Living Shorelines for the Vancouver Region

Ideas for restoring coastal habitats and adapting to sea level rise

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March 2021

Sustainability Scholars Disclaimer

This report was produced as part of the UBC Sustainability Scholars Program, a partnership between the University of British Columbia and various local governments and organizations in support of providing graduate students with opportunities to do applied research on projects that advance sustainability across the region.

This project was conducted under the mentorship of Space2place Design Inc. staff. The opinions and recommendations in this report and any errors are those of the author and do not necessarily reflect the views of Space2place Design Inc. or the University of British Columbia.

Acknowledgements

A big thank you to all of those who gave their time to contribute to this project and to those who shared their images included here. I want to extend a special thank you to Sarah Primeau for her guidance throughout this project. Finally, I would like to thank my feathered office mates that always had to add their two-sense.

Cover art “Lo-fi” watercolor on paper by Natasha Jackson-Drouin

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Executive Summary

This report was created as part of the Fall 2020 UBC Sustainability Scholars Program. This research project was done to inform living shoreline design options for the Vancouver region, specifically for two study areas within which Space2place Design is currently working: north Sturgeon Bank, and False Creek. A range of completed living shoreline projects were researched and selected as precedents to study further. An in-depth literature review was undertaken to identify important considerations for each study area. Interviews with experts and precedent research furthered the overall understanding of living shorelines. This culminated into a collection of examples of precedent work, context information for the sites, recommendations for focal species and a collection of design ideas that align with a living shoreline approach. The author's working definition of a living shoreline approach is as follows: *using a deeper understanding of the natural shoreline and of the natural processes that occur there, to design a more resilient and sustainable shoreline. It is moving away from a hard armoring of the shore to designing soft or green alternatives that are harmonious with the surrounding ecology and overarching coastal system.*

Research Findings

Precedent projects (18) were selected to represent a range of built living shoreline project types.

New Brighton Salt Marsh, *Vancouver, B.C.*
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Living Seawall Tiles, *Sydney, Australia*

Interviews and meetings (9) with living shoreline and other experts provided insight on constructed living shoreline projects and informed design ideas.

Biophysical Conditions such as tides, currents, wind, and wave conditions at each study site are included in this report. Sediment transport was a focus for Sturgeon Bank and water quality was a focus for False Creek. Conditions on the northern portion of Sturgeon Bank appear to be both erosional and accretional (Page, 2011). The main concern for water quality in False Creek is *Escherichia coli* concentrations. It appears that the highest concentrations of *E. coli* occur along the shores of the eastern portion of the inlet (Cummings, 2016).

Focal Species suggestions for Sturgeon Bank are sandpipers (Western Sandpipers and Pacific Dunlin), forage fish (Pacific Sand Lance and Surf Smelt) and juvenile chinook For False Creek they are herring, mussels, and cormorants. Details about habitat requirements are also included.

In terms of living shoreline design, the design ideas for Sturgeon bank consist of a focus on **restoring tidal marshes** and **sediment augmentation** as a tool to help the habitat adapt to sea level rise. **Re-establishing habitat connectivity** through the removal of built structures such as dikes and jetties will also help restore healthy shoreline processes to the area. Using **breakwaters** that encourage **passive accretion** of sediment would help establish tidal marsh habitats and combat erosion. Additional approaches would use breakwaters for habitat and include the incorporation of a **habitat bump** on the seaward side of a breakwater or, where appropriate, the use of the **barrier island** technique, where the island helps reduce erosion and can itself become a place for new tidal marsh to develop.

The design ideas for False Creek comprise of multiple habitat types including **rocky Intertidal**, **eelgrass meadow** and **tidal marsh**. Rocky intertidal habitat would be achievable in False Creek, and it could support mussels, rockweed, and herring. A constructed tidal marsh would provide additional habitat diversity, and eelgrass meadows in the subtidal zone would further contribute to habitat values. False Creek has the opportunity to increase habitat complexity through **engineered habitat structures** and has the potential to reuse existing structures to do so. Finally, the potential for a **floating wetland** to further increase tidal habitat in False Creek is suggested.

Living shoreline design and habitat restoration share many similarities, with both aiming to enhance the ecological health of shorelines. Many of the precedents explored here focus on shoreline restoration as a form of living shoreline design. It is also important to consider the larger system of which these dynamic shorelines belong and to have a thorough understanding of the broader system to ensure success of the design. Finally, additional factors to consider when designing these sites are land use needs, infrastructure, public input, flood protection requirements, and more. The social-ecological system in which these shorelines are found do not occur in isolation, with many stakeholders and variables involved. This should all be taken into consideration when reviewing and applying this work.

Introduction

This project set out to advance understanding of living shoreline design and nature-based flood protection principles to advance local design knowledge of living shorelines, and to identify successful precedents to draw from for this type of work. The project also sought to help inform living shoreline design ideas for two of space2place's ongoing waterfront design projects- one in north Sturgeon Bank with a focus on Iona Island and the other along the east shores of False Creek.

Conventional methods of shoreline design and alteration have relied heavily on hard edges using "grey" infrastructure. This includes a reliance on seawalls, dikes, conventional breakwaters, and other shoreline controlling strategies, specifically to control erosion, establish deep water for access and to increase functionality for human use. This has left coastal regions with shorelines that lack ecological functions. In addition, considerations for sea level rise have brought awareness to the importance of sustainable and adaptive shorelines. The Vancouver region has, for upwards of 150 years, followed the conventional method of hardening shorelines. More sustainable approaches to shoreline design have gained popularity and have become more feasible and favorable options. Many municipalities in the Lower Mainland are starting to understand the threat of sea level rise and have begun implementing strategies to adapt. Living shoreline design and nature-based flood protection are powerful frameworks and tools that can be used to align shoreline design with a resilient perspective of shorelines.

It is important to note that this report does not address all of the considerations that ultimately contribute to project design, such as historical conditions, flood protection requirements, and shoreline programming, among other things. This should be taken into consideration when interpreting this work.

Background

Sea Level Rise and Coastal Habitats

The Vancouver region's shorelines are being affected by climate change through sea level rise, increased storms, more frequent flooding events, increased water temperatures and pH changes. Sea level rise projections for this region recommend planning for +1.0 m sea level rise by 2100 and +2.0m by 2200 (Kerr Wood Leidal Associates Ltd., 2011). One impact of sea level rise on shorelines is the phenomenon of "coastal squeeze" – where a reduction or disappearance of coastal habitat occurs when landward migration of habitats is not possible.

Living Shorelines Concept

The term “living shoreline” first gained popularity on the East and Gulf coasts of the United States and the approaches and strategies associated with living shoreline design are often rooted in the geography and biology of those regions (P. Hummel, personal communication, January 21, 2021). For the purposes of this work, the living shoreline approach is synonymous with a nature-based approach to shoreline design and flood protection. Living shoreline principles take a “win-win” ecoengineering perspective (Simenstad, 2017) that prioritizes both functional design and ecological function, making sure both societal and ecological needs are met.

Ali Canning, in her master’s thesis described living shorelines as designing or enhancing shoreline habitats that naturally protect coasts, such as marshes, dunes and beaches, and utilizing these to create a shoreline that is resilient, stable, and biologically diverse (Canning, 2017). The techniques used under this multilayered approach can be found on a spectrum from “green” to “grey”, where more and more built or hard material is used. Hybrid approaches, such as marsh sill walls and breakwaters, are prevalent features in living shoreline precedents. Some of the living shoreline approaches explored in this report include breakwaters, barrier islands, tidal marsh restoration, and thin-layer sediment augmentation.

The author’s personal understanding developed throughout this work and resulted in the following working definition of a living shoreline approach:

> *A living shoreline approach to coastal design uses a deeper understanding of the natural shoreline and of the natural processes that occur there, to design a more resilient and sustainable shoreline. It is moving away from a hard armoring of the shore to designing soft or green alternatives that are harmonious with the surrounding ecology and overarching coastal system. This approach also recognizes the social and ecological significance of shorelines.*

General Site Descriptions

Study Area 1: North Sturgeon Bank

Sturgeon Bank refers to the area of relatively shallow water immediately west of Lulu and Sea Islands, between the North Arm and the Main Arm of the Fraser River. Iona Island is located at the north end of Sturgeon Bank, north of Sea Island and the Vancouver International Airport. Iona Island is connected to Sea Island by a causeway that cuts McDonald Slough off from the waters of Sturgeon Bank. There are two jetties that extend offshore from Iona Island, one northwest and the other southwest. The bank between these two jetties makes up the upper portion of Sturgeon Bank and is locally referred to as the inter-jetty area.

Study Area 2: East False Creek

False Creek is a small inlet to the south of the peninsula of downtown Vancouver. The inlet and former wetlands used to extend east to modern-day Clark Drive (Wernick, et al., 2012).

Throughout the 19th and 20th centuries, land reclamation was done to promote industrial development and railway infrastructure.

Methodology

Literature Review

An initial search of available resources was done to build understanding of living shoreline design. This review informed the working definition and interpretation of what living shoreline design is and ultimately informed the design ideas that came from this work. A large part of the literature review was an in-depth search for relevant and applicable living shoreline design precedents. A comprehensive look at biophysical characteristics of each study area was done. Important species and habitats at each site were investigated. This was done to further inform the design ideas and to provide recommendations for focal species and habitats.

Interviews with Living Shoreline Experts

Interviews and meetings with living shoreline experts and others in the fields of landscape architecture, geomorphology, coastal engineering, and wetland ecology were conducted to provide insights on constructed living shoreline projects and further inform design ideas for the study areas. Meeting summaries and full meeting notes are included in the internal version of this report (Appendix A).

Design Ideas

Design ideas for the study areas were the culmination of all the above-mentioned research. Visualizations of these ideas were produced and are included in the internal version of this report (Appendix B & Appendix C).

Research Findings

Living Shoreline Precedent Projects

The following 18 precedent projects were selected to represent a range of constructed living shoreline project types. Precedents for both study areas are included here, with local projects appearing first. Precedents range from “green” to “gray” and vary in material, site considerations and strategies.

New Brighton Salt Marsh Creation

LOCATION	*VANCOUVER, B.C.*
LED BY	*Port of Vancouver, Vancouver Port Authority, Stewardship Centre of BC, Moffatt & Nichol, Golder, Hemmera*
SETTING	*Urban, saltwater, tidal marsh*
KEY DESIGN ELEMENTS	*Salt marsh creation, grading*
APPROXIMATE SIZE	*100 m x 100 m*

This project built and established a salt marsh as part of the redevelopment of New Brighton park. The salt marsh provides habitat for juvenile salmon, and also collects and receives treated rainwater runoff from nearby Hastings park. In June 2017, the City of Vancouver reported that juvenile chum and chinook salmon had been seen using the new salt marsh as they moved through Burrard Inlet (City of Vancouver, 2017).

