

# **BETWEEN CITY AND SEA:**

multi-trophic mariculture as urban intertidal catalyst

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Abstract

## **BETWEEN CITY AND SEA:**

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Urban waterfronts can do more than retain the land in spite of the sea. This design project explores and applies multi-trophic mariculture as a means towards enlivening and broadening the disappearing gradient between city and sea. Through the strategic integration of multi-trophic mariculture into a degraded and beleaguered public waterfront, this design research leverages the processes of sediment accretion and intertidal expansion to afford synergistic cohabitation within this living place and dynamic threshold.



# BETWEEN CITY AND SEA:

multi-trophic mariculture as urban intertidal catalyst

a master's thesis by Tatyana Vashchenko



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I would also like to extend a most heartfelt thank you to Zach, my life partner and collaborator: thank you for pushing for poetry and whimsy while also providing the benefit of your engineering knowledge at every step of the way.

**opposite page:** Viewed through the lens of a microscope, these red macroalgae form complex environments for other organisms to inhabit. In these slides, diatoms move through a tangled terrain of algal tendrils.



photo by : Tatyana Vashchenko

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**opposite page:** A tangle of plastic fibers washed up on the beach now serves as a substrate for seaweed.



photo by : Tatyana Vashchenko

## INTRODUCTION

From the top of the bluffs, the Puget Sound and presumably, the shoreline, lie a two hundred foot tumble below. Down a narrow trail, alternating between muddy channel and a downslope-drifting boardwalk, through a tangle of vegetation blanketing the crumbling cliff-face, I emerge at a tiny beach flanked by piles of basalt rip-rap. At this first glimpse of the shore, the path veers to the southwest, running along the top of a rip-rap revetment. Along this stretch, the trail straddles the revetment, defining the shoreline. This crisp, directional edge characterizes arrival on the waterfront in many places along Puget Sound's increasingly segmented shorelines.

The water here appears opaque and choppy, as it slaps across the hard uneven surface of basalt boulders. A reflective pattern dances across the water's agitated surface and guides the eye to the horizon encompassing the seascape. The intertidal gradient extending seaward from the top of the basalt embankment remains invisible and seemingly barren. Its invisibility frames and reinforces the perception of this space as the edge

of land and sea, rather than a vital place between: a ribbon-like swath that has for thousands of years supported a vibrant, rich and dynamic intertidal ecology. Along much of Puget Sound's extensive shoreline, the intertidal zone has been compressed onto the vertical surfaces of seawalls, forming a static, unrelenting edge where a broad, fluxing swath had previously existed.

For the past ten years, I have played, studied and worked in coastal metropolitan centers, enjoying my adjacency to the sea, yet remaining largely unaware of the vital threshold that lies between, increasingly buried and arrested, its invisibility compounded by its contraction. More recently, I have, however become aware of the unleveraged potential of integrated multi-trophic aquaculture, a model of aquatic polyculture based on marine ecosystem dynamics. Some of the aspirational work in this developing branch of aquaculture actively leverages the auxiliary functions and ecosystem services that these cultivation systems offer in tandem with their harvestable outputs.

**opposite page:** North Beach at Seattle's West Point is mostly buried in fill and armored with rip-rap. This staircase provides access to what beach remains at low tides.

“Why is land always expressed as an absolute shape--- a figure situated in the void of “not land”? Why this insistent focus on the dry, when in fact, the wet world with which land lives is itself matter, and the boundaries between the two are dynamic and evolving? ...the ocean remains a glaring blind spot in the Western imagination.”

- Pierre Belanger, *Wet Matter*

Mariculture, aquaculture in the marine environment, has the potential to extend human experience, engagement, and stewardship into a territory that urban development has aimed to control, or at the very least contract over the past one hundred years. On a waterfront confined by armored fill and a steep subtidal drop-off, the options for re-establishing a resilient yet soft intertidal gradient are limited. Integrated multi-trophic mariculture in the nearshore environment has the potential to accrete sediments, improve water quality and enhance habitat for a host of endemic and presently displaced organisms.

This thesis exploration started with my curiosity about what synergies could arise between integrated multi-trophic mariculture in the nearshore and spatial design efforts aiming to create a novel form of intertidal gradient and an experientially rich public space within an urban waterfront. I was curious about how intertidal mariculture could serve landscape architects as a multi-faceted tool for designing and shaping waterfronts, premised on the critique that we

use earthwork and the cultivation of plants as space-shaping tools, yet as a discipline, we largely abandon the use of living media when designing urban waterfronts. However, as I learned more about the urban intertidal environment as setting and multi-trophic mariculture as medium for spatial reconfiguration, I became more fascinated by pursuing the exploration in a more elaborated fashion, upon a site, and less interested in offering a broad critique of waterfront design as it is currently practiced. The following questions shaped my inquiry, guided my research, and focused my design efforts:

**How can multi-trophic mariculture serve landscape architects as a strategy for regenerating, utilizing, and stewarding a revived urban intertidal zone?**

**How can the processes and places instigated by maricultural agents become seen, used, experienced and understood by the public?**



**above:** A fisherman navigates through a maze of earthen dikes at low tide in Fujian Province in China.

**right:** The Dosewallips River delta tideflats are host to millions of oysters. Recreational harvesters from around the Puget Sound come here to dig for Manila clams, Littlenecks and collect oysters at low tides.



photo by : George Stenberg, Dosewallips Oysters, <http://www.georgenbergphotography.com/gallery.html>

"Even if you never have the chance to see or touch the ocean, the ocean touches you with every breath you take, every drop of water you drink, every bite you consume. Everyone, everywhere is inextricably connected to and utterly dependent upon the existence of the sea."

- Sylvia Earle, *The World is Blue*

The city depends on the sea in ways that remain widely unrecognized and unacknowledged. Living systems and the world's water bodies are intimately entangled; humans are deeply dependent on the sea. The ocean and its resources shape human life, urban development and consumption patterns, and the reverse is true as well. Humans have profoundly impacted the oceans, both at the global scale and in more localized reaches. Coastal cities exhibit marine sprawl just as they do on land. However these forms of impacts are often less visible and more insidious than their terrestrial counterparts. Marine sprawl takes on forms that we are not accustomed to noticing, but the evidence is apparent when you know what to look for: extensive shore-form hardening, water pollution, sea-floor modification, and ocean acidification are just a few examples.<sup>1</sup>

The intertidal is perhaps the most accessible place that urbanites can encounter and engage with the sea, however, coastal cities have become

increasingly separated from their receiving waterbodies: both physically and conceptually. Typical cartographic representations of the sea leave it black or grey, suggesting through the means of representation, an implied deprioritization of the sea as an entity.<sup>2</sup>

In his book, *Blue Urbanism*, Tim Beatley argues that the most viable way to curb our extensive negative impacts on marine life is for cities to develop a more meaningful engagement with their adjacent water bodies, in order to perceive them as living and vital places again. He advocates several strategies for strengthening this connection: building awareness of fisheries depletion, implementing new techniques for non-polluting, closed-loop systems, and supporting small-scale fishing enterprises. Multi-trophic mariculture embodies several of these strategies, providing an enterprise for local fisher-folk and operating as a more closed-loop system. When designed as a public space, this strategy offers opportunities for meaningful engagement between a diverse public and a marine environment bristling with life. Kate Orff defines cohabitation as the act of living together "in an intimate relationship", of "dwell[ing] with one another and share[ing] the same space."<sup>3</sup> This research project proposes a layering of programs often deemed incompatible through the implementation of multi-trophic mariculture in a deliberately public space, leveraging the rich potential of their synergy through juxtaposition.

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1 Timothy Beatley, *Blue Urbanism: Exploring Connections Between Cities and Oceans* (Washington, DC: Island Press, 2014), 40.

2 Beatley, 41

3 Kate Orff, *Toward an Urban Ecology* (New York, New York: Monacelli Press, 2016), 86.





photo by : Trevor Bentley

## SETTING

### *City, Sea, and the "In Between" in Puget Sound*

Two thousand five hundred miles of shoreline shape and provide a sense of place to the Puget Sound metropolitan region. This sinuous ribbon of intertidal space sits perched on relatively narrow (usually less than 300 meters across) “wave-cut platforms notched into the steep walls” of fjords and marine basins.<sup>1</sup> Beaches make up about 1,400 miles of Puget Sound's shoreline, often occupying more than half of the intertidal portion of the Sound's tidal platforms, while the lower intertidal and shallow subtidal extensions of this beach shoreform make up the “low-tide terrace”.<sup>2 3</sup> The beaches of Puget Sound, unlike those of Washington's outer coast or of the East Coast, are primarily comprised of sediments released and deposited by the erosional processes that carve away at coastal bluffs or less frequently, in the case of alluvial fans, the sediments carried and deposited by rivers and streams.

This heterogeneous mix of clay, silt, sand and gravel slides and crumbles out of waterfront bluffs and into the sea, only to be tossed and sifted by waves. The resulting mix of gravels and coarse sands typically remains in the upper intertidal on the beach, while finer sediments billow out and away, suspended in the outwash. Here, gravels and sand grains begin their journey through the local drift cell, bouncing along the shore within the agitated arcs of swash that waves leave behind as they approach and retreat. The sand originating from coastal bluffs is pushed and carried by the energy of waves in the direction of the prevailing winds. No sand grain or pebble is fully stationary, yet their restless mass makes up the beaches we see all around the Sound, the very same beaches we attempt to retain and arrest where they appear to erode, and inadvertently eliminate when we erect seawalls, intending to protect our waterfronts.

- 1 David Finlayson, “The Geomorphology of Puget Sound Beaches. Puget Sound Nearshore Partnership Report No. 2006-02” (Seattle, Washington, 2006), iv, <http://pugetsoundnearshore.org>, iv.
- 2 David Finlayson, “The Geomorphology of Puget Sound Beaches. Puget Sound Nearshore Partnership Report No. 2006-02”, iv.
- 3 Hugh Shipman, Andrea MacLennan, and Jim Johannessen, “Puget Sound Feeder Bluffs: Coastal Erosion as a Sediment Source and Its Implications for Shoreline Management” (Olympia, Washington, 2014). p.4

**above:** At the Port of Tacoma, restoration projects are chipping away at non-essential armoring to reestablish tideflats near the Hylebos Waterway.

In its most literal definition, the “intertidal zone” spans from extreme low tide to extreme high tide elevations. The tidal range tends to vary dramatically across an estuarine complex like Puget Sound, increasing as one moves inland. Around Central Sound, the intertidal limits are found at about – 4 feet and + 14 feet respectively, with reference to mean lower low water (MLLW) as the zero datum.<sup>4</sup> Yet a more process and ecology-oriented definition of intertidal includes the photic zone as the lower limit and the backshore as the upper limit. The subtidal area where light reaches the sea floor hosts many of the adaptable creatures who may tolerate desiccation at low tides but prefer to retreat with the receding water into the shallow subtidal reaches of the low-tide terrace. Other such organisms may roost within the intertidal at some stages of their lives and swim freely throughout the subtidal at others. Or alternatively, they may swim throughout Puget Sound during their adult life stage but rely on the upper intertidal beach to spawn, as is the case with surf smelt. A more expansive definition of intertidal encompasses the adjacent zones, both upland of extreme high tide and out beyond extreme low, using indicator species to define the limit of the intertidal’s area of biological influence. This more expansive definition suits the purposes of this maricultural exploration.

Given the tidal and biological limits of the intertidal zone, it follows that the composition and form of this zone varies across Puget Sound’s

2,500 miles of sinuous shoreline. The intertidal zone is not limited to the extents nor composition of the ever-shifting beach morphology. The Puget Sound Nearshore Restoration Project categorizes the Sound’s nearshore environment into four categories: rocky coasts, bluff and beach, smaller embayment and large river delta. At a finer-grained scale, these broad categories comprise a mosaic of more localized shoreforms: lagoons, estuaries, barrier beaches and spits. Different shoreforms are composed of different substrates at a variety of configurations, giving rise to a wide range of ecological processes and functions.<sup>5</sup>

Across the spectrum of intertidal forms the intertidal zone can take, its position as a threshold between land and sea imbues it with the function of buffer, both of wave energy and terrestrial effluents. In an interview with SCAPE, Brian Davis, a member of the Dredge Research Collaborative, expounded on the multi-dimensional value of the intertidal zone to both aquatic ecosystems and urban neighbors: “Shallows are water landscapes perched between city and sea that are both biologically rich and socially significant”, offering food, recreation and protection from the open water. “They are not only a historically sound defense strategy against rising seas and stronger storms, they also offer broad habitable zones, areas rich in habitat and aesthetic experiences. This combination of recreational, educational, economical, and infrastructural performance

4 National Oceanic and Atmospheric Administration, “Datums - NOAA Tides and Currents,” 2018, <https://tidesandcurrents.noaa.gov/datums.html?id=9447130>.

5 Hugh Shipman, “A Geomorphic Classification of Puget Sound Nearshore Landforms,” 2008, [http://pugetsoundnearshore.org/technical\\_papers/geomorphic\\_classification.pdf](http://pugetsoundnearshore.org/technical_papers/geomorphic_classification.pdf).

“Shallows are water landscapes perched between city and sea that are both biologically rich and socially significant...offer(ing) broad habitable zones, areas rich in habitat and aesthetic experiences.”

- Brian Davis, *Toward an Urban Ecology*

means many of these shallows have been culturally important for a long time. People, plants, animals, alga, and sediments themselves grow literally attached to them.”<sup>6</sup>

Home to one of the nation’s most rapidly growing metropolitan regions, the Puget Sound’s shorelines have been experiencing an ongoing transformation into more restrictive, static zones that create short-term stability at the expense of ecological function. When urban development meets the shore, as it increasingly does in rapidly urbanizing regions, what had previously existed as an intertidal gradient has been collapsed and contained within the face of a seawall or sheltered in the darkness beneath a pier or boardwalk. With over twenty-seven percent of Puget Sound’s shoreline hardened by some form of shoreline armament, we are gradually eliminating the beaches and tidelands that have historically

bounded the Sound.<sup>7</sup> As a result of exacerbated erosion beneath armaments, associated sediment starvation of nearby beaches and reduced sediment supply from armored bluffs, sediment is both more mobile- it can’t settle into a relatively stable location, and less plentiful- as it is locked up by walls.<sup>8</sup>

Today, the Puget Sound shoreline is a mosaic of erosion control measures, with each landowner exerting their individual right to protect their property and structure from crumbling into the Sound. The resulting coastal landscape is neither pristinely “natural” nor completely man-made. It is the result of complex geologic and hydraulic processes shifted by the nature of urban development on the coast. The Puget Sound’s 1,400 miles of beaches are either disappearing entirely or shifting towards a substrate dominated by gravel and cobbles as the drift cells to which they belong see their feeder bluffs arrested in motion, suited in the concrete armor that restrains them from tumbling into the sea. By nature of the systems at play within their extents, coastal zones are dynamic, sculpted by waves, tides, ground water and human intervention. Within these zones, coastal cities build upon shifting ground

6 Kate Orff, *Toward an Urban Ecology* (New York, New York: Monacelli Press, 2016). p. 230-231

7 Randy Carman, Kathy Taylor, and Hugh Shipman, “Puget Sound Partnership - Setting Targets for Dashboard Indicators: Shoreline Armoring” (Olympia, Washington, 2011).

8 Shipman, MacLennan, and Johannessen, “Puget Sound Feeder Bluffs: Coastal Erosion as a Sediment Source and Its Implications for Shoreline Management.”





photo by : Tatyana Vashchenko

**above:** At West Point in Discovery Park, a fourteen foot tall rip-rap revetment an abrupt edge on the site of an extant tidal lagoon gradient.

and attempt to arrest it in motion. Here, where water and sediments engaged in an ever-shifting interplay between land and sea, the condition is reduced to a deceptively stable binary.

Washington State Administrative Code 173.26.231, defines shoreline modification as “generally related to construction of a physical element such as a dike, breakwater, dredged basin, or fill, but [it] can include other actions such as clearing, grading, application of chemicals, or significant vegetation removal”.<sup>9</sup> Shoreline armoring generally takes the form of seawalls, bulkheads, retaining walls, bluff walls, concrete groins, gabions and rip-rap revetments. These are typically constructed in an attempt to stabilize a shoreline, in most cases to stop the erosive impacts of wave action on property and built structures. The paradox embodied by the construction of such a structure within a shoreline is apparent when a static wall is considered in juxtaposition with the dynamic forces with which it must contend: currents, floods, tides, wind, wave action and more. These are the forces that shape undeveloped shorelines into dynamic landscapes of flux and they are the forces that fuel the natural sedimentation patterns at play within a fjord like Puget Sound. Underlining the inadequacy of these structures as intertidal form and substrate, recently published studies by marine ecologist, Megan Dethier, have provided evidence

9 Washington State, “Shoreline Modifications”, WAC 173.26.231, (2004)

10 Megan N. Dethier et al., “Multiscale Impacts of Armoring on Salish Sea Shorelines: Evidence for Cumulative and Threshold Effects,” *Estuarine, Coastal and Shelf Science* 175 (2016): 106–17, <https://doi.org/10.1016/j.ecss.2016.03.033>.

11 Dethier et al., p. 116

12 Dethier et al. p. 116

of something planners and marine scientists have guessed at for decades: that shoreline armoring has multi-scalar negative impacts upon the region’s geomorphology and ecology.

Megan Dethier’s decades-long research has shown that the shift from a dynamic intertidal zone, towards one that attempts (however fruitlessly) to resist the forces that move it to and fro, has come with a loss a of biodiversity and ecosystem services along the coast.<sup>10</sup> The combination of shoreline hardening and the narrowing of the intertidal zone has resulted in loss of habitat for spawning forage fish, juvenile salmon, small and large invertebrates, seaweeds and sea grasses, shellfish, seabirds and shorebirds and many other organisms reliant on the tidal flats.<sup>11</sup> Furthermore, the short and longer term impacts of these infrastructural changes reverberate throughout the Sound, beyond the intertidal area.<sup>12</sup> This and other research is influencing contemporary shoreline master planning and state administrative code.

According to the WAC’s description of shoreline modification, the negative impacts associated with shoreline armoring include but are not limited to: beach starvation (resulting in the loss of beaches), habitat degradation (a loss of beach, upper bank, fish spawning habitat), exacerbated erosion (energy is reflected from the walls onto the substrate

beneath, undermining the wall itself), ground water impacts (raising water level behind the wall), loss of shoreline vegetation and large woody debris (both critical to shoreline habitat).<sup>13</sup>

In an effort to respond to these alarming signs of coastal habitat deterioration, governmental and non-governmental organizations are partnering in a more process-driven approach to restoration. Groups like the Puget Sound Nearshore Ecosystem Restoration Project are re-framing what restoration means, eschewing the tendency towards restoring the image of what was lost, and instead focusing on re-establishing or re-invigorating the processes that have been stalled.<sup>14</sup> These process-focused interventions include strategic beach nourishment and targeted efforts to reactivate armored feeder bluffs. One of the more successful Puget Sound projects to-date has been Discovery Park's South Beach restoration project, described in further detail within the Site + Parameters chapter.<sup>15</sup>

Internationally, massive experimental projects such as the Netherlands' Zandmotor, also known as Sand Engine Delfland, test the impact and efficacy of large-scale sediment nourishment. In the case of Zandmotor, 21.5 million m<sup>3</sup> of imported sand is intended to be redistributed along the coast by

wind, waves and currents, explicitly embracing the open-endedness and uncertainty that any large-scale restoration project entails, no matter how conventional.<sup>16</sup>

The Puget Sound Partnership, a state agency leading the Puget Sound region's collaborative effort to restore and protect the Sound, supports and publicizes its efforts through the release of periodic reports titled the "State of the Sound" typically updated every two or so years. Released this past November, the 2017 State of the Sound uses a set of vital signs to measure progress towards the partnership's common goal: the support of vibrant, enduring natural systems and communities through the accelerated and collective effort to recover and sustain the Puget Sound.<sup>17</sup> Among the vital signs monitored is Shoreline Armoring, an indicator of disrupted intertidal ecosystems and the fragmentation of sediment flows. According to the Puget Sound Partnership, "a functioning, resilient Puget Sound ecosystem is defined to include dynamic shorelines maintained by coastal processes such as shoreline erosion and ecological exchange between terrestrial and aquatic systems".<sup>18</sup> However, to date, more than twenty-five percent of the Puget Sound's shoreline has been armored, forming a static and resistant edge to a

13 State, Shoreline Modifications.

14 "Process-Based Restoration," Puget Sound Nearshore Ecosystem Restoration Project, 2016, [http://www.pugetsoundnearshore.org/natural\\_processes.html](http://www.pugetsoundnearshore.org/natural_processes.html).

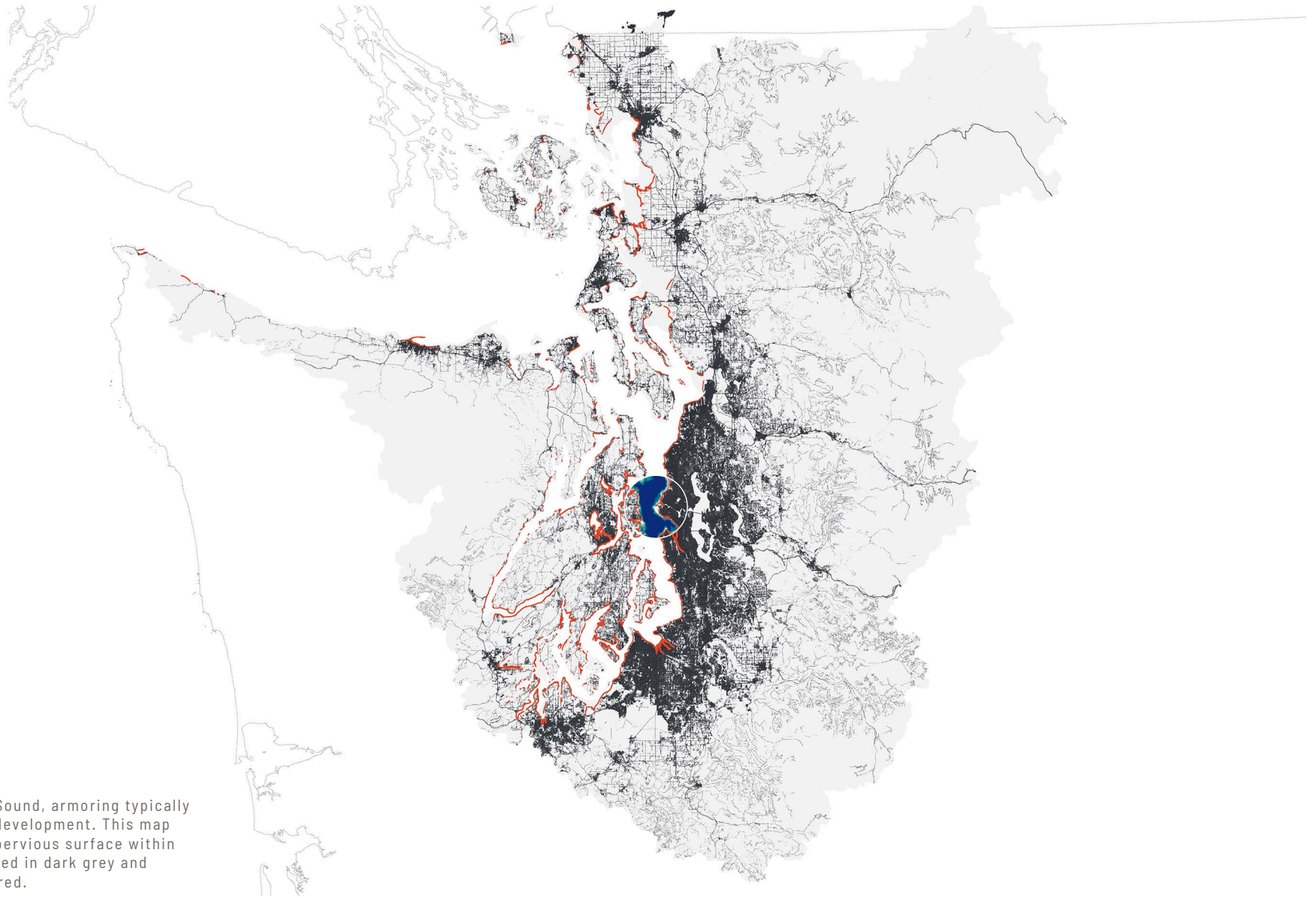
15 Cite conversation with Hugh Shipman but also find academic documentation to support.

