meters.

Additional contributors to SLR are feedback loops. For example, warming oceans cause circumpolar deep water to melt the underside of ice shelves (Figure 1). This causes surface calving, leading to accelerated ice ablation, followed by increased SLR. In a second example, Earth's albedo (reflectivity) decreases as sea ice decreases. As albedo decreases, Earth absorbs more heat and the rate of ice-cap ablation increases. The cycle continues as a positive feedback loop.

Furthermore, the subsidence or uplift of coastal margins also affects how SLR will impact communities. Edmonds is currently subsiding at a rate of 1-2 millimeters per annum; this is relatively little in comparison to other coastal cities and will be inconsequential to the inundation at Edmonds Marsh, assuming the rate remains constant. However, the rate can change over time and will need to

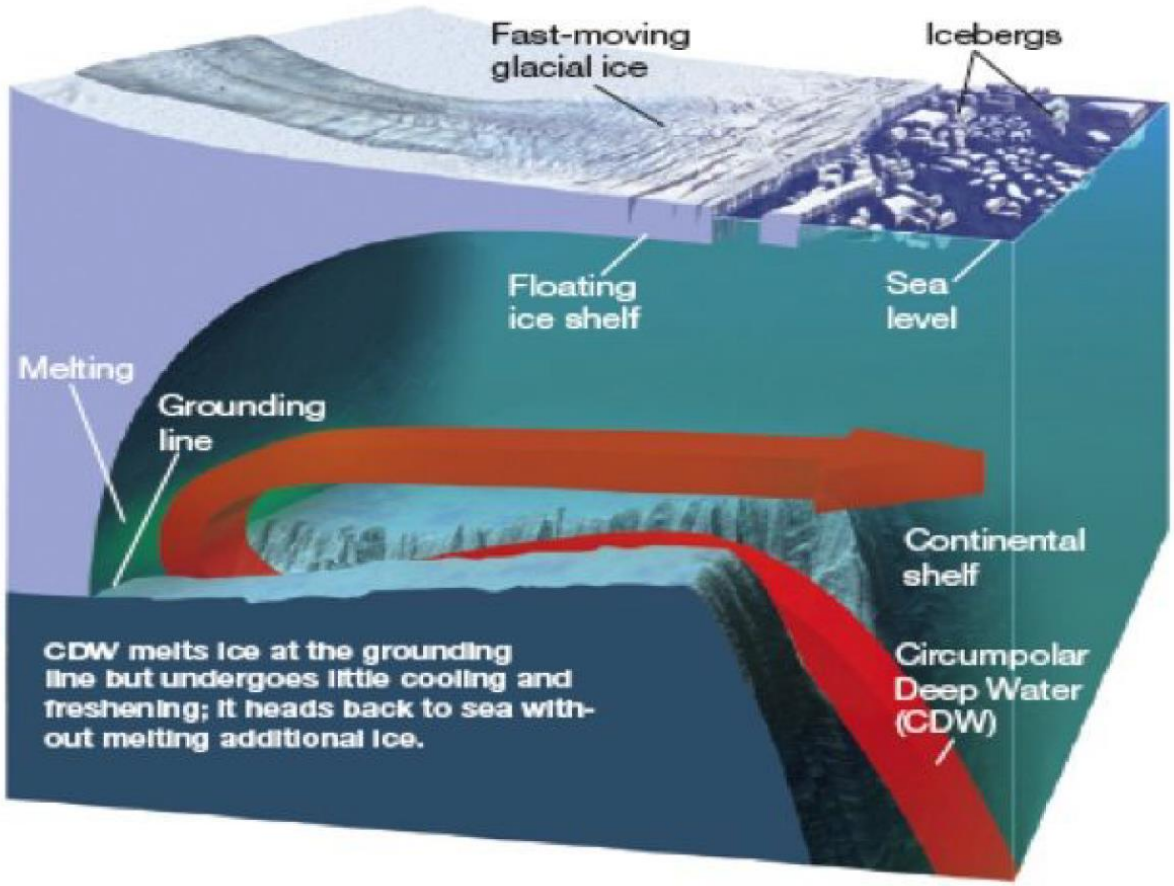

Figure 1: Ocean-ice interaction beneath the Pine Island Glacier ice shelf (Bindschadler 2014).

be included in future monitoring. If subsidence is not currently an issue, then the greatest effects of SLR will come from thermal expansion and the addition of glacial meltwater to the oceans. In order to estimate SLR anticipated at the Edmonds Marsh, we must first consider global SLR projections.

Best known science: global projections

IPCC projections

The IPCC uses somewhat dated models. However, the models are still relevant and remain a great resource for SLR analysis. Projections for SLR by 2100 under RPC8.5 predict a maximum of 0.98 meters in certain areas of the world, with a global average of 0.74 meters (Figure 2). Currently, global GHG emissions are slightly above RCP8.5 projections, indicating that climate forcing and therefore sea level rise may be greater than initially projected under the RCP8.5 scenario. Additionally, the Antarctic and Greenland ice sheets are melting much faster than the estimates used in the IPCC's projections, which has been noted by some of the more conservative papers cited below.

The National Research Council (NRC) (2012) reviewed multiple SLR projections from the most liberal (lowest estimations) to the most conservative (highest estimations), and applied the projections globally and locally. Vermeer and Rahmstorf (2009) project an average of 1.2 meters of

SLR globally, with conservative estimates of 1.8 meters and liberal estimates of 0.8 meters. NRC projections have greater statistical variability, but are more or less as conservative as Vermeer and Rahmstorf (2009). The minimum SLR expected by NRC is 0.1 to 1.4 meters along Washington coastlines. Local SLR projections have wide variability due to inconsistent subsidence rates along the Washington and Oregon coastlines. Projections for 2100 are inherently more variable than projections to 2050, due to the uncertainty associated with subsidence rates, polar ice-cap melting rates, inland glacial melting rates, and the amount of global emissions, among other variables.

Kopp *et al.* (2014) and Horton *et al.* (2014) provide interesting insight in recent years using pooled knowledge from a multitude of experts. They used surveys to compile expert opinions on the subject of SLR. Both reached a consensus that the IPCC estimates for SLR are likely too low. Both take probabilistic approaches to the SLR query and have determined that under RCP8.5, at least 0.5 to 1.0+ meters of SLR is expected, with conservative estimates of approximately 0.5 meters with an RCP3 scenario (Figures 2 and 3). An RCP3 scenario represents a scenario with very low emissions (Horton *et al.* 2014; Kopp *et al.* 2014).

The National Oceanic and Atmospheric Administration (Parris *et al.* 2012) empirically concluded that SLR is bound to be a minimum of 0.2 meters and a maximum of approximately 2 meters globally by 2100 (Figure 2). Locally, that is a rise of a minimum of 0.1 meters and a maximum of 1.7 meters (Parris *et al.* 2012). Unknown future emission rates, ice sheet melting rates, and, thus,

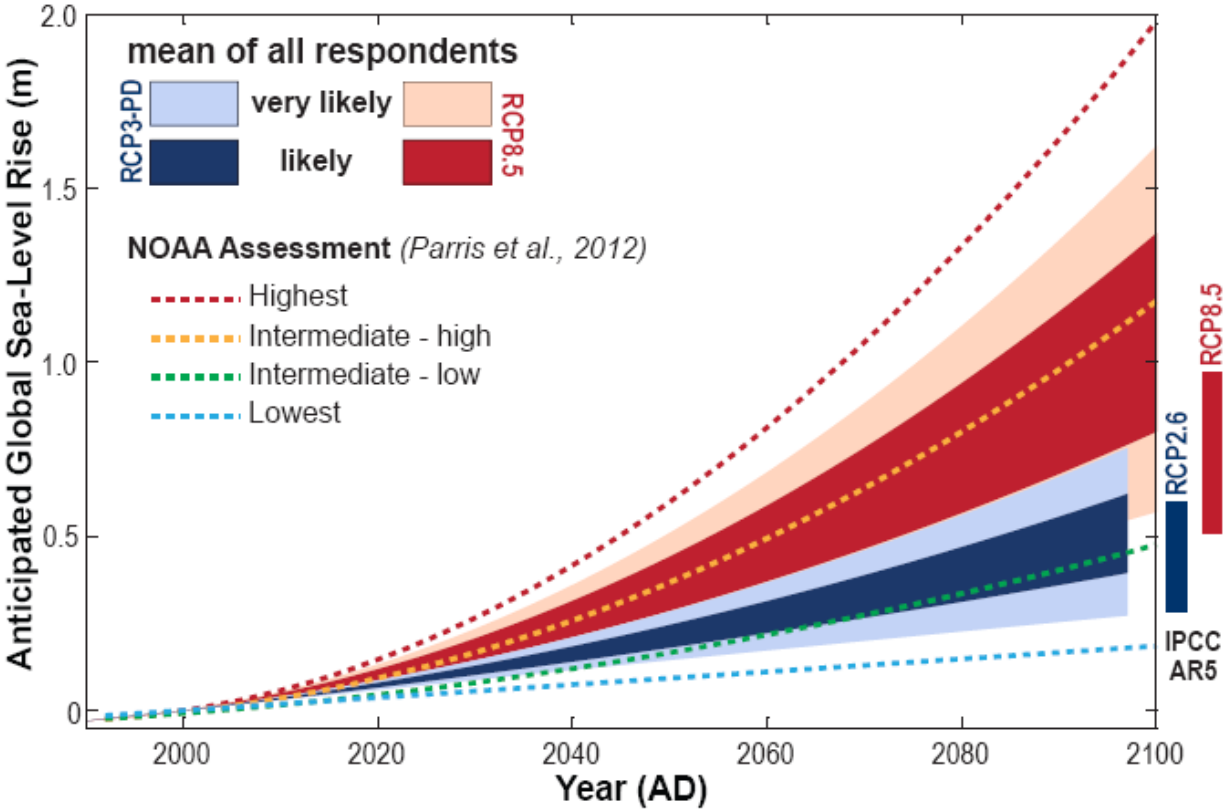

Figure 2: Global sea level rise (SLR) scenarios generated from survey results for two contrasting temperature scenarios (RCP3-PD; blue and RCP8; red). Shading represents mean likely and very likely ranges. The evolution of sea level rise from AD 2000 to the respondent estimates for AD 2100 was described by a quadratic time dependence (Horton et al. 2008).

	RCP 8.5					RCP 4.5					RCP 2.6				
cm	50	17–83	5–95	0.5–99.5	99.9	50	17–83	5–95	0.5–99.5	99.9	50	17–83	5–95	0.5–99.5	99.9
2100—Components															
GIC	18	14–21	11–24	7–29	<30	13	10–17	7–19	3–23	<25	12	9–15	7–17	3–20	<25
GIS	14	8–25	5–39	3–70	<95	9	4–15	2–23	0–40	<55	6	4–12	3–17	2–31	<45
AIS	4	−8 to 15	−11 to 33	−14 to 91	<155	5	−5 to 16	−9 to 33	−11 to 88	<150	6	−4 to 17	−8 to 35	−10 to 93	<155
TE	37	28–46	22–52	12–62	<65	26	18–34	13–40	4–48	<55	19	13–26	8–31	1–38	<40
LWS	5	3–7	2–8	−0 to 11	<11	5	3–7	2–8	−0 to 11	<11	5	3–7	2–8	−0 to 11	<11
Total	79	62–100	52–121	39–176	<245	59	45–77	36–93	24–147	<215	50	37–65	29–82	19–141	<210
Projections by year															
2030	14	12–17	11–18	8–21	<25	14	12–16	10–18	8–20	<20	14	12–16	10–18	8–20	<20
2050	29	24–34	21–38	16–49	<60	26	21–31	18–35	14–44	<55	25	21–29	18–33	14–43	<55
2100	79	62–100	52–121	39–176	<245	59	45–77	36–93	24–147	<215	50	37–65	29–82	19–141	<210
2150	130	100–180	80–230	60–370	<540	90	60–130	40–170	20–310	<480	70	50–110	30–150	20–290	<460
2200	200	130–280	100–370	60–630	<950	130	70–200	40–270	10–520	<830	100	50–160	30–240	10–500	<810
Other projections for 2100															
AR5	73	53–97				52	35–70				43	28–60			
H14		70–120	50–150									40–60	25–70		
J12	110		81–165			75		52–110			57		36–83		
S12						90		64–121			75		52–96		

Figure 3: Global sea level rise projections (Kopp *et al.* 2014). TE: Thermal expansion; LWS: Land water storage; GIC: Glaciers and ice caps; GIS: Greenland ice sheet; AIS: Atlantic ice sheet.

unknown climate forcing rates makes predicting the rate of SLR difficult. However, the most recent evidence regarding future emission rates indicates that future emissions will likely be near RCP8.5 levels, given current and planned fossil fuel infrastructure (Davis *et al.* 2010). In addition, a large volume of scientific literature has recently emerged regarding polar ice sheet melting rates. Ice shelf volume-loss has increased from 25 ± 64 cubic kilometers per year (from 1994 to 2003) to rapid loss of 310 ± 74 cubic kilometers per year (from 2003–2012) (Paolo 2015). The Canadian government recommends planning for SLR of approximately 0.5 meters by 2050, 1.0 meter by 2100, and 2.0 meters by 2200 (BCMOE 2013). This is higher than the 2007 IPCC scenarios, but is consistent with SLR projections used for planning purposes in Europe and the U.S.

Given the SLR projections, it would be prudent for the City of Edmonds to expect and prepare for, at the very least, 0.5 meters of SLR by 2050 and 1.0 meter of SLR by 2100. This is based on both empirical studies and recommendations from both NOAA and the U.S. Army Corps of Engineers. Global sea levels on average could rise as much as 2 meters by 2100, but this scenario has an equal likelihood of a rise of just 0.2 meters by 2100 (Kopp *et al.* 2014). Given that Edmonds' coastline nearest the salt marsh is more than 1 meter above sea level, it would seem as though the coastline would be safe from SLR. However, SLR combined with decadal and centurial flooding cycles creates regular inundation and/or nuisance-flooding events along low lying coastlines (Horton *et al.* 2014; Kopp *et al.* 2014), such as Edmonds' coastline.

Best known science: effect of sea level rise on salt marshes

The effects of SLR on salt marshes will be drastic, with salt marsh communities potentially drowned by salt water, given the shallow topographical gradient within a marsh (Cahoon 2010). Within the salt marsh ecosystem, organisms rely on specific conditions in order to survive. In a salt marsh, there is a delicate balance of salinity, dissolved oxygen, turbidity, bottom composition, and temperature. Interrupting this balance could lead to the collapse of the wetland ecosystem. Many fish and shellfish species rely on salt marshes during some part of their lifecycle. One-half to two-thirds of the food fish harvested from the Atlantic and Pacific Oceans spend part of their lives in salt marshes

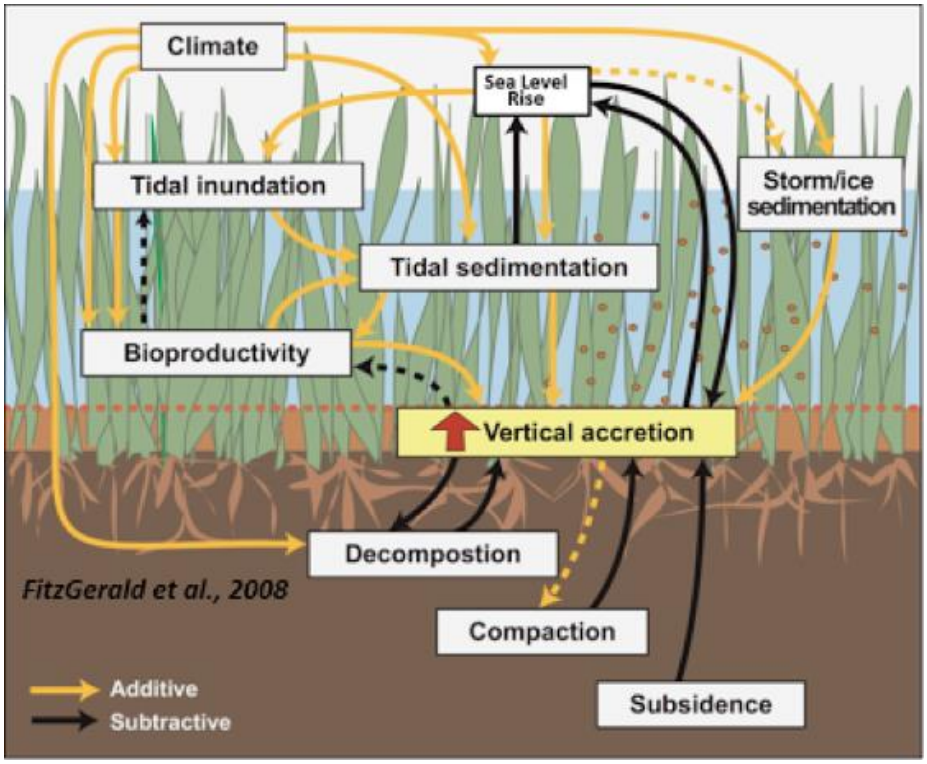

Figure 4: Salt marsh water-soil interactions. Graphic by FitzGerald *et al.* 2008.

or estuaries. Fortunately, salt marshes often have potential for uplift, making SLR effects somewhat dependent on how the rate of land-level uplift compares to that of SLR (Cahoon 2010).

The complex nature and unique features of salt marshes make it difficult to predict how any one marsh will respond to sea level rise. Projecting the sustainability of salt marshes under future climate scenarios is complex because it depends on the relative importance of organic matter to marsh vertical development (Figure 4), the factors governing organic matter accumulation during rising sea level, the importance of subsurface processes in determining surface elevation change, and the role of storm events and hydrologic changes in controlling sediment deposition, soil conditions, and plant growth (NRC 2012). However, reasonable hypotheses for the Edmonds Marsh can be formed based on current elevation data, flood heights, and creek channels.

Determining sea level rise vulnerability

Sea level rise is a relatively slow process, especially relative to the typical municipal long-term planning horizon (e.g., 25-year Comprehensive Plans). Therefore, continued monitoring and adaptive management will be necessary to prepare for and address future challenges caused by SLR. A five-step process can be used to determine current and future wetland vulnerability to SLR (Cahoon *et al.* 2010; Sokolove 2016): (1) collect baseline data; (2) monitor elevation trends; (3) determine rate-controlling processes; (4) model future vulnerability; (5) adaptive management.

Step 1: Collect baseline data

Gathering baseline date regarding geologic, hydrologic (including tidal extent), and biotic conditions will enable future researchers to detect changes to the landscape and determine rates of change necessary for future planning (Sokolove 2016). Geologic parameters to monitor include: soil geomorphology, sediment organic content, grain size, and topography. Establishing the starting elevations through a geospatial survey and/or with LIDAR will be necessary. Edmonds has current LIDAR maps for this area, with the marsh ranging in elevation from approximately 1.5 to 3.5 meters above sea level (ASL) (Tulalip Tribes Natural Resources Department 2015).

Hydrologic parameters to monitor include: water temperature, salinity, tidal extent, and water depth. Tidal extent and water depth measurements will be necessary to determine initial tide and sea levels (Cahoon *et al.* 2010). Measuring the salinity gradient could also be useful in determining rates of inundation. Multiple samples should be taken at consistent points with one transect aligned from the northwest to the southeast, and another from west to east. Plants and animals have varying levels of salt tolerance. Changes in plant cover distribution can thus indicate changes in the influence of tidal waters. Therefore, plant cover surveys are essential in baseline monitoring. Monitoring sites should be dispersed throughout Edmonds Marsh and along the Marina Beach Park (Figure 5).