Figure 1. New Brighton Salt Marsh shortly after construction (Google Earth)

Figure 2. Restored salt marsh at New Brighton Park (used with permission)

Vancouver Convention Centre Habitat Skirt

LOCATION	*VANCOUVER, BC*
LED BY	*WorleyParsons*
SETTING	*Urban, salt water, built habitat*
KEY DESIGN ELEMENTS	*Habitat benches, precast concrete*
APPROXIMATE SIZE	*500 lineal meters*

This first-of-its-kind habitat structure was installed in 2008 as part of the new Vancouver Convention Centre. The “skirt” is built of precast concrete for ease of installation and includes a series of habitat benches cascading from the edge of the wall. The “skirt” was designed as an artificial reef structure meant to encourage species diversity and maximize habitat connectivity (Leonard & Kullmann, 2010).

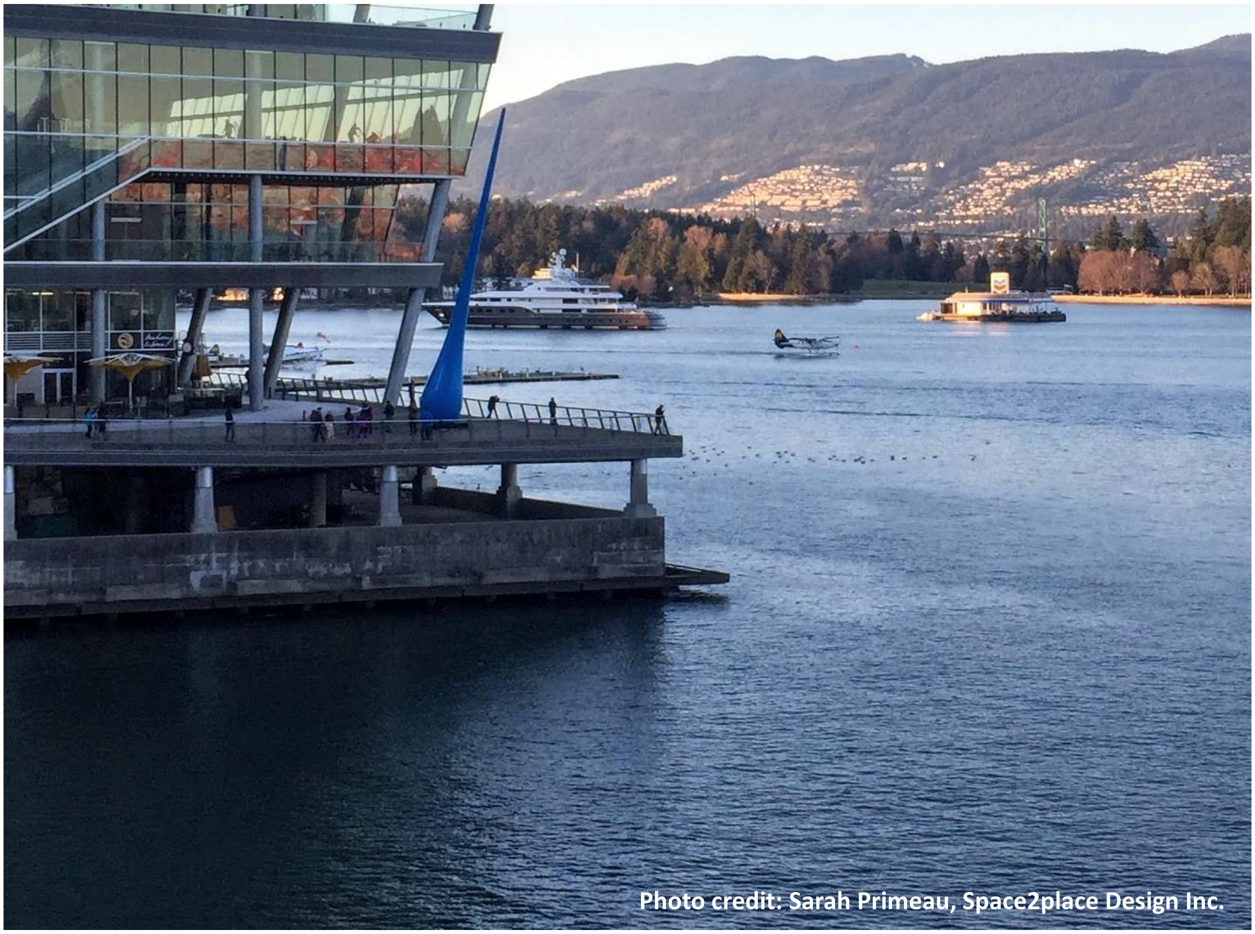

Figure 3. The Habitat Skirt at the Vancouver Convention Centre, visible at the water's surface (used with permission)

Royston Barrier Islands

LOCATION	*COURTENAY, B.C.*
LED BY	*Comox Valley Project Watershed Society (CVPWS)*
SETTING	*saltwater, log dump, natural area*
KEY DESIGN ELEMENTS	*Barrier Island technique*
APPROXIMATE SIZE	*500 m^2*

Expert Interview with Dan Bowen

The project was built to promote habitat connectivity between the subtidal eelgrass meadows and the tidal salt marshes, with a primary focus on restoring tidal habitat for migrating juvenile salmon (Sutherst, 2013). It was designed and constructed by CVPWS who developed the "barrier island" technique for use in the local area. This project was a pilot and a prototype for future work (D. Bowen, personal communication, December 29. 2020). CVPWS claims this was the first time that the barrier island technique was used on the west coast of Canada.

Figure 4. Royston Barrier Islands at centre (Google Earth)

Ala Spit Restoration

LOCATION	*WHIDBEY ISLAND, WASHINGTON*
LED BY	*Coastal Geologic Services*
SETTING	*Saltwater, lagoon, rural*
KEY DESIGN ELEMENTS	*Beach nourishment, log placement, partial grown removal, bulkhead removal*
APPROXIMATE SIZE	*600 m*

Expert Interview with Jim Johannessen

The project consisted of a partial groin and bulkhead removal and the placement of large woody debris as well as beach nourishment. The restoration was in response to a great concern of erosion of the spit. An in-depth understanding of the coastal processes was key to the success of this project (J. Johannessen, personal communication, December 17, 2020). The site continues to be a valuable habitat for salmon and is now more dynamically stable accessible (Coastal Geologic Service, 2018).

Photo credit: Coastal Geologic Services, Bellingham WA

Figure 5. Before shoreline work done by Coastal Geologic Service at Ala spit (used with permission)

Photo credit: Coastal Geologic Services, Bellingham WA

Figure 6. After shoreline work done by Coastal Geologic Service at Ala spit (used with permission)

Figure 7. Ala Spit (Google Earth)

Kilisut Harbour Causeway Breach

LOCATION	*PORT TOWNSEND, WASHINGTON*
LED BY	*Washington State Department of Transportation, Department of Ecology State of Washington, and others.*
SETTING	*Tidal channel, salt marsh*
KEY DESIGN ELEMENTS	*Causeway breach, culvert removal*
APPROXIMATE SIZE	*134 m bridge and 11 hectares of habitat*

This project reconnected Kilisut Harbour to the larger waters of Puget Sound by the removal of part of a causeway (J. Johannessen, personal communication, December 17, 2020). Despite there being two culverts under the causeway, the structure had disrupted the flow of water and sediment, which negatively affected the tidal salt marshes and salmon habitat (North Olympic Salmon Coalition, n.d.). The causeway was replaced with a 134 m-long bridge.

Figure 8. Kilisut Harbour with new bridge crossing over the restored tidal channel (Google Earth)

Leque Island Restoration

LOCATION	*STANWOOD, WASHINGTON*
LED BY	*Washington Department of Fish and Wildlife*
SETTING	*Estuary, wetlands, previous agriculture land*
KEY DESIGN ELEMENTS	*Dike breach, restored flood water, tidal channel construction*
APPROXIMATE SIZE	*100 hectares*

Once entirely salt marsh, the island became too wet to continue to use for agriculture and in 2019 the dikes were breached, and water returned to the island (Desmul, 2019). The project removed over 3.8 km of dikes and created new tidal channels. A 1.1 km wave protection berm was installed on the east side of the island that also serves as an elevated trail (Washington Department of Fish and Wildlife, 2019).

Figure 9. Leque Island (Google Earth)

Elliott Bay - Central Seawall

LOCATION	*SEATTLE, WASHINGTON*
LED BY	*James Corner Field Operations*
SETTING	*Urban, hard edge, salt water, built habitat*
KEY DESIGN ELEMENTS	*Textured concrete, cantilevered walkway, light penetrating blocks*
APPROXIMATE SIZE	*1 km*

Expert Interview with Jeff Cordell

The central seawall is part of the overall revitalization and rebuild of the Alaskan Way Viaduct and Alaskan Way promenade on Elliot Bay. The seawall is unique for the focus on ecological integration, with a salmon corridor that supports migrating juvenile salmon ("Central Seawall Project," 2017). The design uses "marine mattresses" and benches to increase habitat complexity and light penetrating tiles that allow light through the overhanging walkway. These tiles allow enough light to promote fish to use the area under the cantilever (J. Cordell, personal communication, January 22, 2021).