16 Ronald E. Van den Hoek et al., "Analyzing the Cascades of Uncertainty in Flood Defence Projects: How 'Not Knowing Enough' Is Related to 'Knowing Differently,'" *Global Environmental Change* 24, no. 1 (2014): 373-88, <https://doi.org/10.1016/j.gloenvcha.2013.11.008>. p.380

17 Puget Sound Partnership, "State of the Sound" (Olympia, Washington, 2017), [www.psp.wa.gov/sos](http://www.psp.wa.gov/sos).

18 Puget Sound Partnership.

The urban intertidal in Puget Sound consists of over  
**700 miles of armored shoreline.**



**right:** Across Puget Sound, armoring typically accompanies coastal development. This map describes areas of impervious surface within Puget Sound's watershed in dark grey and shoreline armoring in red.

dynamic zone and undermining the vital ecological functions the marine intertidal environment performs.<sup>19</sup>

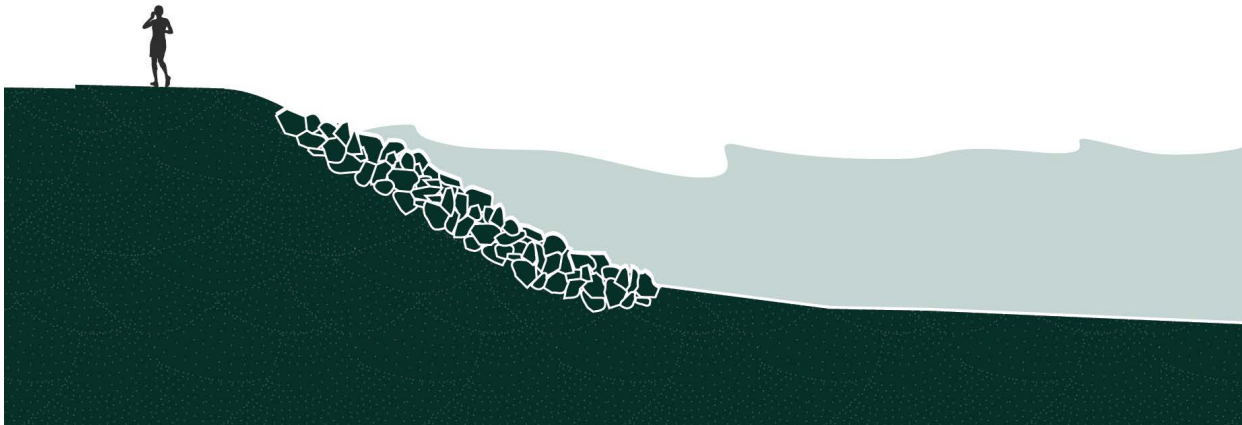
As coastal cities densify and the loss of ecosystem services in urban areas becomes more palpable, the built environment must acknowledge and integrate the systemic forces that play through its extents. Single-purpose “hard” infrastructure that addresses one problem while creating others can no longer remain the conventional approach. Seawalls and the broader strategy of shoreline armoring is just one example of the suite of “hard” engineered solutions that are now conclusively linked to ecological disruptions that have rippled across the Puget Sound.

In this thesis, I explore the medium of intertidal multi-trophic mariculture and propose to thicken and intensify the interstitial life between city and sea, through the cultivation of those degraded and beleaguered zones that are currently built up by walls, doused in sewage and stormwater runoff and invisible to the urban imagination.

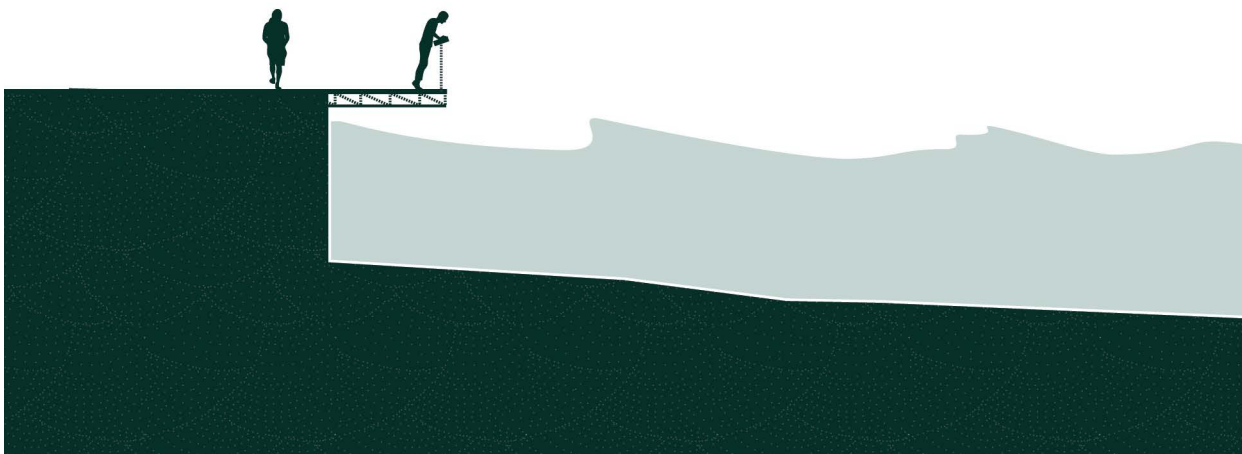


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19 Shipman, MacLennan, and Johannessen, “Puget Sound Feeder Bluffs: Coastal Erosion as a Sediment Source and Its Implications for Shoreline Management.”



**top left:** Puget Sound's "rocky platform" shoreforms support tide pools which can afford people an intimate view of intertidal life.



**top right:** Though rip-rap armoring also comprises a rocky shoreform, it is used to compress the intertidal zone into a more inaccessible and inhospitable surface.

**lower left:** Sand and gravel beaches have historically comprised over half of the Puget Sound shoreline. What beaches remain, play an important role in connecting the public to marine environments.

**lower right:** In more urbanized environments, shallow tideflats and beaches have been filled and armored with seawalls to support industry, boat traffic and land creation. On these waterfronts, the intertidal zone is in its most restricted state, invisible to humans and of limited value as habitat.



photo by : Zachary Moscicki

## STRATEGY

### *Multi-Trophic Mariculture as Intertidal Catalyst*

Along many stretches of urban shoreline, a soldier-pile fissure has supplanted the interstitial gradient that had previously offered access and habitat to a suite of marine and terrestrial life. Integrated multi-trophic mariculture of regionally important species holds unexplored potential for spatially and functionally reviving and synthesizing an urban waterfront that has become visually and performatively bounded.

Through this thesis, I posit that by acknowledging and leveraging the capacity of living organisms, both cultivated and pioneer, to shape this place, we can begin to take on the complex needs and challenges facing the constellation of its potential users. We can more effectively choreograph the interplay between built environment, productive seascape and aqueous ecology while encouraging a more synergistic cohabitation between diverse uses and users. The cultivation of interdependent organisms as a novel and deliberate ecosystem can offer both physical and intangible outputs: biomass

to serve as food, fertilizer, alginate and biofuel. The less tangible system outcomes include habitat provisions to juvenile salmon and other regionally important organisms, strategic sediment accretion, improved water quality, wave energy dispersal and numerous opportunities for the public to engage with and steward intertidal biological communities.

Though to many people the most broadly recognized product of aquaculture is food, it actually serves a much broader range of purposes. The National Oceanic and Atmospheric Administration defines aquaculture broadly as the “cultivation of aquatic organisms” such as fish, shellfish, plant and algae “in controlled aquatic environments for any commercial, recreational or public purpose.”<sup>1</sup> The range of aquacultural products or outputs NOAA lists is vast and includes the “rebuilding of populations of threatened and endangered species, habitat restoration, wild stock enhancement, production of baitfish and fish culture for zoos and aquariums.”<sup>2</sup> Though

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1 NOAA, “What Is Aquaculture?,” 2011, <http://www.noaa.gov/stories/what-is-aquaculture>.

2 NOAA.

**opposite:** Kelp, cultivated on ropes suspended by buoys, is harvested in mid-late May. The kelp long-line also serves as habitat for mussels.

shoreline protection is not often listed as one of aquaculture's applications, several recent interdisciplinary project proposals have explored and promoted the potential of maricultural systems to function as the armature for long-term shoreline protection, (projects described in the subsequent chapter).<sup>3</sup>

Aquaculture is the overarching term used to describe both freshwater and saltwater cultivation operations, open and closed. The distinction between freshwater and saltwater aquaculture is quite tangle: the former taking place in ponds, rivers, lakes and various land-based containerized systems, the later taking place in oceanic conditions and referred to as mariculture. On the other hand, the difference between open and closed systems can be more difficult to distinguish given that they exist on a spectrum and our expanding understanding of anthropogenic ripple effects within aquatic ecosystems has challenged the notion of a "closed" system. Closed systems are typically containerized, "using a barrier to control exchange" between farms and surrounding environment, making it possible to recirculate water and nutrients through them.<sup>4</sup>

Aquaculture currently supplies over fifty percent

of fin-fish and shellfish consumed worldwide, a proportion that marks a global paradigm shift in human civilization's relationship to the sea's resources.<sup>5</sup> In the United States, eighty-four percent of our seafood is imported and more than half of it has been produced through aquaculture, yet domestic aquaculture supplies only about five percent of the seafood we consume.<sup>6</sup> Of the United States' maricultural production, shellfish comprise a majority with Washington State as the largest producer of farmed clams, oysters and mussels nationally.<sup>7</sup>

Until recently, our primary relationship with the sea's aquatic life was one of capture, not cultivation. As a result of many interacting factors, overfishing being chief among them, wild fisheries at the global scale have showed a marked decline since at least the mid-1980s.<sup>8</sup> Within this context, aquacultural production of aquatic organisms is becoming increasingly important globally. However, like the green revolution, the blue revolution is associated with extensive production capacity but also resource-intensive inputs, nutrient pollution and risky monocultures.

Integrated multi-trophic aquaculture (IMTA), originating as an extension of mariculture,

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3 Ronald E. Van den Hoek et al., "Analyzing the Cascades of Uncertainty in Flood Defence Projects: How 'Not Knowing Enough' Is Related to 'Knowing Differently,'" *Global Environmental Change* 24, no. 1 (2014): 373-88, <https://doi.org/10.1016/j.gloenvcha.2013.11.008>.

4 SeaChoice, "Aquaculture Methods," SeaChoice for Healthy Oceans, accessed May 19, 2018, <http://www.seachoice.org/info-centre/aquaculture/aquaculture-methods/>.

5 Adam D Hughes et al., "Beyond Fish Monoculture - Developing Integrated Multi-Trophic Aquaculture in Europe" (Florence, Italy, 2016). p.5

6 NOAA, "What Is Aquaculture?"

7 Peter Tristan and Betsy Peabody, "Reestablishing Olympia Oyster Populations in Puget Sound, Washington" (Seattle, 2005), i.

8 Hughes et al., "Beyond Fish Monoculture - Developing Integrated Multi-Trophic Aquaculture in Europe." p.5

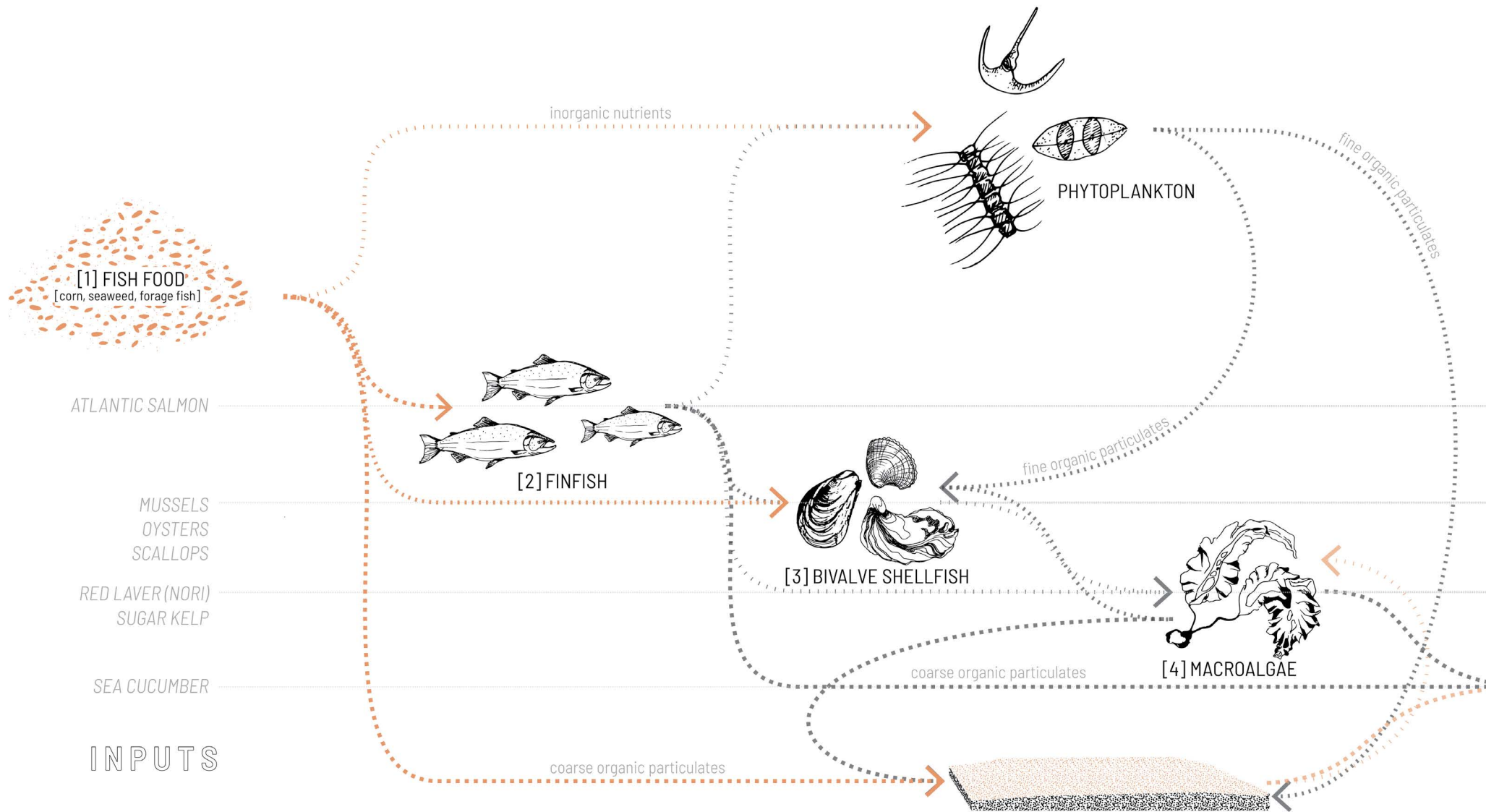
leverages multiple species' trophic roles and their capacity for metabolizing each other's wastes, reducing nutrient pollution of surrounding waters, raising system productivity and forming a more complex marine habitat for other species to inhabit. In positioning IMTA as a more environmentally responsible aquaculture strategy than typical monocultural saltwater systems, IMTA's proponents are challenging the validity of fully monocultural finfish "open" systems and setting a higher standard for mariculture operations at large. As the scientific community generates more definitive evidence of the far-reaching nature of anthropogenic impacts in the marine environment and in the nearshore especially, it is becoming clear that dilution is not always a tenable solution.

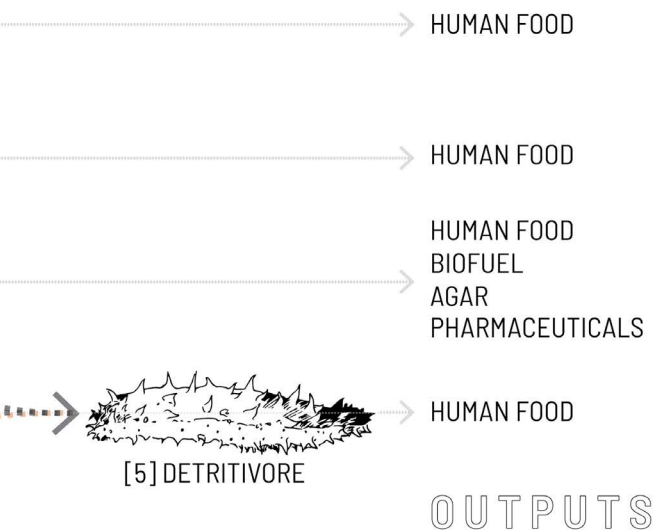
According to the U.S.' first national workshop on IMTA (held in Port Angeles, WA in 2010), Integrated Multi-Trophic Aquaculture is defined as "the rearing of a fed aquatic species... in association with species that occupy other trophic levels, making use of the waste products of the fed organisms. Typically, this association involves species such as seaweeds or plants to assimilate dissolved nutrients, filter-feeders such as mollusks to consume suspended organic materials and deposit-feeders to ingest settleable solids."<sup>9</sup> Within this context, the term "integrated" refers to the "synergistic system in which several different

species play a role in the resulting increased production and reduced waste stream of the aquaculture endeavor." Similarly, "multi-trophic", in this context describes the ecological roles of the various species involved: the photosynthetic production of algae and heterotrophic use of waste solids by filter feeding organisms.<sup>10</sup> Within the field of marine aquaculture, which today is almost exclusively comprised of monoculture systems, IMTA stands out as a particularly robust ecologically-based system. IMTA goes beyond raising productivity to potentially improving ambient water quality and has the capacity to be leveraged for its sediment accretion and wave energy diffusion properties.

In function, IMTA systems are "fabricated facsimiles" of aquatic ecosystems, composing a maricultural ecology within which each trophic functions is performed by a cultivated organism, cycling nutrients that originate as a feed input and leave the system as marketable biomass.<sup>11</sup> As such, IMTA systems reflect an "ecosystem approach to aquaculture" defined at the United Nations' Fisheries and Aquaculture proceedings as "a strategic approach to development and management of the sector, aiming to integrate aquaculture within a wider ecosystem such that it promotes sustainability of interlinked social-ecological systems"<sup>12</sup> The IMTA system is based on the principle of "eco-efficiency", in which the

9 Susan A. Thomas, "Integrated Multi-Trophic Aquaculture: A Workshop," ed. Susan Thomas (Port Angeles, Washington: Peninsula College, 2011), 1-46. p.3  
10 Thomas, 3  
11 Thomas, 25.  
12 Doris Soto, "Building an Ecosystem Approach to Aquaculture: FAO/Universitat De Les Illes Balears Expert Workshop" (Palma De Mallorca, Spain: Rome: Food





transformation of waste streams into secondary raw material for further metabolism closes the aquaculture system’s metabolic loop – a key characteristic defining an ecosystem.<sup>13</sup> According to environmental scientists, Peter Newman and Isabella Jennings, it is the circular flow of carbon through a community of organisms within their environment that helps to distinguish them as an ecosystem.<sup>14</sup> Individual organisms are typically characterized by a linear flow of energy: in as food, out as waste. In that sense, many cities today function much more like organisms than ecosystems. Conventional agricultural and aquacultural practices with their numerous seasonal inputs, monocultures and unaccounted-for externalities can also be described as exhibiting a linear metabolism. In contrast, integrated multi-trophic aquaculture attempts to shift an inefficient production system towards a less wasteful, more cyclical model.

In locations with longer histories of aquacultural practice, industrialized monocultural approaches have not completely supplanted more established, smaller-scale, multi-trophic practices. In China, where aquaculture is thought to have started in 2000 BC with early carp culture systems

integrating duck, pig and mulberry cultivation, some forms of diversified freshwater aquaculture persist.<sup>15 16</sup>

Adapting this ecosystem-based approach, integrated multi-trophic aquaculture has re-emerged in the past fifty years as an exciting potential alternative to the ecologically inefficient form of conventional mariculture that is currently the industry standard. Today IMTA systems are operating commercially only in a handful of locations in the European Union, United Kingdom, China and Canada.<sup>17</sup> IDREEM (Increasing Industrial Resource Efficiency in European Mariculture) is a European research project that works towards understanding some of the bottlenecks and barriers that prevent the industrial adoption of this production system in otherwise promising conditions around the world. Funded by the European Union, and coordinated by IDREEM, IMTA research coalitions exist in Cyprus, Ireland, Israel, Italy, Norway and until recently the UK.<sup>18</sup>

and Agriculture Organization of the United Nations, 2007), 7-11.

13 Peter Newman and Isabella Jennings, *Cities as Sustainable Ecosystems: Principles and Practices* (Washington, DC: Island Press, 2008).

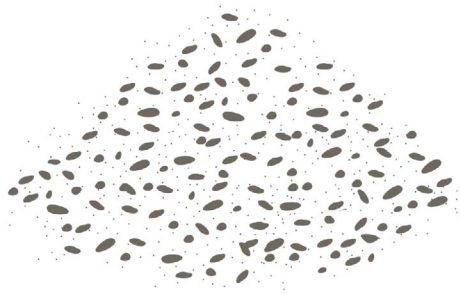
14 Newman and Jennings.

15 Colin E. Nash et al., *The History of Aquaculture* (Ames, Iowa: Wiley-Blackwell, 2011). p. 13-14.

16 Zhong Gongfu, “The Mulberry Dike-Fish Pond Complex: A Chinese Ecosystem of Land-Water Interaction on the Pearl River Delta,” *Human Ecology* 10, no. 2 (1982): 191-202, <https://doi.org/10.1007/BF01531240>.

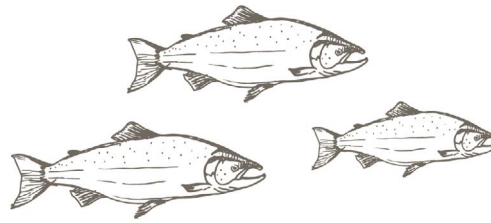
17 Hughes et al., “Beyond Fish Monoculture - Developing Integrated Multi-Trophic Aquaculture in Europe.”

18 Hughes et al.



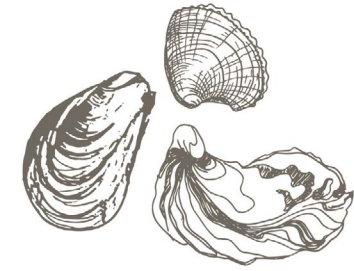
## FEED INPUT

In a typical IMTA operation, the feed input is a pellet that is comprised of a mix of fishmeal made of processing waste from commercial fish and forage fish species, corn and soy derivatives.<sup>1</sup>



## PRIMARY / FED AGENT

Finfish or shrimp are the most typical waste generating “engine” for an IMTA system as they are the fed agents that require energy inputs and generate the primary waste stream that other agents within the system will consume. Current examples of primary agents in IMTA systems include sablefish on a farm in British Columbia, salmon at farms in Scotland and turbot and sea bass on the Atlantic Coast.<sup>2</sup> The waste stream from the primary agent is categorized into inorganic nutrients and organic particulates. Inorganic nutrients are comprised primarily of Nitrogen and Phosphorus and organic particulates include excess feed and fish/shrimp feces.



## SUSPENSION FEEDER [2<sup>ND</sup> AGENT]

Filter feeders in an IMTA system consume suspended solids and bacteria, curbing both particulate and microbial pollution resulting from the culturing of the primary agent. This trophic level is typically composed of bivalve mollusks, but can also include filter-feeding fish, marine polychaetes (bristle worms) and sponges.<sup>3</sup> An experimental IMTA model built in Malaysia in the 1990s showed that 72% of the nitrogen effluent and 61% of the phosphorous emitted from a shrimp farm was removed as marketable shellfish “product”.<sup>4</sup> However, the type of organics to be removed depends directly on the source: it may be that shrimp cultivation generates finer particulates than some finfish cultivation. Research shows that 95% of particles coming from aquaculture systems (fish farms) are ~ 20 microns in diameter and that they tend to settle—and filter feeders tend to be very particular about the particulates they take up, rejecting anything too coarse.<sup>5</sup>

1 Susan A. Thomas, “Integrated Multi-Trophic Aquaculture: A Workshop,” ed. Susan Thomas (Port Angeles, Washington: Peninsula College, 2011), 1-46. p.14

1 Luana Granada et al., “Is Integrated Multitrophic Aquaculture the Solution to the Sectors’ Major Challenges? – a Review,” *Reviews in Aquaculture* 8, no. 3 (2016): 283-300, <https://doi.org/10.1111/raq.12093>. p. 291

3 Granada et al. pp. 291-292

4 Thomas, “Integrated Multi-Trophic Aquaculture: A Workshop.” p.15

5 Thomas. p.15

Consequently, if organic particulate and microbe build-up in the sediments is of concern, it is critical to partner the filter-feeding agent(s) with the cultivation of detritivores (see quaternary agent).