Baseline parameters should be measured as soon as possible, then again in years one, three, and five (Figure 6). Geospatial surveys or LIDAR should be acquired every 10 years. Hydrologic parameters should be measured as often as possible to create a robust dataset. The following are the recommended hydrologic monitoring frequencies:

- Tidal extent: Bimonthly, spring tide, neap tide
- Water depth: Bimonthly
- Salinity: Bimonthly
- Temperature: Continuous

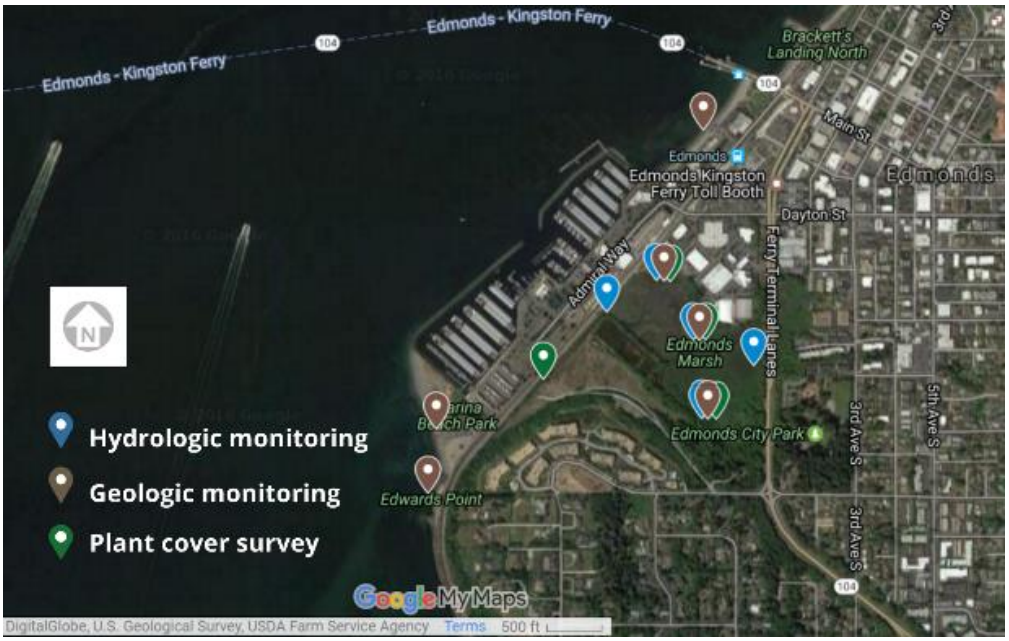

Figure 5: SLR monitoring map for Edmonds Marsh in Edmonds, Washington. Color-coded markers indicate recommended sites of differing types of monitoring.

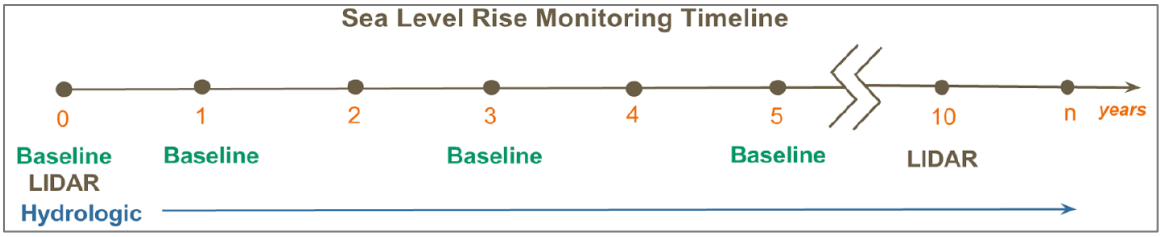

Figure 6: Recommended SLR baseline monitoring timeline. Baseline parameters measured as soon as possible, then years one, three, and five. Baseline measurements include: geologic parameters, hydrologic parameters, and plant cover. Hydrologic monitoring should be continuous. LIDAR or geospatial surveys should be conducted every 10 years.

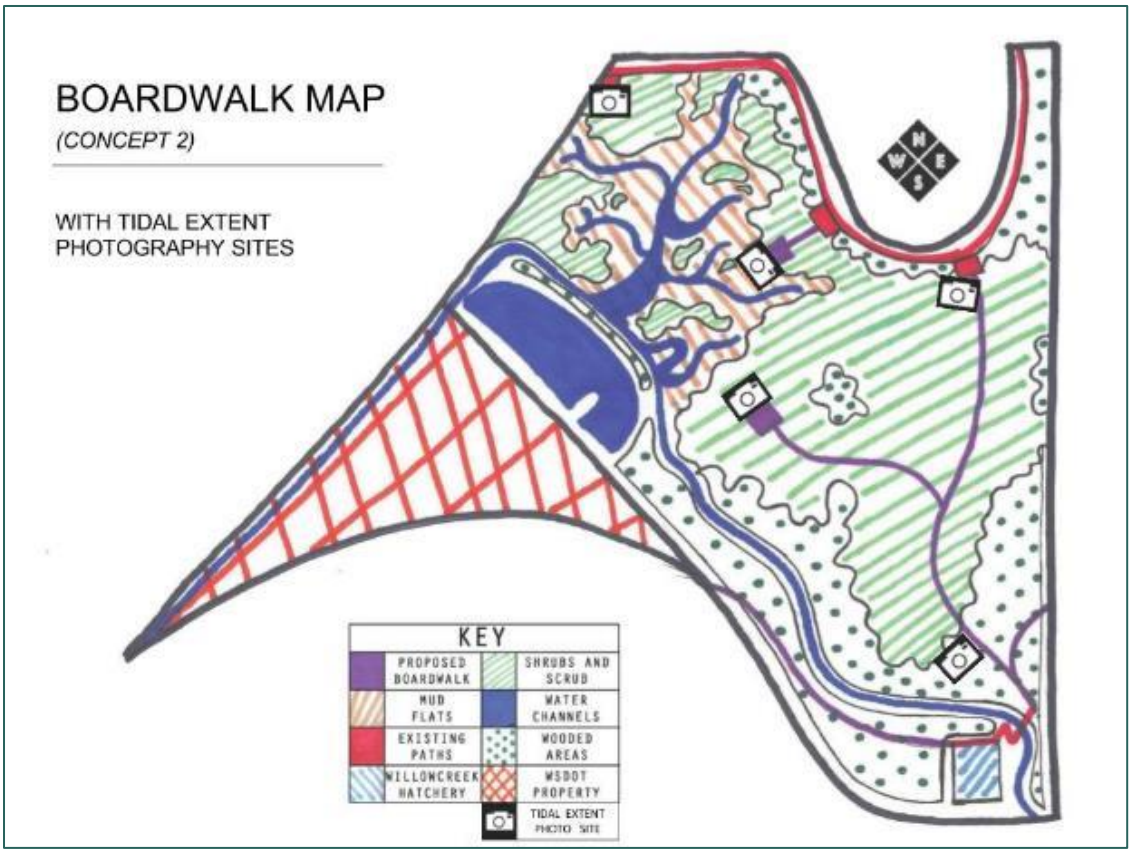

Figure 7: Map of proposed tidal-extent photo sites. Camera icons indicate locations where community members can photograph the tidal extent. Site locations must be indicated clearly to ensure accurate photographic documentation. Base map from Boardwalk chapter.

Community members can help create a tidal-extent archive by providing photographic documentation of the high tide extent within the marsh. Designated tidal-extent photo sites can be placed around the marsh and boardwalk (Figure 7) with signage and orientation controls. Community members would orient their cameras in a defined manner when photographing the tidal extent, allowing for greater comparability between photos over time (Figure 8). Community members can share their photos (along with notes on the time, date, and location) via social media.

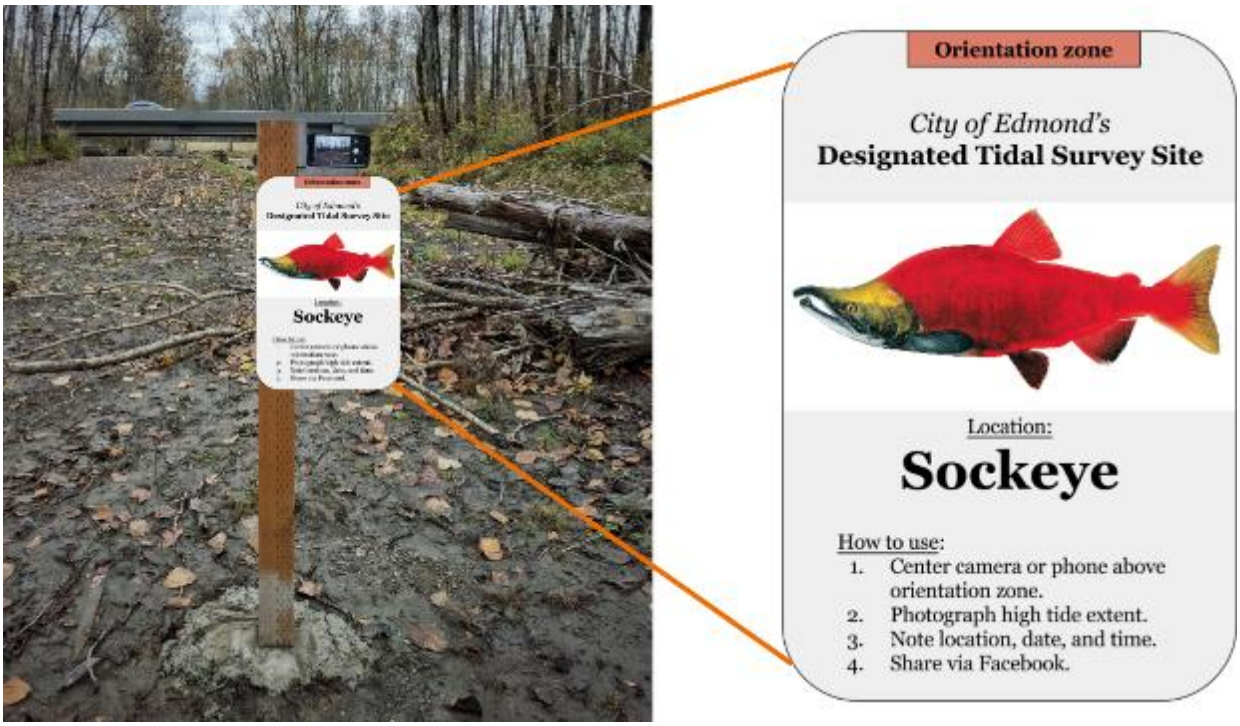

Figure 8: Example of designated survey site sign. Signs should clearly depict the name of the site ("Sockeye" above), orientation zone, and instructions. Locations should be easy to identify. For example, locations could be associated with different types of salmonids (e.g., Sockeye, Chum, Coho). Additionally, images on signs could be a potential outreach to local artists.

Step 2: Determine elevation trends

One way of obtaining high resolution measures of elevation change in a marsh is the surface elevation table method as part of the geospatial survey (Cahoon *et al.* 1995). Elevation trends should be estimated at each successive geologic baseline monitoring event (Sokolove 2016).

Step 3: Determine rate controlling processes

Edmonds Marsh has a slow subsidence rate, as the marsh is mostly safe from common deteriorative forces (e.g., wave erosion). Consequently, SLR at Edmonds Marsh is primarily dependent on rates of sediment deposition. Determining patterns of sediment inputs into the marsh could help predict future marsh migrations, hydrology, and possible areas of focus for future restoration projects. Sediment loads should be measured from both the stream and stormwater inputs, and those values should then be compared to the sediment loads in the outlet from the marsh. In addition to sediment, organic matter accumulation would need to be measured. One way of measuring this could be to conduct surveys of vegetation type and density throughout the area, and then calculate the contribution based upon known rates of organic matter growth and deposition for each species.

Table 1: Effect of SLR on the probability of an event equivalent to today's 100-year coastal flood event in Olympia, Washington. As sea level rises, the probability increases from a 1 percent annual probability to a 100 percent probability at SLR levels of 0.608 meters or more. Table and caption adapted from Mauger 2015.

Sea level rise amount	0 M	0.076 M	0.152 M	0.304 M	0.608 M	1.27 M
Return frequency for a storm tide reaching the current 100-year flood level	100-yr event	40-yr event	18-yr event	2-yr event	< 1-yr event	<< 1-yr event
Equivalent annual probability of occurrence	1%	2.5%	5.5%	50%	100%	100%

Step four: Model future vulnerability

In addition to modeling of *existing* high- and low-flow events, modeling of *future* events under varying SLR scenarios would assist in city planning and preparation. Flood frequency is expected to increase with SLR (Table 1). For example, an increase of approximately 0.3 meters in SLR would result in a four-meter flood event every two years, as opposed to every 100 years (City of Edmonds 2013; Mauger 2015; Table 1). Additionally, social vulnerability modeling would help prepare the community for sea level rise and increased flood events.

Step five: Adaptive management

The results of steps one through four may be used to update knowledge and adjust management actions based on newly acquired insight (Berkes *et al.* 2000; Sokolove 2016). As time progresses, we will gain new information (e.g., sedimentation/erosion rates, actual sea level rise heights, new global sea level rise projections, etc.) and, possibly, new monitoring techniques. An adaptive management approach will increase efficiency, effectiveness, and help provide the flexibility needed for long term planning and monitoring required for SLR preparation.

Sea level rise projections: Edmonds Marsh inundation

Edmonds Marsh is well established, having survived hundreds of years of tides, flood cycles, and human development. The current configuration of the marsh restricts ocean access, given the culverts and tidal gate. With the proposed daylighting of Willow Creek, large volumes of water will be able to move more easily into the marsh, exacerbating the impacts of SLR (Figures 9 and 10).

Hydrodynamic Evaluation Report models predict the marsh's response to low- and high-flow events with and without the proposed channel. The new channel will allow the current water level to rise slightly (AQEA, 2015). With anticipated SLR of approximately 1 meter over the next 100 years, and given inputs and outputs remaining in equilibrium, the marsh will move 1 meter upshore into areas between what is currently inundated by 25-year and 10-year flood events (Figure 11).

This upshore movement means the current site of the marsh will become more saline and more often inundated. In addition to the water level, the salinity gradient will move upshore. We expect an increase in salt-tolerant plant species within the current marsh boundary, and of less salt-tolerant species further away from current locations. Future vegetation projects should consider this

transition. Due to the urban development and higher topography surrounding the marsh, the majority of vegetation changes will likely be constrained to just beyond the current marsh boundaries. Furthermore, the movement of the marsh, to some degree, represents movement of the water table. An elevating water table could pose potential threats to the stability of Harbor Square and to the section of SR 104 adjacent to the marsh. While not an immediate threat, it is yet another reason to monitor marsh migration and consider defenses against SLR.

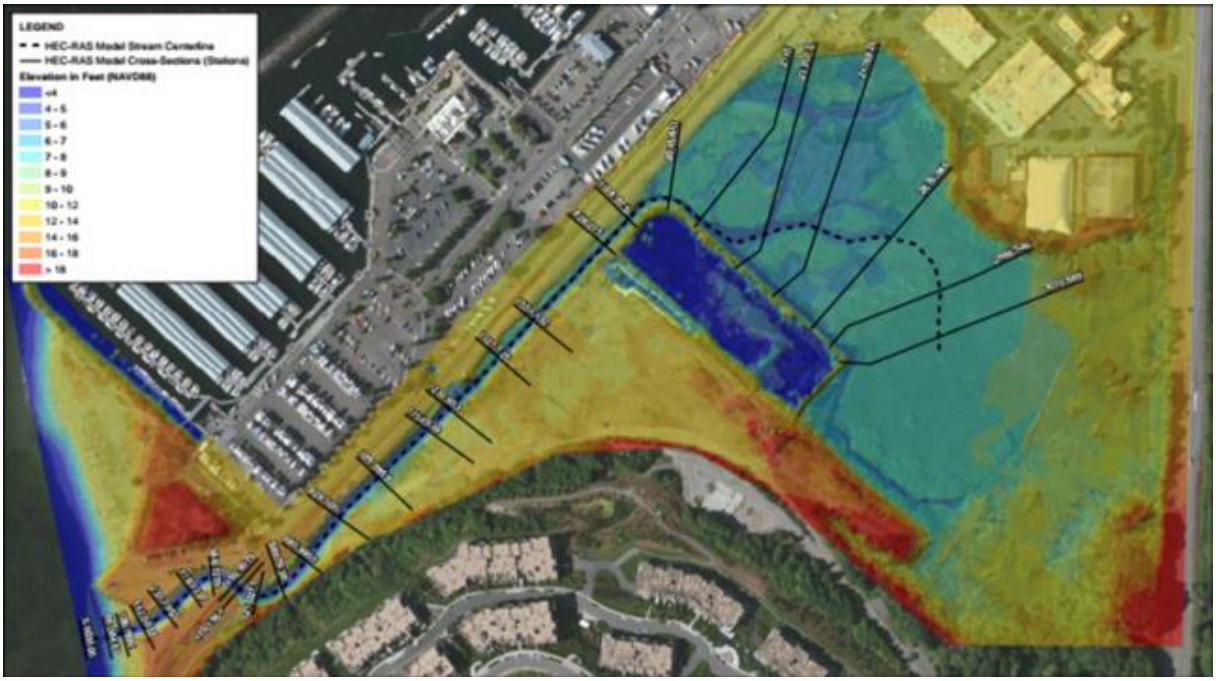

Figure 9: Proposed Daylight Channel Willow Creek A (Shannon and Wilson, Inc. 2015).

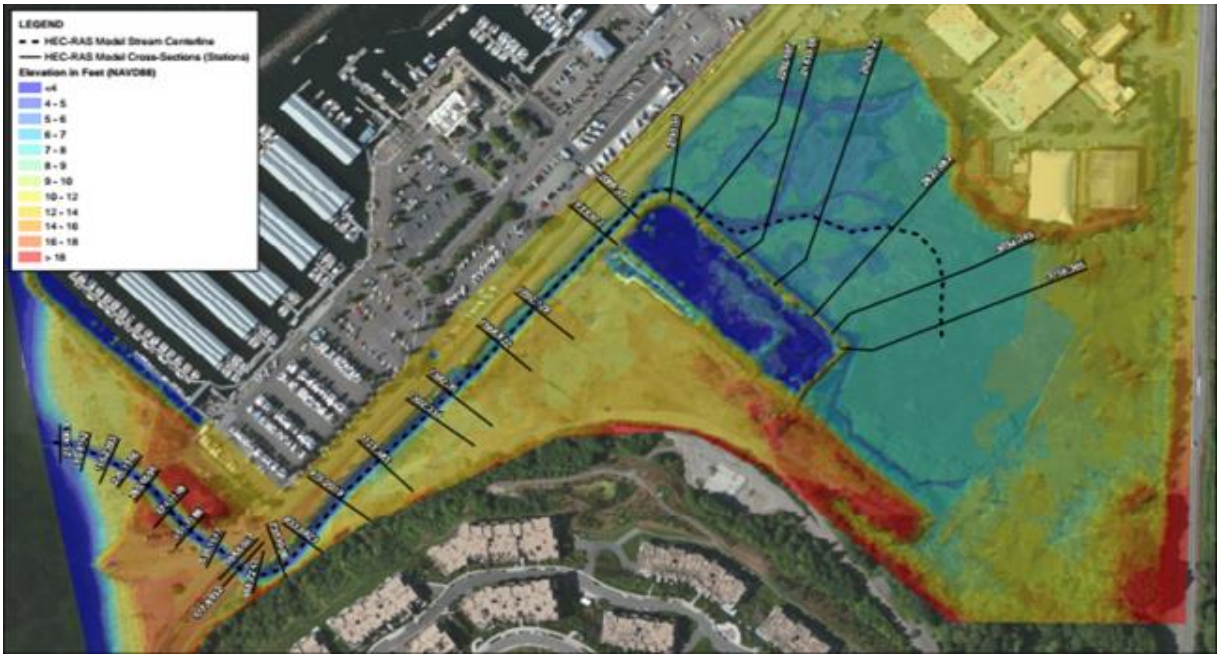

Figure 10: Proposed Daylight Channel Willow Creek B (Shannon and Wilson, Inc. 2015).