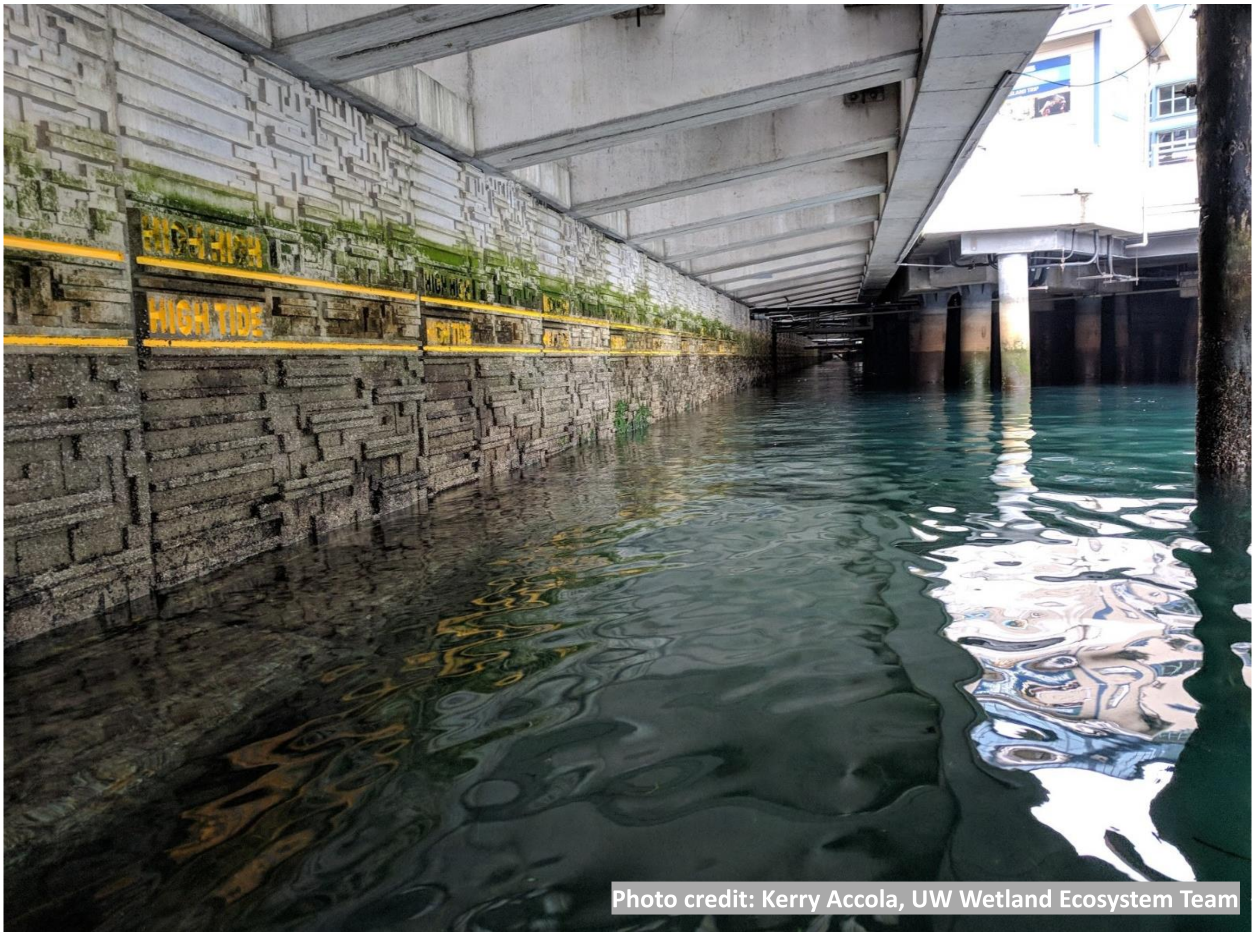

Photo credit: Kerry Accola, UW Wetland Ecosystem Team

Figure 10. Underneath the cantilevered walkway at Elliott Bay (used with permission)

Figure 11. Marine mattresses and benches exposed at low tide at Elliott Bay Seawall (used with permission)

Elliott Bay - Habitat Beach

LOCATION	*SEATTLE, WASHINGTON*
LED BY	*James Corner Field Operations*
SETTING	*Urban, salt water, built habitat*
KEY DESIGN ELEMENTS	*Urban, salt water, built habitat, beach nourishment*
APPROXIMATE SIZE	*60 m*

The revitalization and rebuild of the Alaskan Way Viaduct and Alaskan Way promenade includes additional habitat improvements like the Habitat Beach built between Colman Dock and Pier 48 (“Explore Seattle’s New Waterfront- Pioneer Square” n.d.). The pocket beaches, two in total, along Alaskan way require lots of armoring to keep them in place (J. Cordell, personal communication, January 22, 2021). This beach adds more habitat for juvenile salmon and other species.

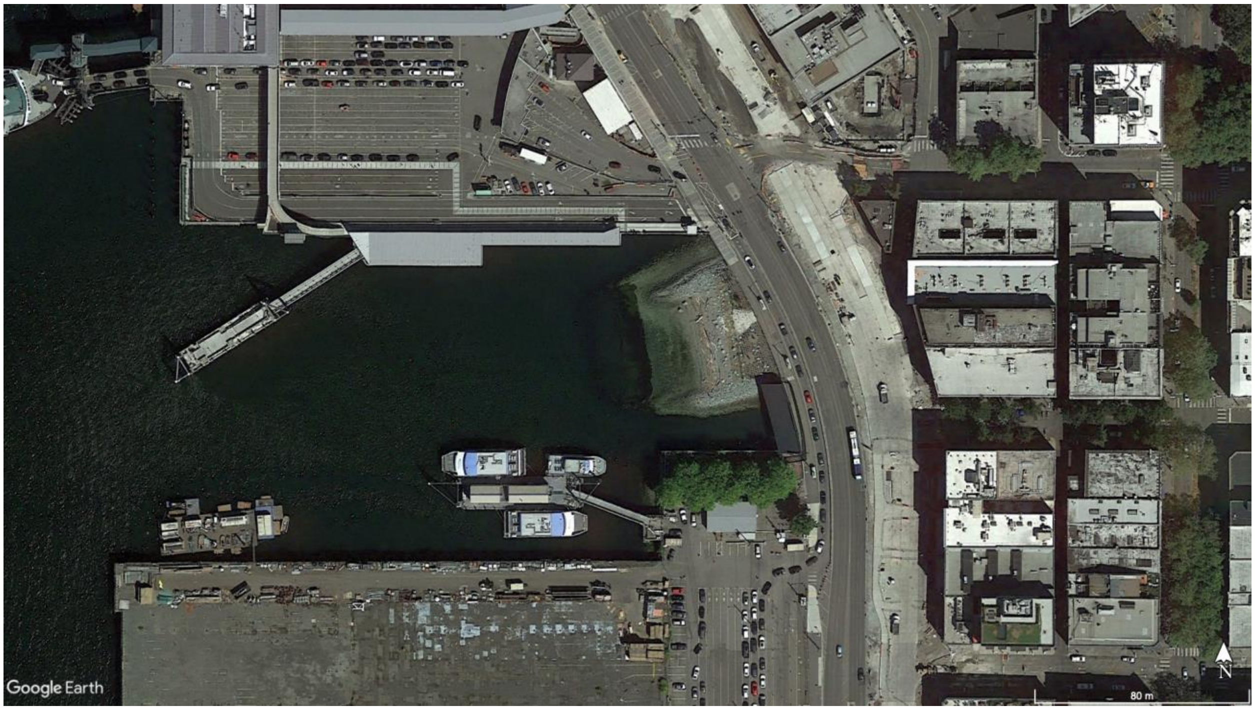

Figure 12. Habitat Beach next to Alaskan Way (Google Earth)

Seal Beach National Wildlife Refuge – Sediment Augmentation

LOCATION	*NORTHWEST ORANGE COUNTY, CALIFORNIA*
LED BY	*Southwest Wetlands Interpretive Association, State Coastal Conservancy, US Fish and Wildlife*
SETTING	*Salt marsh*
KEY DESIGN ELEMENTS	*Thin layer sediment augmentation*
APPROXIMATE SIZE	*4 hectares*

This is a pilot project (with 5 year post-addition monitoring) to determine whether thin-layer sediment augmentation to an existing marsh will increase elevations and if it is a useful tool to help habitat adapt to sea level rise on the west coast (Southwest Wetland Interpretive Association, 2019). Goals of the project include achieving at least 7 cm of elevation of the marsh, stem lengths of cordgrass comparable to before sediment addition and invertebrate biodiversity comparable to that of reference sites (Gilligan, 2018).

Figure 13. Seal Beach National Wildlife Refuge (Google Earth)

Hunter's Point South Park

LOCATION	*QUEENS - NEW YORK CITY, NEY YORK*
LED BY	*SWA/Balsley, Weiss/Manfredi, Arup*
SETTING	*Urban, salt marsh creation*
KEY DESIGN ELEMENTS	*Salt marsh installed behind hard edge, considerations for sea level rise, cantilever viewing platform*
APPROXIMATE SIZE	*4.4 hectares*

The park project was designed to respond to flooding from sea level rise. The created salt marsh is set back from the water's edge with promenades on the edges (McKnight, 2018). The park includes an iconic cantilevered viewing platform (McKnight, 2018). The marsh is flooded at high tide via culverts through the rip rap shoreline.

Figure 14. Salt marsh set inland from rip rap shoreline at Hunter's Point South Park ("Hunter's Point South Park – Phase 2 – Overlook by Daniel Prostak, CC by SA 4.0)

Tide Deck at Pier 26

LOCATION	*HUDSON RIVER – NEW YORK CITY, NEW YORK*
LED BY	*OLIN Studio, Rafael Viñoly Architects, Mueser Rutledge Consulting Engineers, Biohabitats and Tillett Lighting Design Associates*
SETTING	*Urban, brackish and salt marsh*
KEY DESIGN ELEMENTS	*Created salt marsh, tidepools, submerged structures*
APPROXIMATE SIZE	*Marsh area = 1300 m^2*

Located in the Hudson River estuary, the Tide Deck at Pier 26 includes an engineered salt marsh and constructed tide pools. The marsh and tide pool flood and emerge with the tides. The deck features three types of habitat: native planted salt marsh, engineered tide pools and submerged habitat for oysters ("Pier 26 Tide Deck," n.d.). The marsh uses a polyethylene matrix rather than soil. The tide deck is part of the overall revitalization of Pier 26, which also includes additional habitats such as woodland forest, coastal grassland, and maritime shrubs (Young, 2020).

Figure 15. Tide deck at Pier 26 below two overhanging walkways (used with permission)

Leonardtown Wharf

LOCATION	*LEONARDTOWN, MARYLAND*
LED BY	*Crozier Associates, KVO Industries, Biohabitats, David H. Gleason Associates, Cianbro Inc., and W. M. Davis, Inc.*
SETTING	*Urban, saltwater, coastal plain*
KEY DESIGN ELEMENTS	*Planted tidal wetland, observation walkway, boardwalk*
APPROXIMATE SIZE	*1600 m^2*

The project features a boardwalk next to the designed and planted tidal wetlands and marshes, which connect to the existing, natural wetlands ("Leonardtown Wharf Living Shoreline," n.d.). The project is within Maryland's designated Critical Area for natural resource protection and therefore required special consideration for the shoreline.

Figure 16. Leonardtown Wharf (Google Earth)

National (USA) Aquarium Floating Wetland

LOCATION	*BALTIMORE HARBOUR, MARYLAND*
LED BY	*National Aquarium, Ayres Saint Gross, Biohabitats and others*
SETTING	*Urban, salt water, brackish water, harbour*
KEY DESIGN ELEMENTS	*Built wetland, floating wetland, tethered wetlands*
APPROXIMATE SIZE	*35 m^2*

Expert Interview with Charmaine Dahlenburg

The current wetland is custom made with plastic matrix for plants to grow hydroponically, features an s-shaped channel through the center and is tethered to pilings, rather than being anchored. The wetland has bubblers for aeration and successfully sequesters excess nitrogen from the harbour. The current wetland is a third iteration of the concept. There are plans for a full-scale installation in the harbour, with construction potentially starting next year (2022) (C. Dahlenburg, personal communication, February 18, 2021).