Bivalve shellfish are cultured either along seeded ropes or in basket-type structures. The seeded ropes are either suspended in the water column or wrapped around a structural element such as a piling. Baskets can be suspended, floating, in many possible configurations adjacent to the primary agent. Though individuals cultivating shellfish for their personal consumption may often do so in the intertidal to make them easier to access and monitor, experimental and commercial IMTA projects tend to be configured as floating complexes anchored beyond the intertidal zone, yet close enough to access easily by boat.



### NUTRIENT BIOEXTRACTOR [3<sup>RD</sup> AGENT]

Microalgae and macroalgae extract inorganic nutrients emitted by the primary and secondary agents. Bivalve mussels expel ammonia, containing nitrogen, into the water surrounding them as a byproduct of their digestion process. In open marine systems, macroalgae, referred to broadly as seaweed, is the preferred nutrient bioextractor. Seaweeds are divided among the green, red and brown algae. Red and green algae are members of the Plantae kingdom while the brown seaweeds, such as kelp, are grouped into the kingdom Chromista as they are more closely related to diatoms.<sup>6</sup> Seaweeds require light to support photosynthesis and many require a substrate for attachment. Around the Puget Sound, these microalgae and macroalgae function as the primary producers in shallow coastal waters: solar energy is redistributed to animals in the form of algae tissue, drifting and settled detritus and dissolved inorganic compounds. When used as a photosynthetic counterpart to animal respiratory pro-

6 Louis D. Druehl and Bridgette Clarkston, *Pacific Seaweeds: A Guide to Common Seaweeds of the West Coast*, Second (Madeira Park, British Columbia: Harbour Publishing, 2016). p. 157.

cesses, they are highly efficient in their uptake of carbon dioxide, nitrogen, and phosphorous, providing biofiltration for tertiary wastewater treatment (from fish or agricultural runoff).<sup>7</sup> In a typical open IMTA system with macroalgae offsetting the nutrients put out by fish, four to twelve square meters of algae culture is required per square meter of fish culture to optimize nutrient balance.<sup>8</sup>

Marine IMTA research has involved the cultivation of many macroalgae but Red Algae in the Gracilaria and Porphyra genera have featured prominently in global seaweed culture, both multi-trophic and monoculture. Brown algae including Sugar Kelp, *Saccharina latissima* and Winged Kelp, *Alaria esculenta*, are being cultivated both on the Pacific and Atlantic coasts and marketed primarily as food, and a coalition of research projects on Sugar kelp cultivation for biofuel production has been funded by the U.S. Department of Energy in a program called MARINER (Macroalgae Research Inspiring Novel Energy Resource).<sup>9</sup><sup>10</sup> In the Pacific Northwest, sugar kelp can be found in the lower intertidal and throughout subtidal environments where they receive enough light and offer adequate substrate for the seaweed to attach to. Sugar kelp is one of the more resilient and strong macroalgae, and can likely withstand most wave environments in Puget Sound, given that the Sound is mostly sheltered from ocean waves. In relatively low energy environments, kelp is cultivated on horizontal long-line structures, suspended from buoys,

7 Hughes et al., "Beyond Fish Monoculture - Developing Integrated Multi-Trophic Aquaculture in Europe." p.7  
8 Thomas, "Integrated Multi-Trophic Aquaculture: A Workshop."p. 15  
9 U.S. Department of Energy, "MARINER," 2018, <https://arpa-e.energy.gov/?q=arpa-e-programs/mariner>.  
10 Granada et al., "Is Integrated Multitrophic Aquaculture the Solution to the Sectors' Major Challenges? - a Review."p.291

the kelp rising and falling as waves move through the system. In higher energy environments such as are found offshore, it is more ideal to set up kelp lines be taught so that they do not abrade or interact with one another. Seaweeds are remarkably adaptive as environmental conditions can have a profound impact on an individual organism's phenotype, a condition called phenotypic plasticity. This characteristic allows it to respond to longer term changes in environmental conditions or to the specific conditions of the site at which it grows out; for example, a grow-out site exposed to intense wave action would grow kelp with narrower leaves with lower resistance.<sup>11</sup>

With regards to aquaculture in the mid and upper intertidal zone, native species of red algae in the genus *Porphyra* are particularly promising and have are an economically important product in Asia. In Japan, *Pyropia* and *Porphyra* seaweeds are cultivated on nets that are seeded with spores, produced in hatcheries, and planted into the sea as nets for "grow out". These nets must periodically emerge from the water and be exposed to air in order to disadvantage competing algae.<sup>12</sup> University of Washington Professor Robert Waaland is studying the biology and systematics of several species of *Porphyra*. Dr. Thomas Mumford, a phycologist working for the University of Washington Friday Harbor Labs and the Washington Department of Natural Resources was among the first to pioneer *Porphyra* cultivation in North America, however, he was ultimately prevented from continuing those operations as neighboring property owners demanded their removal, citing "visual pollution" of their waterfront views.<sup>13</sup>



### DEPOSIT FEEDER [4<sup>TH</sup> AGENT]

The agents that make up this trophic level are also known as the detritivores or decomposers and often consist of sea cucumbers (echinoderms) which consume organic particulates that settle to the sea floor. Twenty-three species of sea cucumbers that are used to graze and process biosolids are also harvested for food worldwide.<sup>14</sup> There is not a strong market for them in the US, however some South East Asian cultures have culinary uses for them and some prototypical operations in North America are marketing them to immigrant communities.<sup>15</sup> Sea cucumbers are also medically valuable for their bioactive triterpene glycosides or acetylated saponins which are being widely researched for their promising anticancer, anti-fungal and antibacterial properties.<sup>16</sup>

Within their role as detritivores in an IMTA system, sea cucumbers have been shown to perform well as anti-fouling agents for nets and closed aquaculture equipment. They grow very successfully in co-culture with mussels, oysters and shrimp. They can be configured inside fine-net systems with other organisms so that they can climb around and consume the biofilms that accumulate on nets and other surfaces. In other operations, different sea cucumber species have been raised on trays suspended beneath oyster culture, or buried in sand below cultured shrimp. The California sea cucumber, *Parastichopus californicus*, a native of the Puget Sound and along the Pacific Coast, has been found to flourish in conjunction with oyster and fish culture, consuming fish feces, settling fish food, algae and other organic matter settling and growing among sediments.<sup>1</sup> Other mollusks and crustaceans can perform in this trophic role as well.<sup>2</sup>

14 Thomas, "Integrated Multi-Trophic Aquaculture: A Workshop." p.15

15 Thomas, IMTA Workshop, 15.

16 Yadollah Bahrami, et. Al, "Acetylated Triterpene Glycosides and Their Biological Activity from Holothuroidea Reported in the Past Six Decades." *Marine Drugs* 14, no. 8 (2016): 147.

1 Granada et al., "Is Integrated Multitrophic Aquaculture the Solution to the Sectors' Major Challenges? - a Review." p. 293

2 Thomas, IMTA Workshop, 15

11 Ibid, 238.  
12 Ibid, 267  
13 Ibid.

An IMTA system, while it would typically include agents at each of the four trophic niches described above, can be composed of more than four species. Depending on the system's location and composition, there could be multiple suspension feeders, whether shellfish, tube-worms, sponges or filter-feeding fish. It is also possible to cultivate multiple seaweeds in the same area as well, though with greater heterogeneity and complexity comes greater challenges in controlling and managing the system, key considerations as IMTA systems move towards commercialization. On the other hand, as the system becomes more biodiverse it may serve as a richer habitat mosaic for other creatures, an outcome that could be important to IMTA operations implemented for habitat enhancement or restoration purposes.

The characteristic that distinguishes an integrated multi-trophic aquaculture system from a marine or aquatic polyculture is the proximity, both temporal and spatial, of the agents with reference to each other.<sup>1</sup> Each agent is intended to synergistically benefit from its cohabitation among organisms occupying other trophic niches. Consequently, the design of an IMTA system requires consideration of spatial configuration and proportions. In marine systems, finfish are grown in pens offshore with suspension feeders strung along ropes through the water column and macroalgae growing-out on long-lines, buoyed or otherwise raised to the

water's surface to optimize exposure to sunlight. Some suspension feeders, namely scallops and oysters, are often cultivated in lantern nets (10–12 baskets each), instead of being seeded onto ropes as mussels typically are.<sup>2</sup> Meanwhile detritivores and grazers such as sea cucumbers and sea urchins can be suspended beneath the primary agent in pots and oyster baskets to intercept organic particles as they settle onto whatever sits beneath them. An IMTA project run by the “SEA Vision Group” on Vancouver Island features sablefish (black cod) as the fed agent and blue and gallo mussels, Pacific oysters, Japanese scallops and a native cockle as the filtration agents. The shellfish are suspended in two tiers, 15 meters wide, 20 meters deep, and 200 meters long draped around the system like a filtration curtain. For inorganic nutrients, the extractive agents are *Saccharina lattissima* (sugar kelp) and a native *Porphyra* (red laver). Urchins and sea cucumbers are the deposit grazers and live in a tray system beneath the fish.<sup>3</sup>

1 Luana Granada et al., “Is Integrated Multitrophic Aquaculture the Solution to the Sectors’ Major Challenges? – a Review,” *Reviews in Aquaculture* 8, no. 3 (2016): 283–300, <https://doi.org/10.1111/raq.12093>. p. 290

2 Adam D Hughes et al., “Beyond Fish Monoculture - Developing Integrated Multi-Trophic Aquaculture in Europe” (Florence, Italy, 2016). p.8

3 Susan A. Thomas, “Integrated Multi-Trophic Aquaculture: A Workshop,” ed. Susan Thomas (Port Angeles, Washington: Peninsula College, 2011), 1–46. p. 17–18

IMTA leverages the many synergistic exchanges that occur within aquatic polycultures. Bivalve mollusks' excreted waste products contain a form of nitrogen that is more readily usable and digestible to macroalgae. Conversely macroalgae exude polyphenols in their slime coating which is then consumed by zooplankton which provide a supplemental food source to filter feeders consuming organic particulates originating from shrimp and finfish culture. Seaweed cultivation's potential synergy with shellfish aquaculture is currently an exciting field of scientific research. Globally, the pH of the oceans has dropped from 8.2 to 8.1 and predictions seems to indicate that the pH will drop to 7.7 or 7.8 by the end of the century.<sup>4</sup> This is the most acidic oceans have been over the last 20 million years!<sup>5</sup> Ocean acidification threatens the viability of cultured and wild shellfish populations as well as pteropod populations (a major food source for salmon) as the more acidic waters inhibit the shellfish and pteropod larvae from accessing calcium in the water to build their shells.<sup>6</sup> Some oyster hatcheries have already moved from the PNW to Hawaii, where access to deep, less acidic water can help allay the problem temporarily. Preliminary research results are showing that macroalgae such as kelp form a "halo" of sweetened water chemistry, raising the pH of surrounding waters.<sup>7</sup>

Kelp, in particular, has high ecological value regardless of the ultimate purpose for its cultivation because it forms critical habitat for a wide range of aquatic creatures. Dr. Yarish's ongoing research in Long Island Sound has demonstrated the significant potential that aquaculture of shellfish and seaweeds has for the improvement of water quality in urbanized coastal waters. According to the EPA's End of Year report in 2013, "this form of sea farming can reduce nutrient pollution and offer ancillary ecological benefits by creating habitat, supporting green jobs and contributing to the reduction of the national seafood trade deficit."<sup>8</sup>

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4 Louis D. Druehl and Bridgette Clarkston, *Pacific Seaweeds: A Guide to Common Seaweeds of the West Coast*, Second (Madeira Park, British Columbia: Harbour Publishing, 2016). p. 270

5 Druehl and Clarkston. p. 270

6 Druehl and Clarkston. p. 270

7 Joth Davis et al., "Using Seaweeds to Mitigate Ocean Acidification in the Salish Sea" (Seattle, WA, 2017).

8 EPA, "National Water Program: Best Practices and End of Year Performance Report" (Washington, DC, 2013), 45.



photo by : Zachary Moscicki

Dr. Louis Druehl, a well-known phycologist based out of Victoria, British Columbia, describes seaweeds as “the architects of coastal marine meadows and underwater forests”, providing “homes and shelter for entire communities of associated fishes and invertebrates”.<sup>9</sup> Kelp forests are sites of high productivity (measured in the amount of carbon captured and converted into organic compounds per square meter) in our near-shore environments. Kelps native to the West Coast such as *Macrocystis integrifolia* or *Nereocystis luetkeana* (Giant kelp and Bull kelp), form forests in the lower intertidal and upper subtidal regions.<sup>10</sup> Giant kelp, like other kelps is an ecosystem engineer, modifying light penetration, water motion, and creating a diverse range of habitats, it supplies food, substrate for attachment, shelter, and means of transport to other aquatic creatures.<sup>11</sup>

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9 Druehl and Clarkston, *Pacific Seaweeds: A Guide to Common Seaweeds of the West Coast*. p. 12  
10 Druehl and Clarkston. p. 235  
11 Druehl and Clarkston. p.234

**left:** A recently discovered species of kelp, previously assumed to be a variant of sugar kelp, has been cultivated by seaweed farmer, Paul Dobbins, in Casco Bay, Maine. Though this species has yet to be named, the kelp has successfully marketed as food locally, gaining recognition for its superior taste and texture.

## *Barriers to Implementation*

Public concern and skepticism over the use of the nearshore for food production rather than for other purposes remains the most significant barrier to growth in coastal aquaculture and consequently IMTA as well. At the national IMTA workshop held in Port Angeles in 2010, “Lack of social acceptance of aquaculture and the absence of a regulatory framework that would allow aquaculture, including IMTA, to develop in a responsible way” has been identified as the primary reason for delayed development of better aquaculture strategies in the US relative to other countries internationally.<sup>1</sup> Among long-time aquaculturists, there is a perception that coastal communities are experiencing a demographic shift. Increasingly, the people living on the waterfront are well-to-do retirees from outside the community, who lack “traditional” ties to the ocean and consequently, have lower tolerance levels for working waterfronts; rather, their preference is for recreational and tourist-oriented development

if any at all.<sup>2</sup> Among the IMTA workshop attendees in Port Angeles, there was consensus that in most cases involving a proposed near-shore aquaculture operation, coastal communities perceive the waterfront as reserved for recreational use, and consequently, fishermen and aquaculturists face an overwhelming pushback on any projects they propose, conventional or IMTA. The main perceived conflict discussed at the IMTA conference is that “between working people and those who don’t work for a living”.<sup>3</sup> However, this apparent conflict can be distilled down to a lack of knowledge and awareness of marine ecosystem dynamics and nearshore biological communities among waterfront homeowners and land managers.

Meanwhile, the potential of poorly managed monoculture operations to disrupt valued coastal ecosystems has been well documented and often disproportionately emphasized in local media as representative of all aquaculture operations.

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1 Thomas, “Integrated Multi-Trophic Aquaculture: A Workshop.”, 3.

2 Thomas, 6.

3 Thomas, 6.

So while dialogue and advocacy surrounding the proper design and management of mariculture systems in the nearshore is productive and necessary, the widespread rejection of mariculture on basis of view-shed pollution or incompatibility with recreational use is, in part, based on limited understanding and engagement with nearshore ecology and aquaculture practice. As is evidenced by the continued armoring of Puget Sound's shorelines, individuals who own waterfront homes remain comfortable with the environmental degradation associated with armoring their waterfront but express alarm at the vague and sometimes unfounded prospect of ecological disruption surrounding seaweed or shellfish culture.

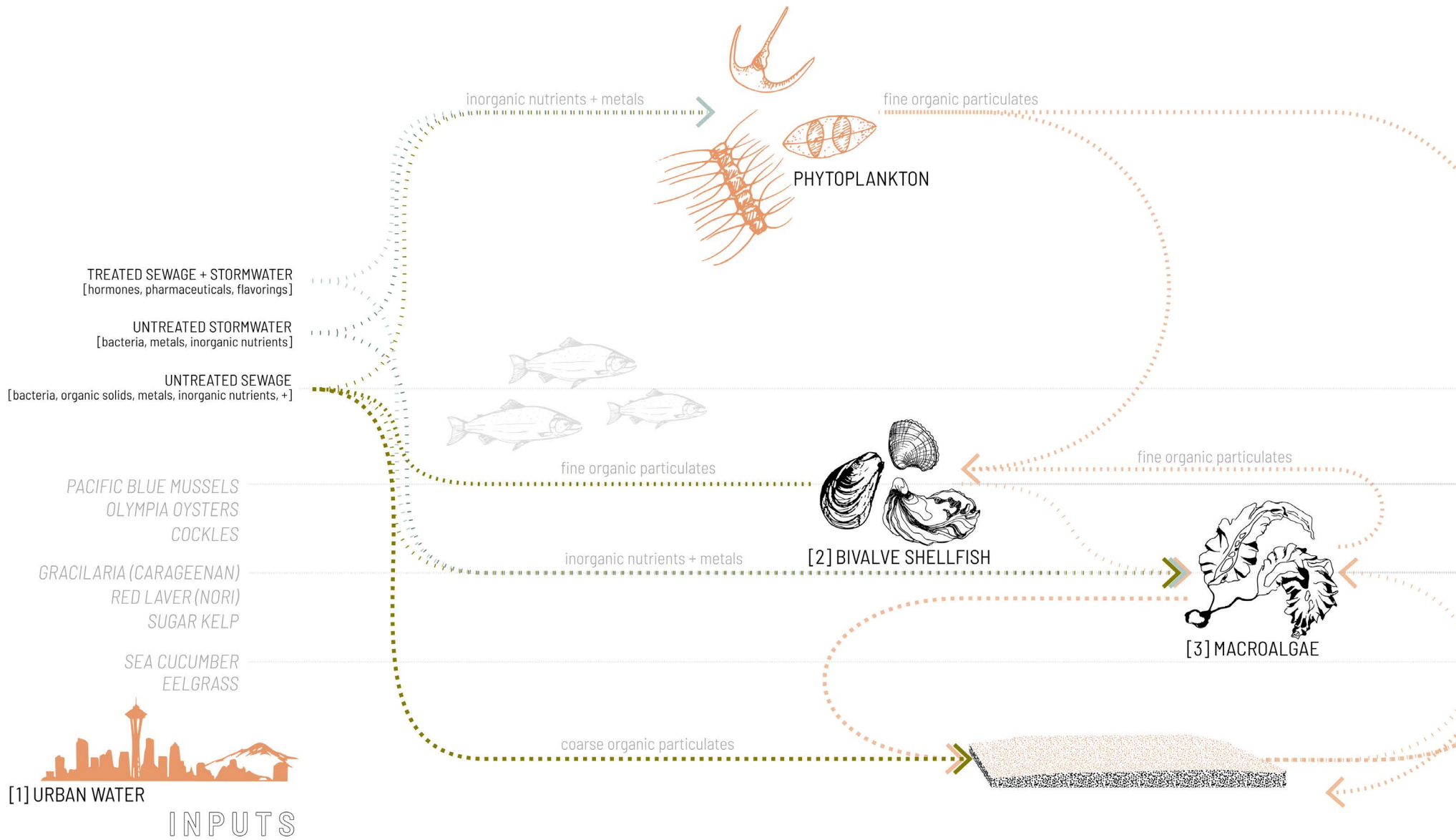
Based on the general discourse on marine aquaculture within the United States, it seems that individuals involved with IMTA over the past few decades have become jaded by the hostile reception most proposals receive from

communities resulting from a lack of information on aquaculture operations.<sup>4</sup> There also seems to be agreement among North American aquaculturists and marine scientists that IMTA is a system that is difficult to explain concisely and even more difficult for people to picture, a situation that exacerbates the public's suspicion and scrutiny of proposed farms. Meanwhile in Europe, IDREEM has sponsored a few public opinion surveys in order to better understand the perception of IMTA among both stakeholders and the broader public. The 2016 IDREEM report also encounters widespread public misconceptions of what IMTA proposes to do and how it would impact the surrounding environment. Some concerns, however, were focused on the potential naturalization of broadcast spawners that release eggs and sperm into the water for external fertilization: sea urchins and oysters for example. This valid concern highlights the importance of cultivating native species where environmental sensitivity is paramount.<sup>5</sup>

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4 Thomas, 6.

5 Hughes et al., "Beyond Fish Monoculture - Developing Integrated Multi-Trophic Aquaculture in Europe," 15.

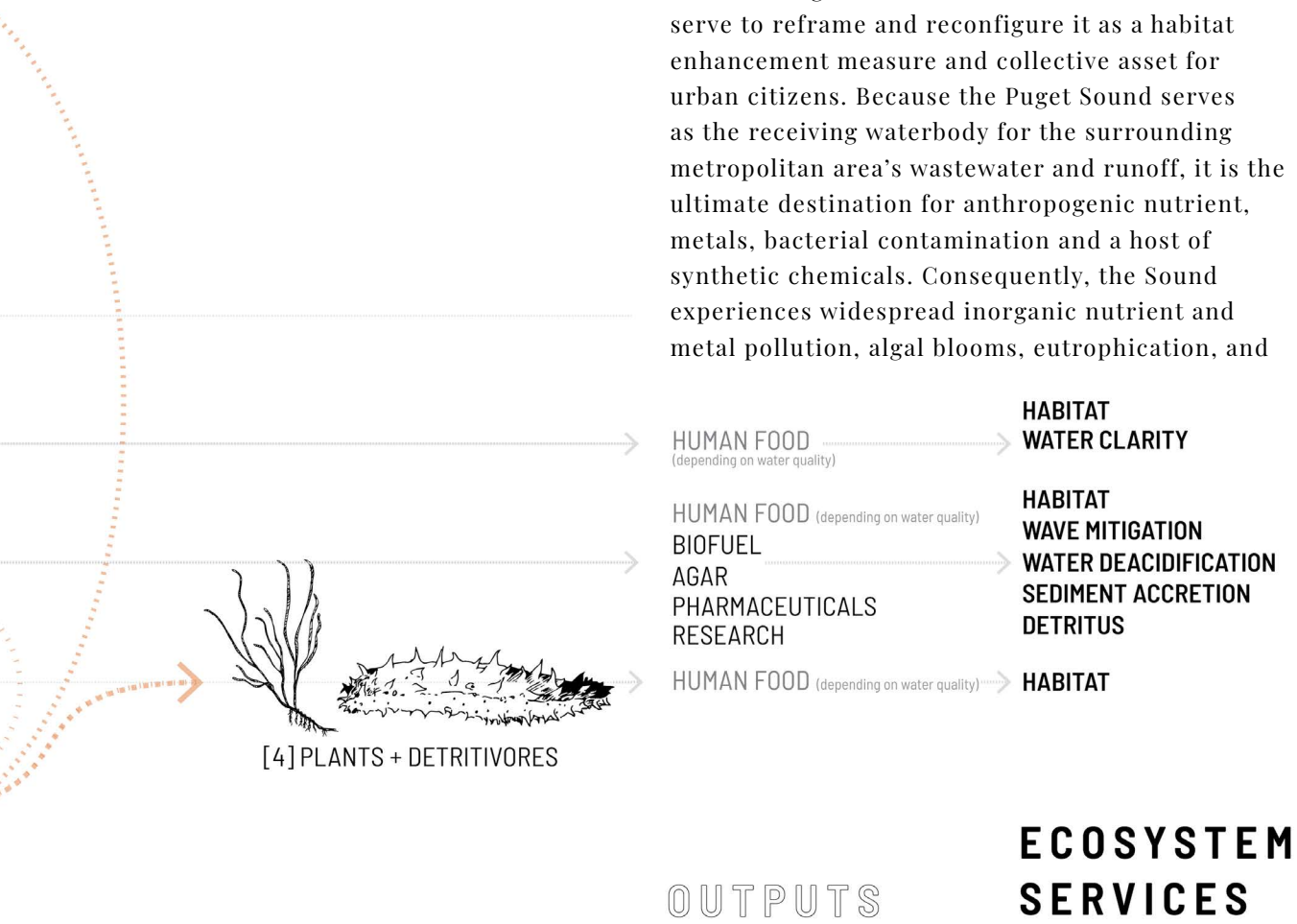


## IMTA as an Urban Intertidal Strategy

Though integrated-multi-trophic mariculture is primarily being researched and implemented for food production, this mode of cultivation in the marine environment holds potential for a broader range of functions and outcomes that can serve to reframe and reconfigure it as a habitat enhancement measure and collective asset for urban citizens. Because the Puget Sound serves as the receiving waterbody for the surrounding metropolitan area's wastewater and runoff, it is the ultimate destination for anthropogenic nutrient, metals, bacterial contamination and a host of synthetic chemicals. Consequently, the Sound experiences widespread inorganic nutrient and metal pollution, algal blooms, eutrophication, and

more localized pollution from leaky septic systems, industrial activity and catastrophic sewage overflows. In many ways, the Sound is rich in the type of effluent and particulates that suspension feeders, nutrient bioextractors and detritivores serve to consume in an IMTA system. I propose to hybridize the IMTA model we have come to know, to consider the City the primary agent expelling its effluent and waste in the form of treated and untreated wastewater, stormwater, sewage and all that is carried within those waters.