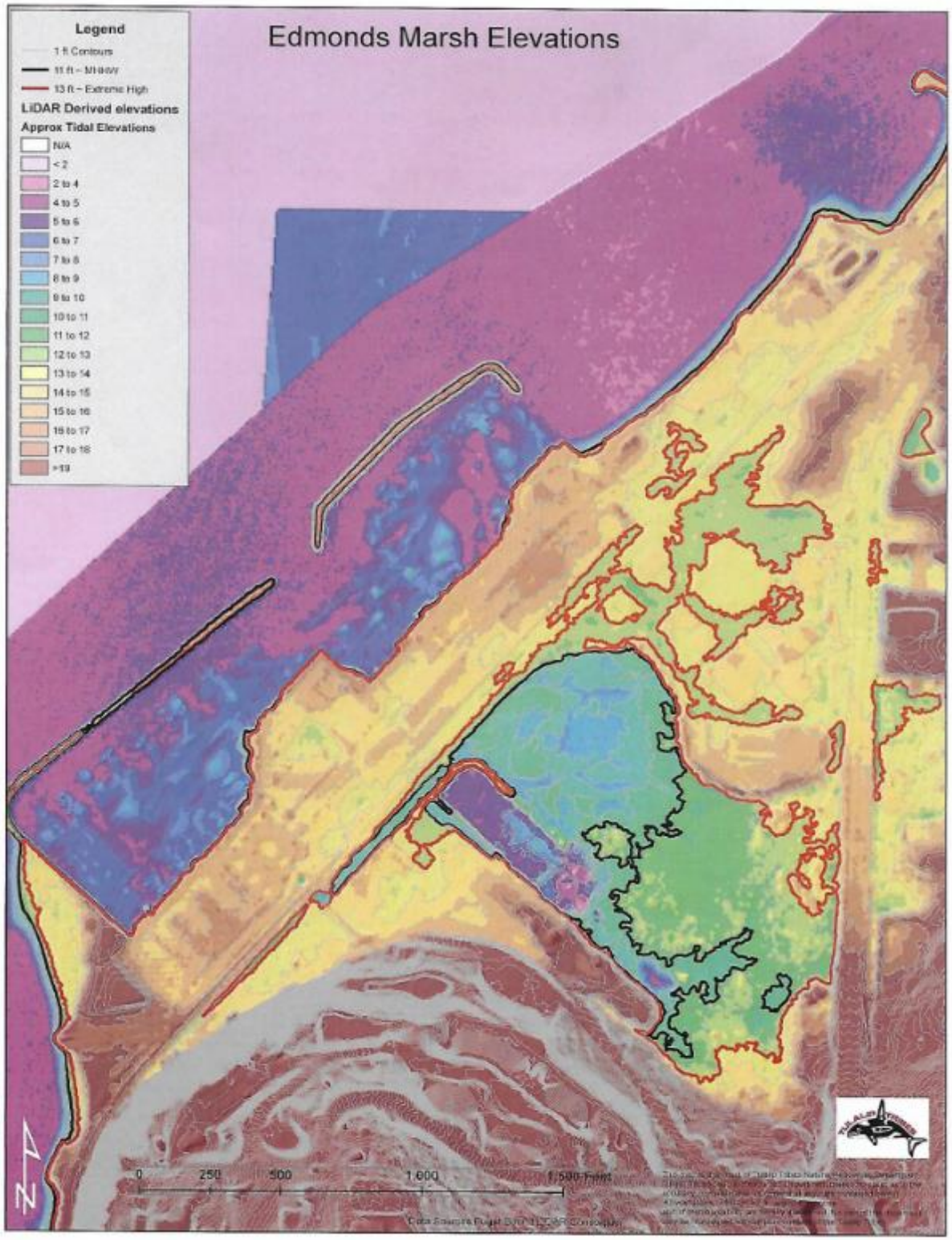

Figure 11: Edmonds Marsh elevations showing extent of 25-year flood in black contour and 100-year flood in red contour. These zones may represent future salt marsh boundaries as the water naturally travels there (Tulalip Tribes Natural Resources Department 2016).

Figure 12: White-shaded areas will be below sea level after 0.5 meters of SLR has occurred. This degree of SLR is predicted by 2050.

With 0.5 meters of SLR by 2050, inundation will be confined within Edmonds Marsh (Figure 12). With 1.0 meter of sea level rise, all of the marsh will lie below sea level (Figure 13). One meter of SLR, paired with 10-, 25-, and 100-year storm tide events, could result in the marsh being inundated with seawater at such high frequency that the marsh might be at risk of ecological degradation or destruction. Infrequent inundation may prove to be inconsequential for the salt marsh, as it is well known that salt marshes form on coastlines from a combination of terrestrial freshwater and occasional inundation and flooding by saltwater. However, a regularly inundated tidal flat can cause an unhealthy rise in both salinity and the water table underneath the salt marsh, potentially destroying habitat that has already been established, or drastically altering the ecosystem.

Figure 13: White-shaded areas will be below sea level after 1.0 meter of SLR has occurred, projected by 2100.

A 1.25 meter increase of SLR by 2100 is within the 0.5-99.5 percent likelihood range, established by Kopp *et al.* (2014). With this increase, the entire marsh will be flooded, as will portions of SR 104 and other roads. This scenario is more likely in the timeframe of 2125 to 2150, but it has been highlighted by us as the tipping-point scenario in which the marsh is entirely inundated with saltwater. Although this scenario will not come to fruition for at least two human generations, we feel it necessary to identify the degree of SLR necessary to inundate the marsh. This gives a frame of reference as to when action must be taken either to armor the coastline, retreat from the coastline, or a combination of both.

Preparing for sea level rise

Permanent barriers

Tidal Gate

To mitigate sea level rise and help prevent extreme flood events affecting the area around the marsh, AQEA (2015) recommends a self-regulating tidal gate. Once installed, the gate would close at water elevations between 2.4 and 2.9 meters ASL, unlike the current gate which is closed October through March. The proposed gate would not block fish passage (AQEA 2015). Models confirm fish can pass through such a barrier during both low- and high-flow events (AQEA 2015). Some community members may be apprehensive of such a gate, as the current gate decreases fish and bird biodiversity through the summer. However, increased community education may counteract opposition. Additionally, we recommend using the proposed tidal gate during flood events. With increased frequency of major flood events due to sea level rise, a tidal gate could slow the inflow of water into the marsh and surrounding areas and decrease erosion and property damage due to flooding.

Shoreline armoring

Preserving and enhancing the salt marsh is an excellent start to building the City of Edmonds' resilience and robustness against SLR and increased flooding events. Salt marshes slow storm surges and flooding. Creating additional barriers could also slow water entering the city and decrease flood damage. This is known as "shoreline armoring." Traditional shoreline armoring involves constructing bulkheads, seawalls, or riprap. While these structures are successful in reducing the direct impacts of waves and surge, they can create new issues (e.g., increased coastal erosion, decreased habitat complexity, decreased biodiversity; Dugan *et al.* 2008). Rather than using cement walls or large rocks that disrupt the ecosystem, restoring and creating new habitats would increase the robustness of the ecosystem while decreasing flooding damage (Currin *et al.* 2010).

Constructed oyster reefs could be the first line of defense (Figure 14). The reefs would dissipate wave energy and slow surges entering the marsh (Scyphers 2011). Additional benefits of oyster reefs include: water filtration, carbon sequestration, refuge from predation, habitat for invertebrates and fish, and increased fishery resource (Coen *et al* 2007; Grabowski and Peterson 2007; Scyphers 2011).

Constructing six 1.5 x 60-meter oyster reefs would go a long way to protect Edmonds Marsh (Figure 15). A feasibility study should be conducted to ensure these sites are suitable for construction. Once deemed suitable, oyster reefs could be constructed by piling bags of aged oyster shells (Whalen *et al.* 2016). With a total reef length of 360 meters, approximately 5,800 mesh oyster bags filled with 4,400 bushels of oysters would be needed to construct the oyster reefs (SCORE 2003).

Oyster bag production and piling can be completed with the help of community members. Total estimated labor hours for the project is 1,740 person-hours, with oyster-shell bagging and bag-stacking each requiring an estimated 870 person hours (SCORE 2003; Heck *et al.* 2010). Volunteers of all ages can participate in the bagging and stacking projects. By engaging community members and educating them regarding the benefits of living breakwaters such as oyster reefs, costs and potential objections to the project can be minimized.

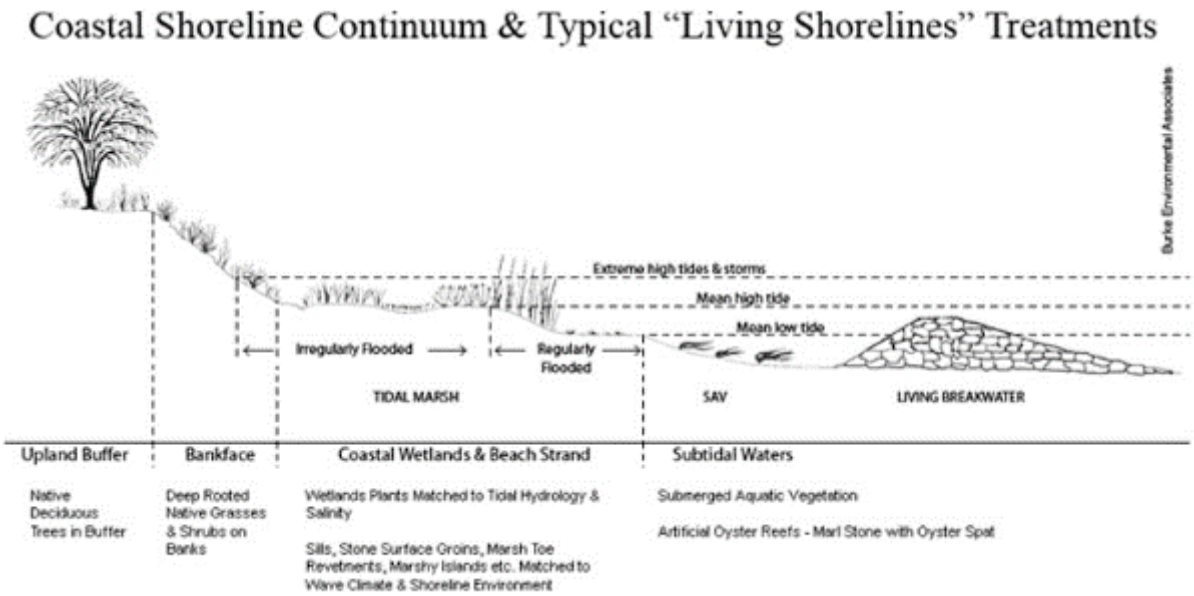

Figure 14: A living breakwater, such as an oyster reef, could enhance the ability of the salt marsh to armor the shoreline. Diagram created by Burke Environmental Associates.

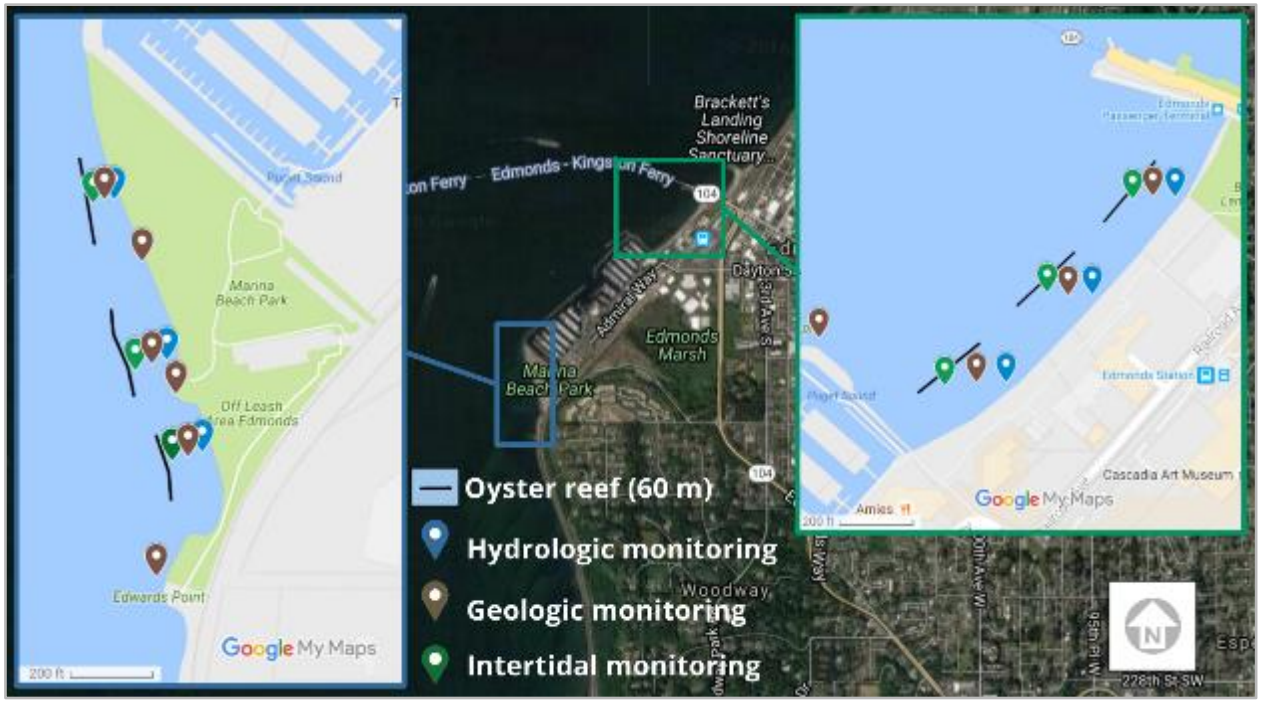

Figure 15: Proposed oyster reef locations in Edmonds, Washington. Each black line represents one 1.5 x 60-meter oyster reef. Blue markers represent hydrologic monitoring sites, brown markers represent geologic monitoring sites, and green markers represent intertidal monitoring sites.

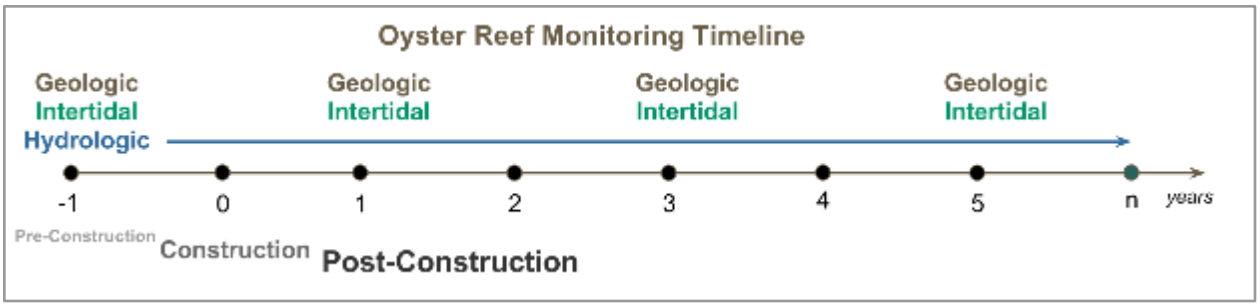

Figure 16: Oyster reef monitoring timeline. Geologic and intertidal parameters should be monitored one year prior to construction and in years one, three, and five after construction. Hydrologic parameters should be monitored bimonthly for one year prior to construction and onwards.

Once installed, construction and performance monitoring will be essential to (1) ensure the oyster reef construction project has been built correctly and reefs are initially functioning as designed, (2) assess the effects on shoreline stabilization and water quality, and (3) identify ways to improve future construction projects (Davis *et al.* 2016). Hydrologic parameters (e.g., temperature, salinity, dissolved oxygen, pH, light attenuation, typical wave energy regime, and range of shear force at sediment surface) should be monitored bimonthly one year prior to construction and continued bimonthly post-construction (Figure 16). Geologic parameters (e.g., geospatial survey, sediment organic content, soil geomorphology, grain size, and erosion/sedimentation rate) and intertidal parameters (e.g., intertidal survey, oyster recruitment, and fish composition and abundance) should be evaluated one year prior to construction and in years one, three, and five post-construction. Monitoring sites would be located between the oyster reef and the shorelines, including south of Edwards Point (Figure 15).

Temporary flood barriers

While the above-described permanent barriers will slow the water and mitigate some destruction during high flow events, flooding around the marsh will become more of a problem as the decades pass and the sea level rises. In addition to permanent barriers, a temporary flood barrier can be used to constrain the flood waters within the marsh, particularly away from SR 104 and Admiral Way. One effective temporary barrier is the Water-Gate barrier manufactured by Hydro Response, Ltd (Hydro Response 2016). This barrier can be moved and installed quickly and easily. Once unrolled in place, the Water-Gate inflates automatically and deflates once the water subsides (Figures 17, 18).

These water barriers can be placed strategically around the salt marsh to slow or prevent water from flooding into the streets. Water-Gates come in a variety of sizes (0.38 x 7.6 meters, up to 1.5 x 15.2 meters) and are relatively inexpensive ($1,150 to $13,400; Hydro Response, Ltd, pers. Comm. 2016).

HOW THE WATER-GATE WORKS

The principle is simple: water accumulates inside the barrier and exerts pressure on the bottom of the fabric, which keeps the barrier in place. The speed or direction of the incoming water is not important, as it is the water pressure that causes the barrier to open up.

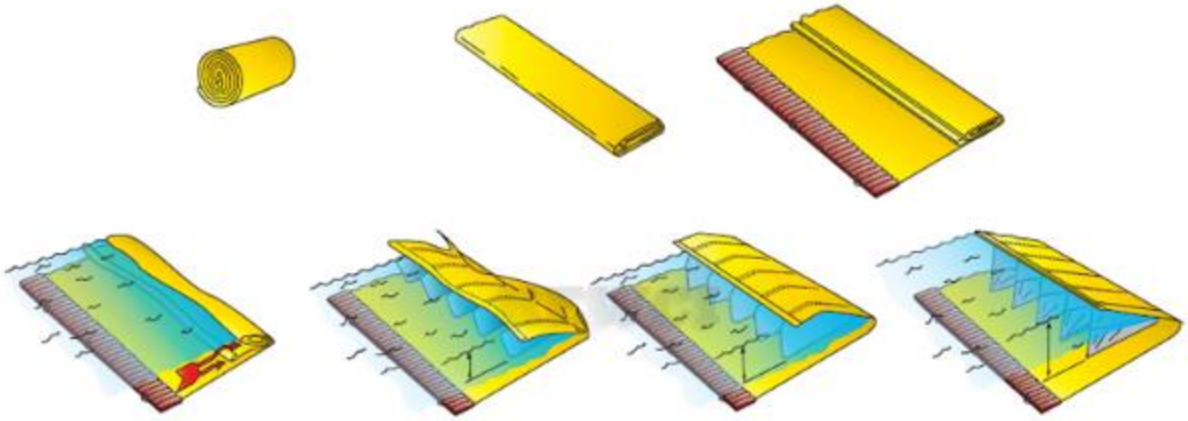

Figure 17: Water-Gate water barrier. Once the barrier is unrolled, the water inflates the barrier. As the water subsides, the barrier automatically deflates (Hydro Response, Ltd 2016).

Figure 18: Water-Gate barrier blocking flood waters from entering a city street.

Managed shoreline retreat

As sea levels rise and flood frequency increases, a managed retreat will be necessary for the safety of community members and for the protection of shoreline property and habitats. Retreat strategies include: land acquisition, alongshore buffers, and enacting a rolling setback (Macadangdang and Newmons 2010; Figure 19). While land acquisition is costly, acquiring shoreline properties will allow Edmonds to expand the living shoreline and increase protection from floods and erosion.

Enacting an alongshore buffer could also help to create a robust living shoreline. The alongshore buffer would start upland of the mean high tide line and extend to the sea. Structures within the alongshore buffer should plan for inundation. Strategies to prepare for inundation include being elevated, being temporary, or being otherwise adaptable to sea level rise. Deep rooted grasses, shrubs, and trees can be planted within the alongshore buffer to help slow erosion.

Rolling setbacks can be used to limit new development in areas most vulnerable to SLR. For new developments, the rolling setback distance is determined by multiplying the annual erosion rate (meters/year) by the estimated years the structure will have economic value, plus the width (meters) of the alongshore buffer (Macadangdang and Newmons. 2010).

These strategies will allow the shoreline to naturally retreat while decreasing property damage, and they will help build a robust and resilient living shoreline.