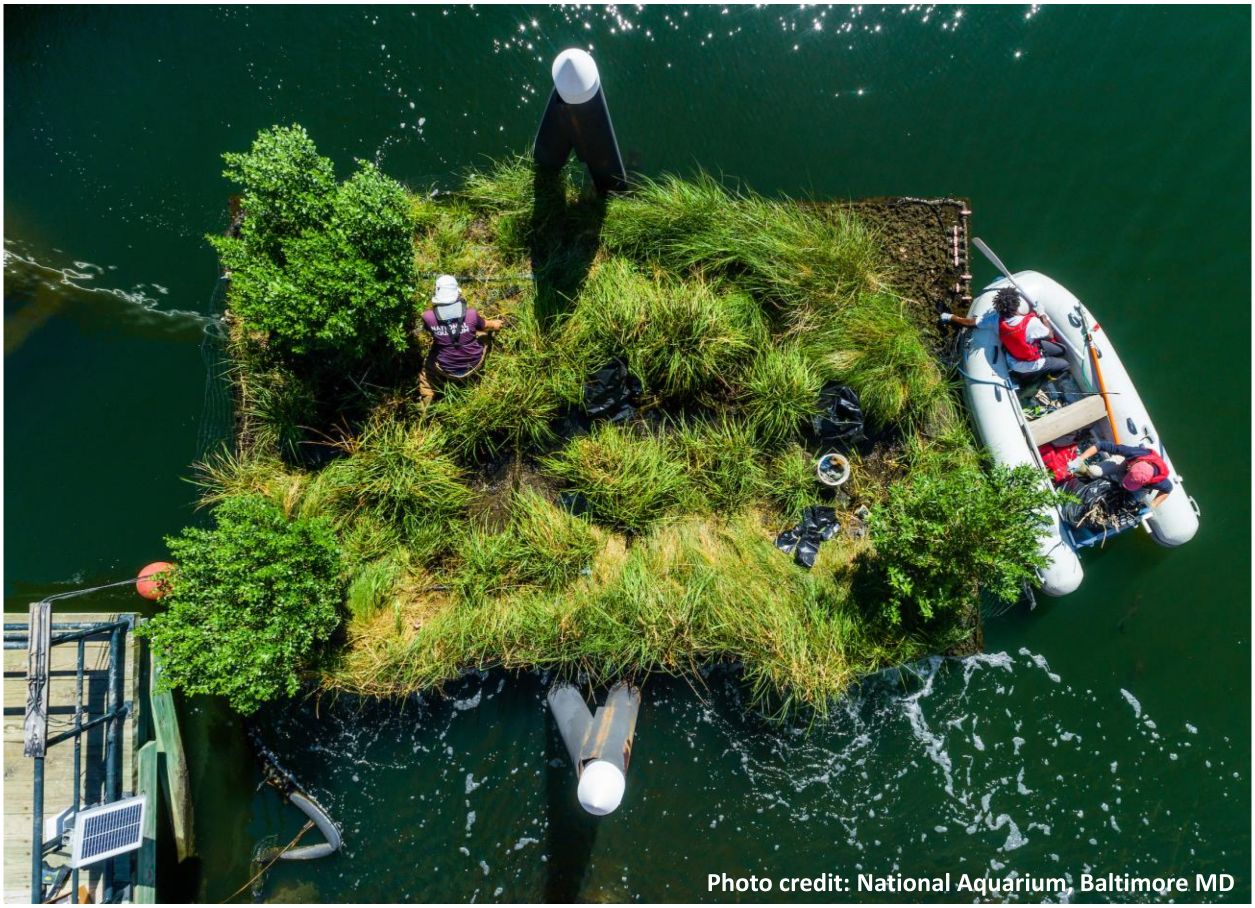

Figure 17. Overview of the Floating Wetland in Baltimore Harbour (used with permission)


Photo credit: National Aquarium, Baltimore MD

Figure 18. The Floating Wetland in Baltimore Harbour attached to two pilings (used with permission)


Photo credit: National Aquarium, Baltimore MD

Figure 19. Wetland plants growing in a polyethylene/plastic matrix (used with permission)

Hancock County Living Shoreline

LOCATION	*HANCOCK COUNTY MARSH COASTAL RESERVE, MISSISSIPPI.*
LED BY	*Anchor QEA*
SETTING	*Wetland, coastal reserve, saltwater*
KEY DESIGN ELEMENTS	*Breakwaters, salt marsh creation, subtidal reef*
APPROXIMATE SIZE	*9.5 km*

Expert Interview with Wendell Mears

There are three components to the overall project: the construction of 9.5 km (5.9 mi) of living shoreline with breakwaters to reduce erosion, the construction of 19 hectares (46 acres) of marsh with dredged materials, and the creation of subtidal reefs in an adjacent bay (Mears, et al., 2018). The completed breakwater is a segmented design intended to reduce the wave energy of a 1 ft [0.3m] wave (W. Mears, personal communication, November 20, 2020), and is able to reduce a 1 – 1.2 m wave to a 0.15 m wave (W. Mears, personal communication, January 8, 2021).


Photo credit: Wendell Mears, Mobile AL

Figure 20. Living shoreline breakwaters in Hancock County, MS (used with permission)

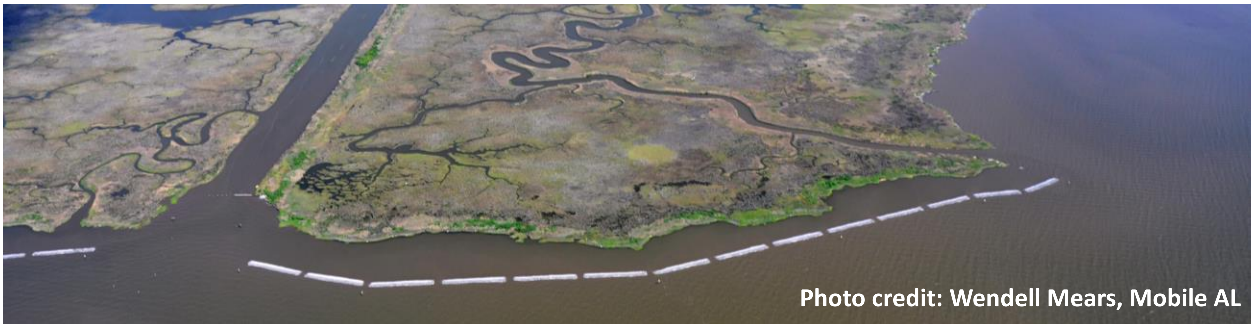
Photo credit: Wendell Mears, Mobile AL

Figure 21. Straight on view of living shoreline breakwaters in Hancock County, MS (used with permission)

Deer Island Salt Marsh Restoration

LOCATION	*BILOXI, MISSISSIPPI*
LED BY	*Anchor QEA*
SETTING	*Gulf Coast plain, salt marsh*
KEY DESIGN ELEMENTS	*Salt marsh cell*
APPROXIMATE SIZE	*16 hectares*

Lost salt marsh habitat on the island was restored using 279 000 m^3 of dredge material from the local Federal navigation channel (Roth et al., 2012). The “cell” or placement area was contained by a dike that was constructed at about 2 m lower low mean tide, with a hardened riprap to refract waves (Roth et al., 2012).


Photo credit: Wendell Mears, Mobile AL

Figure 22. An example of a salt marsh cell being constructed in Heron Bay, Hancock County, MS (used with permission)

Recycled Park floating wetlands

LOCATION	*ROTTERDAM, NETHERLANDS*
LED BY	*Recycle Island Foundation*
SETTING	*Urban, harbour*
KEY DESIGN ELEMENTS	*Recycled materials, created salt marsh*
APPROXIMATE SIZE	*46 m^2 (each)*

In 2018, a prototype of wetlands made from recycled plastic was installed along with a floating park (Berke, 2018). In addition to the wetlands, the park also included seating areas, all made with the same recycled material (Berke, 2018). The islands are hexagonal in shape and fit together to create a sprawling, floating wetland are seating area. The Recycle Island Foundation utilized litter traps to collect plastic heading for the ocean to create the islands (Solar Impulse

Foundation, n.d.). The islands create wetland habitat that is engaging and publicly accessible in an urban setting.

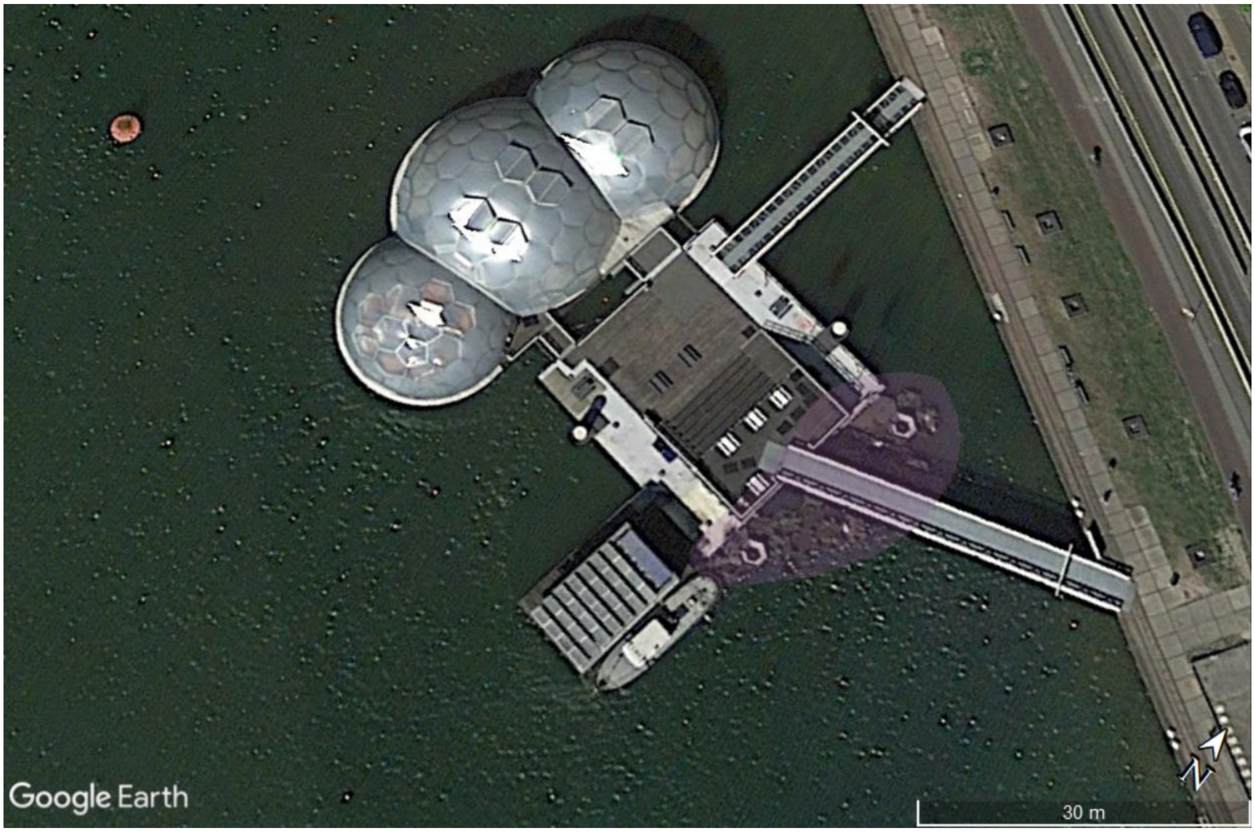

Figure 23. Recycled Park in Rotterdam, Netherlands. Islands and floating wetlands are highlighted in pink (Google Earth)

Figure 24. Recycled park's floating wetlands (used with permission)

Photo credit: clearwater.eu

Figure 25. Recycled park with floating wetlands and seating area (used with permission)

Carss Bush Park

LOCATION	*KOGARAH BAY – SYDNEY, AUSTRALIA*
LED BY	*Georges River Council*
SETTING	*Urban, saltwater, park land*
KEY DESIGN ELEMENTS	*Salt marsh bench, rocky intertidal, tidal mudflats*
APPROXIMATE SIZE	*1375 m^2 saltmarsh and 112 m^2 rockpool habitat*

Failure of the park's outdated seawall and erosion behind it, led to the development of an ecologically engineered shoreline solution. Multiple habitat types were considered in the shoreline design including salt marsh benches, rock pools/tide pools, rocky intertidal and tidal mudflats. Considerations made for the site design included balancing the amount of riparian habitat installed and the playing fields in the park for recreational use. The project resulted in improved biodiversity, aesthetics, social and cultural values, and improvements to the natural ecology of the site (Heath & Council, 2017).