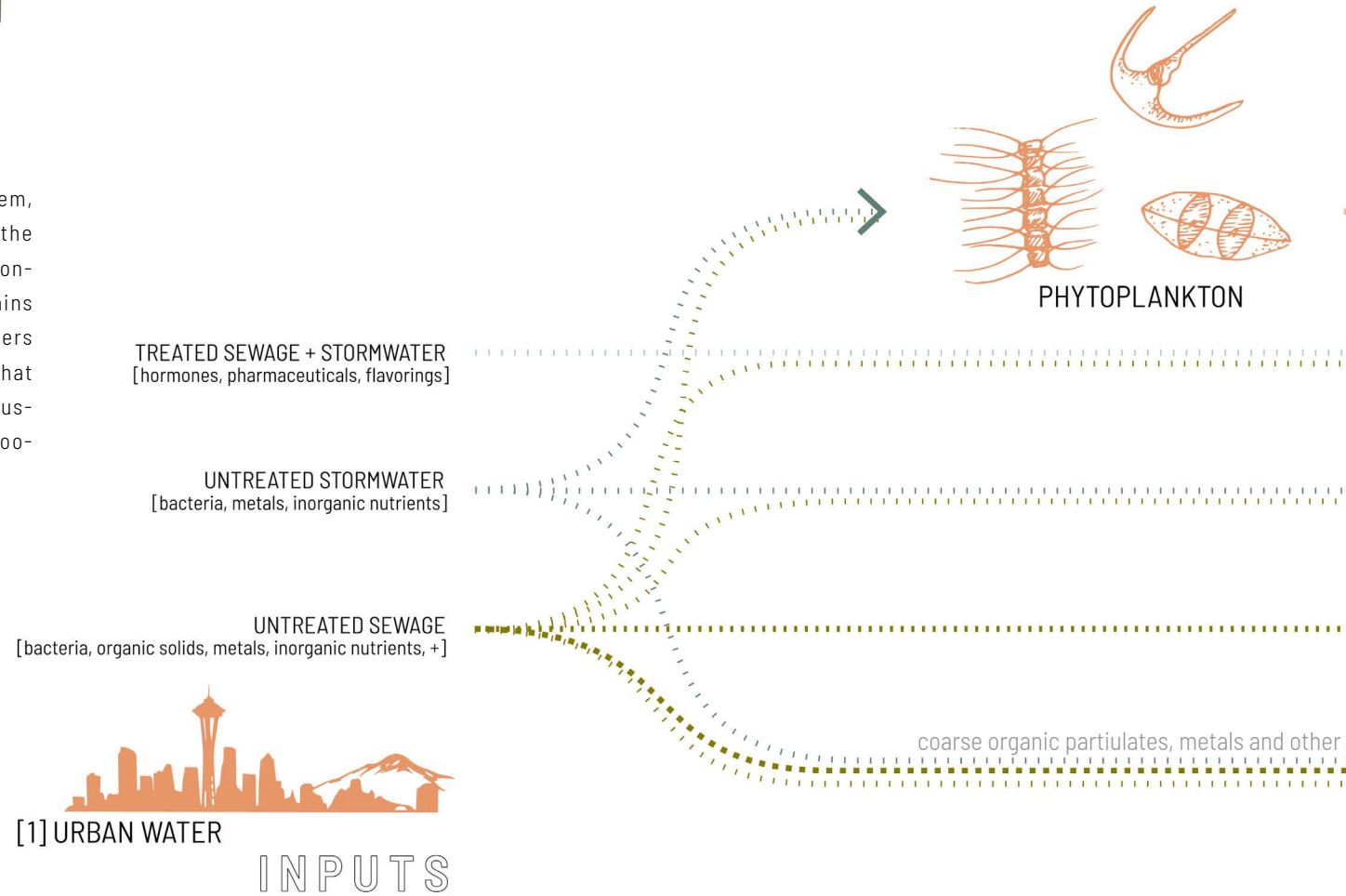
While green urbanism strategies work to curb and intercept the stream of pollutants before they reach the Puget Sound, blue urbanism in the form of a modified IMTA system can serve to ameliorate and leverage the nutrients and particulates circulating through and in some cases stagnating in the Sound. Designing this hybridized multi-trophic mariculture system within the urban intertidal provides the added advantages of positioning the system near point sources of the City's aqueous effluent, enhancing biodiversity and habitat in a highly modified and disrupted intertidal environment and affording the public an opportunity to access and engage with this biological infrastructure system.

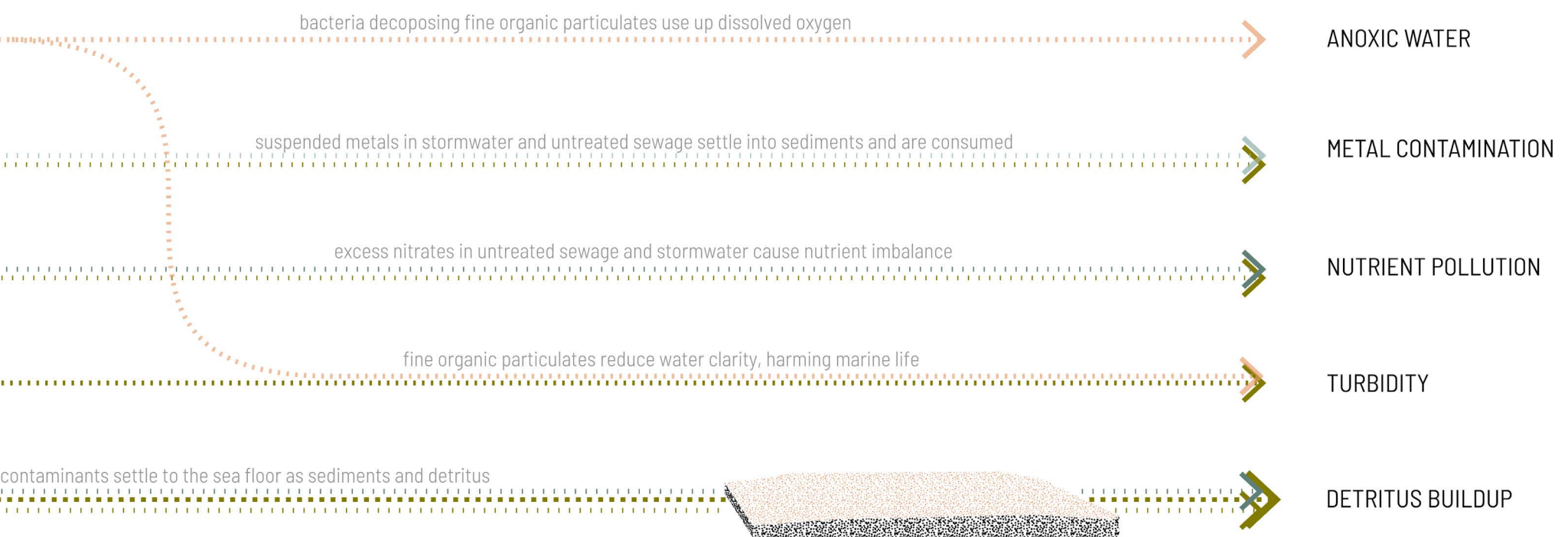




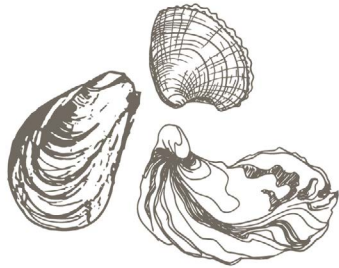
## CITY [PRIMARY AGENT]

In the proposed hybridized version of the IMTA system, the City is conceptualized as the primary engine for the system, supplying nutrient-rich runoff in normal rain conditions and extremely nutrient rich sewage in heavy rains causing a combined sewer overflow event. These waters are rich in a range of other pollutants as well: some that settle into sediments, and others that may remain suspended in the water column and may be consumed by zooplankton.





# OUTPUTS



## SUSPENSION FEEDERS [2<sup>ND</sup> AGENT]

Bay Mussel (*Mytilus trossulus*), Olympia Oyster (*Ostrea lurida*), Native Littleneck (*Leukoma staminea*), Eastern Soft Shell (*Mya arenaria*) Butter Clams (*Saxidomus gigantean*) Horse Clams (*Tresus capax*), Cockles (*Clinocardium nuttallii*)

### Bay Mussels (*Mytilus trossulus*)

Grow up to 3 inches and prefer sheltered. These mussels filter significant volumes of water, with a pumping rate up to 2.5 liters/h per gram of body weight, consuming plankton and suspended detritus particles. Bay mussels spawn during April and May. Its larvae are planktonic veligers swimming freely for 4-7 weeks. They settle into areas with filamentous algae, byssal threads, hydroids, *Semibalanus cariosus*, or bare rock. Once they tether to a surface, they live in a shellfish stage another 2-3 years, sometimes longer. Bay mussels serve as food to many different creatures including anemones, large crabs, sea snails, seabirds, shorebirds, perch, and sea otters. They are already being cultivated in the Puget Sound for restoration and habitat quality monitoring purposes.

The shellfish species profile data comes from Washington Department of Fish and Wildlife: Washington Department of Fish and Wildlife, "Clams," Fishing and Shellfishing, 2018, <https://wdfw.wa.gov/fishing/shellfish/clams/>.

### Olympia Oyster (*Ostrea lurida*)

The Olympia Oyster prefers mud-gavel flats, intertidal pools with freshwater seepage, but its habitat can extend remarkably far out to depths of 165 feet. This oyster is small compared to the widely cultivated non-native Pacific Oyster as it grows to only about 3.5 inches.

### Native Littleneck (*Leukoma staminea*)

Native Littlenecks prefer gravel-mud environments in protected waters, and are mostly found at mid-tide levels. These clams are commercially and recreationally important as it is delicious. Spawns in spring and early summer.

### Eastern Soft Shell (*Mya arenaria*)

Originally thought of as a transplant from the East, the Eastern Soft Shell is now known to be native to the Pacific Coast. Prefers sandy-mud substrate, at upper half-tide level in brackish waters.

### Butter Clam (*Saxidomus gigantean*)

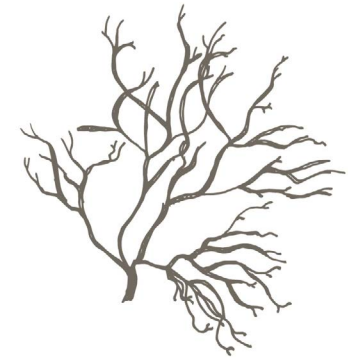
Butter Clams prefer sandy-gravel beaches at lower intertidal and shallow subtidal zones all the way out to 60 foot depths. They spawn in the summer and swim freely for a 3-4 week larval period before settling into substrate.

### Horse Clam (*Tresus capax*)

Butter Clams prefer sandy-gravel beaches at lower intertidal and shallow subtidal zones all the way out to 60 foot depths. They spawn in the summer and swim freely for a 3-4 week larval period before settling into substrate.

### Cockle (*Clinocardium nuttallii*)

Cockles prefer sandy-mud beaches throughout intertidal zone and spawn in summer.



## NUTRIENT BIOEXTRACTOR [3<sup>RD</sup> AGENT]

### Gracilaria species

The genus Gracilaria contains over 100 species of red algae found all over the world, many of which are used for human food, animal feed and for its phycocolloids used to make agar. Gracilaria species tend to be densely branching and bushy. In the Puget Sound it grows in dense mats on sandy flats, anchoring onto pebbles buried several inches below the surface and capturing drifting sediments in the tangle of their foliar mass.<sup>1</sup> These seaweeds occupy mid-intertidal levels at a range of +2 to +6 feet with reference to mean lower low water. They propagate vegetatively, making the process of cultivation significantly easier. If they are cultivated through vegetative propagation however, they will not form holdfasts and consequently vegetative segments must be firmly intertwined between two strings to retain them during grow-out. Biomass can be harvested throughout the summer growing season by trimming its outer growth and leaving the core to regrow.<sup>2</sup>

1 Tom Mumford in discussion with the author, January 2018.

2 Sarah Redmond et al., New England Seaweed Culture Handbook-Nursery Systems (Connecticut Sea Grant, 2014), <http://seagrant.uconn.edu/publications/aquaculture/handbook.pdf>, 33, 40.

## URBAN NUTRIENT BIOEXTRACTION

Dr. Charles Yarish, a phycologist based at University of Connecticut, is currently researching and publishing on the nutrient bioextraction properties of seaweed cultivated in urban waters beside several East Coast cities. Among the seaweeds Yarish is cultivating and studying is the red algae, *Gracilaria tikvahiae*, a summer crop which is commercially marketable as agar, sea vegetable and as a component in animal feed. It is cultivated on long-lines, structural ropes that are wrapped with a string seeded with starts. Based on Yarish's preliminary results, nitrogen removal in a 1-hectare farm of *Gracilaria* long-lines, spaced at 2-4 meter intervals, extracts 33-66 kg of Nitrogen per month (July) and 8-16 kg N/ha/month in October. Dr. Charles Yarish is also cultivating and studying sugar kelp as a winter nutrient bioextraction crop with strong proven potential as an edible sea vegetable, alginate, and biofuel. In his preliminary research results, 1 hectare of sugar kelp, cultivated on long-lines spaced 1.5-6 meters apart, removes 71-280 kg of Nitrogen over the growing season.<sup>1</sup>



### Sugar Kelp (*Saccharina lattisima*)

Sugar Kelp is a brown algae native to both the East Coast and West Coast. It prefers subtidal environments though it can be found attached to cobbles in the low intertidal as well. It has a winter growing season and extraordinarily high biomass production making it attractive as a potential source of biomass for biogas and bioethanol energy sources.<sup>1</sup> It is growing in popularity as a delicious sea vegetable and is used as a nutritional supplement in animal feeds, as a soil amendment and in a variety of biotech and pharmaceutical applications as it contains alginate, an increasingly important polysaccharide.<sup>2</sup>

Sugar kelp's long, tapering blades are usually a luminous ochre to orange. They appear as broadly ruffled or completely smooth and narrow and can reach a length of 16 feet depending on the environmental conditions of the grow-out site. These long, phenotypically plastic blades

form a complex and baffled path for water to travel and offer an opportunity for wave energy dissipation through their dense bronze canopies. Though they are often cultivated on long-lines that are buoyed in such a way that their full length remains near the water's surface for maximum light exposure, their light requirements should be satisfied through the entire water column of the shallow subtidal where they would be cultivated to buffer an intertidal mariculture system from rare winter storms on a North facing beach. Consequently, to maximize their wave buffering capabilities, sugar kelp would be cultivated on vertical long-lines attached to a buoy at one end and a low-lying horizontal anchor line at the other.

1 Charles Yarish, et al., "Seaweed Farming in Long Island Sound-- An Updated From Connecticut." Presentation, 2013 1

1 Sarah Redmond et al., New England Seaweed Culture Handbook-Nursery Systems (Connecticut Sea Grant, 2014), <http://seagrant.uconn.edu/publications/aquaculture/handbook.pdf>, 17

2 Redmond et al. p.17



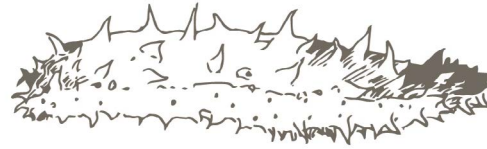
### Red Laver (*Porphyra abbottiae*)

This is a red algae native to the Pacific Northwest and culturally important to Coast Salish people as a food source and continues to be foraged around the Puget Sound today. <sup>1</sup>This seaweed belongs to the genera *Porphyra* which, together with the genus *Pyropia*, is the most economically valuable cultured seaweed in the world in its “Nori” form.<sup>2</sup> *Porphyra* and *Pyropia* seaweeds take up inorganic nutrients at very high rates and are consequently a good choice of seaweed for nutrient bioextraction. Their cultivation in an urban mariculture system would provide an opportunity to prototype and refine local Nori cultivation techniques, while extracting anthropogenic nutrients at a mid-intertidal level that sugar kelp cannot occupy. *Porphyra abbottiae* grows from February to August, occupying a tidal niche between elevations +2 and +4. In Asia, *Porphyra* and *Pyropia* are cultivated on nets suspended on poles, hanging in semi-transparent red-purple sheets during low tide. In cultivation, this seaweed requires daily exposure to air in order to disadvantage epiphytic growth on the nets and reduce competition from epiphytes.<sup>3</sup>

1 Tom Mumford in discussion with the author, January 2018.

2 Sarah Redmond et al., *New England Seaweed Culture Handbook-Nursery Systems* (Connecticut Sea Grant, 2014), <http://seagrant.uconn.edu/publications/aquaculture/handbook.pdf>, 54

3 Redmond et al, 54.



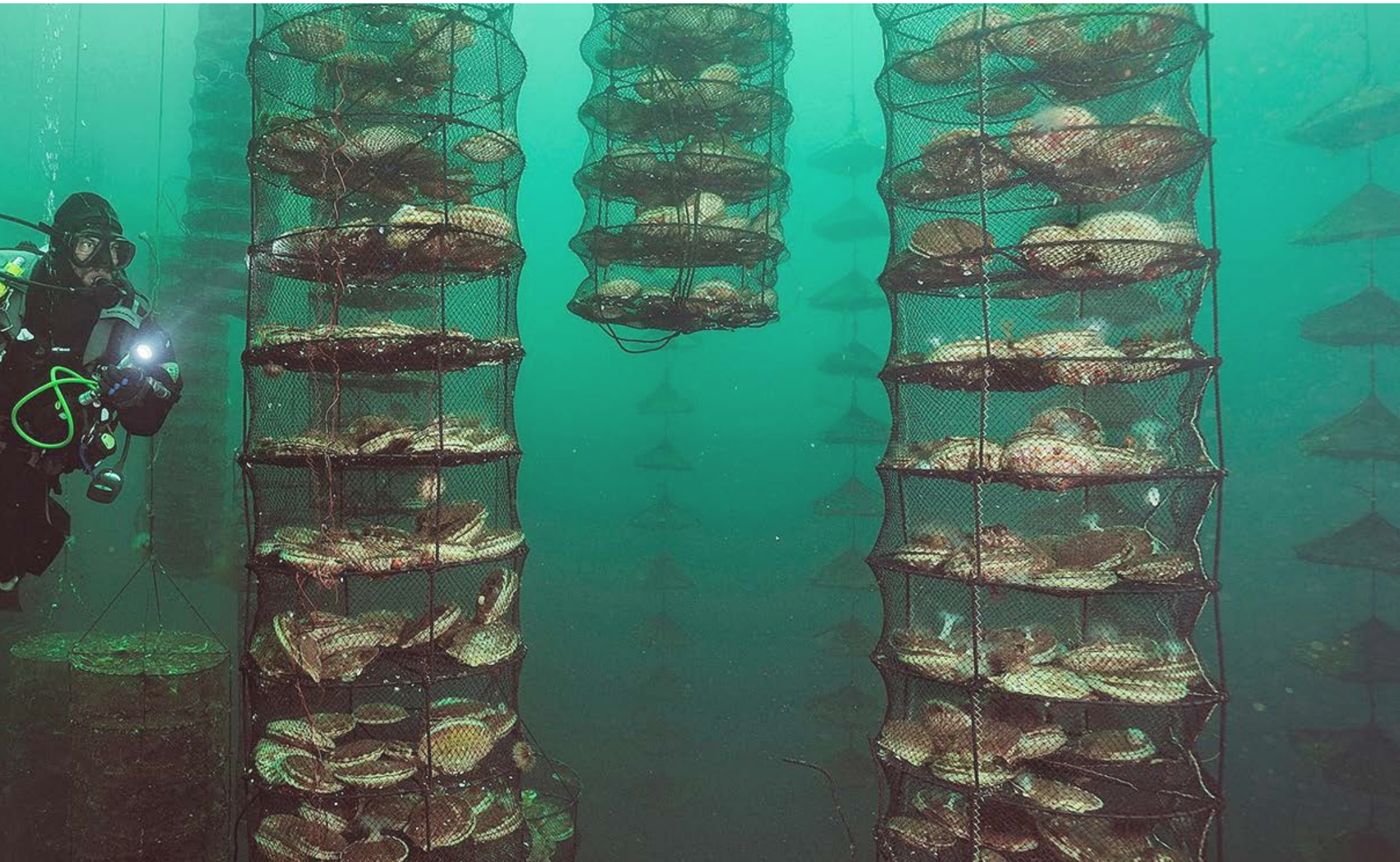
### DETRITIVORE [4<sup>TH</sup> AGENT]

#### Sea Cucumber (*Parastichopus californius*)

Because an intertidal multi-trophic mariculture system would not be suspended and floating in one cohesive cluster as off-shore systems tend to be, sea cucumbers cannot be cultivated in containers or suspended trays beneath the primary agent. Rather, in an intertidal system, they could occupy the same habitat as *Olympia* Oysters inhabit: on pebbly gravel flats kept inundated by dikes, essentially enlarged tide pools, deep enough to keep the oysters cool throughout the year. In such an environment, the sea cucumbers can climb around and consume particulate waste from the oysters and any organic particulates settling out of the water trapped by the dike. Because of the urban location and likelihood of sediment contamination from wastewater and stormwater pollutants, sea cucumbers may not be suitable for consumption but could be propagated for restoration and remediation purposes.

photo by : Brian Skerry, 18, <https://www.brianskerry.com/portfolio/aquaculture-3/attachment/18-3/>





**above:** Giant Japanese scallops hang suspended in lantern nets at an IMTA farm off British Columbia's Vancouver Island. Sea cucumbers, kelp and sablefish make up the rest of the trophic levels in this system



photo by : NASA <https://earthobservatory.nasa.gov/IOTD/view.php?id=86747>

**above:** A NASA satellite image shows the pattern of Nori and Wakame cultivation in the shallows surrounding the South coast of South Korea.