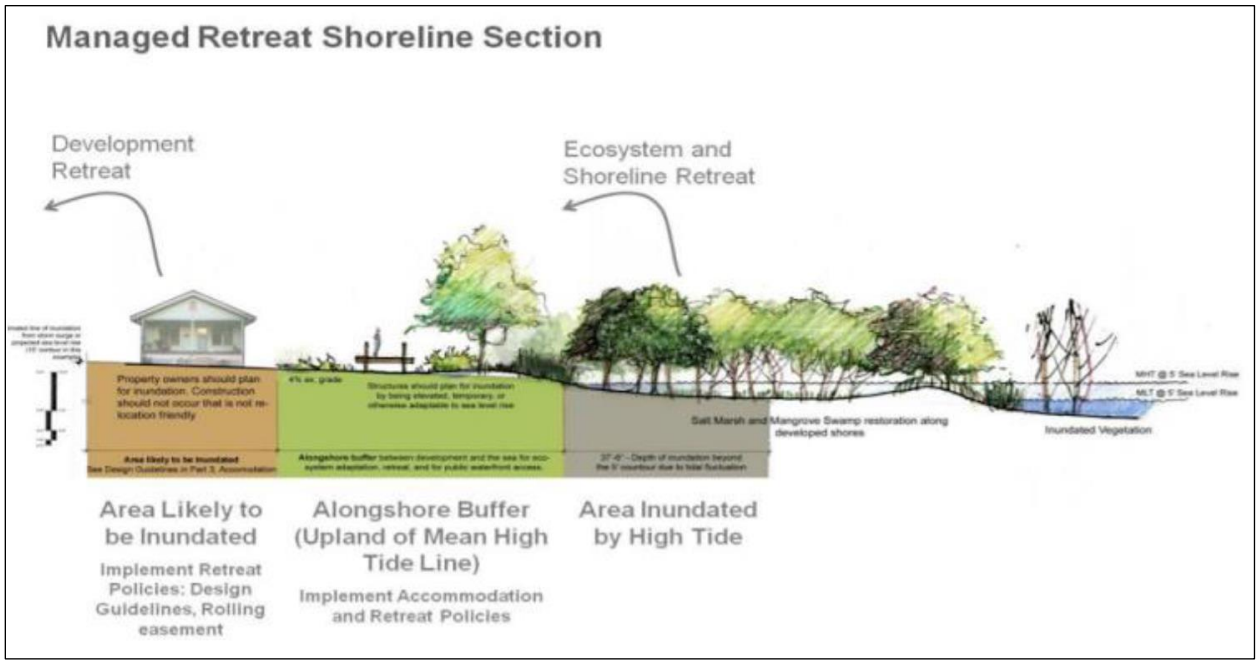

Figure 19: A managed shoreline retreat allows the salt marsh to migrate naturally inland, decreases economic hardships associated with coastal erosion, and may help mitigate flooding events (Macadangdang and Newmons 2010).

Conclusion

The City of Edmonds Marsh Restoration Project is within a coastal flooding zone susceptible to sea level rise caused by a warming climate. Our research shows the vulnerability of this marsh habitat to rising sea levels. The City of Edmonds should prepare for a rise of at least 0.5 meters by 2050, and 1.0 meter by 2100. The resulting influx of salinity could potentially degrade this unique ecosystem and damage habitat for the species who inhabit the marsh at various points during their lifecycles. We recommend serious consideration of actions to counter the effects of SLR estimated to occur over the next 50-100 years (and sooner if flood cycles are taken into account). Daylighting Willow Creek exacerbates problems with salinity inundation and increases the risk of high flooding. Some of the effects of SLR could be mitigated with recommended permanent and temporary barriers. In order to measure the overall health of the Edmonds Marsh, future monitoring is required and can be undertaken in various ways and within limited budgets, while engaging and educating community members.

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ASSESSMENT OF THE ECOLOGICAL AND ECONOMIC BENEFITS OF THE PROPOSED WILLOW CREEK DAYLIGHT PROJECT WITH REGARD TO CHINOOK SALMON

S. Gamblewood, L. Miller, B. Morin, S. Sasek, Z. Thompson

Introduction

The proposed Edmonds Marsh enhancement project would include restoration of approximately 22.5 acres of tidal salt marsh located in the upper South Puget Sound region along the Edmonds coastline. Additionally, the project could include the daylighting of Willow Creek. The goals of the daylighting project are to reduce flooding, improve water quality, maintain nutrient and sediment retention, and promote bank and channel stabilization, as well as enhance the community of Edmonds by reestablishing a healthy habitat for salmon.

Willow Creek presently drains from the marsh into Puget Sound through 1,600 feet of underground culvert that presents a barrier to Pacific salmon (*Oncorhynchus* spp.) that attempt to access the marsh. The daylighting of Willow Creek would reconnect the Edmonds Marsh to Puget Sound, restoring important habitat that would enhance and support regional recovery efforts for salmon listed under terms of the Endangered Species Act (ESA). The objective of this report is to assess the ecological and economic benefits that the proposed Edmonds Marsh restoration, in connection with the daylighting of Willow Creek, would provide with regard to salmon.

Ecological and Economic Importance of Salmon

The Pacific Northwest is home to seven native species of salmonids: Chinook (*O. tshawytscha*), Sockeye (*O. nerka*), Coho *(O. kisutch*), Pink (*O. gorbuscha*), and Chum (*O. keta*), as well as Rainbow or Steelhead trout (*O. mykiss*) and Cutthroat trout (*O. clarki*). The migration of adult salmon from the ocean back to their natal streams transports vast amounts of marine-derived nutrients to freshwater ecosystems (Mathisen et al. 1988, Naiman et al. 2002). Salmon provide an essential food source for estuarine, freshwater and terrestrial wildlife, feeding more than 137 different species of predators and scavengers (Cederholm et al. 1989, Hilderbrand et al. 2004). These consumers depend on the nutrients derived from returning salmon, and in turn they play a crucial role in dispersing salmon-derived nutrients into the foliage of the surrounding forests (Ben-David et al. 1998, Hilderbrand et al. 1999). The decomposing carcasses that are moved into the terrestrial ecosystem enhance the growth of streamside vegetation. For example, in Southeastern Alaska, salmon contribute 25 percent of the nitrogen found in riparian tree foliage, often resulting in enhanced tree growth near salmon spawning streams (Helfield and Naiman, 2001). These nutrients are then absorbed into the region's food webs, benefitting species that do not consume salmon directly. For example, isotopic analyses indicate that songbirds acquire marine-derived nitrogen through consumption of salmon-enriched insects, seeds, and fruit (Lovette, 2006). Accordingly, activities that threaten the health and populations of wild salmon adversely affect the nutrients that flow within and between ecosystems (Hilderbrand et al. 2004).

The Salish Sea is a 16,925 square kilometer bi-national ecosystem that includes the Puget Sound and the Strait of Juan de Fuca in Washington State, and the Gulf Islands and the Strait of Georgia in British Columbia. It is one of the world's largest and most biologically diverse inland seas, and provides ecosystem services to approximately 8 million people (SeaDoc Society 2016). Anthropogenic pressures have taken their toll on the Salish Sea, however, and currently 113 species that reside within the Salish Sea are listed as threatened, endangered, or are candidates for listing under the Endangered Species Act (ESA). Among these are Chinook salmon, the largest species of Pacific salmon. The Puget Sound Chinook salmon evolutionarily significant unit (ESU) consists of 22 independent populations (Fresh et al., 2005). Puget Sound Chinook salmon populations have declined by as much as 90 percent since the 1960s, and were listed as threatened under the ESA in 1999 (WADOE, 2016).

For centuries, salmon have played an important cultural, economic, and ecological role in the Pacific Northwest. Prior to European contact, salmon served as the basis of trade and underpinned the economy of the native peoples of the Northwest. These fish have also played a significant role in spiritual and ceremonial traditions, as well as being a food staple. Today, wild salmon are considered a totem figure and cultural icon, a vital marker of coastal identity, history, ecological harmony, and community (Lichatowich et al. 1999). Salmon remain an essential resource for tribal and non-tribal commercial fisheries, generating an estimated $3 billion in income, and supporting 35,000 jobs in North Pacific countries in 2007 (Wild Salmon Center 2009).

Importance of Estuarine Habitat to Salmon

Estuaries and pocket estuaries are essential habitats for juvenile salmon, providing productive foraging, refuge from predators, and the conditions necessary to undergo the physiological changes (i.e., smoltification) necessary for transition from freshwater to marine life (Simenstad et al., 1982). Pocket estuaries are small sub-estuaries that form behind spit or barrier beach landforms, and are typically comprised of tidal lagoons, saltmarsh, and tidal channels. Pocket estuaries are important rearing habitat for non-natal juvenile Chinook (i.e., juvenile Chinook that originate in watersheds other than those that drain into a given pocket estuary), many of which follow what is called a fry migrant life history type, wherein they out-migrate as sub-yearlings, bypass rearing in their natal delta, and move directly into Puget Sound (Beamer et al., 2003). Due to lower density of predators of sufficient size to prey on juvenile salmon, pocket estuaries provide important refuge from nearshore predators (Figure 1). Hering et al. (2010) found that residence times of sub-yearling Chinook in salt marsh channels varied from hours to months. Beamer et al. (2003) found that the abundance of wild Chinook in pocket estuaries more closely mimicked that of Chinook in natal river deltas than that of nearshore environments, and that juvenile Chinook were 10 times more abundant in pocket estuaries than in nearshore environments, and 100 times more abundant than in offshore environments. These findings indicate extensive use of pocket estuaries by non-natal fry migrants.

Since body size at smoltification is strongly correlated with marine survival rates, the availability of productive estuarine habitat during the nearshore life stage can have a significant effect on escapement and overall production (Greene et al., 2003). Beamer et al. (2003) reported that juvenile Chinook rearing in pocket estuaries from February to May were on average four to six millimeters longer than those found in deeper nearshore habitats. Magnusson and Hilborn (2003) estimated that Chinook utilizing fully intact estuarine rearing habitat had marine survival rates of 1.77 percent, whereas populations with no access to intact estuarine habitat had marine survival rates of 0.5 percent (Figure 2). This represents survival rates more than three times greater when salmon

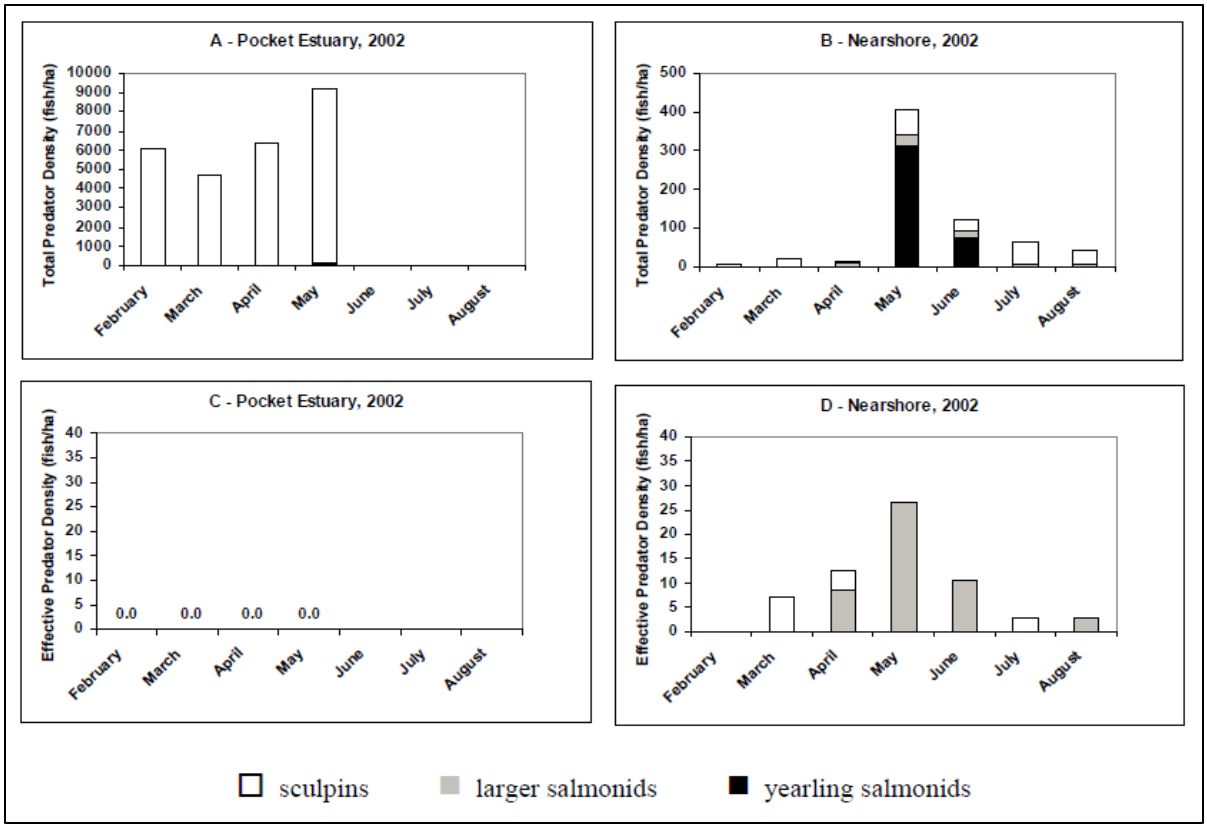


Figure 1. Density of all significant predators of juvenile Chinook in pocket estuaries in the Skagit Delta, as compared to nearshore habitat. (Beamer et al., 2003)

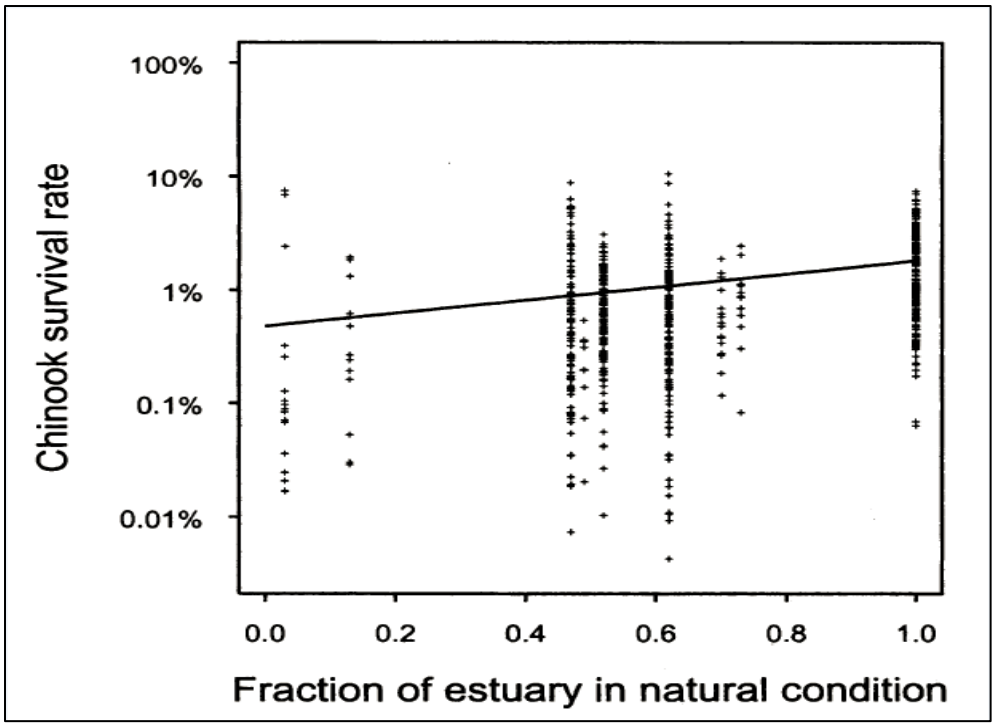
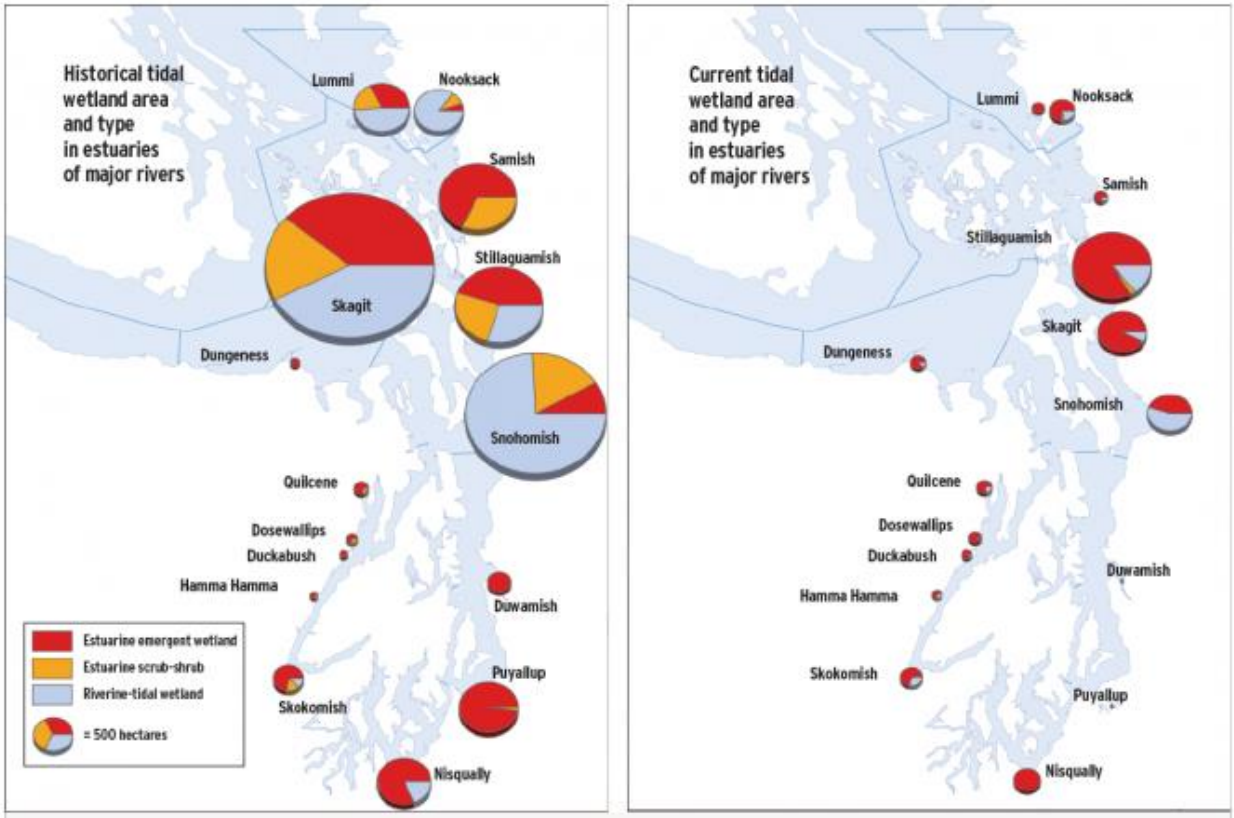


Figure 2. Poisson regression of survival rates in coastal Oregon of Chinook salmon. (Magnusson and Hillborn, 2003).



Loss of historical habitat types in Puget Sound. Image: Collins 2006.

Figure 3. Loss of tidal wetlands in estuaries of major river systems in Puget Sound. (Encyclopedia of Puget Sound, 2016).

populations have access to quality estuarine rearing habitat. Despite the importance of this type of habitat, however, over 70 percent of the tidal wetlands in the Puget Sound have been lost due to extensive urban development and agriculture (Figure 3). Correspondingly, the population of wild salmon has dropped to less than 10 percent of historic levels in the greater Puget Sound region, as native salmon have been driven toward extinction for over 150 years.

Use of Edmonds Marsh by Salmon

The Edmonds Marsh is estimated to have covered 100 acres when it was first mapped in 1870, and is one of the few remaining tidal salt marsh between the cities of Tacoma to the south and Everett to the north. From the late 1800s, the area was rapidly industrialized. Three turning points for the City of Edmonds were its improved accessibility through the extension of the Great Northern Railroad in 1891, the construction of the ferry dock in 1923, and the establishment of the marina in 1969. Until about 1951, the waterfront was used for up to 10 working lumber and shingle mills, polluting what once was pristine habitat. When the marina was constructed, the dredged material was poured directly into/onto the marsh, forming the foundation of the Harbor Square complex that was completed in 1976 (Port of Edmonds, 2009). The current marsh area has been reduced to 22.5 acres, a more than 70 percent loss of important habitat. Under historical conditions, small

numbers of Coho and Chum salmon likely traveled through the marsh in order to spawn further upstream in Willow and Shellabarger Creeks.

Currently, there are multiple obstacles restricting connectivity between the marsh and Puget Sound. Water leaving the marsh travels through 600 feet of channelized stream which lacks instream structure and overhanging riparian vegetation. It then travels through 1,600 feet of underground culvert, making two 90 degree turns before entering Puget Sound via a submerged outlet pipe (Figure 4). There is also a tide gate which mutes tidal exchange, while restricting access of fish into the culvert system. This blocks all fish access into the marsh, as well as restricting nutrient flow and biodiversity within the marsh (Shannon and Wilson, 2015). The proposed marsh enhancement, along with the daylighting of Willow Creek, would effectively remove current barriers for salmon seeking access to the marsh.