Figure 26. Carss Bush Park (Google Earth)

Living Seawall Tiles

LOCATION	*SYDNEY, AUSTRALIA*
LED BY	*Sydney Institute of Marine Science (SIMS), Reef Design Lab*
SETTING	*Urban, hard edge, harbour*
KEY DESIGN ELEMENTS	*"Greening" seawalls*
APPROXIMATE SIZE	*Customizable*

The concept of increasing the habitat value of seawalls has manifested in different designs and forms. The Living Seawall tiles created by the Sydney Institute for Marine Science (SIMS) and Reef Design Lab use a hexagonal shape and are designed with recruitable habitat in mind. SIMS has installed these tiles in multiple locations with success (Sydney Institute of Marine Science, 2021).

Figure 27. Living Seawall tiles installed on a seawall in Sydney, AUS (used with permission)

Figure 28. Closer look at the Living Seawall tiles (used with permission)

Interviews and Meetings

Meeting summaries and full meeting notes are included in the internal version of this report (Appendix A).

Sturgeon Bank: Biophysical Conditions and Selected Focal Species

Biophysical Conditions

Sturgeon Bank is part of the complex Fraser River estuarine system. A broad summary of some of the key aspects of the coastal dynamics of the area are described here. General data and information about the biophysical conditions of the estuary and Sturgeon Bank exists, but there is a need for additional research to further understand sediment and current dynamics. Modelling is needed to fully inform shoreline restoration work.

Sediment Transport

A key interest for Sturgeon Bank and Iona Island is the sediment regime and flow. The sediment and deltaic regime of the region relies on the freshwater discharge from the Fraser River which is approximately 12 million cubic meters per year (Atkins et al., 2016). This discharge is dominated by the late May to early June freshet, and the sediment carried by the freshet is typically made up of 50% silt, 35% sand and 15% clay (Williams et al., 2009). Most of the sediment is carried through the Main Arm of the Fraser River, with very little (3%- 4%) sediment being discharged through the Middle Arm onto Sturgeon Bank (McLaren & Tuominen, 1998) . Sediment is delivered from the Main Arm to Sturgeon Bank by northward currents (McLaren & Tuominen, 1998). The flood tide on Sturgeon Bank is the dominant tide and brings in most of the sediment with the influx of water (Atkins et al., 2016).

There is a long list of human alterations to the Fraser River Delta, including dikes, channel training structures, and dredging, all of which have altered the natural sediment deposition patterns on Sturgeon Bank. The current conditions on Sturgeon Bank are considered erosional (Atkins et al., 2016; McLaren & Tuominen, 1998). Though erosional conditions are noted for the island, it is more likely there is a mix of erosion and accretions occurring. Shoreline change from 1952 – 2009 were analyzed by Nick Page (2011) and found that the shores of the northern sections (North Arm Jetty) was variable, with periods of accretions and erosion with the region of the eastern bay being less variable with a consistent rate of progradation (Page, 2011).

Tides

Tides on Sturgeon Bank are mixed and semidiurnal with a tidal range of 5.0 m (extreme tidal range of 5.9 m) (Atkins et al., 2016). On Sturgeon Bank, tides typically flood to the northwest and ebb to the southeast (Atkins et al., 2016).

Tidal elevations for north Sturgeon Bank are as follows (Fisheries and Oceans Canada, 2019):

- Higher High Water Large Tide (HHWHT): 2.1 m
- Higher High Water Mean Tide (HHWMT): 1.5 m
- Mean Water Level (MWL): 0.0 m
- Lower Low Water Mean Tide (LLWMT): -2.0 m
- Lower Low Water Large Tide (LLWLT): -3.1 m

Currents

The surface current north of the Steveston Jetty often flows north (Figure 29), moving fresh water northward across Sturgeon Bank. This happens even during strong ebbs, which typically flow southeast. This nearshore current is more likely to be present between May and September (Thomson, 1981). This current disperses sediment across Sturgeon Bank but does not cause a significant deposition at Iona Island (McLaren & Tuominen, 1998).

Wind & Waves

Waves from storm events are particularly important in the region of Sturgeon Banks (Williams et al., 2009). All wave heights are limited by the fetch of the wind and in Sturgeon Bank, the most extreme wave heights come from the northwest, which develop over a possible fetch of 120 km (Thomson, 1981). Wave data for Sturgeon Bank (February 1974- April 1976) shows that significant waves never exceeded 2.7 m and the max heights were always less than 4.0 m, with calm conditions occurring 27% of the study time (Thomson, 1981). The largest significant wave heights, up to 2.5 m with periods of 7 to 8 s, occur on occasion on Sturgeon Bank due to the opposing current created from the flow out of the North Arm of the Fraser River (Thomson, 1981).

There is a drastic change from southeasterlies to easterly winds off the Fraser River, largely influenced by air moving through the Fraser Valley. This pattern persists through the colder months (from October to March). In the spring, winds are mostly southeasterly to easterly and by summer wind speeds are generally less than 4.5 m/s but are more erratic than the rest of the year (Thomson, 1981). The northern part of the estuary, including Sea Island and Iona Island, are considered to be relatively protected from the full strength of winter winds in comparison to the estuary's southern areas, largely due to the topography of the estuary (Thomson, 1981). In the summer, the sea-land breeze circulation, influenced by the warming of the land, dominates the winds that occur.

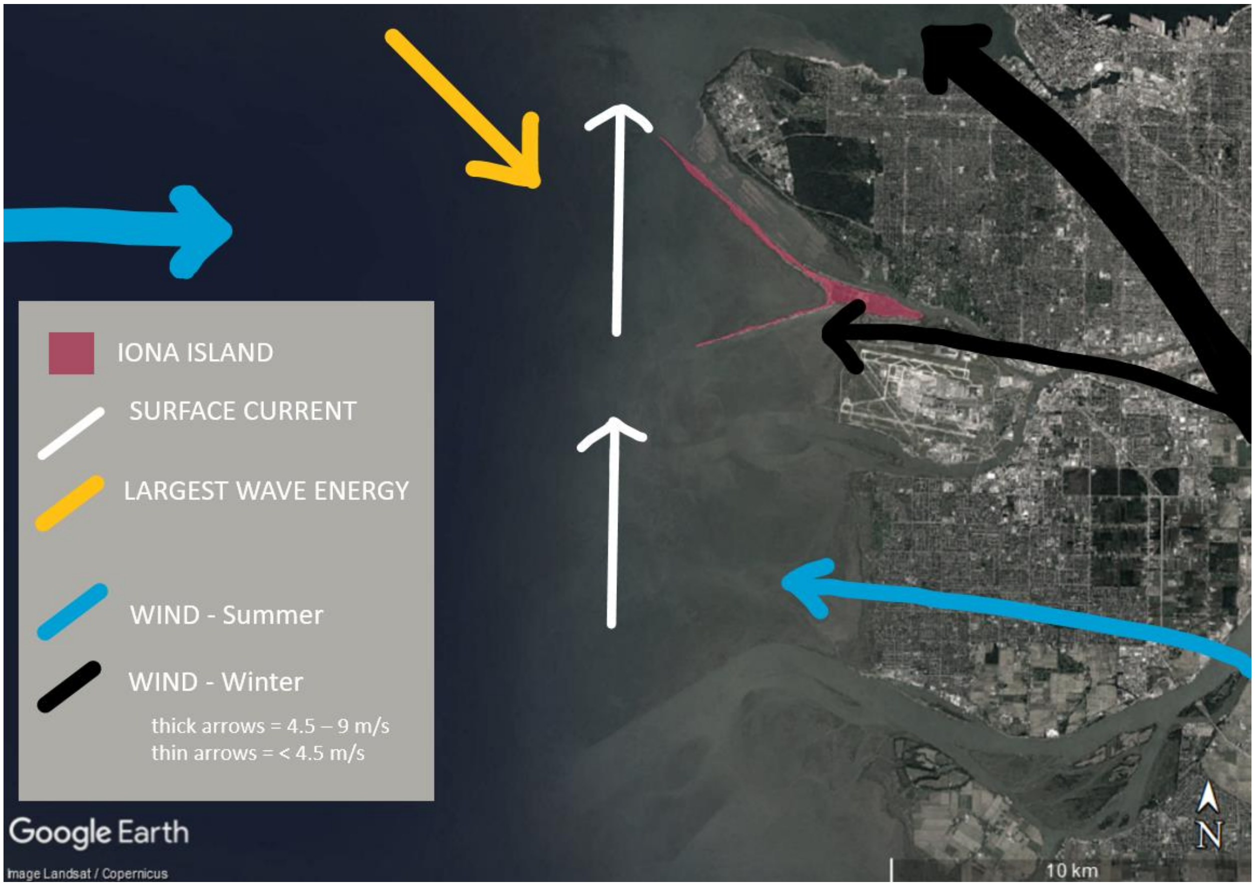

Figure 29. Regional wind patterns and surface currents occurring at Iona Island. Adapted from Thomson (1981)

Data from a weather station at the Vancouver International Airport is depicted below (Figure 30). Winds with speeds of 4-11 m/s occur around 20% of the time year-round with most winds coming from the east and southeast.