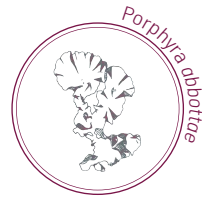
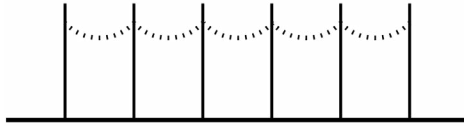
## MUSSEL POSTS

sediment accretion  
organics filtration



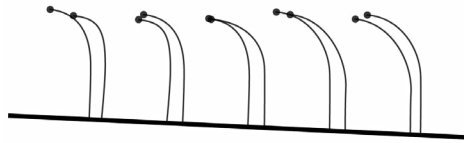
## NORI NETS

nutrient absorption



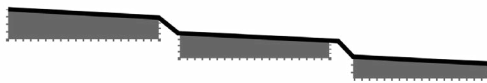
## KELP LINES

wave attenuation  
nutrient absorption  
de-acidification



## TIDAL TERRACING

sediment retention  
habitat formation



## CLUTCH DIKES

seawater retention  
habitat formation



## An Intertidal Mariculture Toolkit: Earth, Posts and Ropes

Though IMTA system infrastructure is customized to support and host each unique suite of agents, these systems typically take the overarching form of an anchored but floating conglomeration of long-lines, lantern-nets and pens. Intertidal mariculture, on the other hand, requires a different set of cultivation structures and surfaces, as it has the advantage of earthen substrates to host bivalve mollusks and aquatic plants as well as the potential to afford access to a variety of human visitors, ranging from recreational kayakers to aquaculturists harvesting the crops.



photo by : Trevor Bentley

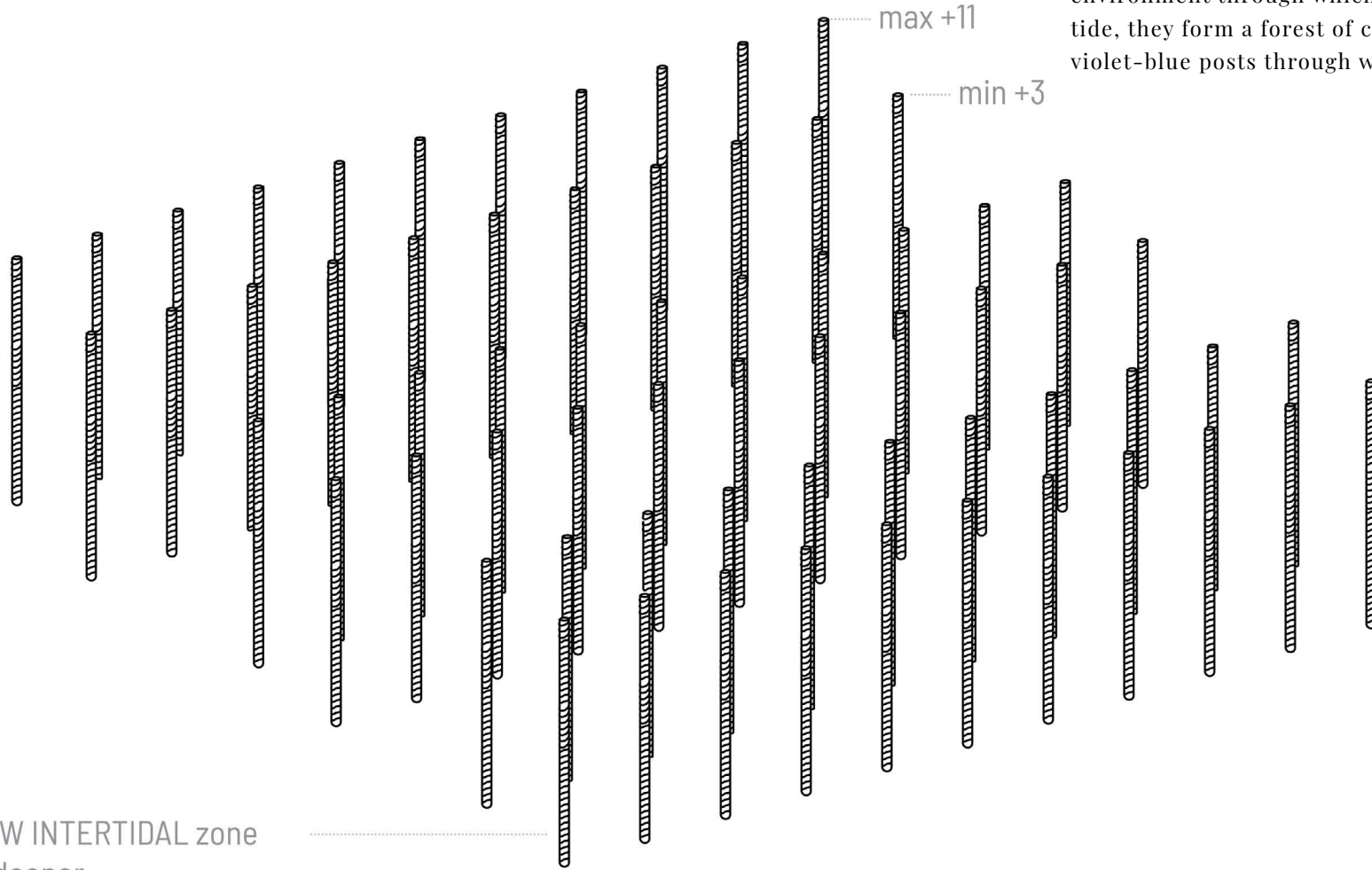
**above:** Mussel and barnacle encrusted pilings bring marine life to eye level at the Tacoma tide flats.



## MUSSEL POSTS

sediment accretion  
organics filtration

MUSSEL POSTS consists of pilings wrapped with a string/rope seeded with mussel spat. In aggregate, the piles act as a porous barrier to swash and waves, slowing and baffling the water's path as it moves between them. Mussels grow in a wide tidal range so these piles can be located in numerous locations across the intertidal gradient. At high tide, they can create an interesting environment through which to kayak, and at low tide, they form a forest of coarsely-textured violet-blue posts through which to wander.

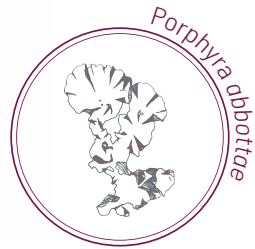
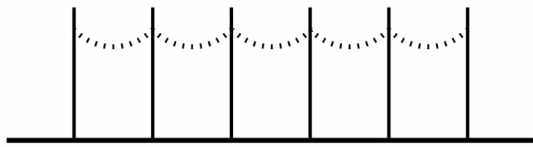


MID- LOW INTERTIDAL zone  
+5 and deeper



photo by : [Prairie Stuart-Wolff, Nori Sunrise](https://artofeating.com/ichibanzumi-japans-finest-nori/), <https://artofeating.com/ichibanzumi-japans-finest-nori/>

**above:** Nori is the Japanese name for a number of *Porphyra* and *Pyropia* species grown throughout Asia as a food crop. This delicate red seaweed grows-out on seeded nets suspended on poles in shallow near-shore conditions.



*NORI NETS*

nutrient absorption

NORI NETS form a matrix of light-weight posts and gridded ropes, upon which deep maroon Porphyra blades hang suspended like curtains. To privilege the growth of Porphyra, the nets must be positioned at a narrow elevation range that allows the seaweed adequate time out of water at low tides and enough time in water to continue growing. By placing grommet-type stoppers on the posts at the lower limit and upper limit of the range, the cultivated nets can hang suspended at low tides and drift near the water surface at higher tides.

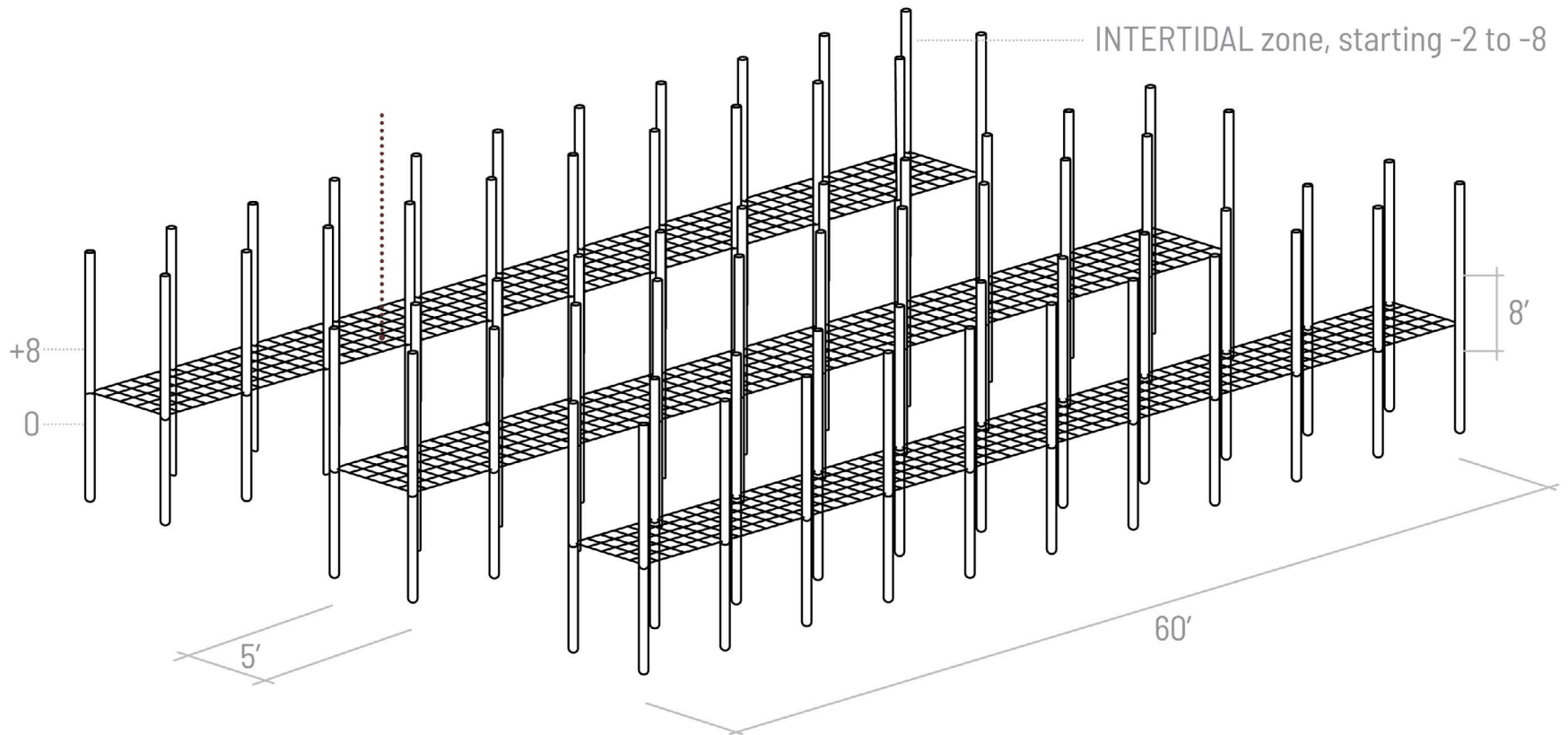
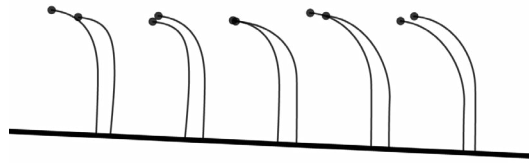




photo by : Zach Moscicki

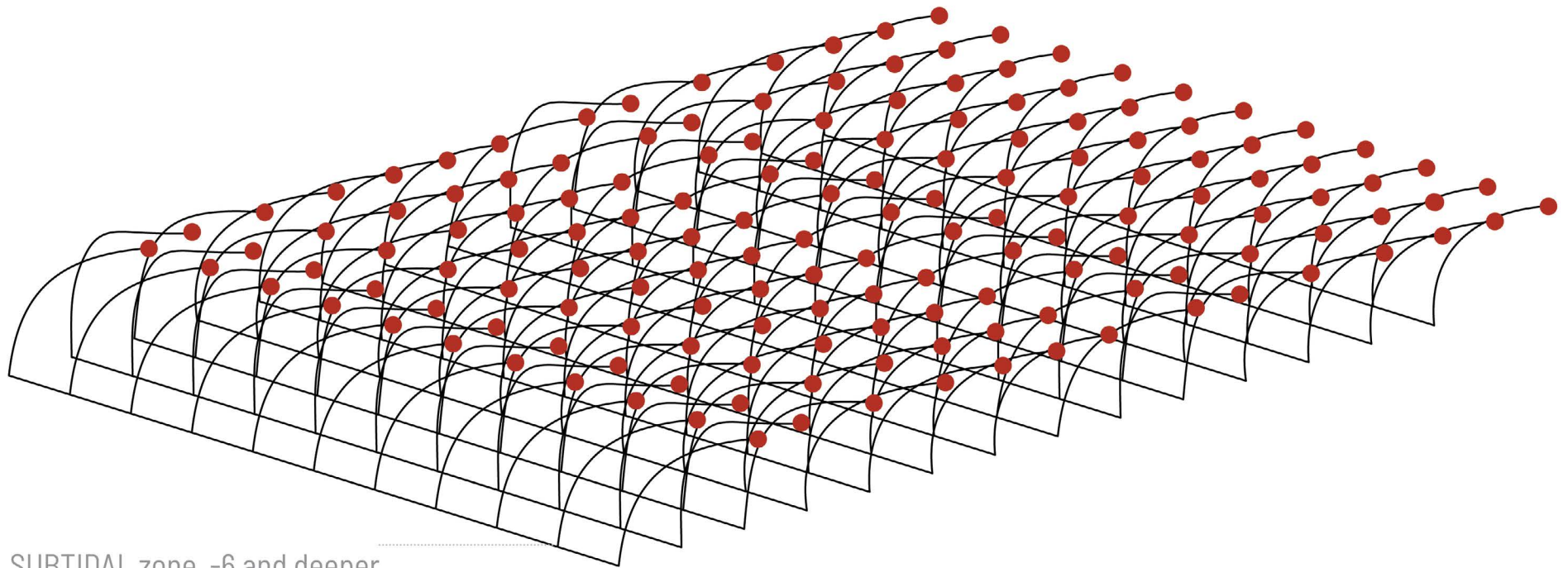
**above:** Buoys bob at the surface of a kelp cultivation operation in Maine.



## KELP LONG-LINES

- wave attenuation
- nutrient absorption
- de-acidification

KELP LINES designed to assist mitigate wave energy, protecting terrace walls and coastal sediment accretion, take the form of long-lines that span the water column. In many existing kelp cultivation operations, kelp is cultivated on long lines that are suspended by buoys horizontally, near the water's surface. However, with this vertical configuration, the kelp forms richer 3D habitat while also providing more surface area and complexity for waves to move through. In aggregate, these kelp lines form a constructed kelp forest which provides habitat, diffuses wave energy and deacidifies a halo of seawater in its vicinity, increasing survival rates for nearby shellfish larvae and pteropods.



SUBTIDAL zone, -6 and deeper

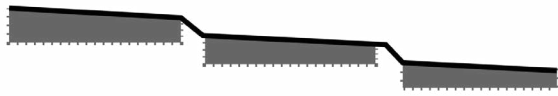


photo by : Mary Morris

**above:** This thousand-year-old tidal terrace or (clam garden) is one of many hundreds constructed in the Broughton Archipelago at the northeast end of Vancouver Island.

Coastal First Nations people used cobbles and boulders to construct the terrace walls, locating sandy substrate at the optimal elevation for enhancing clam productivity.<sup>1</sup>

<sup>1</sup> Christina M. Neudorf et al., "Between a Rock and a Soft Place: Using Optical Ages to Date Ancient Clam Gardens on the Pacific Northwest," PLoS ONE 12, no. 2 (2017): 1



**TIDAL TERRACING**  
 sediment retention  
 habitat formation



TIDAL TERRACES are composed of low walls that retain sediment. First Nations people have modified the coastline of British Columbia for thousands of years, constructing "clam gardens"-tidal terraces optimized for clam productivity.<sup>1</sup> In an armored waterfront condition, a tidal terrace offers a means for expanding gently sloping sediments in conditions where upland fill and subtidal grade-breaks create limited space for more conventional beach restoration. The terraces offer opportunity to cultivate and naturalize shellfish and eelgrass. In the mid to upper intertidal, the terraces also offer critical habitat for surf smelt to spawn. The cobble walls offer valuable habitat for seaweeds to attach to and, at lower elevations, for octopi to occupy.

<sup>1</sup> Christina M. Neudorf et al., "Between a Rock and a Soft Place: Using Optical Ages to Date Ancient Clam Gardens on the Pacific Northwest," PLoS ONE 12, no. 2 (2017): 1, <https://doi.org/10.1371/journal.pone.0171775>.

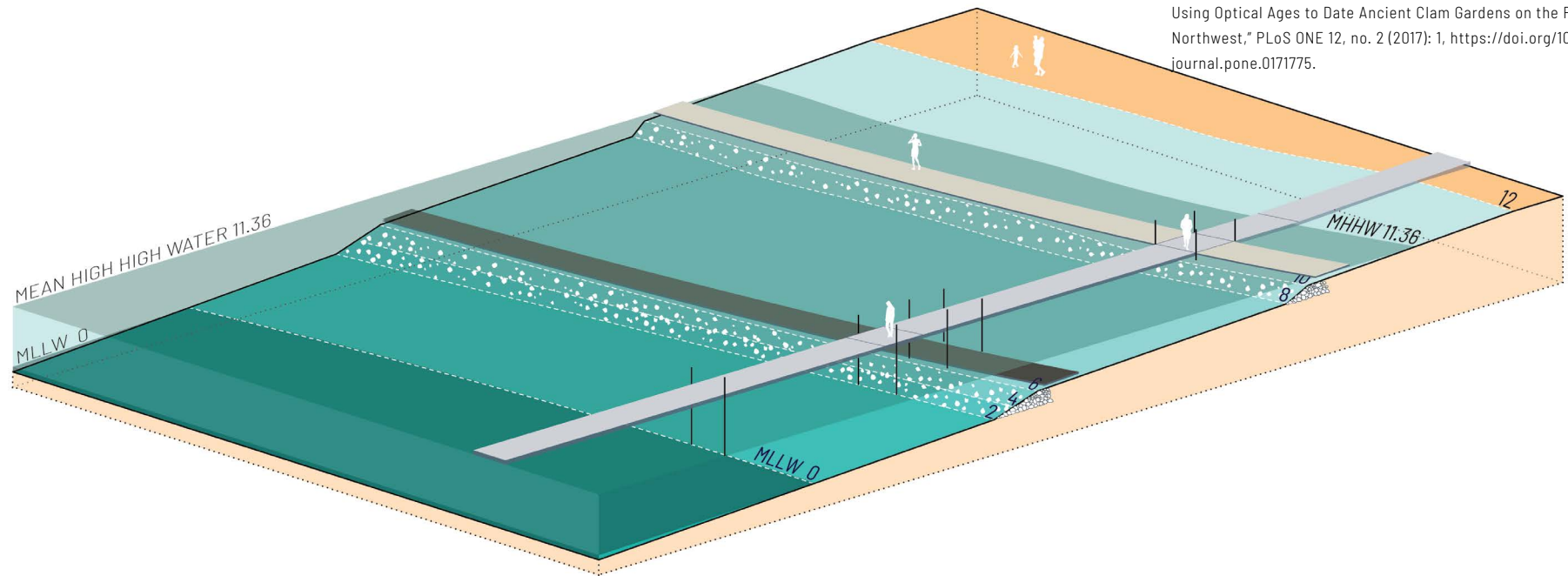
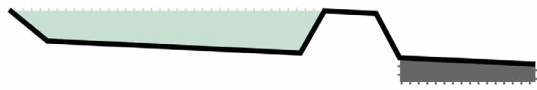




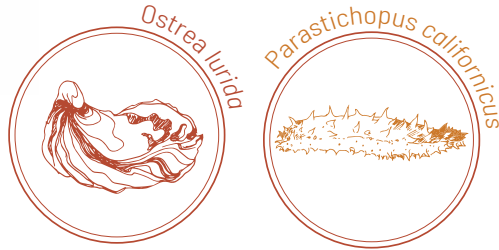
photo by : **Matthew Gray** (CC BY-SA 2.0)

**above:** Olympia oysters clump and cluster onto clutch. They prefer gravelly flats as substrate.



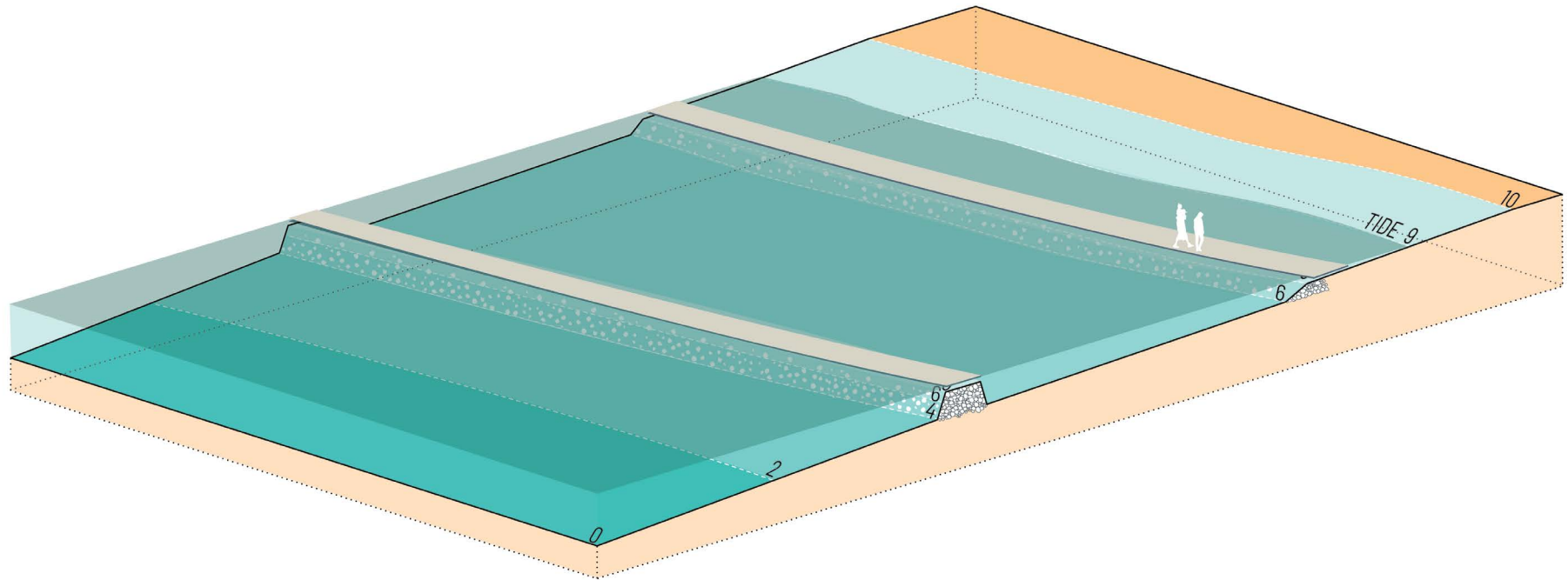
## DIKE + OYSTER POND

seawater retention  
habitat formation



A DIKE made of cobbles and oyster shells (clutch) supports a brackish pond for Olympia Oyster and sea cucumber cultivation. At high tide, seawater flushes into the depression behind the dike, and at low tide, the pond remain inundated. As Olympia Oysters prefer brackish water, the pond can be positioned downslope of a freshwater seep.

An expanded steel walkway attaches to the top the terrace walls and dike, allowing access to the brackish pond's perimeter when the tide recedes below the path surface. A floating walkway, running perpendicular to the shoreline spans the oyster pond, allowing visitors the opportunity to walk across the pond and peer down at the oysters, sea cucumbers, and juvenile fish swimming below.





HARSHER FUNCTION FOREST

TOTEM POLE

WATERWALLS



FLOOD TANKS = OYSTER GARDENS

WATER WALLS DISTRIBUTE WATER TO BEHIND THE PRODUCTION AREA, WHILE PROVIDING HABITAT FOR COMMUNITY ORGANISMS AND COLONIAL BIRDS AND LEARNING ABOUT MARINE ORGANISMS.

EPYTHOGRAPHS

HERON ROOKERY

CONCRETE UNITS



ONE EASTERN OYSTER (CRASSOSTREA VIRGINICA) FILTERS 25 GALLONS OF WATER A DAY. OYSTER REEFS ACCUMULATE INTO GROWING ADAPTIVE COASTAL STRUCTURES THAT CAN BE HARNESSSED FOR RESILIENCY AND GROWN TO ADAPT TO SEA-LEVEL RISE.