A beach outlet channel leading into a daylighted stream would allow non-natal salmon (of all seven species) from other river and stream systems throughout the Puget Sound to use the marsh as pocket estuary rearing habitat. The Edmonds Marsh is located within Washington state's Water Resources Inventory Area 8 (WRIA 8, 2005). WRIA 8 is home to three populations of Chinook salmon: Cedar River, North Lake Washington and Sammamish, all of which are at high risk of extinction. The WRIA 8 Chinook salmon recovery plan (WRIA 8, 2005) places habitat types into three tiers according to level of priority for conservation and restoration (Figure 5). If connectivity were restored, the Edmonds Marsh would provide migratory/rearing corridor habitat and would be classified as a tier one priority. The marsh would benefit non-natal Chinook salmon populations

Figure 4. Shellabarger and Willow Creek connections through the Edmonds Marsh to the ocean. The blue lines represent water that is above ground, and the green lines represent water that is in an underground pipe.

throughout the region. Chinook populations most likely to use the marsh include North Lake Washington, Sammamish, Cedar, Duwamish/Green, White, Puyallup, and Nisqually, as these are the populations which are most proximate to the Edmonds Marsh (Ruckelshaus et al., 2006). Washington Department of Fish and Wildlife forecasts for the 2016-17 fishing season (WDFW 2016) estimate a combined escapement of 66,709 summer- and fall-run Chinook from these populations, with a total escapement of 165,150 for all of Puget Sound. These numbers include both hatchery- and wild-spawned, and are low relative to the average abundance over the past decade (NOAA, 2016).

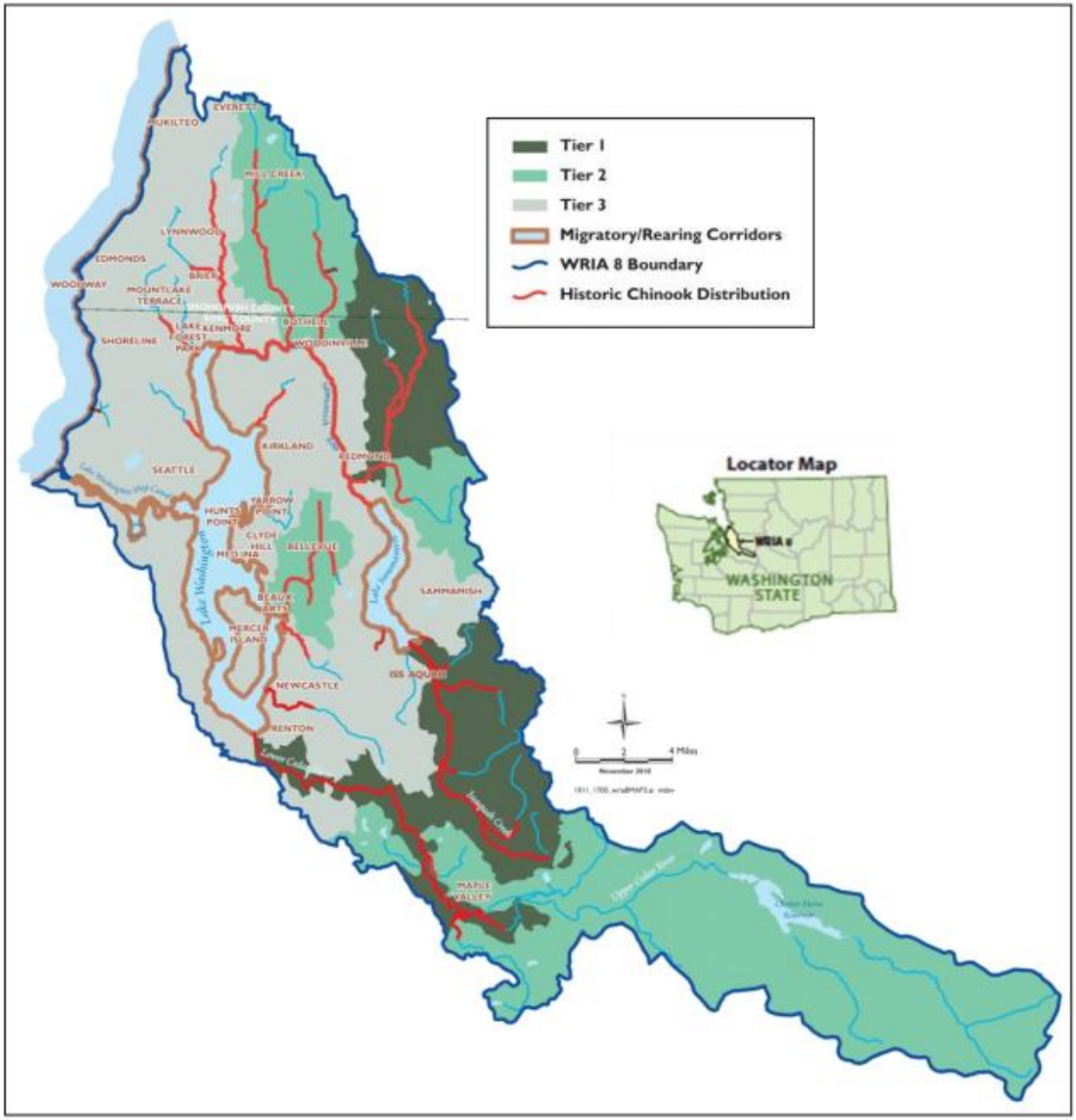


Figure 5. Map showing the extent of WRIA 8 including restoration and habitat priority based on habitat function. (WRIA 8, 2016).

Peak juvenile Chinook use of the marsh is likely to occur in June or July, though some degree of marsh use would likely occur from February to October (Brennan et al., 2004). Juvenile Coho and Chum use of the marsh is likely to peak in May or June, though some degree of marsh use would also likely occur from May to October (Brennan et al., 2004). Peak juvenile Pink use of the marsh is likely to occur in April, with some degree of use through the end of May (Brennan et al., 2004). Juvenile Cutthroat use of the marsh will be highly variable, but will likely peak in October, June, or May, with some degree of use from May through October (Brennan et al., 2004).

Economic Benefit of Marsh Restoration and Willow Creek Daylighting

In order to assign a dollar value to restoration of the Edmonds Marsh, we used a per-acre valuation of salt marsh habitat in the Puget Sound basin created by Earth Economics (Batker et al., 2010). Earth Economics used a method known as "benefit transfer," as well as the results of numerous studies cited in peer reviewed literature, to assign a range of values to each ecosystem service offered by salt marsh habitat (Table 1). Benefit transfer is a method of ecosystem services valuation used when site-specific benefit studies are not possible. It estimates economic value of ecosystem services by transferring available information from other studies to another location or context. After ecosystem service values were assigned, a 3 percent discount rate was assigned based on economic convention. Given the increased rarity of this type of habitat in Puget Sound, and the importance of pocket estuarine habitat to the adult recruitment of Puget Sound Chinook salmon, we propose assignment of, at a minimum, the upper bound of the per-acre valuation range of the ecosystem goods and services provided by salt marsh habitat (Table 1). That would value the restoration of this type of habitat at $122,098.87 per acre. The 22.5-acre Edmonds Marsh thus has a monetary value of $2,747,224.58, based solely upon the benefit transfer methodology.

	Wetland		Salt Marsh	
Ecosystem Service	**Minimum**	**Maximum**	**Minimum**	**Maximum**
Gas & Climate Regulation	$31.32	$284.58		
Water Regulation	$6,765.49	$6,765.49		
Genetic Resources				
Aesthetic & Recreational	$33.49	$9,946.87	$5.19	$103.82
Habitat Refugium & Nursery	$6.30	$13,341.27	$1.25	$1,082.32
Water Supply	$193.92	$33,418.85		
Disturbance Regulation			$258.49	$102,105.30
Waste treatment			$116.82	$18,807.44
Soil Formation				
Nutrient Cycling	$7,346.62	$7,346.62		
Biological Control				
Soil Erosion Control				
Pollination				
Medicinal resources				
Total by Cover Type	**$14,377.14**	**$71,103.69**	**$381.75**	**$122,098.87**

Table 1. High and low dollar-value estimates of ecosystem services offered by habitat type in Puget Sound Basin. (Batker et al., 2010).

Given the rarity of non-natal pocket estuarine habitat and the benefits that restoration will provide to endangered Puget Sound Chinook populations, we derived monetary value by a second means. We estimated the per-fish value of each Puget Sound Chinook using values from the published literature. Economic valuations generally account for direct values of commercial, recreational and tribal fisheries, as well as indirect values associated with employment and multiplier effects related to economic activities of people employed in fisheries and fishery-dependent communities. Using two independent studies (Meyer, 1982; Battle et al. 1996) and accounting for inflation (BLS 2016), we arrived at per-fish values of between $160 and $272 for each Chinook salmon. Using the marine survival rates reported by Magnusson and Hilborn (2003) for Chinook populations with and without access to estuarine rearing habitat (i.e., 1.77 percent vs. 0.5 percent), and assuming Edmonds Marsh will provide estuarine rearing habitat to salmon populations which currently lack access to such habitat, we estimate that restored connectivity to the Edmonds Marsh will result in a 1.27 percent increase in returning adults for Chinook salmon populations in proximity to the marsh. Based on 2016-17 forecasts for the populations most likely to use the restored marsh (i.e., North Lake Washington, Sammamish, Cedar, Duwamish/Green, White, Puyallup, and Nisqually; WDFW, 2016), this would equate to an increase of 847 fish. Using high and low estimates, this represents a monetary value of between $135,520 and $230,384, annually. One major assumption associated with this valuation is that Chinook salmon using the restored marsh currently have no access to estuarine rearing habitat. Moreover, this analysis does not account for potential changes in salmon abundance due to factors other than the availability of estuarine rearing habitat (e.g., spawning habitat in natal streams, ocean conditions). Nonetheless, we believe this assessment provides an approximate estimate of the economic benefits that may result from restoration of the Edmonds Marsh and daylighting of Willow Creek, with respect to endangered Puget Sound Chinook populations.

Conclusions

By restoring connectivity between Edmonds Marsh and Puget Sound, the daylighting of Willow Creek could provide valuable estuarine habitat for all species of salmon, including the iconic ESA-listed Chinook salmon. Consequently, daylighting could have economic benefits for the commercial, subsistence, and recreational fisheries in the region and the communities that depend on those fisheries. To the extent that increased salmon abundance would provide a food source for birds and mammals in Edmonds Marsh, daylighting could also enhance biodiversity as well as recreational opportunities (e.g., bird watching), thereby providing a valuable component to the broader marsh enhancement project.

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VEGETATION IN THE EDMONDS SALT MARSH: INVASIVES MANAGEMENT, NATIVE REINTRODUCTION, AND PLANNING FOR THE FUTURE

Cara Congelli, Skylar King, Evan Matz, Lauren Øde, Danielle Vandenberg

Overview

The goal of our project is to contribute to the preservation of long-term ecological functioning at the Edmonds Marsh. Our research team sought to analyze potential impacts to vegetation of future changes in the marsh's hydrology, identify harmful invasive flora currently present at the marsh, make recommendations for removing and/or mitigating the impacts of invasive species, and make recommendations for future vegetation management and monitoring.

This report identifies sea level rise from anthropogenic climate change, dredging of sediment-filled Shellabarger Creek, and daylighting of Willow Creek as major agents of potential hydrologic change in the marsh. We propose using a combination of annual spring quadrat sampling, fixed plot, and aerial photographic surveys to monitor the effects of hydrologic change on native and invasive plant species distribution and abundance within the marsh. Depending on the success of native species adapting to new hydrologic conditions and the threat posed by invasive species present at the Marsh, the results of such monitoring should reveal whether reintroduction and replanting of native vegetation in disturbed areas is warranted. Recommendations of native plant species to be reintroduced are based on their capacity to compete with invasive species and their ecological requirements and tolerance to potential hydrologic change.

Introduction

Tidal salt marshes, like coral reefs and seagrass beds, are unique biogenic communities. Biogenic communities are formed and maintained by a foundation of resident halophytic (salt-loving) species that thrive in anoxic sediments along shorelines. These pioneer species stabilize shorelines and act as buffers to ameliorate wave stress for the interior marsh. Marsh plants also buffer the entry of pollution into water bodies, by trapping sediments and filtering excess nutrients, chemicals, and heavy metals. Species that occupy salt marshes must be able to tolerate various physical stresses such as flooding, saline conditions, nitrogen limitation, and anoxic root zones. Within estuarine marshes, there is a gradient of habitat types that forms conforming to the gradual rise in elevation from lowland marine to upland terrestrial zones. Gradients establish zonation patterns of plant species, and when a zone arises that can provide appropriate growth conditions, marsh species must be able to colonize rapidly in order to compete with other co-occurring species. Unlike terrestrial habitats, marshes have longer growing seasons due to smaller temperature fluctuations in aquatic and nearshore environments. These conditions support large food webs by promoting the growth of photosynthetic organisms, such as phytoplankton and algae. This degree of primary productivity supports a high level of species richness across trophic levels, including insects, snails, slugs, worms, clams, fish, birds, and mammals (Pennings and Bertness 2001).

Only a fraction of the four million acres of salt marsh within the United States exist along the Pacific Coast, due to this region's high wave energy and mountainous topography. Of that fraction surrounding the Puget Sound, much of what originally existed has been heavily impacted by urban development over the past 150 years. The Edmonds Marsh is a Category 1 wetland, meaning that it

represents a "unique or rare wetland type," is "more sensitive to disturbance than most wetlands," "contain(s) ecological attributes that are impossible to replace within a human lifetime," and "provide(s) a high level of functions" (Hruby, T. 2004).

According to the Edmonds Parks, Recreation and Cultural Services Department (2015), over 80 species of birds belonging to 23 families have been observed within the city limits of Edmonds (Appendix B). The Marsh is utilized seasonally by a variety of bird species, many of which are listed as species of concern by governmental and non-governmental organizations. Many of these species of interest have populations in decline, largely due to loss of usable habitat and other environmental stressors. Included on this list are species such as the great blue heron (*Ardea herodias*), short-billed dowitcher (*Limnodromus griseus*), and western sandpiper (*Calidris mauri*), which seek refuge at the edges of creeks and marshes to preen their feathers and feed on fish and invertebrates**.** Other important avian species present in the marsh include the long-billed marsh wren (*Cistothorus palustris*), which winters and nests in upper salt marshes and feeds on marsh insects, snails, and spiders within the grasses. The house finch *(Haemorhous mexicanus)* and purple finch *(Haemorhous purpureus)* have been observed eating the seeds of arrow-grass *(Triglochin maritima)*. The Northern harrier *(Circus cyaneus)* builds its nests on the marsh surface and, like other raptors, glides over high marsh habitat searching for and diving on small mammals. The Virginia rail *(Rallus limicola)* uses its long, curved bill to forage for worms, snails, and larvae in the mud, as well as plant seeds. They also build well-concealed nests that are situated close to the ground within the marsh (Seliskar and Gallagher, 1983).

During extreme storm events, the Edmonds Marsh serves as a sheltered zone for birds to rest and feed. As a part of the Pacific Flyway, a major North American migration route, the marsh provides prime habitat for feeding and wintering of numerous migratory waterfowl (Oberrecht). According to the National Audubon Society, several bird species of special concern observed in Edmonds are also top priority species that use the Pacific Flyway (Appendix B).

The Edmonds Marsh is bordered by SR 104, the Harbor Square Business Complex, BNSF railroad tracks, and the Chevron/Unocal property. Current and prior surrounding land uses (agricultural and industrial) have resulted in increased abutting impervious surfaces, restrictions in tidal exchange, and chemical contamination. Urban infrastructure and impacts surrounding the marsh (including narrow culverts, a tide gate, and polluted runoff) have made it virtually impossible for salmon to access the marsh. Currently, only Coho salmon (*Oncorhynchus kisutch*) are documented to use the surrounding accessible channels. However, with the implementation of future restoration work, the marsh could be utilized by all seven species of salmon, including endangered Chinook.

The visible effect of these human-caused disturbances is an overall shift in the Edmonds Marsh plant community composition, primarily the proliferation of invasive plant species such as Japanese knotweed (*Polygonum cuspidatum*) and common reed (*Phragmites australis)* (Anchor QEA 2015). The consequences associated with colonization of the marsh by invasive species include loss of tidal marsh habitat due to sediment trapping and subsequent raising of the marsh elevation, thus removing low-lying areas from regular tidal influence (Richards et. al. 2008). This is directly linked to the productivity and composition of a saltmarsh community, affecting the marsh's ability to function as nursery grounds for salmon and feeding, breeding, and nesting grounds for waterfowl and other migratory birds. For example, when compared to native Pacific Northwest marsh meadows, invasive monocultures do not provide suitable bird habitat, especially for birds that nest in marshes, such as the Northern harrier and the Virginia tail (Seliskar and Gallagher, 1983). Plant invasions can also alter detrital characteristics, which are drivers of trophic dynamics within salt marsh ecosystems. For example, compared with native plant communities, stands of common reed (*Phragmites australis*) were found to support lower densities of invertebrates, a major food base (Talley & Levin 2001).

Management of invasive species and improved hydrologic connectivity between the marsh, Puget Sound, and upland freshwater flow will aid in restoring the functional integrity of this ecosystem.

Objectives of this report are to make recommendations that will enhance the ecological integrity of Edmonds Marsh by increasing the presence and diversity of native plants, and reducing the presence of invasive species. Additionally, with the knowledge that future marsh conditions will be dynamic, we seek recommendations that will improve the resilience of marsh plant communities to changes in hydrologic patterns, salinity, and environmental stressors. Our project plan involves establishing information baselines regarding overall plant diversity and the extent of invasive vegetation within the Edmonds Marsh. These baselines include specific information on the characteristics of the plant community and the effects of tidal impulse and freshwater inputs. Using these data, we recommend adaptive management and monitoring plans that could be implemented within the marsh. One aspect of this project we address in detail is the impact of scenarios involving the surrounding hydrology. These scenarios include the daylighting of Willow Creek, the dredging of sediment from inflowing Shellabarger Creek, and predicted sea level rise caused by anthropogenic global warming. Given these scenarios, we aim to develop appropriate strategies for monitoring changes in marsh vegetation resulting from altered hydrology, prevent colonization by invasive species into areas where die-off of native vegetation occurs due to such hydrologic changes, and develop plans for long-term monitoring needs.

Hydrologic Scenarios

The following figures identify current habitat zones associated with hydrologic conditions in the Edmonds Marsh, and attempt to predict how those habitat zones will change under three scenarios: (1) a one-meter rise in sea level rises, (2) the dredging of Shellabarger Creek culvert, and (3) the daylighting of the Willow Creek outlet channel. We cannot definitively predict which scenario (or combination of scenarios) is most likely to drive hydrologic conditions and habitat distribution in the Edmonds Marsh, or how precisely those changes will affect native and invasive species distribution. Nonetheless, we know that the marsh environment will change over time, and this accounting of possible pathways of change is useful for framing efforts at managing invasive species and aiding the maintenance of native plant communities.