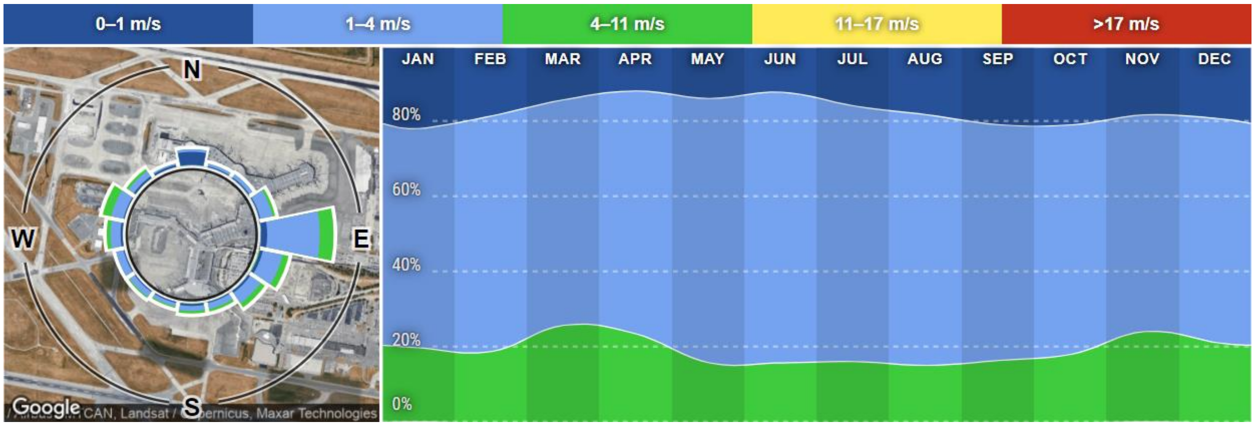

Figure 30. Wind data from Vancouver International Airport https://www.windfinder.com/windstatistics/vancouver_airport

Focal Species and Habitat requirements

Habitat Overview

Sturgeon Bank is part of the provincially designated Sturgeon Bank Wildlife Management Area (SBWMA) which spans from the north tip of the North Jetty and south to the most southern outflow of the Main Arm of the Fraser River. The SBWMA hosts all five species of Pacific salmon during migration, using its habitat for shelter and acclimatization, as well as 27 species of other non-salmonid fish (Government of B.C., n.d.). The area is also part of the Fraser River Estuary Important Bird and Biodiversity Area which supports several nationally, continentally, and globally significant populations of bird species. The island is also an important location along the Pacific Flyway, supporting millions of birds on their spring and fall migrations (Williams et al., 2009).

Species and habitats that are supported at Iona Island in particular are influenced by historical and current activities there (Page & Schaefer, 2019). For example, previous deposition of dredge material on top of wetlands created conditions for establishment of rare, early successional ecological communities (Page, 2011). Page identified three such communities considered rare in British Columbia within the regional park, these are: large-headed sedge, dune wildrye and seashore salt grass dominated communities (Page & Schaefer, 2019). In addition to these rare communities, there are other noteworthy species at Iona, such as the locally rare Yellow-headed Blackbird (*Xanthocephalus xanthocephalus*), Little Brown Bat (*Myotis lucifugus*) and the likely presence of the Lower Fraser River population of White Sturgeon (*Acipenser transmontanus*) (Page & Schaefer, 2019). Each species is considered representative of the habitat they occupy.

Sandpipers and Mudflat habitat

Sandpipers in the Genus *Calidris* have been identified as focal species and representatives of mudflat habitat. Both Western Sandpipers (*Calidris mauri*) and the Pacific population of Dunlin (*Calidris alpina*) are considered.

The most numerous shorebird on the Pacific coast is the Western Sandpiper (Butler et al., 1996) and they use the Fraser River Estuary as a stopover location during their northbound (spring) and southbound (fall) migrations (Butler et al., 1996). The Fraser River Estuary alone supports 70% of the world's Western Sandpiper population (Rantanen, 2019), so they are celebrated birds in the region. Unlike the migratory Western Sandpipers, the entire Pacific population of Dunlin are found here (Rantanen, 2019) and at Iona, Dunlin are common from November through to April (Toochin, 2014).

The mudflats can be a very productive habitat, and recently it has been understood that a key source of primary production in mudflats is biofilm. Biofilm is a layer that develops on the surface of mudflats, and it contains microbes, diatoms, and other fauna (Schnurr et al., 2020). Western Sandpipers are specialized to graze on this thin layer, with biofilm present in dropping samples (Jardine, 2015) and stomach content samples (Kuwae et al., 2008; Mathot et al., 2010). This foraging method is also utilized by Dunlin, though it appears to a lesser degree (Mathot et al., 2010). Western Sandpipers are common in the Fraser River Estuary in the later part of April through to mid-May as well as from July to September (Toochin, 2014) aligning with the species' spring and fall migrations (Butler et al.,1996). The Western Sandpiper is smaller than the Dunlin, and the presence of both species often affect feeding behaviours ("Western Sandpiper", 2019). For sandpipers who use this region as a stopover location, it is paramount that they acquire the energy needed for their journey, so conditions that promote a healthy biofilm habitat are key. The migratory patterns of Western Sandpipers differ with direction and season, with large flocks travelling together and stopping at a few large estuarine sites travelling northward and smaller, more dispersed flocks travelling southward (Butler et al., 1996). One recent explanation may be that the northward migration aligns with the increased lipid and fatty acid production by diatoms in biofilm on Roberts Bank (Schnurr et al., 2020). This contributes to the quality of Roberts Bank and the Fraser River Estuary as a stopover site (Schnurr et al., 2020). This increased lipid and diverse fatty acids production in diatoms has been observed on mudflats at a higher elevation (~ 1m – corresponding to geodetic elevations) and that have high environmental stress (salinity and temperature changes), which induce lipid storage (Schnurr et al., 2020). Though biofilm habitat is important, it appears that the sandpipers on Sturgeon Bank, and around Iona Island in particular, may rely more heavily on small invertebrates than on biofilm (Jardine et al., 2015). The size of the small invertebrates ranges from 1 mm to 10 mm and includes amphipods, cumaceans, bivalves and gastropods and made up the majority of dropping samples (Jardine et al., 2015). Ultimately, sandpipers rely on mudflats not only as a migratory fuel source, but also as a yearlong habitat. These habitats should be prioritized to promote healthy biofilm production and healthy invertebrate populations.

Forage Fish and Gravel Beach habitat

Both Pacific Sand Lance (*Ammodytes personatus*) and Surf Smelt (*Hypomesus pretiosus*) have been considered as focal species and represent the gravel beach habitats that they use to spawn. Though there is little formal documentation of their presence at Iona and no observations on iNaturalist for either species, there is anecdotal evidence pointing to great potential for spawning habitat at Iona Island.

Pacific Sand Lance and Surf Smelt are small schooling fish that are key prey animals that support many ecosystems and food webs in the Salish Sea and beyond (Penttila, 2007). Iona island may already provide spawning habitat for these species. As of 2017, spawning habitat surveys have not been widely done in British Columbia, so specific locations with suitable and potential spawning beaches are not formally documented (de Graaf, 2017). Immediate action to map and identify spawning habitat has been recommended (Buchanan, Lesperance, McArdle, Sandborn, & Curran, 2019). Extensive work has been done in Puget Sound, dating back to the 1970s, to investigate and map spawning habitat (Buchanan et al., 2019; Penttila, 2007). Though not well mapped locally, spawning habitat requirements are well understood, with some modelling of suitable habitat for both Pacific Sand Lance and Surf Smelt having been done (Cook, 2018; de Graaf & Penttila, 2014). Surf Smelt and Sand Lance spawn near the high tide line on beaches composed of pebble, gravel and sand with vegetation that provides shade (Province of British Columbia, 2014). In addition, a healthy spawning beach has an intact marine riparian zone and clean water (de Graaf, 2017). Shade vegetation is particularly important for the populations/stocks of Surf Smelt that spawn in the summer (de Graaf, 2017) but is less so for Sand Lance and other Surf Smelt stocks who spawn in the winter (Penttila, 2007). Sand lance tend to use the same beaches and intertidal zone as Surf Smelt, but are also found lower, near the initial beach slope (de Graaf, 2017; Province of British Columbia, 2014). The highest densities of embryos (of both species) are found within the seaweed wrack lines (de Graaf, 2017).

Little information has been documented about the presence of suitable habitat on Iona Island, but there is likely potential to incorporate elements of suitable habitat into the shoreline design. Raincoast Conservation Foundation sampling in 2018 did find Pacific Sand Lance present around

Iona Island (Page & Schaefer, 2019). Penttila (2007) goes into detail about spawning habitats in the technical report for the Puget Sound Nearshore Partnership *Marine Forage Fishes in Puget Sound* and this information is briefly summarized in Table 1.

TABLE 1. SUMMARY OF DETAILS - SURF SMELT AND PACIFIC SAND LANCE SPAWNING HABITATS (PENTTILA, 2007)

	Grain Size (*bulk of material*)	Spawning Range (*shoreline*)	Spawning Season
Surf Smelt	1- 7 mm	Extreme High Water +/- 2.1 m tidal elevation	Throughout year
Pacific Sand Lance	0.2- 0.4 mm	Mean High Higher Water +/- 1.5 m tidal elevation	November-February

Juvenile Chinook Salmon and Tidal Marsh Habitat

All five species of Pacific salmon are found in the SBWMA during their migrations (Government of B.C., n.d.). The focus for this report will be on juvenile Chinook salmon (*Oncorhynchus tshawytscha*) as they are the life stage that utilizes tidal marsh habitat for the longest amount of time, and due to their cultural, environmental, recreational, and economic importance. Chinook play an important role as a key prey species for the southern resident killer whale population (Ford et al., 2010). Healthy habitat for juvenile salmon in their rearing years and migration is key to their overall health. Estuaries play an important role as they offer relatively safe and productive habitat for many species of fish. Of the many habitat types found within an estuary, it is the estuarine marshes that host the greatest numbers of juvenile Chinook (Chalifour et al., 2019; Levy & Northcote, 1982). While eelgrass meadows have been found to have a larger species richness, meaning they host a larger amount of species overall (Chalifour et al., 2019), Chinook juveniles are most abundant in the marshes of the Fraser River Estuary (Chalifour et al., 2019; Levy & Northcote, 1982). This demonstrates the species' dependence on this type of habitat. From March to June (Page & Schaefer, 2019) Chinook juveniles reside in estuaries, spending the longest amount of time relative to other species (Levy & Northcott, 1982), staying for up to a month (Page & Schaefer, 2019). There is less competition for space and food in the marshes (Levy & Northcott, 1982) and high growth opportunities. The highest valued habitat type in estuarine marshes is sedge and rush habitat (Levings, 1991). Adams (2002) distinguishes between lower and upper estuarine marshes, distinguished by the limit of the salt wedge. The lower estuarine marsh type that is likely to occur at Iona is a brackish marsh, which occurs at the most downstream reaches of the main channels, and is characterized by species like Olney's sedge (*Scirpus pungens*) or American three square bulrush (*Scirpus americanus*), softstem bulrush (*Schoenoplectus tabernaemontani*), Lyngby's sedge (*Carex lyngbyei*) and Baltic rush (*Juncus balticus*), typically occurring in a consistent zonation pattern from lower to higher elevation (Adams, 2002). The tidal marsh present on the southeast side of Iona Island is dominated by cattail species (*Typha spp.*) and is considered lower quality (though still very high quality) fish habitat, as the cattails grow very densely (Page & Schaefer, 2019). McDonald Slough is an area of importance for juvenile Chinook, evidenced by their presence during Raincoast Conservation Foundation's 2018 sampling program (Page & Schaefer, 2019).