CONSTRUCTED TIDEPOOLS PROVIDE SHELTERED SPACES FOR SMALLER INVERTEBRATES AND BRIBURE FISH TO THRIVE. PLACED IN THE INTERSTICES, WATER IS FILTERED THROUGH THE BOTTOM OF THE STRUCTURE.

FISH SPAWNING HABITAT

OYSTERCATCHERS

SOUTHERN SEA TURTLE

Image by : SCAPE Studio

## CASE STUDIES

*How is aquaculture is being operationalized in proposals for the urban waterfront?*

There are few speculative or proposed projects that engage mariculture as an urban ecological strategy, and those that do rarely go beyond indicating on their plans the intention of cultivating shellfish or algae in a given location. Several projects do, however, explore this strategy in greater depth and dare to employ this system as infrastructure and design tool, venturing beyond just specifying it as a bullet point item on a solutions list. In their design proposals **Oyster-Tecture and Living Breakwaters**, SCAPE Studio advocates the use of oyster cultivation as a remediation and wave attenuation infrastructure. Guy Nordenson & Associates' speculative design "**On the Water: Palisade Bay**" proposes a range of soft infrastructures as a risk mitigation strategy; among them oyster cultivation beds and algae cultivation for biofuel feature a secondary though supportive role. At **Remediation Site 1** Interstice Architects proposes an award-winning redesign of a defunct coastal military site into a public aquaculture park, cultivating oysters, eelgrass and other aquatic organisms in order to stock regional restoration efforts.

Michael Ezban's speculative projects **Working Water and Aqueous Ecologies** both evidence more than a superficial understanding of aquacultural systems and methods, engaging boldly with the operational aspects of freshwater and marine aquaculture, linking these practices with productive landscape theory, landscape infrastructure and systems thinking. I will describe and analyze each project in greater detail in the subsequent sections.

**opposite page:** Adapting a rip-rap reinforced shoreline, SCAPE proposed using EConcrete blocks that function as tidepools at low tide.

## *Oyster-Tecture*

Commissioned by the Museum of Modern Art for the Rising Currents exhibition in 2010, this project envisions a physical and metaphorical armature for shellfish mariculture that SCAPE conceptualizes as an evolving expression of a socio-ecological system. This infrastructure reshapes and re-purposes the landscape of the Gowanus waterfront and canal, proposing the siting of nurseries/hatcheries along the canal, “flupsy” floats in the canal and an oyster cultivation reef in the harbor. The design is predicated on a heightened value for cohabitation, or the capacity of “people and animals to co-exist and prosper on mutually beneficial terms”.<sup>1</sup> This project promotes a “pragmatic entanglement of industrial and ecological uses.”<sup>2</sup>

The aquacultural system consists of oysters and mollusks which are hatched along the Gowanus canal, incubated in flupsy floats situated within the canal, allowing for the acclimatization of the mollusk larvae before their relocation to the harbor, where they are seeded onto a grid

of polyethylene” fuzzy ropes” which are then attached onto old wharf piles. More specifically, the proposed design is made up of several interrelated parts:

**The heavily contaminated Gowanus Canal:** has long experienced significant nutrient pollution. This project leverages this concentration of organic nutrient to sustain oyster larvae (spat) which are raised on “flupsy” rafts, (floating upwelling system nursery rafts) on the canal edges. A flupsy path meanders through the raft system, accommodating public education and recreational use. When ready, the young oysters are then “seeded” onto a grid of fuzzy rope, where they are intended to thrive and aggregate, forming “wave-attenuating reef structures”.

**The Palisade Reef (stick-culture beds):** which consists of this grid of oyster-seeded fuzzy rope suspended on pylons within both subtidal and

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1 Kate Orff, *Toward an Urban Ecology* (New York, New York: Monacelli Press, 2016), 86.

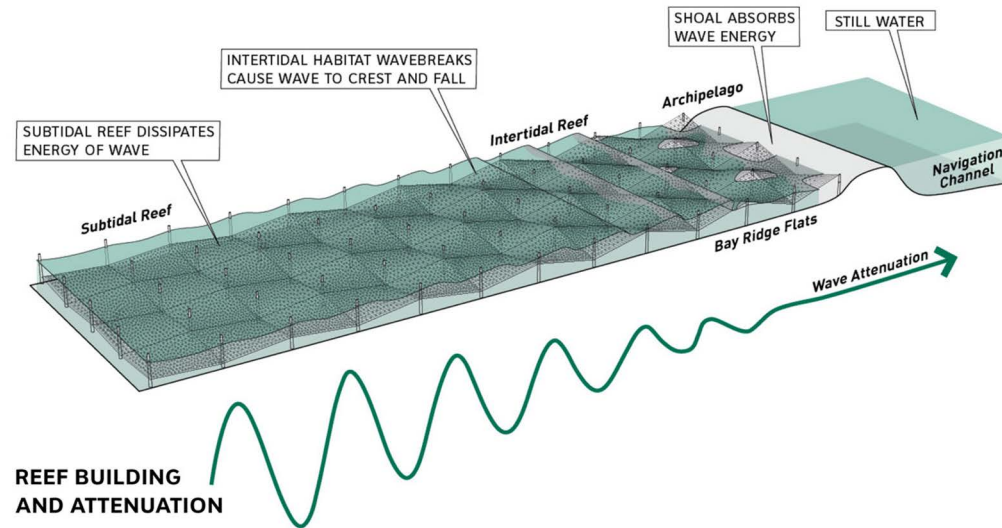
2 Ariane Lourie Harrison, “Animal Interfaces for a Post-Human Territory,” in *ACSA 101: New Constellations New Ecologies*, ed. Ila Berman and Edward Mitchell (ACSA Press, 2013), 361.

intertidal areas. It emerges at low-tide forming a new aquatic public space within the harbor. The life cycle unique to oysters sets them up as “ecosystem engineers” which, given accommodating conditions, means they will continue to multiply, accreting onto older shells, ultimately forming a reef that diffuses wave energy and creates habitat islands for birds and aquatic species, all while allowing people to observe and experience these places in a variety of ways, from a variety of vantage points. Scape envisions this reef as navigable by kayak.

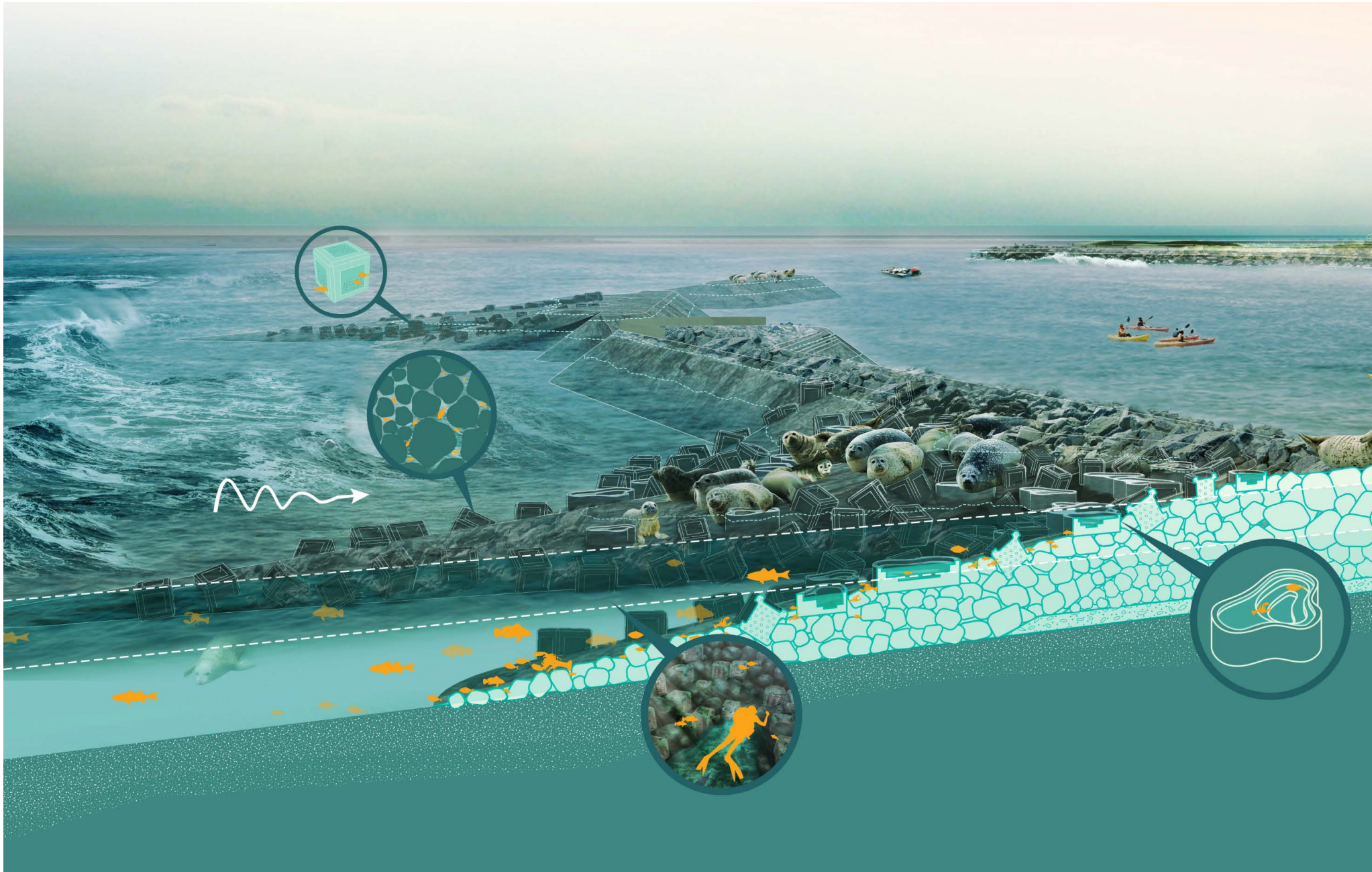
Across the **reef island network**, human visitors are accommodated with slips, boat anchor poles, BBQs, diving platforms, and “amphibious trails” which form a new park typology. This is envisioned as a jointly working and recreational landscape.

The reef grows and as sea level rises, the intertidal and subtidal zones creep up as the shellfish and associated biotic communities shift to adapt. SCAPE posits that the strategic insertion of a substrate that supports the re-culturing of the native Eastern Oyster, *Crassostrea virginica*, will help create a rich, three-dimensional mosaic landscape, both in the harbor and along the inland shores. The actual success of the oysters would depend in part on whether or not the harbor water acidifies to a pH that prevents naturalized oyster larvae from surviving, a condition that Scape does not explicitly address in their design.<sup>3</sup> The proposal eloquently advocates an oyster aquaculture strategy for enlivening the Gowanus canal and a design for a constructed Palisades Reef which aims to mitigate storm surges, and offer water-based recreation.

<sup>3</sup> Kristy J. Kroeker et al., “Impacts of Ocean Acidification on Marine Organisms: Quantifying Sensitivities and Interaction with Warming,” *Global Change Biology* 19, no. 6 (2013): 1884–96, <https://doi.org/10.1111/gcb.12179>.



**right:** A undulating constructed oyster reef dissipates waves approaching the shoreline and functions as wave attenuating and water cleansing infrastructure.



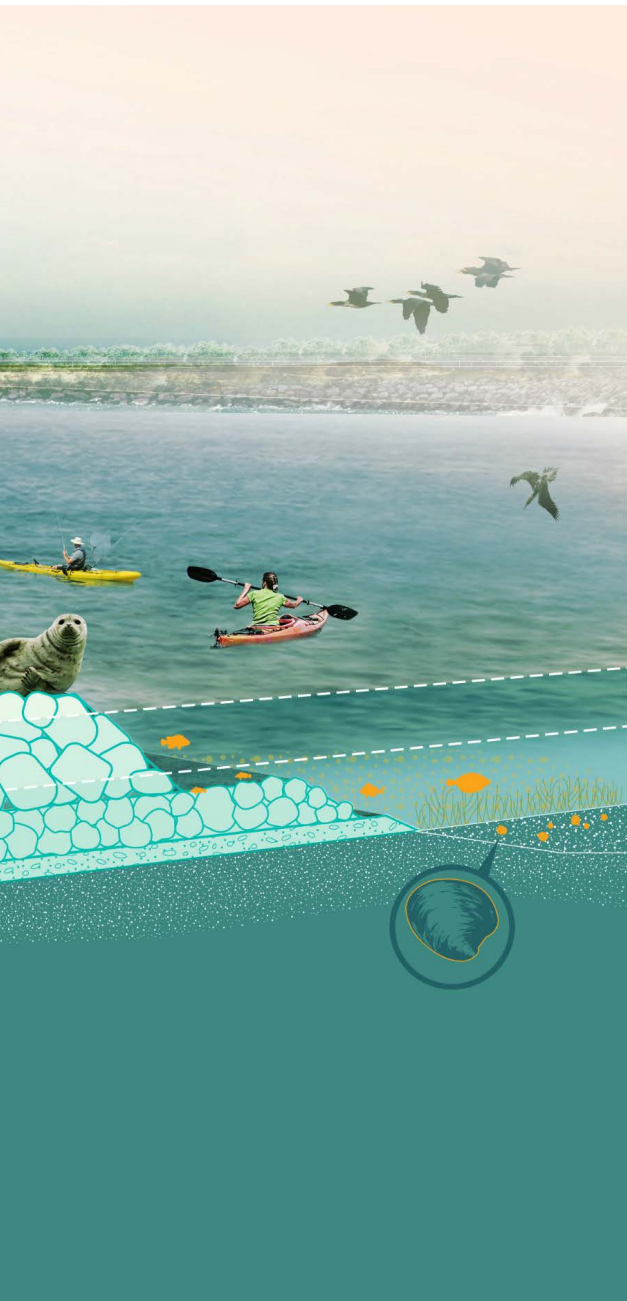


Image by : SCAPE Studio

## Living Breakwaters

Officially adopted by the US Department of Housing and Urban Development, this conceptual design uses an array of thoughtfully detailed breakwaters to form a framework for habitat development, flood protection and social resilience, with the longer term intent of instigating new shoreline cultures, economies and ecologies.<sup>4</sup> Living Breakwaters is the product of an interdisciplinary collaboration led by SCAPE with the larger objectives of reducing risk, reviving ecologies and connecting educators to the shoreline.<sup>5</sup> “Living Breakwaters fits in with a vision of a New York Harbor repopulated with oysters... the project helps put the right substrate in the right places with the right texture and materiality, integrating that into larger-scale planning initiatives—this project puts in 13,000 linear feet of reef.”<sup>6</sup>

In attempting to mitigate risk associated with storms, floods and sea-level rise, the project approach embraces layered functionality,

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- 4 Orff, *Toward an Urban Ecology*, 237.  
5 Orff, 237.  
6 Orff, 131.

moving beyond single-use flood infrastructure and encouraging water access, interaction and shoreline regeneration. The project team also leverages scalable strategies, anticipating how a block within the breakwater might create valuable substrate, how the physical form of the breakwater can create a range of habitats, how the breakwater impacts sedimentation as it moves closer to shore and how the system of breakwaters works together in a storm event. For example, rather than proposing linear breakwaters, the team designed them with deep undulations, forming “reef streets” where multiple forms of aquatic life prefer to gather: finfish, lobsters, shellfish. Meanwhile, juvenile fish can find shelter in the crevices of the EConcrete blocks that make up the breakwater. The breakwaters provide habitat through the entire water column, from subtidal zone to the surface where seals and seabirds are likely to gather. Eelgrass and clams can occupy the sedimented zones that will form in the leeward side of the

**above:** Scape's Living Breakwaters project uses pre-cast concrete units that improve the quality of habitat that breakwaters can provide, while also making space for experimental oyster culture prototypes.

breakwater. The EConcrete blocks are seeded with oyster spat in hope that this will catalyze oyster reef development over time. The growth of oysters on these blocks will form calcium carbonate deposits over their surface, eventually encasing the blocks and extending their lifespan.

Across the project, oyster aquaculture is taking place through the use of several techniques:

- 1) “**Spat on Disk**” where spat are seeded onto disks which are placed onto EConcrete units
- 2) “**Subtidal Oyster Gabions**” which contain shells seeded with oyster spat and are located at the base of the breakwaters
- 3) “**Spat Sanctuary**” a more traditional oyster cultivation technique which places spat and shells in cages suspended by floating buoys in the near-shore water column
- 4) “**Tank-less Setting**” where spat are released into containment nets anchored on the windward side of the breakwaters.

The diversity of aquaculture techniques meets the different performative roles that oysters play in the project: some are part of the infrastructure, building up the reef by growing directly on the breakwaters, others are readily accessible for harvest, all techniques serve as pilot and demonstration projects. The design of Living Breakwaters is integrated with the intention of gathering information from every aspect of this

project- the aquaculture system is experimental and flexible: if one technique fails, others might flourish, meanwhile a new approach can be developed and deployed.

The entirety of this effort is linked to a robust educational campaign: through collaboration with school groups, the Billion Oyster Project which is as much an aquaculture and restoration project as an education program, hosts classes and workshops engaging the local community and especially children in the operations taking place within the hatchery and out in the field. As a part of the conceptual design for this project, the project team created an Oyster Gardening Manual that has been widely disseminated within the community and region. The design proposal also prominently features plans for a network of outdoor educational spaces called “water hubs” that facilitate outdoor learning for school groups and double as community meeting spaces.

The Living Breakwaters design proposal leverages the potential for a rather conventional “hard” infrastructure to host a rich and complex ecology and to strategically instigate desirable sedimentation processes while acting as a porous storm-surge defense. The breakwaters have the potential to accommodate and support the design team’s goal of cohabitation as they are paired with an environmental education strategy and recreational programming. Here too, the designer uses aquaculture and the living agents within that system to help aggregate a sense of place for the surrounding community.

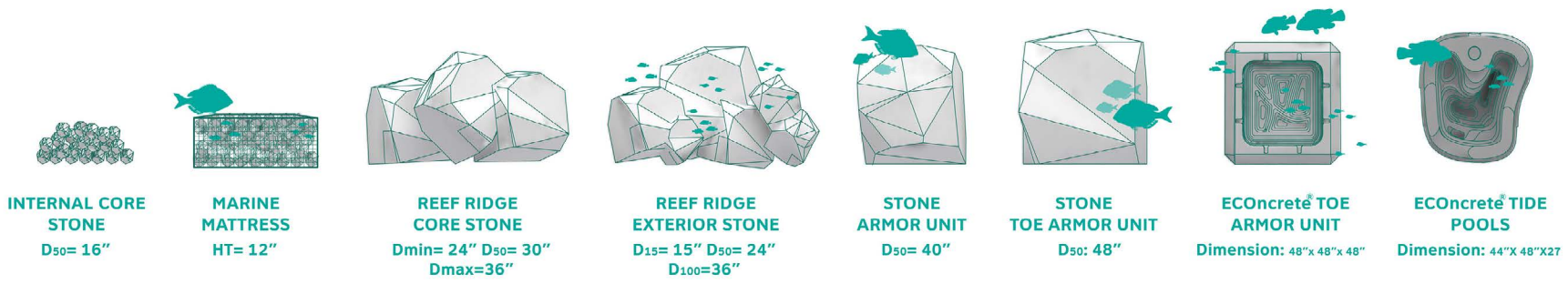
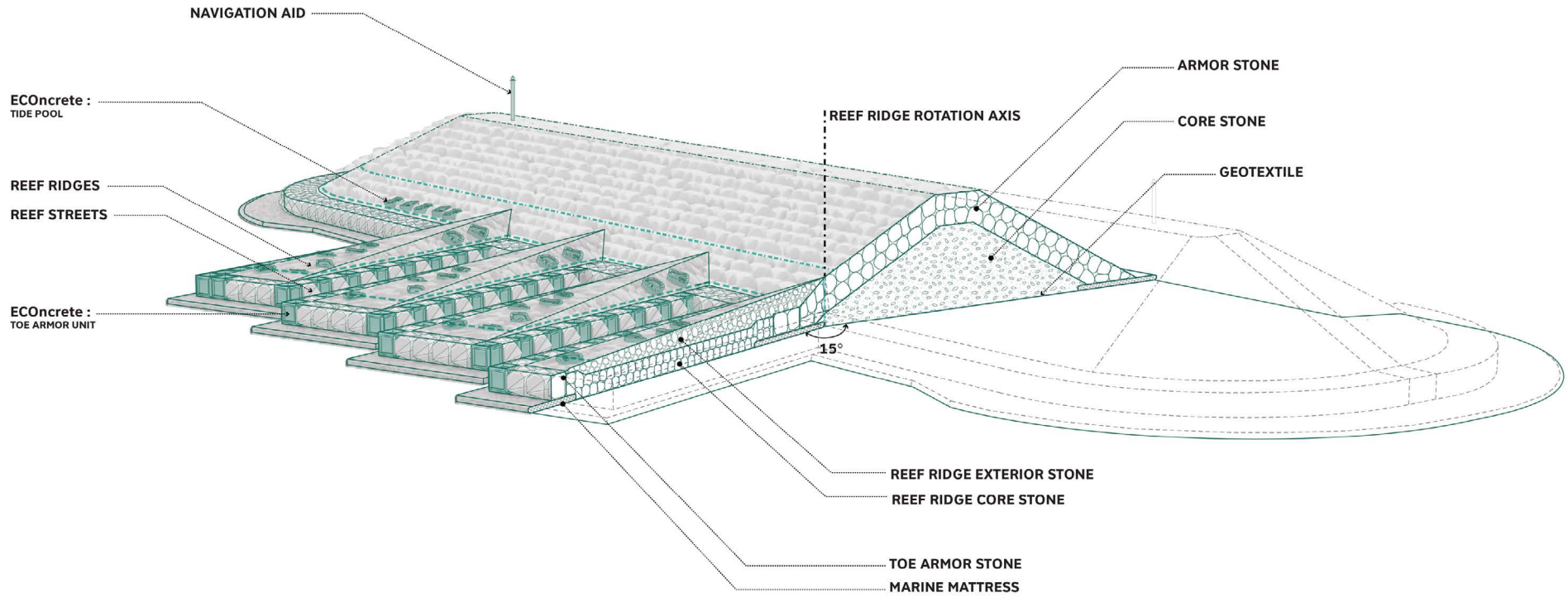


image by : SCAPE Studio

**above:** Because the aquaculture system is used for wave mitigation, food production and habitat regeneration, it involves and attracts many different kinds of users and can consequently gain enough prominence to afford a unique sense of identity to the place it occupies and creates.

## *On the Water: Palisade Bay*

Another entry for MoMA's 2010 Rising Currents competition, the interdisciplinary design team, headed by Guy Nordenson & Associates, proposes a speculative design with a range of soft infrastructures as a risk mitigation strategy for New York City. This response envisions the City choosing to cooperate with the sea rather than attempt to banish it, proposing a more reciprocal relationship with the adjacent waterbody, with infrastructures that aim at enhancing habitat and ecological function while also protecting the adjacent city from the impact of future storm surges. Among the strategies proposed, oyster and algae cultivation as discrete interventions feature a relatively minor role. The project is however, worth examining for the extremely thorough hydraulic analysis it undertook in order to more fully comprehend the complexity of the project site and the potential impacts that re-grading the bay might have.

On the Water's design proposal is centered around

the concept of "soft infrastructure" which positions their interventions as more than a defense system, as places for recreation, agriculture, and urban development. The design team adopts an operational mode of design, declaring "we insert our project within the current space of the harbor as a series of conditions which will be enveloped into the larger and uncertain processes of ecological transformation," acknowledging the indeterminate nature of any operational strategy situated in a condition as variable as a marine waterbody undergoing transformation as a result of climate change.<sup>7</sup> Consequently, their exploration and discussion of the project's context emphasizes its porosity and fluidity. The design framework adopted eschews any single solution to storm-surge, sea-level rise and flooding that seems large and monolithic: a flood barrier for example. Instead, they propose an array of soft infrastructure interventions asserting that these would make for a more resilient response.

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Guy Nordenson, Catherine Seavitt, and Adam Yarinsky, *On the Water: Palisade Bay*, ed. Hatje Cantz, 1st ed. (New York, New York: Museum of Modern Art, 2010), 22.

The project can be described as having three spatial strategies:

1) **“On the Water”** Constructing an archipelago of islands and reefs along the shallow shoals of the New York–New Jersey Upper Bay to dampen powerful storm currents as well as encourage the development of new estuarine habitats.