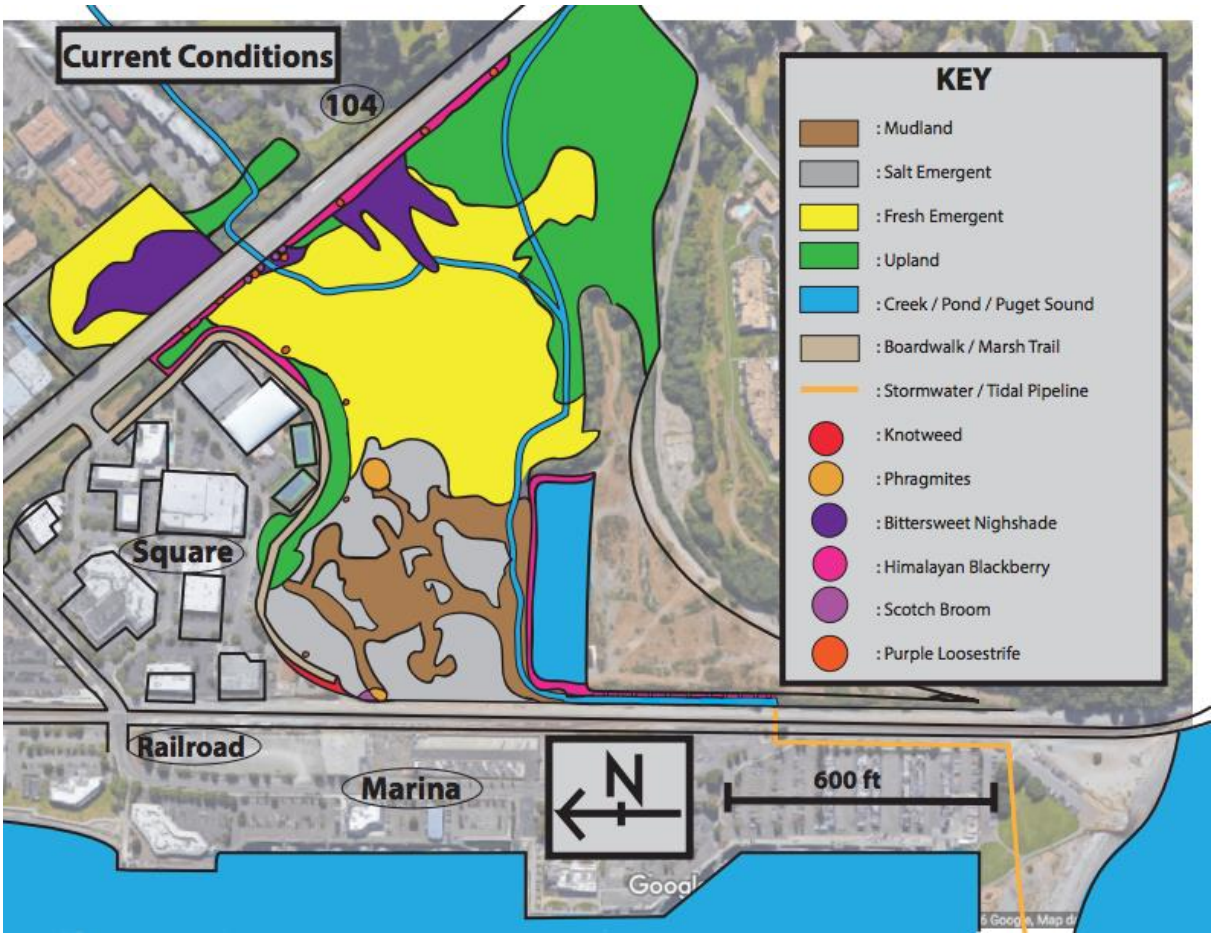

Figure 1. Current habitat and hydrologic zones within the Edmonds Marsh are generally categorized into mudflats, saltwater emergent wetland, freshwater emergent wetland, and upland regions. The low-lying region at the marsh's westernmost extent is dominated by tidal influence, and as such is largely comprised of saltwater emergent vegetation and mudflat habitat. As elevation and freshwater influence increases, habitat shifts from emergent to upland, and from being saltwater to freshwater-dominated, although there is a gradient of change across all of these plant communities. Current invasive species infestations are largely distributed around the perimeter of the marsh.

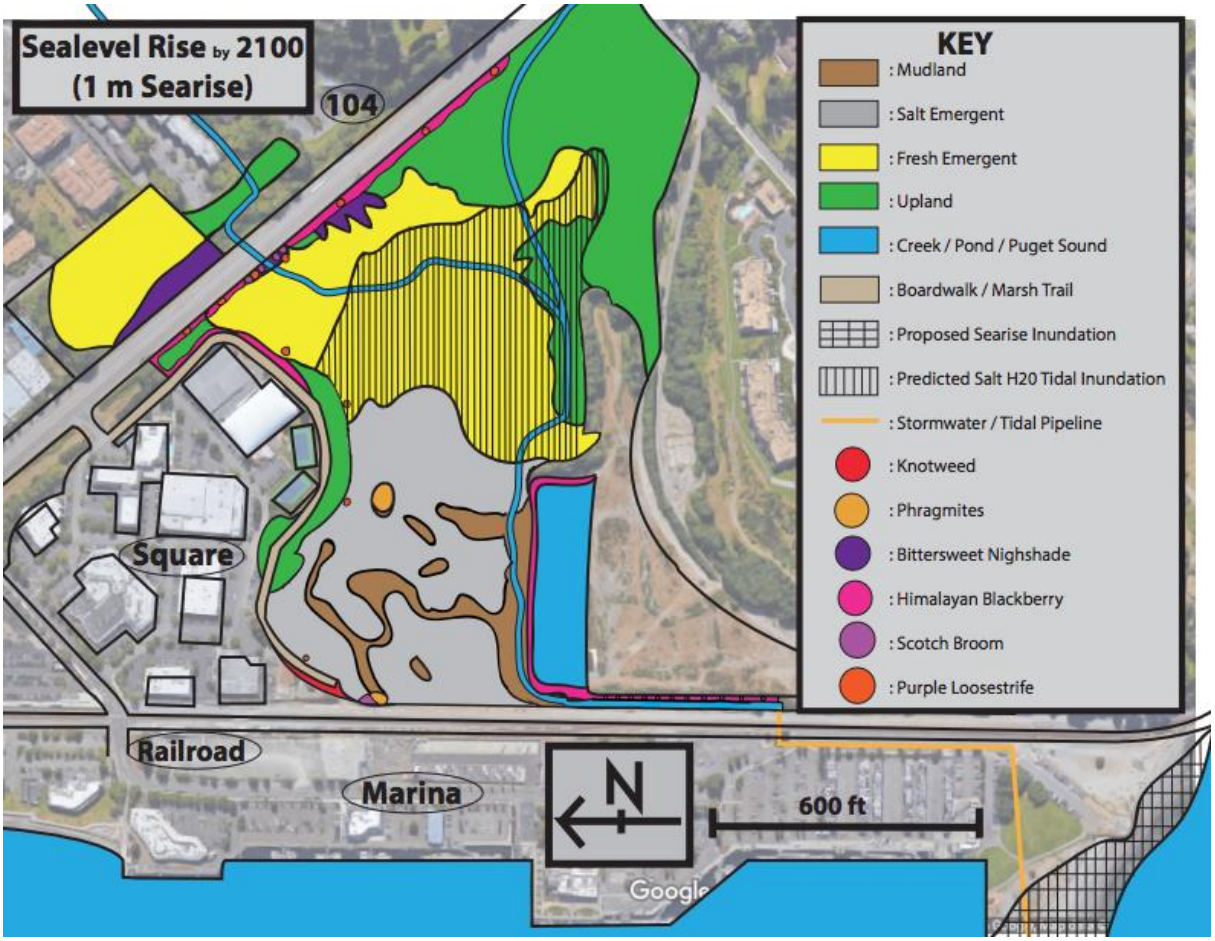

Figure 2. With a predicted sea level rise of one meter by 2100, the marsh will not be inundated completely with seawater. However, daily tidal fluctuations will allow a large portion of the marsh to be regularly inundated by saltwater. Much of the current freshwater emergent marsh habitat would take on mudflat and saltwater emergent habitat characteristics akin to historical conditions. This will drive change in the distribution and composition of vegetation throughout the marsh, with saltwater-tolerant species dominating areas where regular tidal inundation occurs. In contrast, models accounting for a sea level rise of 1.25 meters project the marsh being completely inundated by seawater, as the marsh's low elevation and gentle gradient make this area very vulnerable to sea level rise effects.

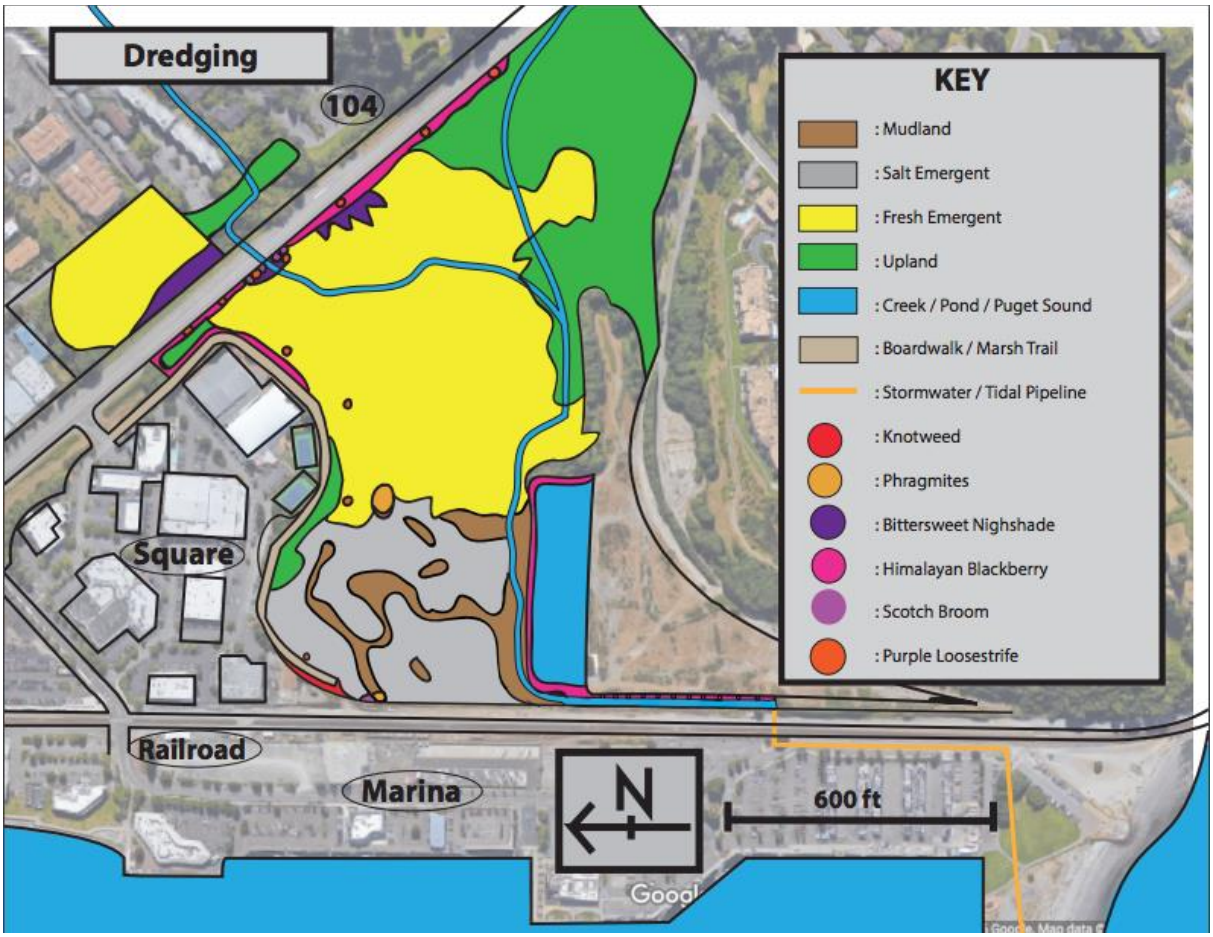

Figure 3. With the dredging of Shellabarger creek, hydrologic conditions are predicted to shift with the improved passage of fresh water into the marsh. We anticipate that increased freshwater flow would cause erosion of some of the mudflat within the saltwater emergent area, while expanding the extent of the freshwater emergent zone. After the dredging occurs it will take a number of years to see significant mudflat erosion, with the higher inputs of freshwater occurring during the winter months. Because plans for dredging the creek include tilling and manually removing some of the bittersweet nightshade (*Solanum dulcamara)* currently present in the marsh, a reduction in nightshade prevalence is shown in this scenario.

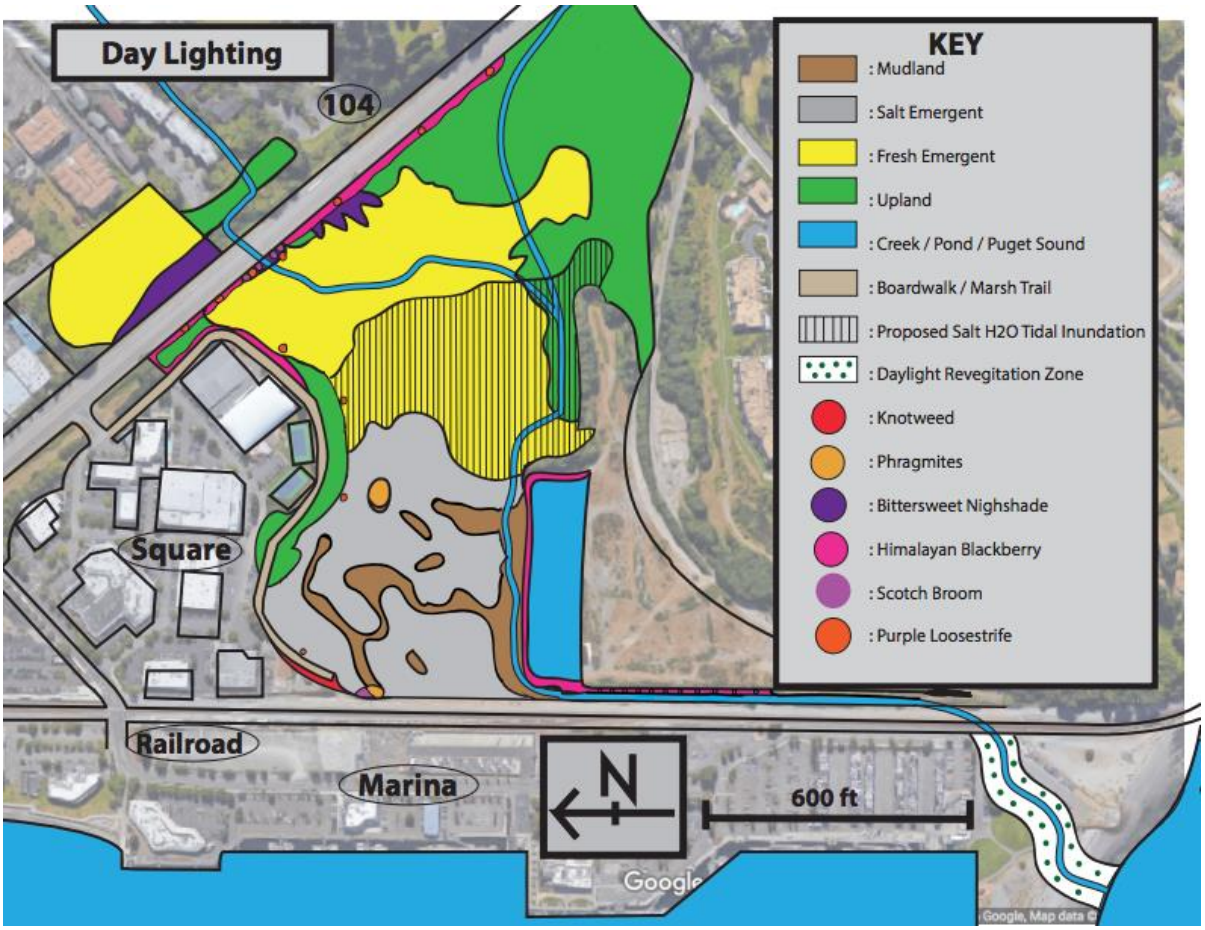

Figure 4. Daylighting of Willow Creek will restore historical hydrologic connectivity between the Edmonds Marsh and Puget Sound, allowing regular tidal flow to occur throughout the year. With improved hydrologic connectivity and regular tidal flushing, we predict incremental mudflat erosion within the westernmost extent of the marsh. The figure also indicates a region where salt water inundation is expected to expand from its current extent during tidal events. This will drive the expansion of habitat where vegetation tolerant of saltwater exposure will dominate. Finally, because the daylighting project also incorporates the dredging of Shellabarger Creek (O'Connell, *pers. comm.*), an associated reduction in the extent of bittersweet nightshade (*Solanum dulcamara*) is depicted, similar to that shown in Figure 3.

Invasives Management

Invasives Baseline

In order to establish a baseline of knowledge regarding the diversity and distribution of invasive plant species at the Edmonds Marsh, we reviewed research and records pertaining to the presence of invasive species at the site. This included reports produced by the City of Edmonds, including collaborations with EarthCorps and with a student from Edmonds Community College.

In their 2014 buffer enhancement annual report, EarthCorps discussed their plans for removing Himalayan blackberry (*Rubus armeniacus)*, morning glory (*Convolvulus arvensis)*, and bittersweet nightshade (*Solanum dulcamara)* from two different buffer sections in the northeastern part of the

Figure 5. Buffer regions where EarthCorps and volunteer work crews removed invasive species.

marsh. They recorded a 5 percent total coverage (85 sq. ft.) of Himalayan blackberry in the 1,700 square-foot area of Section A. The Section B buffer (4,500 square feet) was recorded as having 75 percent (3,375 square feet) total coverage of Himalayan blackberry, morning glory, and bittersweet nightshade (Figure 5).

Volunteer teams led by EarthCorps used manual hand-pulling to remove much of the aforementioned vegetation, including root structures and rhizomes. EarthCorps is now working on a third buffer zone (Section C); details regarding percentage initial cover and percentage of removal are not yet available for this area (O'Connell 2015). This area of the marsh is easily reached by volunteers, and thus has been the target of much invasives removal work. Documentation of invasive species is less complete along the buffer at the southern edge of the marsh.

A 2011 report by an Edmonds Community College student documented the extent of invasion by *Phragmites australis* in the marsh. At the time, 4,200 square feet of *P. australis* were present (Ohlmann 2011). The report did not explicitly identify the distribution; we surmise the report was referencing a known, large monoculture of *P. australis* present in the southeastern portion of the saltwater emergent zone (Figures 1, 6). A secondary patch of *P. australis* also has established over the past several years in the marsh's western extent (O'Connell 2016, *pers. comm.*).

A 2013 survey in the north end of the marsh, near the EarthCorps restoration site, identified approximately 15,500 square feet of purple loosestrife (*Lythrum salicaria*) within upland, freshwater emergent, and occasionally saltwater emergent areas of the marsh (EarthCorps 2013).

Additional site-specific data on the presence and distribution of invasive species within the Edmonds Marsh were difficult to find. During our site orientation, we identified patches of Japanese knotweed (*Polygonum cuspidatum*), Scotch broom (*Cytisus scoparius)*, morning glory (*Convolvulus arvensis)*, and reed canary grass *(Phalaris arundinacea)*. Quantitative documentation of the distribution and extent of these invasive species is not yet available.

Plant-specific Invasives Management Recommendations

Controlling invasive species in the Edmonds Marsh presents unique challenges. As a semi-aquatic environment, many recommended methods for managing invasive species, such as tilling or herbicide application, could damage the surrounding habitat if not performed carefully. The recommendations given in this report attempt to balance minimizing ecological impact with cost-effectiveness, while also introducing opportunities for community engagement where possible.

In managing the invasives listed in this report, all actions which call for the removal of invasive species and exposure of bare ground should be followed by careful monitoring and replanting of native species if it appears to be warranted. This is an important step in suppressing the reestablishment of invasive species at the site. Some invasive plant populations present at the Edmonds Marsh may decline on their own due to changes in marsh hydrology, but others may not. The following plans, coupled with long-term monitoring of changes in marsh plant community composition, should aid in maintaining a native species-dominated ecosystem. Appendix A identifies native species recommended for introduction in areas where invasives have been removed (or are likely to colonize in the future).

In our management recommendations, we refer to the noxious weed classification of various plants. Noxious weeds in Washington State are classified according to their current distribution in the state and the feasibility of controlling them (Table 1). No Class A invasive species are present at the Edmonds Marsh; most of the species we address are Class B and C. Japanese knotweed is also on the noxious weed quarantine List.

a. Japanese Knotweed (*Polygonum cuspidatum*)

Japanese knotweed is a Class B noxious weed on the quarantined plants list in the State of Washington (King County Noxious Weed Control Program 2015). It is widely distributed throughout the state and spreads readily in disturbed soils and along habitat fringes. It can have devastating impacts on native habitat profiles, as it often forms dense colonies of 6 to10 foot (2-3m) tall plants with broad leaves that outcompete understory vegetation for nutrients and sunlight. *P. cuspidatum* is challenging to control, as it spreads through rhizomes (which can extend up to 10 feet underground) and can propagate from vegetative fragments as small as ½ inch (1 centimeter) (Nice 2016). *P. cuspidatum* is present in small patches along the northern edge of the marsh, next to the boardwalk (Figure 1). Some invasive species observed at the marsh don't tolerate haline or aquatic conditions and potentially pose less of a threat to the marsh's native plant communities, especially given projections for future sea level rise and/or creek daylighting and dredging. However, *P. cuspidatum* has been found in lab studies to tolerate a wide range of habitat conditions, including regular saltwater inundation and anaerobic soils from freshwater flooding (Rouifeld et. al. 2012). As such, while it is currently not a management priority at the site, we recommend early control and eradication of *P. cuspidatum* before it becomes a chronic, aggressive presence (King County NWCP 2015).