False Creek: Biophysical Conditions and Selected Focal Species

Biophysical Conditions

False Creek is an urban site with most of its shoreline hardened, and some natural shores incorporated. A broad summary of the key coastal dynamics is described here. Additional work by the City of Vancouver and others is in progress to better understand the physical, chemical, and biological characteristics of False Creek.

Water Quality

In False Creek the water quality parameter that has received the most study is *Escherichia coli* and fecal coliforms in general. Cummings (2016) reported that *E. coli* concentrations increased from west to east, evidenced in two data sets (1993 to 2012, and 2013 to 2016). Shoreline concentrations of *E.coli* are consistently higher than mid-channel values. A 30-day average for July 2016 for both mid-channel and shoreline sites found the mid-channel average in east False Creek to be 142.3 MPN/100ml whereas the average of the associated shoreline samples ranged from 60- 1799 MPN/100ml. One sample exceeding the secondary contact guideline of 1000 MPN/100ml. Fecal coliform concentrations were higher in the winter, but there was not enough data to confirm a seasonal pattern nor a consistent correlation with temperature (Cummings, 2016).

Salinity & Temperature

Cummings (2016) found that from 2013 to 2015 "the average winter salinity was 23.8 PSU, while the average summer salinity was 16.8 PSU" (p. 27). Depth profiles (salinity and temperature) were collected and showed that the eastern part of False Creek is the most stratified, meaning the layers of warm/less saline, and cold/more saline water are most distinct and less mixed. In

July 2016 in eastern False Creek, this interface occurs somewhere between 3 and 4 meters deep, here temperatures dropped from 17.2°C to 13.8°C and salinity rose from 16.4 PSU to 24.2 PSU (Cummings, 2016). This contributes to the unmixed and stratified nature of the eastern region of the inlet. Cummings also noted that temperatures are slightly higher in east False Creek (2016).

Tides

Tides in False Creek are mixed and semi-diurnal. Generally, large influx of water into the inlet occurs only during large flood tides, with drainage occurring with large ebb tides (Figure 31).

Tidal elevations for east False Creek (provided by Kerr Wood Leidal) are as follows:

- Higher High Water Large Tide (HHWHT): 2.0 m
- Higher High Water Mean Tide (HHWMT): 1.5 m
- Mean Water Level (MWL): 0.1 m
- Lower Low Water Mean Tide (LLWMT): -1.8 m
- Lower Low Water Large Tide (LLWLT): -2.9 m

Figure 31. Surface currents during tidal changes in Burrard Inlet that influence False Creek. Adapted from Thomson (1981)

Currents

A detailed understanding of the hydrology of False Creek is lacking. Efforts to document the hydrology are currently being done by the City of Vancouver (Angela Danyluk, personal communication, January 29, 2020)

Wind & Waves

Wind speeds in western False Creek are typically between 2 and 13 km/h and predominantly come from the southeast and north (Figure 32). Waves in False Creek are largely created by boat traffic and any wind generated waves are small.

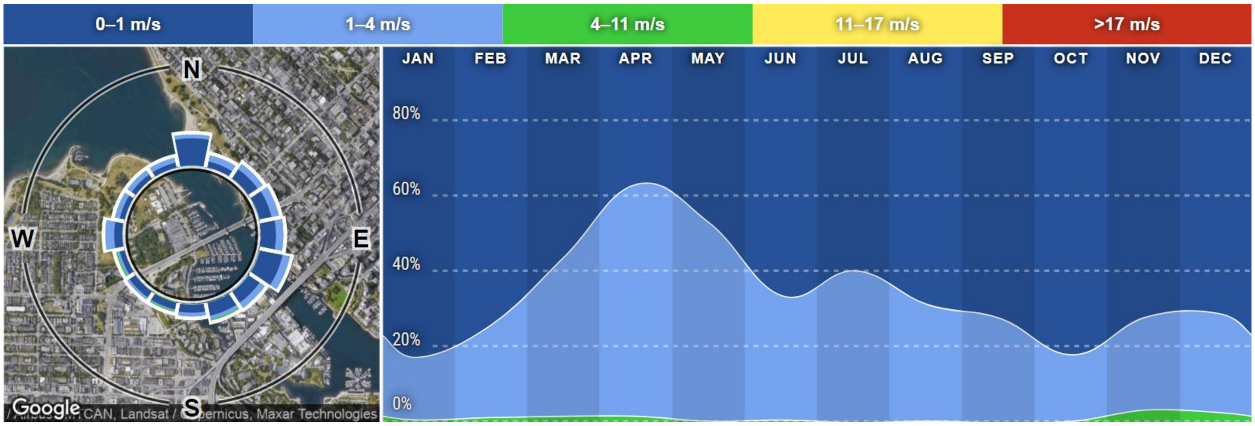

Figure 32. Wind data from western False Creek https://www.windfinder.com/windstatistics/false_creek_fuels_vancouver

Focal Species and Habitat Requirements

Habitat Overview

False Creek is an urban location with important habitats. False Creek is part of the English Bay, Burrard Inlet and Howe Sound Important Bird and Biodiversity Area, which supports many coastal and marine birds. The False Creek shoreline has transitioned from tidal marsh and wetlands, to industrial shores, to its current condition. The current intertidal biodiversity in east False Creek is low, but efforts like Habitat Island have increased habitat complexity and biodiversity in the area (Wernick, et al., 2012). The species chosen to help inform the design of living shorelines in False Creek are described below.

Herring and Open Water

Herring, like other forage fish species, are fundamental parts of aquatic food webs. Herring in particular play a critical role as forage for larger animals and transfer energy to higher trophic levels in the Pacific Northwest.

Herring stocks are managed in Canada (Fisheries and Oceans Canada, 2021) and relative to other forage fish, stocks are well-understood. Spawning locations and requirements are also well understood. In Puget Sound, it has been observed that herring tend to spawn at specific locations, generally in sheltered bays with perennial seaweed and clear water (Penttila, 2007). The presence of marine vegetation is important for spawning herring, but it appears that location plays a key role, as not all vegetated beaches are equally attractive to herring (Penttila, 2007). Locally, herring have been observed to lay eggs on built and artificial structures, most notably on pilings. Dr. John Matsen of the Squamish Streamkeepers, says that the creosote preservative layer on pilings results in a 90% mortality rate of eggs, with only a small amount successfully hatching (Fieldwalker, 2019, 1:44). The Squamish Streamkeepers have had success increasing the spawning rate by wrapping the creosote pilings with landscaping cloth as well as suspending gill nets in the water in Squamish Harbour and Fisherman's Wharf in central False Creek (Fieldwalker, 2019, 1:44). Once it was understood that the nets needed to be suspended completely below the water (at both low and high tide), so none of the eggs came in contact with oil or other substances at the surface, they had virtually 100% hatch rate (Fieldwalker, 2019, 2:10). Alternatives to pilings could include textured additions on built structures such as seawalls, or surfaces that encourage or promote *Fucus sp*. (rockweed) growth to provide a more natural substrate to spawn on (P. Lilley, meeting communication, December 4th, 2020).

Herring can spawn in a range of conditions. Viable eggs have been found from 3 ppt to 35 ppt salinity, with decreased survivability at less than 5 ppt and substantial mortality above 20 ppt (Lassuy, 1989). Optimal salinity range is 12 ppt to 26 ppt (Lassuy, 1989). Temperature requirements are also broad, with natural spawning occurring between 3^{o}C to 9^{o}C with optimal levels at 5.5^{o}C to 8.7^{o}C (Lassuy, 1989). Locally, herring spawn 3 to 4 times between late January and early April, with demonstrated success in 2020 (Buu, Wang, Yang, & Yerxa, 2020).

Mussels and the Intertidal Zone

Mussels are considered ecosystem engineers, creating habitat complexity and in turn increasing biodiversity and species richness (Borthagaray & Carranza, 2007). Bivalves in general are bioindicators of ecosystem health and can be indicators of pollution from heavy metals (Azizi et al., 2018). False Creek is less suitable for oysters, particularly the native oyster species, *Ostrea lurida* or Olympia oyster, as they are generally found in mud and gravel flats (Harbo, 2011). Though oysters are the species of choice in many living shoreline design implementations, it is likely more appropriate to facilitate mussel colonization and recruitment, particularly Blue Mussels (*Mytilus trossulus*). Mussel species have been observed encrusting the hard surfaces of False Creek (Wernick et al., 2012) but actively promoting mussel habitat creation has not been undertaken in False Creek. The Habitat Skirt of the Vancouver Convention Centre (Leonard & Kullmann, 2010) is a demonstration of creating habitat that would encourage mussel growth and increase habitat complexity. In addition to habitat complexity mussels might contribute to improving the water quality of the area. In her 2016 report, Cummings suggested the use of native Blue Mussels as a useful approach to reducing the concentration of *E.coli* in False Creek. Freshwater mussels have been shown to directly reduce *E.coli* concentrations in the Pajaro River in California (Ismail et al., 2016). Cummings (2016) suggested deploying mussels either on ropes or in cages. To expand on this suggestion, the incorporation of mussel habitat (ie. rocky intertidal) would also increase their presence. Mussels have great potential to recruit into the farthest reaches of False Creek, as they are present in some capacity now and are found in different compositions in various other locations in the region (Walton et al., 2019). Intentional and large-scale mussel habitat, with the supplementary use of ropes or cages, would increase species diversity of the inlet. Utilizing ropes or cages would create a way to manage mussel populations, allowing controlled access if reduction or removal was required. The gradual zonation of a natural intertidal zone is what allows for diversity in the rocky intertidal, but it is unlikely this will be possible in False Creek. A compressed intertidal zone does not allow for as much diversity (Walton et al., 2019) or encourage mussels to establish. Blue Mussels are typically found in quiet, sheltered areas in the intertidal zone up to 5m deep (Harbo, 2011). Angela Danyluk, Senior Sustainability Specialist from the City of Vancouver, recommends the use of large and rugged boulders, diameters greater than 60 cm, along with a gradual slope where possible, to promote a rocky intertidal habitat that would promote Blue Mussel recruitment and establishment (Danyluk, 2020).

Cormorants and the Interface of Land and Sea

Danyluk, in a memorandum about the area (2020), highlights the importance of incorporating and considering marine birds in a rocky intertidal design because they can be indicators of overall ecosystem health. Marine birds indicate the health of the interface between marine and terrestrial habitats. Cormorants common to False Creek include the Pelagic (*Phalacrocorax pelagicus*) and Double-Crested (*Phalacrocorax auritus*), and are both primary examples of this interface, as they only enter the water to feed and bathe, and perch afterwards to dry their feathers (Sibley, 2003). Found from rocky coasts (Pelagic) to ponds, rivers, and open ocean (Double-Crested) the cormorants of False Creek dive to feed on fish close to and offshore (Sibley, 2003). Designs should include suitable perching areas for birds to rest (Danyluk, 2020).

Design Ideas

The following design ideas are supported by visuals that are part of the internal version of this report (Appendix B & C). Living shoreline design and restoration options to support habitats are discussed first for each study area. These ideas are informed by the literature reviews and interviews.