2) **“On the Coast”** Revitalizing the waterfront by designing a broad, porous, “fingered” coastline which combines tidal marshes, parks, piers and slips for recreation and community development.

3) **“In the Communities”** Enacting zoning that adapts and re-distributes land uses in order to increase community resilience to future natural disasters.

The deep channels slated to be re-dredged remain clear to accommodate boat traffic. The edges however remain relatively shallow and flat. In keeping with the design strategy for the coast and tidelands, the shallows are “Roughened” through the addition of artificial islands which can slow storm surge energy. The coastal and water strategy is composed of wetlands, piers and slips, and islands. The more singular and small-scale interventions include oyster beds and offshore windmills which are used more to generate habitat and a sense of place.

Constructed wetlands filter and are positioned around combined sewer outfalls. Piers and slips

building into the coastline slow water and allow for siltation beneath. These are described as a feathered edge, a fringe of piers. The piers dampen wave action and the slips intercept and infiltrate stormwater runoff. Detached piers positioned perpendicular to wave action are intended to diminish wave velocities: in shape and size they recall a New York City block and their scaffolds emerging from the water are envisioned as a novel form of bird habitat. Constructed islands are arrayed extensively to form an archipelago with the shallower, smaller islands forming reefs. The proposal conceptualizes these as a “porous land infill”.

Oyster aquaculture is used primarily for habitat enhancement in areas where salt marsh is being restored through regrading of the intertidal zone and planting with a mix of two native species: *Spartina patens* and *Spartina alterniflora*, also forming habitat for opportunistic mollusks and crustaceans. The native eastern oyster, *Crassostrea virginica*, is cultivated on a grid of oyster racks within the constructed salt marsh. The beds are anticipated to grow, agglomerate and eventually form reef habitat for worms, shrimp, crustaceans and fish.

The algae aquaculture component of the proposal seems quite vague and underdeveloped compared to other aspects that have been more thoroughly thought-through. The algae is proposed to be a non-native species, though it is not clear whether the proposal is for micro or macro algae, and is intended to generate material for the production of biofuel. Given further investigation and design, the team may have arrived at a proposal that advocates the cultivation of *Saccharina latissima*, Sugar Kelp, which is native to New England, and actively cultivated both commercially and for research purposes. Like the oyster, it forms 3-D habitat for aquatic creatures and is the preferred macro-algae for biofuel-oriented aquaculture.

The project's most significant strategy towards climate-change "risk-reduction" is the construction of islands and breakwater piers and towers in the water. Consequently, the team's strongest interventions are additive strategies, not partnerships with other species or organisms. In looking to this project as a model or case study for work within the Puget Sound, it is important

to recognize that because of the significant role that piers and overwater structures play in this proposal, similar strategies in Puget Sound would not gain traction as they would likely form habitat for species that prey on juvenile salmon, a species of primary concern for the Sound.

Though the proposal starts with a remarkably robust analysis of climate change related risk and hydraulic impacts of island formation, it does not pay an equal degree of attention to the living systems it proposes to employ. And though it identifies six zones of intervention in Palisade Bay, only the design for zone 0- Lower Manhattan, is elaborated. The aquacultural aspects of their strategy are located in zones 2 and 4 which are described and represented relatively abstractly and diagrammatically on the overall site plan. All in all, this proposal is stronger in its hydrodynamic analysis and porous infill strategy than at a detail level or in its ecological dimension.

**right:** On the Water: Palisade Bay took on an extensive project site and divided soft infrastructure strategies into discrete zones.

Image by: Guy Nordenson and Associates

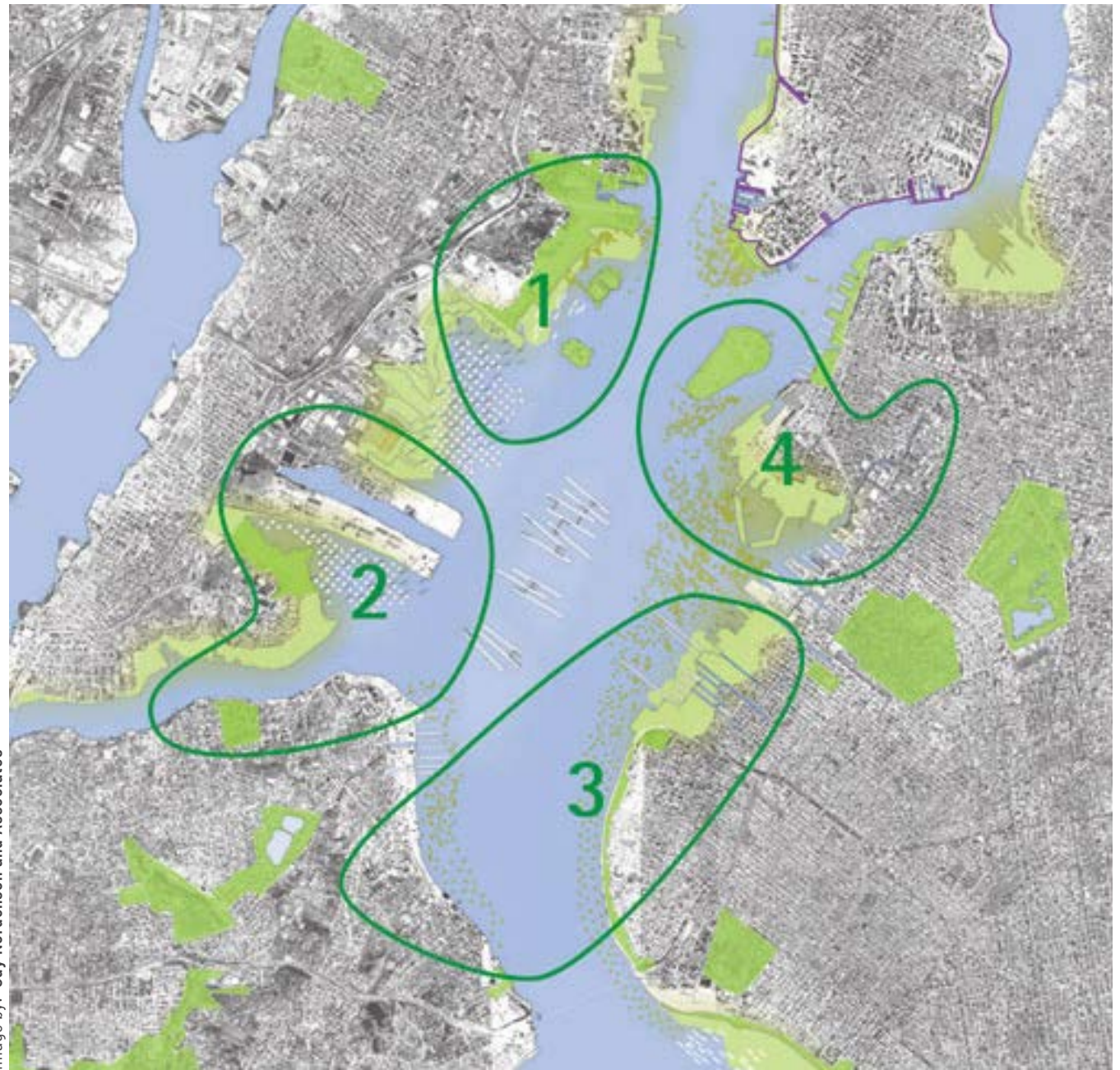




image by: Interstice Architects

## Bay Remediation Site 1

Bay Remediation Site 1 is Interstice Architect's entry for a 2009 ideas competition held by the California Architectural Foundation. Sited at an old waterfront military site currently comprised of a narrow parking lot and a seawall at Horseshoe Cove in Sausalito, the proposal centers around "a forgiving infrastructure" that replaces the old seawall with an expansion of the littoral zone, reestablishing tidal wetlands that function as a "native species production bed" and cultivating native eelgrass that can be transplanted to restoration sites across the bay.<sup>8</sup>

8 Lee, Lydia. Sea change: Interstice Architects pushes a new kind of aquaculture. *Landscape Architecture*, 102(7), 2012, 38.

9 Lee, 41.

The design features a carefully orchestrated array of maricultural zones: "Olympia Oyster filter", "eelgrass littoral habitat", Delta Smelt breeding grounds, "oyster fences", "seeding Buoy array", and breakwater habitat "islands".<sup>9</sup> The design is centered around the idea of a public aquaculture park, a compelling vision of a public nursery of species to be bred, cultivated and transplanted to other restoration sites around the San Francisco estuary. This is a site that can function as a center for ecological tourism and public education while also performing as an aquaculture operation and forming a rich habitat for wild species.



**left:** Interstice Architects' aquacultural park's form takes inspiration from mid-western agricultural landscapes. Circular microalgae and eelgrass plots form a mosaic throughout the project site.

**right:** The aquacultural operation centers around eelgrass cultivation and propagation operations, ultimately contributing to the restoration and enhancement of other coastal sites around the San Francisco Bay Area.

## *Aqueous Ecologies: Parametric Aquaculture and Urbanism*

Sited at Willets Point, an underutilized peninsula in Queens, NYC, Michael Ezban's speculative project features integrated multi-trophic aquaculture as a core strategy for wastewater treatment while simultaneously functioning as an island-building infrastructure, forming rich intertidal ecology where it had previously been lacking. This design proposal was developed by Michael Ezban in a Masters landscape architecture studio at the Harvard Graduate School of Design, led by Chris Reed. The design project promotes the role of this aquacultural landscape as a catalyst for new cultural identities in what was previously a leftover space surrounded by a tangle of elevated roadways.

The IMTA component of the design is composed of fish, mussels, sea cucumbers and seaweed. This mix of agents is highly typical of IMTA project species composition in the Northern Hemisphere. Interestingly, in Ezban's design, the IMTA infrastructure is expressed as a physical armature

made up of concrete groins, a conventional form of shoreline armoring that initiates sedimentation where it might not otherwise have occurred.<sup>10</sup> In this proposal, the concrete groins serve multiple functions: performing as substrate for kelp cultivation and harvest, while simultaneously building up habitat islands as sediment accretes along their length. The IMTA system also generates food by ostensibly producing edible fish, sea cucumbers and mussels while treating storm water and grey water from anticipated urban development upslope. Because stormwater often carries heavy metals and other toxic pollutants in addition to nutrient runoff, the edibility of the fish, mussels, sea cucumbers and seaweeds will depend on their capacity for bio-accumulating toxic pollutants.<sup>11</sup> Other harvestable and marketable products generated by the IMTA system could include kelp-based fertilizer and pharmaceuticals.

The aquacultural system Ezban proposes is not just

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10 Jack Cox, et al. *Engineering and Geotechnical Techniques for Shoreline Erosion Management in Puget Sound*. Coastal Erosion Management Studies Volume 4. Shorelands and Water Resources Program, Washington Department of Ecology, Olympia. Publication 94-77, 1994.

11 La Kenya Evans and Matthew S. Edwards, "Bioaccumulation of Copper and Zinc by the Giant Kelp *Macrocystis Pyrifera*," *Algae* 26, no. 3 (2011): 265-75.

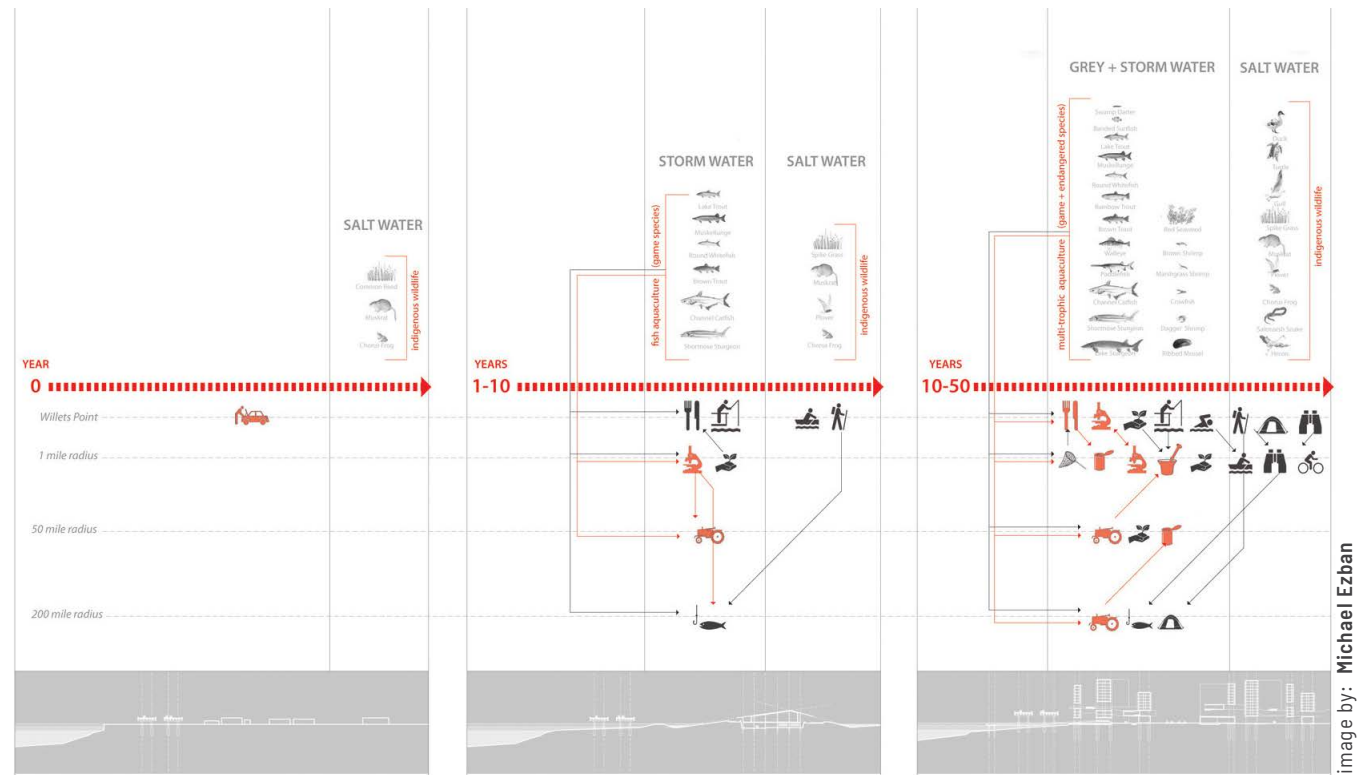


image by: Michael Ezban

**right:** Ezban traces the incremental expansion of aquaculture operations on the site over time in tandem with the "reach" that aquaculture products and uses might have within the landscape.

highly functional in the agricultural or remediative sense, it is also publicly accessible, through a network of boardwalks which allow for immersive experience in a hybrid coastal landscape. Aqueous Ecologies proposes an intertidal landscape that is highly constructed but that catalyzes processes that become self-perpetuating; as sediment accumulates around the concrete groins, seaweed, mussels and oysters reseed and spread and opportunistic plants, protists and animals colonize the new habitat. These novel ecologies deliberately configured into forms unmistakable for "natural," have the potential to draw visitors' attention

and to help communicate the story of intertidal ecological relationships, their role in filtering water, buffering wave energy and their broad value to human society. Reaching beyond the productive and ecological capabilities of this system, Ezban highlights the potential of such a landscape to foster local cultural identity and to bolster local economies as the city grows.

## *Working Water: the Productive Tailwater Fishery as Landscape Architecture*

While this project is focused on promoting a vision for a freshwater aquaculture landscape, it offers some valuable precedent for any aquacultural landscape design project that fits the time scale and scope of a master's thesis. Michael Ezban developed this design proposal over the course of a three-month artist in residency program at the Isabella Stewart Gardner Museum, with the help of his advisors: Anita Berrizbeitia, Alan Berger, Julia Czerniak, Teresa Gali-Izard, Charles Waldheim and Richard Weller. His book *Working Water*, starts by examining the “calculated fabrication” that is the Swift River tail-water trout fishery and landscape. This highly regulated and modified river (tailwater) forms the ideal habitat for a stocked recreational trout fishery. The fishery is itself a product of aquaculture as the trout originate in a hatchery. Ezban inventories a range of aquacultural operations along this river and throughout Massachusetts, however, he notes that they are most typically closed monocultural systems that produce exotic species. Ezban terms these

operations “warehouse aquaculture” and critiques them as unsustainable ecosystems divorced from both their native and their adopted environment on the river while also remaining hidden from the public.

His larger critique is of agricultural or productive operations that are disparate, fragmented monocultures, “broken out of local ecologies” and failing to offer “diverse public experience.”<sup>12</sup> Situating himself within the theoretical framework of productive landscape design, he aims his proposal towards a more synergistic condition between agriculture, waste management, recreation and biodiversity. By proposing an alternative, more embedded and integrated form of aquaculture landscape, he strives towards a greater legibility for humans and a more “congruous system of cultivation, sport and conservation.”<sup>13</sup>

The resulting project is a design proposal for an aquaculture landscape heavily informed by Miguel

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12 Michael Ezban, *Working Water* (Isabella Stewart Gardner Museum, 2015), 18, [https://issuu.com/gardnermuseum/docs/workingwater\\_final](https://issuu.com/gardnermuseum/docs/workingwater_final).

13 Ezban, 18.

Medialdea's brand of ecological aquaculture as manifested at Veta la Palma in Spain. It capitalizes on the river's existing recreational fishing use and intensifies its productive capacity through an aquaponic landscape system: a combination of facilities that include a fish hatchery, agricultural greenhouses, constructed wetlands and a tailwater optimized for angling and other recreational uses. The "productive" layer of the design is completely public and clusters along a relatively short stretch of tailwater emerging from its artificial headwaters at the base of the dam and includes a hatchery paired with a greenhouse and constructed wetlands for the purification and recirculation of water within the system. An interpretive walking trail and bike path weave through the tailwater landscape, linking the Pump House marketplace at the base of the dam, to the aquaponic system, and ultimately to an angling camp that features boat access, camp grounds and other recreational facilities.

Ezban's design for the Swift River tailwater is predicated on progressive public/private partnerships which generate a possible synergy between cultivation, recreation, conservation and waste management. He makes use of numerous metabolic synergy maps which contrast "conventional aquaponic" systems with "aquaponic landscapes". He also uses parametric modeling to generate numerous permutations of aquacultural intensity at this site as well as seasonal intensity graphs that identify when different facets of the designed system are most active. Working Waters offers a compelling vision of how the infrastructures supporting our engineered waterways can be designed and perceived as landscapes and how a more public and ecological form of aquaculture infrastructure can contribute to ecotourism and recreation as well as a more honest representation of the nature of a place. Though several of the above case studies utilize

**right:** Ezban's Working Water project proposes a contained aquaculture system that takes is open to the public and serves to make a visual and spatial connection between the tailwater landscape and the aquacultural operations that help define it.



image by: Michael Ezban

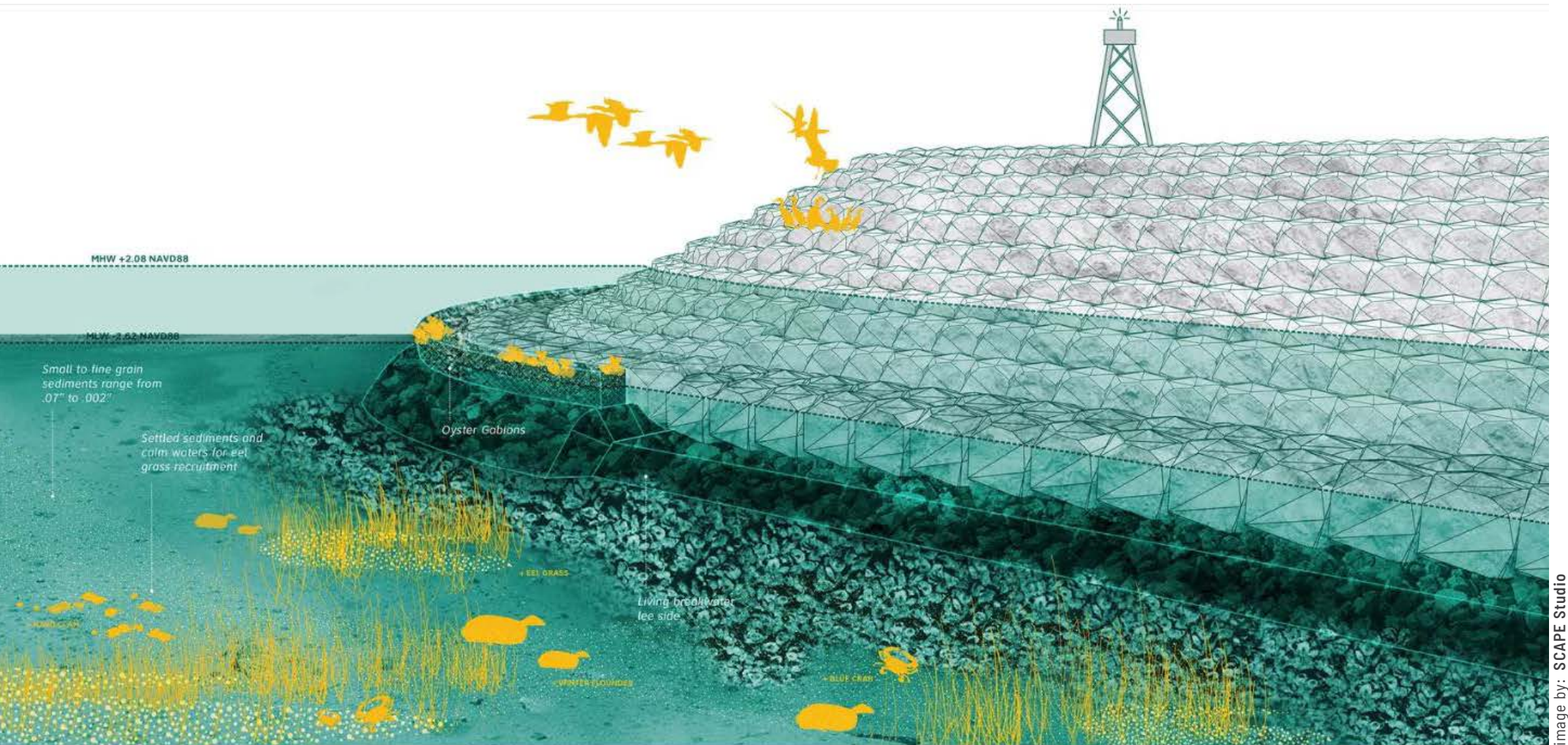


image by: SCAPE Studio



## *Reflection*

aquaculture as a form of “ecological infrastructure”, only Ezban’s proposals take advantage of the possibilities offered by an integrated multi-trophic aquaculture system. And while Ezban engages with the potential of an IMTA system as a form of urban and ecological armature, he does not adequately discuss or explore the potential engagement of the system with surrounding communities, nor the systems’ impacts on the existing ecology of the site. The concept of a pragmatic entanglement of infrastructural and ecological uses as represented in Interstice Architects’ competition entry is particularly relevant to me. Within a multi-trophic maricultural waterfront, bioextractive seaweeds

cultivated for biofuel generation could create hospitable aquatic environments for the culturing and propagation of shellfish, which in turn help clean water and accrete sediments, forming habitat for smelt and other small fish which support salmon, an important food source for orca. Such an overlay of program and performance could manifest an integrated and productive entanglement of ecology and infrastructure.

**left:** The Living Breakwaters project adapts conventional shoreline armoring infrastructure with thoughtful detailing and experimental remediative aquaculture. The proposed breakwaters incorporate “oyster gabions”, coupling hard infrastructure with mariculture in a creative approach to coastal restoration.



photo by : Tatyana Vashchenko

## SITE + PARAMETERS

Given the nature of a maricultural design intervention at the threshold between land and water, several design considerations emerged as particularly critical for understanding how maricultural system might impact this site and how this site's dynamics might impact the maricultural system.