Table 1. Summary of noxious weed classifications as per the Washington State Noxious Weed Control Board.

Noxious Weed Classification	
A	Non-native species with limited distribution in Washington state • Eradicating existing infestations and preventing new infestations are the highest priority. • Eradication of all Class A plants required by law.
B	Non-native species with distribution limited to portions of Washington state • Species are designated for control in state regions where they are not yet widespread. Prevention of new infestations in these areas is the primary goal. • In regions where a Class B species is already abundant, control is decided at the local level. Containment of these weeds is the primary goal so they do not spread into un-infested regions. • The Washington State Noxious Weed Board or a county noxious weed board can designate a Class B noxious weed for mandatory control. • Class B designations at the state level are listed in WAC 16-750-011, and are based on our designation region map.
C	Widespread in Washington or are of special interest to the agricultural industry • The Class C status allows a county to enforce control if it is beneficial to that county (*for example*: to protect crops). • Other counties may choose to provide education or technical support for the removal or control of these weeds.
Quarantine	Plants prohibited for sale or distribution in Washington state (includes all Class A noxious weeds). These species are of particular concern to Washington's agricultural industry, and this list is maintained by the Washington State Department of Agriculture.

Generally, manual removal methods are recommended for small infestations (less than 50 stems) of *P. cuspidatum*, and critical areas ordinances often prohibit other removal mechanisms. Cost estimates for manual removal can be very low (negligible for volunteer work crews) to about $500 per day for trained workers (Soll 2004). Follow up management to prevent regrowth from remaining roots and rhizomes is recommended as often as possible (at least once monthly) for at least three to five years after initial treatment, and regenerating plants should not be allowed to grow taller than 6 inches (King County NWCP 2015). However, this method may not be ideal for

the Edmonds Marsh, as any plant fragments left behind can be readily transported and transplanted by water, allowing *P. cuspidatum* to colonize new areas and making future management even more challenging (King County NWCP, 2015).

While herbicide use should be approached with extreme caution in semiaquatic habitats such as the Edmonds Marsh, hollow stem injection or similar highly targeted methods of herbicide application may be appropriate for this site, especially since the current infestation is relatively small, and the likelihood of accidentally spreading *P. cuspidatum* as a result of manual removal efforts is great. Multiple effectiveness studies have recorded *P. cuspidatum* control in excess of 95 percent in the first year of hollow stem-injection treatment, and it largely eliminates problems of propagation from vegetative fragments (King County NWCP 2015). Cost estimates associated with this method vary depending on the experience of the person(s) performing the treatment. At small sites, however, hollow stem injection is often the most cost-effective method, as total eradication can be achieved within one to two years (compared to manual or other herbicide-based removal methods, which often require multiple treatments over three to five years) (King County NWCP 2015). Glyphosate formulations designed for use near aquatic sites such as Aqua Neat or Rodeo are recommended to reduce unintended impacts on the surrounding ecosystem. A combined approach of hollow stem-injection followed by manual maintenance and reintroduction of a shade-providing canopy buffer would decrease the frequency of management required for removing *P. cuspidatum* from the site, and would likely be more cost-effective and less resource- and time-intensive than current management methods (Soll 2004).

b. <u>Common Reed</u> (*Phragmites australis*)

While Washington State is home to a native subspecies of common reed (*Phragmites australis* var. *americanus*), the invasive species *P. australis* is a Class B noxious weed. *P. australis* grows rapidly in dense patches, and its tight growth pattern and extensive rhizomes (up to 60 feet, or 18 meters, in length) can crowd out native species and impact hydrologic flow by trapping sediment, which changes the flow and sediment deposition patterns of the surrounding habitat (Michigan Department of Environmental Quality 2014). *P. australis* is currently present in a patch near the Harbor Square Business Complex (Figure 6), and in smaller patches at other locations (e.g., the small patch at the marsh's western edge, as seen in Figure 1). *P. australis* spreads by rhizomes, and small fragments left behind from manual removal efforts can easily grow into new plants.

An often effective method of controlling invasive species is by introducing multiple stressors on the species of concern. For *P. cuspidatum,* management guidelines often recommend herbicide application as a primary control step. However, as *P. australis* is located in a more aquatic portion of the marsh than *P. cuspidatum,* herbicide use introduces a greater risk of environmental contamination, and applications would need to be highly targeted in order to avoid this. Among commonly recommended herbicides, glyphosate is better suited for direct applications in aquatic environments. Other herbicides, like imazapyr, migrate along the root system and can kill other plants (Michigan Department of Natural Resources 2014).

In order to avoid contaminating native plants or the surrounding environment, cut-stem injection or hand swiping methods are recommended, with cut-stem injection being the preferred method. Direct herbicide application methods are time consuming and require trained personnel to conduct. To perform cut-stem injection, plants must be cut to waist height, and a drop of glyphosate must be added to the hollow stems with a squirt bottle or syringe (Michigan Department of Environmental Quality 2014). It is important to remove seed heads from the site

Figure 6. *P. australis* colony at the Edmonds Marsh (infestation in black stippling).

or to perform cut stem injection early in the season in order to prevent seed spread. Hand swiping is recommended in areas where native vegetation must be avoided, and also as a follow-up treatment to cut-stem injection. For hand swiping, herbicide is applied by covering each individual stem using a cotton wicking glove worn over a chemical resistant glove (Michigan Department of Environmental Quality 2014). It is important not to oversaturate or drip herbicides on the surrounding environment. Three years of either herbicide treatment method could cost about $5,000, accounting for materials and trained personnel (Ohlmann 2011).

Mechanical treatment is recommended after herbicide application has weakened the plants. It is most effective following an herbicide treatment to remove dead stems and promote native plant growth. Mowing should not occur until at least two weeks after herbicide application, to allow plant absorption of the herbicide. To remove dead stems on dry sites after an herbicide treatment, mechanically cut the treated plants once between fall and spring (Michigan Department of Environmental Quality 2014). Many departments recommend mechanically cutting the treated plants after the ground has frozen in order to avoid disturbing the soil, though this is unlikely to be a frequent option at the Edmonds Marsh. Mowing can be done with a weed whacker or small mower depending on the size of the stand. In mechanical removal, most costs are incurred during debris removal, with disposal costs running around $18 a trip or $103 a ton (Ohlmann 2011). This may add up to about $2,000 for three years, depending on the patch size.

Several studies have shown that *P. australis* responds poorly to saltwater conditions. In one such laboratory trial where *P. australis* plants were intermittently exposed to water at a salinity of 7.5 percent with application of freshwater between saltwater exposures, there was a resultant 50 percent decrease in *P. australis* biomass (Mauchamp and Mésleard 2001). While the current extent of saltwater influx in the Edmonds Marsh does not cause the *P. australis* patches to be inundated with saltwater, increased saltwater influx associated with the Willow Creek daylighting project and with sea level rise may be a long-term factor in limiting *P. australis* in much of the Edmonds Marsh (Figures 2, 3, 4).

c. Purple Loosestrife (*Lythrum salicaria*)

L. salicaria, a Class B noxious weed in Washington State, is scattered in patches throughout the Edmonds Marsh, though largely along its northern extent. It is characterized by square-like stems and bright purple-magenta flowers that bloom along spiked stalks. As with many other species of concern in the marsh, *L. salicaria* propagates readily through seed dispersal and root fragmentation and is tolerant of wetland, brackish, and upland growing environments, making it a challenge to eradicate (Natural Resources Conservation Service 2006). *L. salicaria* does not tolerate long-term flooding, meaning some of it may be eliminated by hydrologic changes in the marsh (Robinson 2002). However, not all patches are in locations that will be impacted (Figures 2, 3, 4).

When controlling *L. salicaria*, mowing is not recommended, as it can spread vegetative fragments that start new infestations. As with common reed and Japanese knotweed, glyphosate can be used to control *L. salicaria*, but it must be in a form that contains a non-ionic surfactant, such as Rodeo or AquaNeat, that has been approved for use in aquatic environments (Natural Resources Conservation Service 2006). Herbicide application should be performed after the period of peak bloom, and the same methods for spraying phragmites are recommended for *L. salicaria* (cut-stem injection and hand swiping). Herbicide application can cost between $250 and $500 per acre, depending on terrain and patch size (Soll 2004). Cut-stem injection is more time consuming than other application options, but is less likely to adversely impact the surrounding environment. Spraying should be accompanied by hand pulling, ideally before the plants have set seed (Natural Resources Conservation Service 2006).

A non-toxic option for managing and removing *L. salicaria* is biological control. The USDA has approved three European insect species as biological control agents. These plant-eating insects include a root-mining weevil (*Hylobius transversovittatus*), and two leaf-feeding beetles (*Galerucella calmariensis* and *Galerucella pusilla*) that selectively feed on *L. salicaria* and not closely-related native species (Malecki et al. 1993). This biological control method has been implemented as a successful alternative to herbicide treatment, and may be a more cost-effective option over several years, as it does not require trained technicians or multiple herbicide applications to be successful. While there are always risks associated with introducing new species to an environment, no competition between native insects and *L. salicaria* biological control agents for feeding on native plant species has been documented (Malecki et al. 1993).

d. Himalayan Blackberry (*Rubus armeniacus*)

R. armeniacus is a Class C noxious weed in Washington State. It is a familiar sight to local landowners, with robust, thorny canes and plump, dark fruit. *R. armeniacus* regularly competes with native vegetation, sprawling over and shading out understory plants, while impeding passage of large animals. This plant is readily dispersed by birds that consume the berries, and it can form daughter plants from canes that come into contact with the ground (King County NWCP 2016a). Fragments left behind from manual or mechanical removal methods can also produce new plants.

R. armeniacus currently persists in fringe habitat regions along the Edmonds Marsh perimeter, notably along the northeastern border with the Harbor Square Business Complex (Figures 1, 5). This plant does not pose an immediate threat to existing established native wetland plants within the marsh, as its roots do not tolerate anaerobic soil conditions (Soll 2004). However, competition with *R. armeniacus* impedes the ability of young native plants in the marsh's upland region to establish and provide erosion control and bank stabilization services, or habitat and food for native birds at the site.

Current management methods at the marsh for *R. armeniacus* include manual removal followed by replanting with native vegetation by EarthCorps and teams of community volunteers. This method has been effective in eliminating *R. armeniacus* from the site in patches, though it can be very labor intensive. An additional control method worth consideration is the introduction of periodic managed grazing pressure to eliminate large patches of *R. armeniacus*. Depending on current manual management efforts by the City of Edmonds, it may be a less time- and cost-intensive method ($200 to 500 per day) for initial removal of *R. armeniacus* prior to native replanting (Soll 2004). This method has been used effectively since 2007 on City of Seattle properties to suppress English ivy (*Hedera helix*), *R. armeniacus*, and other invasive species (McDonald 2007). According to a 1974 study (Armor), while 96 percent of *R. armeniacus* plants produced daughter plants when ungrazed or untreated, the introduction of grazing pressure completely eliminated the establishment of new plants. Allowing chickens to follow up grazing by goats or sheep (prior to the reintroduction of native vegetation) can also serve a valuable function, as chickens can consume and neutralize *R. armeniacus* seeds remaining in the seed bank (Soll 2004). Regardless of the removal method used, replanting of native vegetation at the site should take place, focusing on dense shade-providing canopy plants to ensure continued exclusion of *R. armeniacus* (King County NWCP 2016a).

e. Bittersweet Nightshade (*Solanum dulcamara*)

S. dulcamara is a woody perennial shrub with brilliant red berries and characteristic purple flowers with five petals. While it is not a classified noxious weed in Washington State, it is listed as a "Weed of Concern" by the King County Noxious Weed Control Board, as it can form dense patches, crowding out native vegetation and, as with common reed, can impede fish passage by altering sediment dynamics in aquatic systems (King County NWCP 2016b).

The current extent of *S. dulcamara* is within the eastern edge of the marsh, including an area that is separated from the main body of the marsh by SR 104 and a buried culvert (Figure 1). This freshwater portion of the marsh is dominated by cattail (*Typha latifolia*, a native species) and other freshwater wetland vegetation. *S. dulcamara* rapidly colonizes disturbed areas, and the first appearance of this plant at the marsh was observed a handful of years ago in association with die-off of *Typha latifolia* (Waggy 2009). The *S. dulcamara* patch has persisted over the past few years, but it appears to have recently decreased somewhat in size (O'Connell, *pers. comm.*).

While this plant, like *P. cuspidatum*, can reproduce through rhizomes and from vegetative fragments, it does not grow as aggressively or propagate as readily. *S. dulcamara* seeds can also be spread by birds that eat its fruit – a certainty for the marsh, with its prodigious native bird population – though, as of yet, *S. dulcamara* does not appear to have migrated to other parts of the marsh (King County NWCP 2016b). Continued monitoring for the spread of *S. dulcamara* and other invasive species should be conducted as a cautionary measure. *S. dulcamara* is particularly well-suited for monitoring through experimental UAS-based methods (see below), as it is clearly visible in standard airborne color photography. Early spring or late fall and winter may provide

ideal conditions for distinguishing bittersweet nightshade from the surrounding vegetation by its bare branches and bright red berries (Waggy 2009).

Recommended management approaches for *S. dulcamara* include manual pulling, root digging, and cutting for small infestations, and mowing or applying geotextile fabric in larger areas. Any practices that would disturb soil in order to eliminate *S. dulcamara* should be accompanied by replanting of native species to suppress regrowth. Cost estimates for managing *S. dulcamara* in this way would likely be similar to those estimated for Japanese knotweed and common reed, costing up to $1,000 per acre (depending on whether volunteer or trained personnel were utilized) for manual removal methods with additional associated follow-up removal costs (Soll, 2004). It should be noted, however, that in recent years the patch of *S. dulcamara* has appeared to decrease in size without the use of any external control pressures. As this species appears to be relatively well-contained, is not in an area where it could have a dramatic impact on the associated community function, and the nearby *T. latifolia* is self-propagating in areas away from the receding *S. dulcamara* patch, we recommend continuing to monitor the size of the *S. dulcamara* patch and to only intervene with manual removal methods if it appears to grow or exert adverse effects on the nearby vegetation. Preliminary designs for dredging as part of restoring flow in Shellabarger Creek and dredging from the Willow Creek daylighting project both include manually removing *S. dulcamara*, and changes in the water table from dredging may also aid in controlling this species (O'Connell, *pers. comm.*).

f. Reed Canary Grass *(Phalaris arundinacea)*

P. arundinacea is a rhizomatous perennial grass that grows in dense clusters and can reach 3 to 6 feet in height. As with many other persistent invasive species, it can grow from vegetative fragments, making it a challenge to remove (Weinmann et al 1984). *P. arundinacea* impacts habitat by crowding out native species and altering sediment and water flow dynamics as it grows across waterways (Weinmann et al 1984).

Options for controlling *P. arundinacea* include burning, grazing, applying herbicide, flooding, excavating, and localized heating through solarization with plastic or fabric (Wisconsin Department of Natural Resources 2009). Some success has been documented in controlling *P. arundinacea* with twice-annual mowing in June and October, to remove seed heads and control spread. However, this method could also facilitate the spread of the reed canary grass infestation through vegetative fragments. Since mowing does not remove the underlying system of rhizomes and dormant buds, this is not a long-term eradication method (WDNR 2009).

With the possibility of dredging Shellabarger Creek, much of the *P. arundinacea* patch at this site would be disrupted. If the work of dredging the culvert was coupled with excavating the *P. arundinacea* patch and seed bank, this could quickly and effectively remove most of the infestation. Follow up planting with native species would be essential in order to prevent *P. arundinacea* from regaining its territory, and monitoring of the site should occur for the next three to five years after dredging, to ensure that *P. arundinacea* has been eliminated (WDNR 2009). Excavation by tractor for this size of site could cost up to $500 per acre, though this would be offset somewhat by coupling removal of *P. arundinacea* with the dredging project (Soll 2004).

g. Morning Glory Vine (*Convolvulus arvensis*)

C. arvensis is a Class C invasive species in Washington State. It is not currently widespread at the Edmonds Marsh, but its vining growth form allows *C. arvensis* to spread rapidly and overtake native vegetation at the site. As with many other invasives of concern at the marsh, *C. arvensis*

reproduces vegetatively from plant fragments, as well as from seeds, making early detection and removal essential for effective control (King County NWCP 2007).

Removal of the top growth of *C. arvensis* can help weaken and curb expansion of the infestation, but this alone will not eradicate the plant. An effective management method can include the use of landscape fabrics to cover mature plants, or an area where pulling has recently occurred (Wright et al. 2011). The area would need to be monitored to ensure plants do not break through the cloth. Although this is an effective method for removing *C. arvensis*, it is a slow process, taking about three to five years to completely kill the plants (Wright et al. 2011). However, it is less impactful on the surrounding environment than herbicide-based removal methods.

Tall, canopy-forming native plants can be used to shade out further *C. arvensis* infestation in a manner similar to landscape fabric application. *C. arvensis* reproduces readily by rhizomes, so hand pulling control methods must remove all vegetative fragments from the area. Hand pulling is recommended in early spring when the ground is wet and it is easier to remove roots from the soil without breaking them (King County NWCP 2007). This is a more labor-intensive removal method, but it allows for immediate replanting with native fauna to help shade out and prevent regrowth of *C. arvensis* – a desirable option at a scenic site like the Edmonds Marsh. Hand clearing could cost up to $1,000 per acre, but with a volunteer group those costs could be mitigated (Soll 2004). Groups of eight to 10 volunteers could clear over half an acre of invasives per day, smaller than the area currently affected by morning glory at the marsh (Soll 2004).

h. Scotch Broom (*Cytisus scoparius*)

C. scoparius is a Class B invasive species in Washington State. This shrub is commonly seen growing in tall stands along roadsides throughout the state and is present in upland areas at the Edmonds Marsh. Each *C. scoparius* plant produces thousands of seeds annually, competing with native vegetation for sun and space. This species would likely not be impacted by future hydrologic changes from dredging, daylighting, or sea level rise, as the infestation at the marsh is located in an upland extent that is unlikely to experience hydrologic inundation (Figure 1).

Unlike the aforementioned invasive species, *C. scoparius* does not reproduce rhizomatously from vegetative fragments, and can be removed effectively by hand pulling (Hulting et. al. 2008). Hand removal can take up to 300 hours per acre and equate to about $2,000 per acre if work is performed by trained staff (Huckins and Soll 2004), but volunteer teams could be effectively deployed to perform this work as well. As with managing other invasive species, removal of *C. scoparius* should be followed by replanting with native species to prevent reestablishment by *C. scoparius* or other invasive species. Native trees such as Douglas fir (*Pseudotsuga menziesii*), red alder (*Alnus rubra*), and other tall trees can be planted to shade soil and make conditions less suitable for *C. scoparius* (Hulting et. al. 2008). Intermittent monitoring should be conducted for one to three years after removal, to ensure that reinfestation does not occur from the seed bank (Soll, 2004).

If hand pulling is not an option, growth of *C. scoparius* can be slowed by cutting below the basal node, the area that is more yellow than green (Huckins and Soll 2004). Any cutting should be performed before the seeds are set in order to prevent further seed dispersal (King County NWCP 2008). Cutting and pulling are both time consuming methods, but they would be less detrimental to the surrounding environment than herbicide application, and are reasonably effective methods of control for this species. Such manual methods are also more cost-effective than herbicide application in this instance, as volunteer labor can be used. Mowing work can be performed with a chainsaw and can cost as little as $100 per acre, whereas chemical removal methods would require trained technicians and specialized equipment (Huckins and Soll 2004).