Sturgeon Banks and Iona Island

Tidal Marsh Restoration

Tidal marshes are vital habitats for salmon and other species. Tidal marshes also have the potential to build resiliency from sea level rise as some marshes contribute to sediment accretion. Tidal marsh restoration is best suited for low energy areas where sedimentation can occur. This may require human interventions through breakwaters and other restoration efforts. Precedents such as the New Brighton saltmarsh offer an example of the process and challenges of building a tidal marsh from beginning to end. Another example of establishing salt marshes is Deer Island in Mississippi, which utilized salt marsh cells for protecting and establishing the habitat.

Thin-layer Sediment Augmentation

The addition of thin layers of sediment has been considered as an option to assist tidal habitats (mudflats, tidal marsh) in adapting to sea level rise. Seal Beach National Wildlife Refuge in California has been used as a research site for the use of thin-layer augmentation on the west coast. Sediment dredged from the Fraser River may be a potential source for this use. One consideration for this method is that placing sediment on land or in the foreshore is more costly than dumping the sediment in deep waters offshore (Gilligan, 2018).

Re-establishing Habitat Connectivity

Restoring aquatic connectivity by removing or changing built structures in Sturgeon Bank, such as jetties, will play a big role in the restoration and rehabilitation of the foreshore. Precedents such as Kilisut Harbour and Leque Island, both in Washington State, can help inform these changes to the shoreline. Each of these precedents removed previously built coastal structures to align with the evolving perspective of prioritizing ecological function over shoreline control. Both sites allowed water to return to areas where it was previously, reestablishing important flow dynamics and allowing for restoration of habitats. In Kilisut Harbour, a driving force for the causeway breach was reestablishing a juvenile salmon corridor along with restoring tidal marsh and other habitats. The breach improved water quality in both Kilisut Harbour and adjoining Oak Bay

(Washington State Department of Transportation, 2020). The Leque Island dike breach was successful in restoring the island’s estuarine conditions (Desmul, 2019). An up to date understanding of the sediment dynamics along Sturgeon Bank will be key to the success of restoration work in this area. This was highlighted by Jim Johannessen and DG Blair as they emphasized the importance of considering the shore as part of a much bigger system.

Breakwaters

The use of breakwaters is common in living shoreline design. Breakwaters built in the water just off a shore and are used to break up wave energy before it reaches the shore. In the case of living shorelines on the east coast, breakwaters are often used as submerged habitat for oysters. Variations on the basic breakwater concept are discussed below.

Passive Accretion

The use of breakwaters to help accrete sediment may be useful at Iona Island and in other areas of Sturgeon Bank. The breakwaters in Hancock County, Mississippi, can serve as a precedent for general breakwater design. Wendell Mears suggested that sediment trapping could be further encouraged by having the breakwaters be wider, flatter and extending at an angle to the shore, rather than parallel to it (W. Mears, personal communication, January 8, 2021).

Habitat Bump

Also mentioned by Wendell Mears was the incorporation of a “habitat bump,” which is a secondary breakwater on the landward side of the primary breakwater. The intent is for it to increase habitat complexity and encourage species recruitment.

Barrier Island

A habitat breakwater, like the barrier island technique used at Royston in Courtenay, may be a useful technique for some areas at Iona. The larger barrier islands are used to control erosion and are appropriate for project sites with lower wind energy. The incorporation of vegetation and terrestrial habitat on the breakwater is a unique opportunity to create additional habitat.

Eastern False Creek

At our meeting with Angela Danyluk, she asked a hypothetical question: “Could we imagine a future for False Creek where we could harvest shellfish?” At first this seemed like an impossible proposition, but the idea that the shores of eastern False Creek may one day be healthy enough to provide nourishment became a guide to developing these design ideas.

Rocky Intertidal Slope

Establishing rocky intertidal habitat would encourage the establishment of mussels, rockweed, and other intertidal species. Riprap shorelines typically provide habitat to only a few species, most notably Acorn barnacle (Walton et al., 2019). A more gradual rocky slope, with boulders of diameter greater than 60 cm (Danyluk, 2020; Walton et al., 2019), is recommended. Creating a gradual slope is likely to be a challenge for False Creek, as it is constrained by space.

A rocky intertidal habitat would encourage the recruitment of rockweed through increased texture and stable substrate (Walton et al., 2019). Encouraging the recruitment of rockweed and other macro algae would also be beneficial to many species, including herring, as it creates usable substrate for spawning. Herring are known to spawn on a variety of substrates, from eelgrass to gravel beds (Penttila, 2007).

Eelgrass Meadow

The potential for eelgrass is largely dependent on the creation of suitable water quality and substrate conditions. This may be more feasible than initially thought. A recent underwater survey of False Creek identified the area south of Science World as one of many locations that have a suitable depth and substrate for eelgrass (Rao, 2020). Restoring the site to sustain eelgrass would require eliminating boat anchoring and removing woody debris. If the site is improved to the point where it can sustain eelgrass, the eelgrass will likely recruit and grow naturally, without requiring transplanting (J. Cordell, personal communication, January 22, 2021).

Tidal Marsh Slope and Benches

Tidal marsh is another habitat type that may be appropriate for the intertidal area in False Creek. A gradual slope or tidal “benches” are some options for establishing a marsh. This would depend on the upland use of the shore. A gradual tidal marsh, much like the gradual rocky intertidal, would be preferred, as it allows for more space and opportunity for species to establish and co-exist.

Engineered Habitat Structures

Precedents like the Elliott Bay Seawall, the Habitat Skirt at the Vancouver Convention Center or the Living Seawall tiles used in Australia all contribute to increasing habitat complexity and will likely function well within an urban condition like False Creek. A cantilevered deck, like that at Elliott Bay, would allow for the creation of engineered vertical habitat on the wall underneath an overhanging deck or walkway. These options would increase the habitat complexity and encourage local species to recruit through increased prey species, available space and provided shelter.

Incorporating a boardwalk above the water could provide an opportunity for people to engage with the water without direct contact. A boardwalk like the Leonardtown Wharf, which wraps around a tidal marsh, would align well with this idea. There could be potential to incorporate a deck with tide pools and additional rocky intertidal features much like the Tide Deck at Pier 26. The deck could align with an upper intertidal habitat, encouraging species such as barnacles, sea lettuce (*Ulva latuca*) and other invertebrates and algae that are resistant to desiccation.

Reusing old features in the inlet, such as pilings, as engineered habitat could benefit all of the focal species mentioned here by providing spawning substrate for herring, potential mussel habitat and offering perching opportunities for marine birds.

Floating Wetlands

A floating wetland would be a unique opportunity to promote tidal marsh species that would have been present in the False Creek flats prior to industrialization of the area. A floating wetland would be an ode to this once present habitat that would otherwise be a challenge to establish due to the limited space and the narrow border between the land and water. These conditions will make it difficult to establish a low gradient wetland. A highlight of the floating wetland in Baltimore Harbour is the demonstrated potential for the use of recycled materials to foster natural elements in a built and heavily modified site. In False Creek, many considerations would have to be made for the installation of a floating wetland. The establishment of eelgrass in the inlet is one consideration, as the impacts of shading and anchoring from a floating wetland could be detrimental to eelgrass. In addition, turbidity caused by the anchoring or movement of the wetland may further impact eelgrass and fish. In Baltimore, the first floating wetland was the only green place in the harbour (C. Dahlenburg, personal communication, February 18, 2021) and now has the potential to bring over 900 m^2 of wetland habitat to Baltimore. The Floating Wetland in Baltimore Harbour is a remarkable precedent for floating wetlands in estuarine systems.

Additional Ideas

An additional design idea for the above-mentioned boardwalk is the incorporation of a viewing platform, such as that at Hunter's Point South Park in New York. This could serve as a location for educational material, such as signage, and has the potential to serve as a location for cultural and recreational events, including ceremonies, presentations, or large events.

Conclusions

Living Shorelines and Restoration

While conducting this research it became increasingly clear that there is a lot of overlap between landscape design and habitat restoration. This work created the opportunity to explore the intersection of living shorelines and restoration. From a layperson's perspective, landscape design and coastal restoration may be viewed as separate entities with different goals. When living shoreline and nature-based approaches are implemented and prioritized, the goals align quite closely. Many of the precedents presented here focus on restoration by improving habitat and natural structures. This speaks to the overlap of the concepts and the great opportunity for collaboration and deepen the understanding of both disciplines. Despite this overlap, living shorelines may not be considered true restoration, with their results positioning more with rehabilitation (improvement of function) and reallocation (conversion of one habitat type to another) (Simenstad, 2017). Habitat creation, the creation of habitat that was not there before and would not exist without human intervention (United States Environmental Protection Agency, 2016) also aligns with the work that living shorelines do. Many of the precedents explored in this report align well with rehabilitation, with goals to restore more natural function to an area with the overall goal to design a more resilient and sustainable shoreline.

Dynamic Systems

During this research it also became clear that a thorough understanding of the broader coastal systems is vital to the success and longevity of any shoreline redevelopment project. In addition to an understanding of the system during the design and planning stage, the establishment of long-term monitoring of both biological and physical changes to the site are key to informing and promoting future work. According to Peter Hummel, "projects rarely behave the way you expect them to" (personal communication, January 21, 2021), so closely monitoring the way the site changes overtime is a powerful tool to inform future living shoreline design work.

Considerations

It is important to reiterate the singular perspective this report has taken regarding habitat restoration and sea level rise adaptation. This focus allowed for a deeper dive into the realm of living shoreline design and the potential of each site. Of course, there are many additional factors to consider when putting together the final design of a location. Additional factors that will be necessary to consider when designing these sites include land use needs, infrastructure, public input, programming opportunities, flood protection requirements, and more. The social-ecological system in which these shorelines are found do not occur in isolation, with many stakeholders and variables involved. This should all be taken into consideration when reviewing and applying this work.

Reciprocity

As a final note, the research above speaks to a shift in perspective of “progress” for shores and coastal lands redevelopment. The shift from attempting to control the shores with armoring and hard structures, to actively promoting natural function and natural adaption, speaks to this profound change in perspective. I encourage a continuation of this and advocate the incorporation of the perspective of *reciprocity*. Reciprocity not only with stakeholders and participants in this work, but with the shores and ourselves. Incorporating reciprocity in this context is considering the give and the take with the shore, the land and the waters - considering what we are gaining and what we are taking from the shore, while simultaneously being thoughtful of what we are contributing and being sure that it is relevant for all involved. These coastal areas are deserving of immense respect and it is important to keep that perspective in mind when working with and on the land. I believe this is a key piece to ensuring the work done on these shores is meaningful and powerful. I also believe that living shoreline principles align nicely with the incorporation of reciprocal relations with the shorelines. In the larger scale, these projects are not the final renditions of their accompanying shores, they are one of many versions of the shores over the course of history. With the contextualization of this moment in mind, it is our responsibility to do this work with respect, rootedness, and reciprocity to ensure the shores are healthy and functional for this and future generations.

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