V. Monitoring Plan

Goals of the monitoring work envisioned for Edmonds Marsh are to document the current presence, distribution, and abundance of native and invasive species at the marsh, and to identify changes in marsh vegetation composition over time in response to management of invasive species, changes in marsh hydrology, and other influences.

A combination of invasive species management techniques will be implemented over the course of many years. As such, our monitoring plan is designed with longevity in mind. We also favor monitoring methods that are cost-effective and require limited training to implement successfully. Our objective is to conserve resources for other marsh management work, while providing opportunities to involve community members in monitoring.

The first component of our recommended monitoring is an annual random quadrat sampling of the Edmonds Marsh along a transect. The number of species present and the percent cover of each species will be recorded for each quadrat. We recommend sampling during the spring growing season, when species are easy to identify and plant biomass is highest, allowing for estimation of maximum percent cover. We recommend sampling 1 percent of the total marsh area in order to obtain a representative sample of the marsh (Krebs 1999). In his study on quadrat sampling techniques, Daubenmire (1959) found diminishing returns with increasing number of samples. Thus, for an area as large as the Edmonds Marsh, we recommend using a 4 meter by 4 meter quadrat size, instead of the typical 1 meter by 1 meter quadrat. This allows 1 percent of the marsh to be sampled more quickly while reducing redundant sampling, as well as lessening the impact on the surrounding marsh habitat from treading through the sampling sites. Random transect sampling provides a measurement of marsh diversity, while simultaneously watching for the spread or appearance of invasive plants throughout the marsh in response to disturbance processes.

To determine how invasive species respond to removal efforts, we suggest monitoring with subjectively placed permanent plots. Permanent plots can indicate pathways of ecological succession, and may also aid in generating hypotheses on mechanisms or causes of change (Bakker et al. 1996). Given that our interest lies in whether or not known patches of invasive species are increasing or decreasing in size as a result of control efforts, exact plant counts or weights are not necessary. Instead, inside each large fixed plot, we recommend recording the number of species and percent cover for each species using 1 meter by 1 meter quadrats. Given our plan to plant competitive native plants around invasive species patches, if our monitoring showed an increase in native plant percent cover and diversity, and a decrease in the percent cover of invasive plants, then restoration efforts could be judged as having been helpful.

A third sampling method involves the use of Unmanned Aircraft Systems (UAS), commonly referred to as drones, to gather images of the marsh that can be analyzed using Geographic Information Systems (GIS) software to identify and monitor large patches of invasive weeds. Certain invasive species in the Edmonds Marsh, such as common reed and bittersweet nightshade, can be identified from lower-resolution photographs and videos, making monitoring of these invasive species through the imagery collected by UASs very feasible at this site. The Utah Department of Agriculture and Food currently uses UAS imagery to document restoration projects similar to those being conducted at the Edmonds Marsh (Quilter and Anderson 2006).

Figure 7. Aerial imagery of the Edmonds Salt Marsh collected by small UAS (date unknown) (K. O'Connell, *pers. comm.*). A large patch of *P. australis* is circled in red. Image distortion is relatively low in the center of the photo, but increases dramatically at the edges of the image.

The City of Edmonds has deployed UASs at the marsh to collect photos in the past, and has been successful in identifying large patches of invasive species. Quantitative applications of raw aerial imagery are limited, as distortion makes determining the size of such patches very challenging (Figure 7). However, there are various methods that can be used to create image mosaics with limited distortion and centimeter-resolution accuracy from UAS-collected aerial photography. The easiest and most accurate is the Image Footprint Projection (IFP) method (Lisein 2013). The IFP method uses a series of overlapping images taken with nadir-facing, drone-mounted cameras to create two-dimensional maps, orthophotos, digital elevation models, and/or three-dimensional models (similar to a last-return LIDAR layer). Creating the orthophoto mosaic requires the use of specialized computing and analysis programs such as AgiSoft, OrthoMapper, and PhotoModeler. Once made, however, these outputs can be analyzed using conventional GIS software. While it may not be possible to monitor all invasive plant species using this method, IFP has the advantage of allowing for very accurate measurements of vegetation patches (with numerous other potential applications such as monitoring marsh hydrologic changes and bird nesting habitat) while minimizing human impact on the marsh (Figure 8). Designing an automated flight path makes it possible to obtain a consistent photographic coverage year after year.

It would be advisable to conduct a preliminary feasibility study to determine the effectiveness of UAS-collected imagery with IFP processing for identifying and measuring the extent of invasive species in the marsh. Western Washington University (WWU) currently offers coursework in UAS operation for ecological monitoring, GIS analysis, and remote sensing. Collaboration between WWU

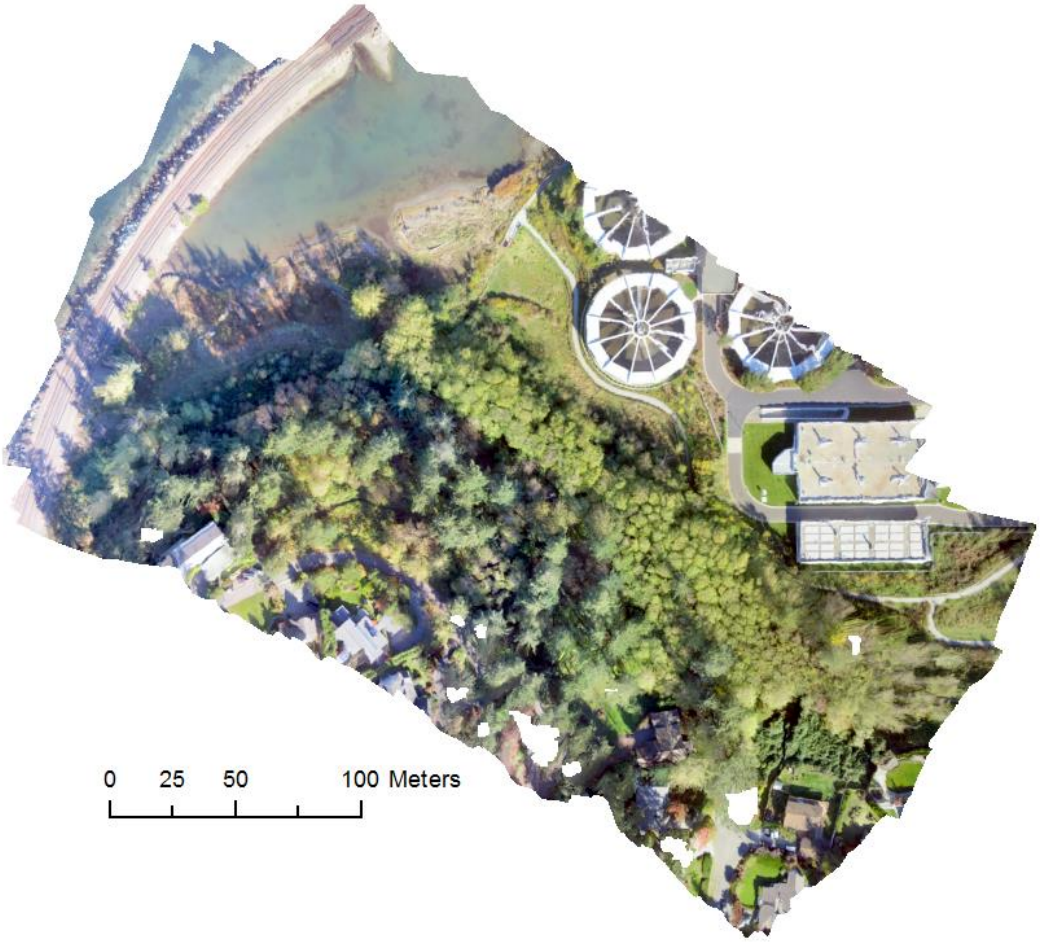

Figure 8. An example of an orthographically-corrected photo (orthophoto), assembled from a mosaic of UAS-collected images using IFP methodology. This orthophoto of the Post Point Wastewater Treatment Plant in Bellingham, Washington, was created using the Agisoft software suite and has a pixel resolution of 2 centimeters (image credit: Lauren Øde, 2016).

students and the City of Edmonds may serve as a low-cost option for performing such a feasibility study, while also providing a student the opportunity for an independent research project or internship. If this method is found to be effective in the feasibility study, it would greatly reduce the cost, time, and ecological impact associated with field surveying.

Given our project goal of decreasing costs by involving citizen-scientists and other volunteer groups in the monitoring efforts, it is important to consider the time and effort required to fulfill our monitoring goals. Project Greenshores, a similar salt marsh restoration in progress in Pensacola, Florida, is now several years into the monitoring phase. Working together, a pair of individuals takes approximately five to ten minutes to identify each plant or animal species, estimate percent cover, measure average canopy height, count stem numbers, and identify the sediment type for each 1 meter by 1 meter plot in their transect (Z. Schang, *pers. comm.*). With several groups working at once, it takes approximately two full days of work to monitor the 15 acres of the Project Greenshores site. Although the data collection monitoring by Project Greenshores is more extensive than our proposed monitoring at the Edmonds Marsh (number of species, percentage cover by species), taking into account the likely slower work pace of untrained volunteers compared to trained technicians and a longer travel time between sites at the Edmonds Marsh, this five- to ten-minute

estimate per plot is likely accurate. The time at each site could decrease by using individuals who are trained at identifying salt marsh plants, and by deploying multiple sets of volunteers simultaneously. Depending on the location of the proposed boardwalk, access to different areas of the marsh may be improved in the future, resulting in less time moving between plots, and less damage from foot traffic.

Our monitoring recommendations were chosen on the basis of being efficient, effective, and relatively easy to implement by individuals lacking specialized, costly training (with the exception of the UAS monitoring program). Although a few trained individuals would be needed to guide restoration and monitoring efforts, a large fraction of the person-hours required for monitoring could be achieved by engaging community members and citizen-scienctist groups. Local schools and community groups, such as the Friends of the Edmonds Marsh or members of the local chapter of the Native Plant Society or Audubon Society, may be interested in assisting with monitoring efforts.

Conclusion and Overview

The Edmonds Marsh is a thriving community hub for humans and nonhumans alike, and efforts to remove invasive species and perform long-term site monitoring are based around allowing human community members to aid in preserving the biotic functionality and contribute to the base of knowledge about this rare ecosystem. The monitoring and invasive species management recommendations included in this report aim to establish a baseline of information that will allow for adaptive management of the Edmonds Marsh in the face of uncertain future environmental conditions. Eliminating invasive species enables native vegetation to thrive and contribute to a functional salt marsh ecosystem, making the marsh more resilient and capable of responding positively to anticipated hydrologic changes.

We recommend beginning a vegetation monitoring program within the next few years in order to establish baseline data on species composition and distribution that can then be compared to site conditions in the future. Additionally, documentation allows future decision-making regarding the marsh to be based on quantifiable results. As the Edmonds Marsh is but one of many estuarine salt marshes nationwide facing the challenges of changing hydrology, climate, and encroachment by invasive species, the lessons learned in attempting to manage this site can be shared with other groups attempting to do the same work.

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Appendix A. The following tables detail native plants that are present in the Edmonds Marsh, or that are appropriate candidates for native revegetation efforts. These native plants are divided into categories based on the ranges of habitat types and conditions they can occupy. Situational management plans within the report identify plant categories that should be introduced to different planting zones.

Plant Spp. (common name)	**Plant Spp. *(scientific name)***	**Native/ Invasive?**	**Present in Marsh?**
Low Salt Tolerant Spp. (Upland)			
Scouler's willow	*Salix scouleri*	native	Yes - common upland
Western red cedar	*Thuja plicata*	native	Yes - common upland
Black hawthorne	*Crataegus douglasii*	native	No
Cascara	*Rhamnus purshiana*	native	Yes - planted by EarthCorps
Low Salt Tolerant Spp. (Understory)			
Skunk cabbage	*Lysichitum americanum*	native	Yes - common in understory
Salmonberry	*Rubus spectabilis*	native	Yes - dominant in understory
Moderate Salt Tolerant Spp. (ranked from highest to lowest elevation) location in intertidal l zone)			
Cattail	*Typha latifolia*	naturalized	Yes - dominant in freshwater marsh
Bentgrass / Redtop	*Agrotsis gigantea*	native	Yes - dominant in low-saline estuarine marsh
Lyngby's sedge	*Carex lyngbyei*	native	Yes - present in low-saline estuarine marsh, uncommon upper intertidal
Spear Saltbrush	*Atriplex patula*	native	Yes - dominant in lower intertidal region of high-saline estuarine marsh
High Salt Tolerant Spp. (ranked from highest to lowest (elevation) location in lower intertidal zone)			
Pacific crabapple	Malus fusca	native	No
Seaside arrowgrass	*Triglochin maritima*	native	Yes - Uncommon in lower intertidal region of high-saline estuarine marsh
Seashore / Inland saltgrass	*Distichlis spicata*	native	Yes - <10% cover in low intertidal
Fleshy jaumea	*Jaumea carnosa*	native	Yes - <10% cover in low intertidal
Pacific Silverweed	*Pontentilla anserina spp. Pacifica*	native	Yes - present in low-saline estuarine marsh, uncommon on fringe
Pickleweed	*Salicornia virginica*	native	Yes - dominant in lower intertidal region of high-saline estuarine marsh

Plant Spp. (common name)	Competitive w/ what Invasive spp.	Salt tolerance	Freshwater tolerance	Indicator status
Low Salt Tolerant Spp. (Upland)				
Scouler's willow	Himalayan blackberry, morning glory, scotch broom	Low	High	Lowland
Western red cedar	Himalayan blackberry, morning glory, scotch broom	Low	Moderate	Facultative
Black hawthorne	Himalayan blackberry, morning glory, scotch broom	Low	High	Facultative
Cascara	Himalayan blackberry, morning glory, scotch broom	Low	High	Facultative
Low Salt Tolerant Spp. (Understory)				
Skunk cabbage	Himalayan blackberry	Low	High	Obligate
Salmonberry	Himalayan blackberry	Low	Moderate	Facultative
Moderate Salt Tolerant Spp. (ranked from highest to lowest (elevation) location in intertidal zone)				
Cattail	Purple loosestrife, bittersweet nightshade, reed canary grass	Moderate	High	Obligate
Bentgrass / Redtop	Bittersweet Nightshade	Moderate	Moderate	Facultative
Lyngby's sedge	Phragmites	Moderate	High	Obligate
Spear Saltbrush	Phragmites	Moderate	High	Facultative Wetland
High Salt Tolerant Spp. (ranked from highest to lowest (elevation) location in lower intertidal zone)				
Pacific crabapple	Himalayan blackberry	High	High	Facultative Upland
Seaside arrowgrass	Knotweed	High	High	Obligate
Seashore / Inland saltgrass	Phragmites	High	Moderate	Facultative Wetland
Fleshy jaumea	Phragmites	High	Moderate	Obligate
Pacific Silverweed	Knotweed	High	High	Obligate
Pickleweed	Phragmites	High	Moderate	Obligate

Appendix B. The following table (adapted from Edmonds Parks, Recreation, and Cultural Services Department, 2015) catalogues over 80 different bird species observed at the Edmonds Marsh by local birders. Seasonal occurrence: c = common, u = uncommon, o = occasional, r = rare, x = accidental. Concern for the persistence of each bird species comes from the Federal and State Endangered Species Lists, as well as the National and Washington Audubon Bird Watch Lists.

Species	Spring	Summer	Fall	Winter	Federal Endangered Species List	Audubon/American Bird Conservancy Watch List	State Endangered Species List	Audubon Washington Vulnerable Birds List
Waterfowl								
Brant	c			u				Early Warning
Cackling goose	r		r	r			Monitored	Early Warning
Trumpeter Swan				r		Yellow List		High Concern
Canvasback				o				Early Warning
Redhead				x				Early Warning
Harlequin duck	o		o	o				Early Warning
Hooded Merganser	u		u	u				Early Warning
Loons and Grebes								
Common loon	o		o	u			Sensitive	Early Warning
Yellow-billed loon				x		Yellow List		
Honed grebe	u		u	c			Monitored	
Western grebe	u		u	c			Candidate	High Concern
Clark's Grebe	r		r	r		Yellow List	Monitored	Early Warning
Tubenoses								
Sooty Shearwater			x			Yellow List		
Short-tailed Albatross				x	**Endangered**	**Red List**	Candidate	
Pelicans and Herons								
American White Pelican			x				**Endangered**	Early Warning
Brown Pelican			r		**Endangered**		**Endangered**	Early Warning
Brandt's Cormorant	o		o	o			Candidate	Early Warning
Pelagic Cormorant	c		c	c				Early Warning
American Bittern	r	r	r					**Immediate Concern**
Great Blue Heron	c	c	c	c			Monitored	
Great Egret	x						Monitored	
Green Heron	o	o	o	o			Monitored	
Vultures and Raptors								
Turkey vulture			o				Monitored	
Osprey	o	u	o				Monitored	
Bald eagle	c	c	c	c	Delisted - Recovered		Sensitive	Early Warning
Northern Goshawk				x			Candidate	**Immediate Concern**
Swainson's Hawk			x			Yellow List	Monitored	Early Warning
Golden Eagle				x			Candidate	High Concern
Falcons								
Merlin	u		u	u			Candidate	Early Warning
Peregrine Falcon	o		o	o	Delisted - Recovered		Sensitive	Early Warning
Cranes								
Sandhill Crane	x						**Endangered**	Early Warning
Shorebirds								
Black Oystercatcher	x		x				Monitored	Early Warning
Wandering Tattler			x			Yellow List		
Whimbrel			r					Early Warning
Ruddy Turnstone			x					Early Warning
Black Turnstone			o			Yellow List		Early Warning
Surfbird			x			Yellow List		Early Warning

Sanderling	u		u	u		Yellow List		Early Warning
Semipalmated Sandpiper			o			Yellow List		
Western Sandpiper	c		c			Yellow List		
Rock Sandpiper				x		**Red List**		
Stilt Sandpiper			r			Yellow List		
Short-billed Dowitcher			o					Early Warning
Wilson's Phalarope	x		x					Early Warning
Gulls								
Heermann's Gull			c	o		Yellow List		Early Warning
Thayer's Gull			r	r		Yellow List		
Western Gull	o		o	o				Early Warning
Terns								
Caspian Tern	o	u	o				Monitored	High Concern
Arctic Tern		x					Monitored	Early Warning
Forster's Tern			r				Monitored	
Elegant Tern			x			Yellow List		
Alcids								
Common Murre	o		u	u			Candidate	Early Warning
Marbled Murrelet	u	o	o	o	Threatened	Yellow List	Threatened	**Immediate Concern**
Ancient Murrelet	r		u			Yellow List		
Cassin's Auklet		x	x				Candidate	Early Warning
Tufted Puffin		x					Candidate	Early Warning
Pigeons								
Band-tailed Pigeon	u	u	u	u				High Concern
Owls								
Short-eared Owl				x		Yellow List		High Concern
Swifts								
Black Swift		r				Yellow List	Monitored	**Immediate Concern**
Vaux's Swift	u	u	u				Candidate	Early Warning
Hummingbirds								
Black-chinned Hummingbird			x					Early Warning
Calliope Hummingbird	x					Yellow List		Early Warning
Rufous Hummingbird	u	u	u					Early Warning
Woodpeckers								
Red-breasted Sapsucker	u	o	u	u				Early Warning
Pileated Woodpecker	u	u	u	u			Candidate	Early Warning
Flycatchers								
Olive-sided Flycatcher	u	u				Yellow List		**Immediate Concern**
Willow Flycatcher	o	u				Yellow List		Early Warning
Hammond's Flycatcher	o	u						Early Warning
Gray Flycatcher		x					Monitored	
Dusky Flycatcher	x							Early Warning
Pacific-slope Flycatcher	o	o						Early Warning
Vireos								
Cassin's Vireo	o	o	o					Early Warning
Larks								
Horned Lark	r		r				**Endangered**	**Immediate Concern**
Purple Martin		u					Candidate	High Concern
Thrushes								
Western Bluebird			x				Monitored	Early Warning
Varied Thrush	u		u	u		Yellow List		
Mimids								
Sage Thrasher	x						Candidate	High Concern
Warblers								
Yellow Warbler	u	o	o					Early Warning
Black-throated Gray Warbler	o	r	o					Early Warning
MacGillivray's Warbler	r		r					Early Warning
Sparrows								
Chipping Sparrow			r					Early Warning
Brewer's Sparrow			x			Yellow List		High Concern
Lazuli Bunting		x						Early Warning

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