Though integrated multi-trophic mariculture as it is being designed and deployed today typically takes shape as floating cultivation systems located beyond the intertidal zone, a public urban intertidal multi-trophic mariculture system would necessarily be reconfigured to suit a different set of conditions and parameters. Within this thesis, I conceptualize intertidal multi-trophic mariculture as a living infrastructure that can be reconfigured and repurposed to respond to complex site dynamics that function at multiple scales: sediment drift, seasonal wind and wave patterns, tidal fluctuation, and dramatically variable water quality, just to name a few. Meanwhile the spatial framework that the mariculture system provides could afford public access and engagement with intertidal habitat and novel biological communities.

In many locations around Puget Sound, the low-tide terrace extends several hundred feet beyond the ordinary high water mark (OHWM). However today, some of the most extensive tide-flats have either been buried in fill to form new land, or dredged to accommodate boat traffic. Areas of Seattle such as Pioneer Square, Interbay and portions of the Duwamish, though they may have once supported a rich intertidal ecology, are now heavily modified, hardened and extensively polluted. Though mariculture may serve a role in filtering pollutants and providing habitat on sites such as these, it must accompany a much more robust suite of cleanup and habitat enhancement measures in order to recover some of the ecological functions that have been eliminated over the past one hundred plus years and to support safe public use of these places. On the other hand, a coastal site without armoring, point source pollution or any serious ecosystem disruption taking place may also not be the optimal location for an urban intertidal IMTA system as I have conceptualized it. If deployed in such a location, it may potentially displace existing ecologically and culturally valuable functions.

**opposite page:** The majority of what used to be North Beach is currently buried. A rip-rap revetment has replaced the extant tidal gradient, a condensed and hardened intertidal edge taking its place.



photo by : Tatyana Vashchenko

For this thesis I operate under the assumption that to support integrated multi-trophic mariculture as an urban intertidal expansion and enhancement strategy, a waterfront site must:

- be situated within an urban context
- feature a gently sloping shoreform or the remnants of one
- be undergoing a trajectory of shoreline armoring
- be accessible to the public
- face water quality issues
- host a variety of programmatic uses
- offer potential for synergies between infrastructural operations, environmental education, recreational facilities and commercial uses

### ***SITE: North Beach, Discovery Park***

North Beach, located along Discovery Park's western limit fits all of these criteria, posing both interesting topographical challenges and numerous opportunities for synergy between recreational, educational and infrastructural function.

Discovery Park's westernmost boundary culminates at West Point, a "cusate foreland" shoreform built

up through the convergence of two sediment drift cells and the gradual merging of two sand spits. For thousands of years up until the 1960s, West Point contained a tidal lagoon that fluxed between rocky and sandy substrates, experiencing periods of sediment buildup, erosion and more abrupt seismic episodes resulting in subsidence and sediment-laden tsunamis.<sup>1</sup>

Across the Point's many states, it served as an important site for the harvest, processing, and preservation of shellfish, finfish, and other seafoods by the ancestral Duwamish, Muckleshoot, and Suquamish Tribes, who had named this place Pka'dz Elue, "thrust far out".<sup>2, 3</sup> With the arrival of Euro-Americans, this site experienced dramatic transformations of form and function in increasingly rapid succession. In 1911, the City of Seattle constructed a sewer line to discharge untreated wastewater from central Seattle to West Point. In the 1960's the Point's tidal lagoon was drained, filled and armored to protect the wastewater treatment plant that was built upon it.<sup>4</sup> Amid treatment plant upgrades in the 1980s, South Beach, which had been filled and armored to contain a sewage lagoon, was restored to a more naturally functioning state. Today, South Beach serves as one of Puget Sound's most successful examples of large-scale beach restoration through

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1 The Burke Museum of Natural History and Culture, "The Archaeology of West Point," The Burke Museum, 2003, <http://www.burkemuseum.org/static/west-point/>.

2 The Burke Museum of Natural History and Culture.

3 Hugh Shipman, "West Point, Seattle, Washington," Coastal Care, 2011, <http://coastalcare.org/2010/11/west-point-seattle-washington/>.

4 Hugh Shipman, "West Point November 12, 2009," Gravel Beach, 2009, <http://gravelbeach.blogspot.com/2009/11/west-point.html>.

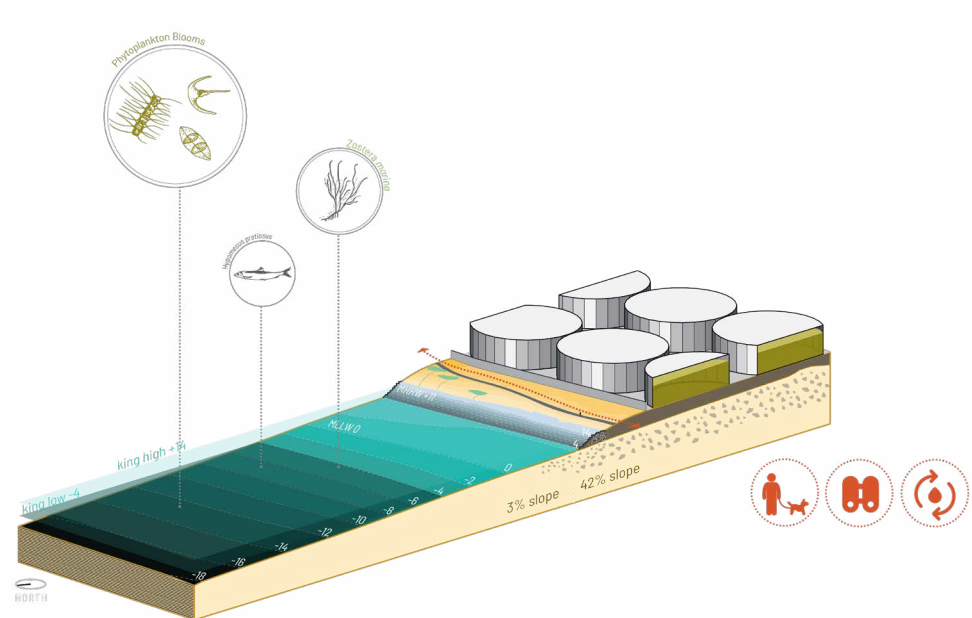
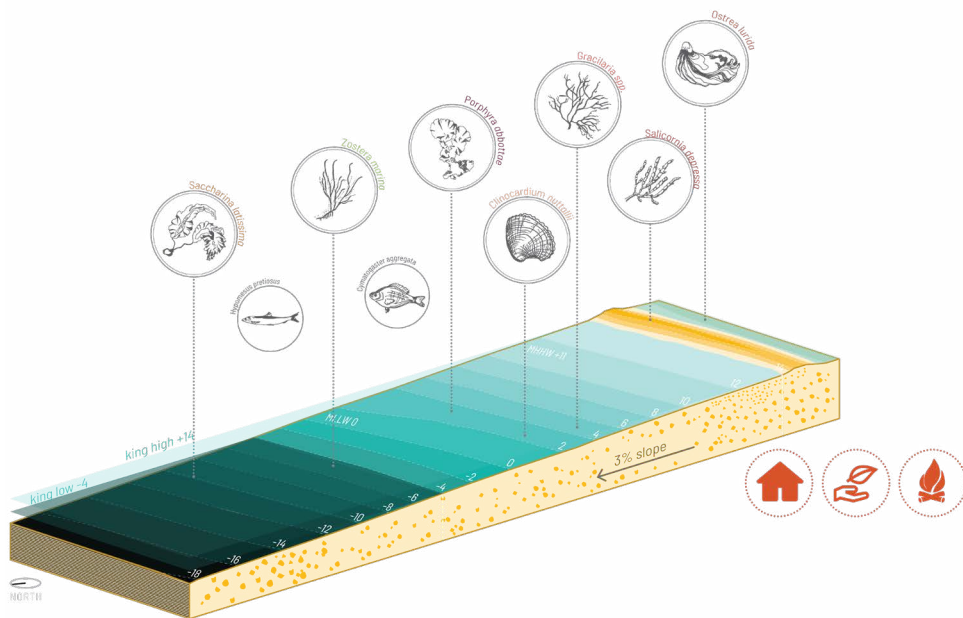
**opposite page:** The tip of West Point was formed through the convergence of two sediment drift cells.



Image by: Tatyana Vashchenko



NORTH



**above:** Today, more than half of North Beach's intertidal gradient is occupied by the West Point Treatment Plant, a rip-rap wall keeping the fill in place. For thousands of years this site served as a seasonal and year-round home to Coast Salish people, a source of seafood and a place to preserve clams for other seasons. In its filled and armored form, it no longer supports the vibrant ecology that once flourished here and instead features a recreational walking trail, a wastewater treatment plant and offers views of the Sound.

sediment nourishment and de-armoring.<sup>5</sup> West Point's North Beach, on the other hand, remains heavily armored almost continuously along its length. A large portion of this beach is buried and occupied by the West Point Wastewater Treatment Plant which spans the now extant tidal lagoon, sand bar and beach. Despite the fact that much of the historic beach is buried, North Beach extends out up to 400 feet at low tide and its subtidal terrace only narrows as it wraps around the Point. One quarter of its length has been nourished with sand to form a relatively short and steep stretch of beach near the tip of West Point while the rest of the site consists of gravel and in some areas, cobble, exposed through the scour of sediment from the base of rip-rap armoring.

North Beach, or rather, the asphalt trail running along the top of its armoring, is publicly accessible, though for obvious reasons, not quite as inviting for lingering as South Beach around the bend. Visitors to this beach have the option of moving along the trail, lined on one side by concrete walls and a humming wastewater treatment plant, on the other by rip-rap revetments. At low tide, it is possible to wander out onto the gravelly low-intertidal zone by scrambling across the rip-rap or cutting around it at the segment of constructed beach. North Beach's mid and high-intertidal substrate consists of the rip-rap armoring along the trail. Discontinuous patches of eelgrass, *Zostera marina*, are scattered across the lowest reaches of the intertidal along this site and at least one relatively flat patch of gravel hosts a few butter and horse clams.

5 Hugh Shipman (coastal geologist) in discussion with the author, April 2018.

**opposite page:** North Beach's filled and armored form is made of three linear segments, each experiencing varying degrees of sediment drift dynamics.



photo by: Tatyana Vashchenko

**above:** The lower intertidal portion of the site is still a beach, though few finer grained sediments remain.

Like many coastal sites around Puget Sound, this beach deals with water quality issues associated with urban runoff and air pollution. However, North Beach also experiences periodic overflows of untreated sewage and stormwater from an emergency bypass outfall located about 500 feet offshore at a depth of about 30 feet below MLLW. However, the wastewater treatment plant's primary outfall through which treated wastewater flows is located about 3,000 feet west of West Point at an elevation of about -400 feet. Situated well below the thermocline, the treated wastewater is rapidly flushed out and away by currents. Though this water has been treated for bacterial contamination and filtered of heavy metals, it still contains inorganic nitrogen, phosphorous and a host of other chemicals we have no technology for removing at this time.

Aside from receiving point-source pollution, the Central Puget Sound's waters suffer from broadly dispersed nutrient over-enrichment as a result of anthropogenic inputs. Though inorganic and organic nutrients enter the Puget Sound from the Pacific Ocean, and a variety of non-human sources, heightened nitrogen and phosphorous levels and the resulting algal blooms in Puget Sound have been linked to human land-use activities.<sup>6</sup> Anthropogenic nitrogen can reach Puget Sound's water through the air (atmospheric deposition of vehicle and industrial emissions), treated and untreated wastewater (most wastewater treatment plants do not remove inorganic nitrogen), and stormwater (leaky septic systems, animal manure, and plant

fertilizers).<sup>7</sup> The excess nutrient and organic carbon in urban waters result in phytoplankton blooms which, as they die off, decompose through a process that consumes significant amounts of dissolved oxygen and may leave the water anoxic and inhospitable to most marine organisms.

North Beach's ongoing and episodic water quality issues coupled with its dramatic shoreform transformation have resulted in a shoreform composed of primarily hard vertical substrates from the low to high intertidal juxtaposed with more gently sloping gravel and cobble substrate to subtidal depths. Hardened shoreform and substrate combine to make this a relatively barren site, where the insertion of maricultural agents and cultivation infrastructure, coupled with strategic sediment nourishment could offer a more biodiverse, productive and experientially rich mosaic of substrates and ecosystems for both cultivated and pioneering species, ecosystem managers and casual visitors to enjoy. Given its location at both a wastewater treatment facility and public park, this site could serve as a public IMTA demonstration site, communicating the story of water treatment, sediment dynamics and coastal ecology while also affording the public an opportunity to encounter and steward intertidal biological communities in an urban context. North Beach's location just one and a half miles (as the crow flies) from the Ballard Locks also suggests an opportunity to synergize with the environmental education and ecotourism programs that the Ballard Locks' fish ladder offers.

6 Dustin Bilhimer, "Reducing Puget Sound Nutrients," Department of Ecology- Water & Shorelines, 2018, <https://ecology.wa.gov/Water-Shorelines/Puget-Sound/Helping-Puget-Sound/Reducing-Puget-Sound-nutrients>.

7 Bilhimer.



photo by: Tatyana Vashchenko

**above:** North Beach affords expansive views of the Olympics to the West. Currently, these views are only accessible where the shoreline trail which follows the shoreline armoring.





photo by: Tatyana Vashchenko

**above:** Mussels, barnacles and anemones claim a boat launch as substrate in the mid-intertidal zone at Redondo Beach.

## PARAMETERS

Given the nature of a maricultural design intervention at the threshold between land and water, several design considerations emerged as particularly critical for understanding how maricultural system might impact this site and how this site's dynamics might impact the maricultural system.

### *Tidal Range*

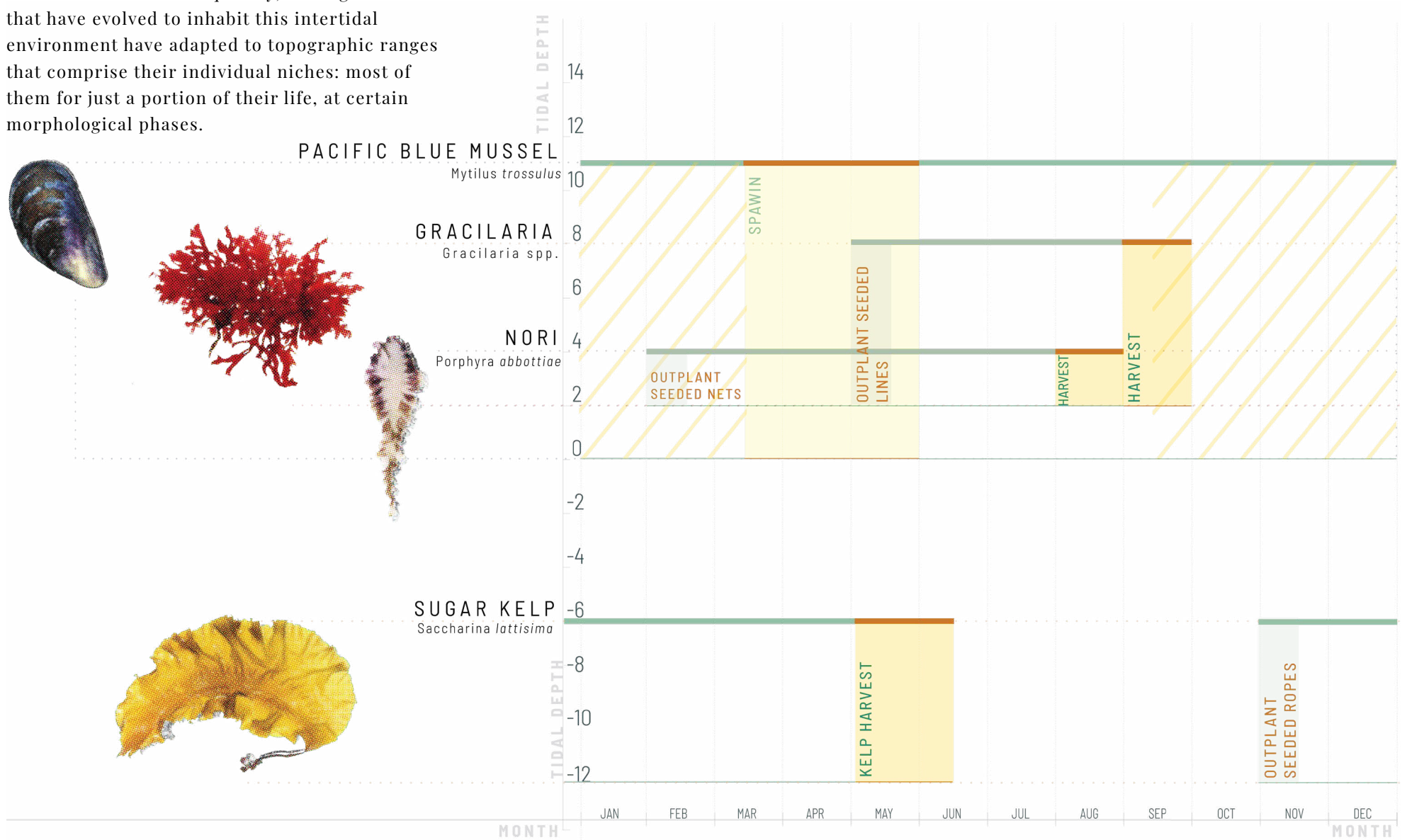
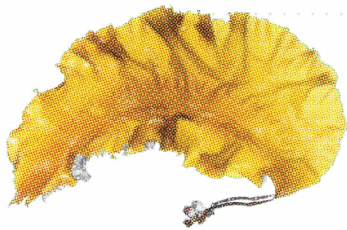
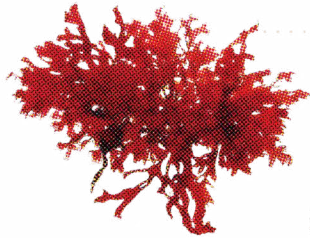
Tides are essentially very long period waves moving across the Earth in response to the combined with gravitational forces of the sun, the moon and Earth's water and further influenced at a local scale, by air pressure and weather patterns.<sup>1</sup> Puget Sound, like most West coast areas, experiences a mixed semi-diurnal tide- in which the two high and two low tides differ from each other in height.<sup>2</sup>

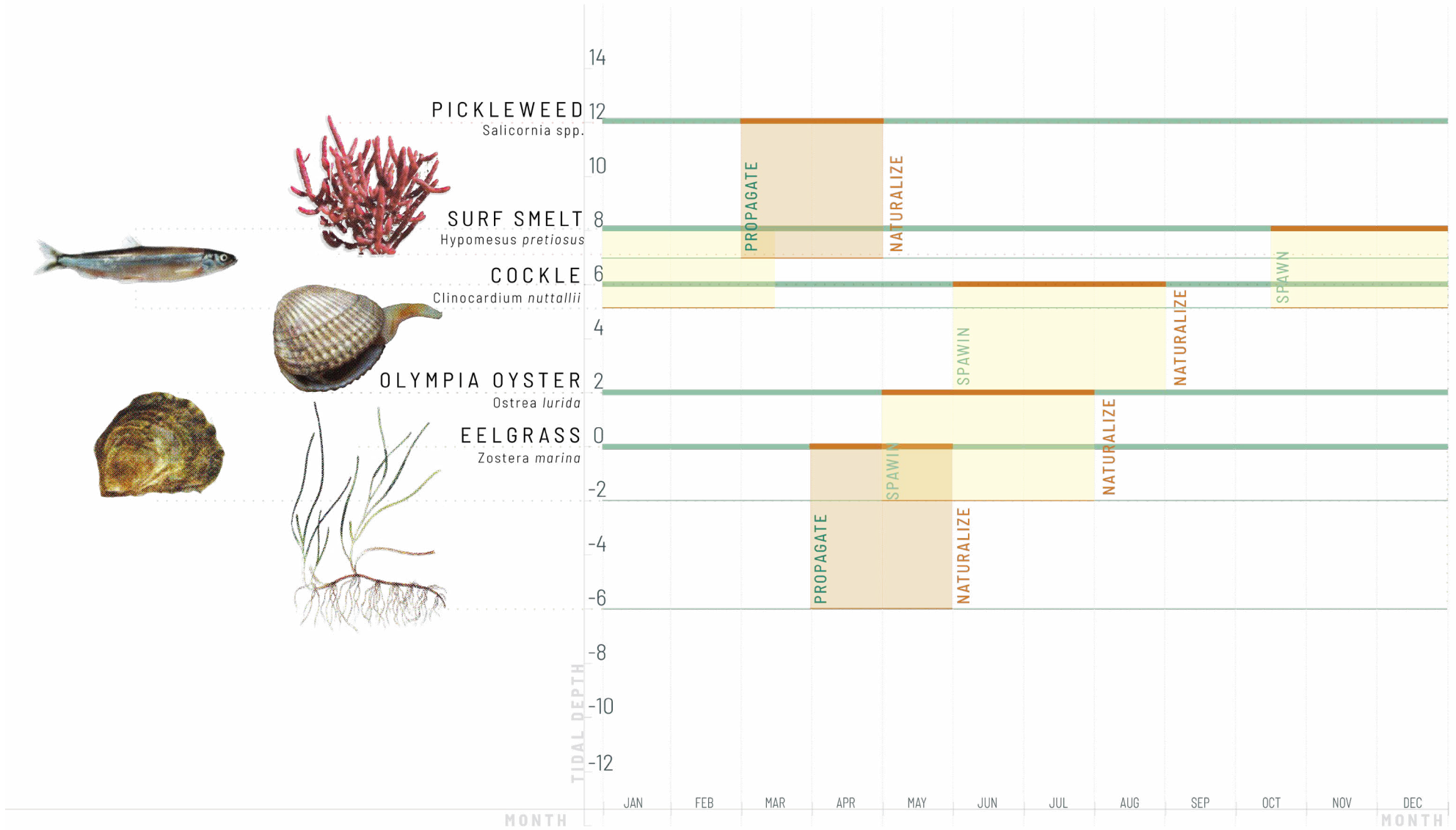
Puget Sound' shape and bathymetry amplifies the intensity of the tides, increasing the tidal range in this region the further one moves from the Sound's ocean inlet.<sup>3</sup> At North Beach, the tidal range between MLLW and MHHW is about 3.5 meters or 11.4 feet. However, taking extreme (king) tides into account, the range is closer to 5.5 meters, or 18 feet.

- 1 National Oceanic and Atmospheric Administration US Department of Commerce, "NOAA National Ocean Service Education: Tides and Water Levels," NOAA Ocean Service Education, 2017, [https://oceanservice.noaa.gov/education/kits/tides/tides02\\_cause.html](https://oceanservice.noaa.gov/education/kits/tides/tides02_cause.html).
- 2 D.A. Ross, Introduction to Oceanography (New York, New York: HarperCollins, 1995).
- 3 Hugh Shipman, "A Geomorphic Classification of Puget Sound Nearshore Landforms," 2008, 12, [http://pugetsoundnearshore.org/technical\\_papers/geomorphic\\_classification.pdf](http://pugetsoundnearshore.org/technical_papers/geomorphic_classification.pdf).

## Tidal Ecotones as Biological Niches

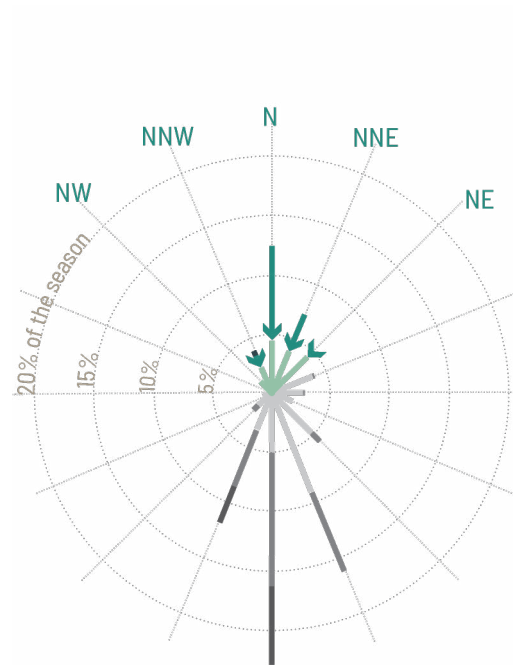
Puget sound's tidal landscape is characterized by multi-faceted gradients: topographical, saline and desiccation. Consequently, the organisms that have evolved to inhabit this intertidal environment have adapted to topographic ranges that comprise their individual niches: most of them for just a portion of their life, at certain morphological phases.



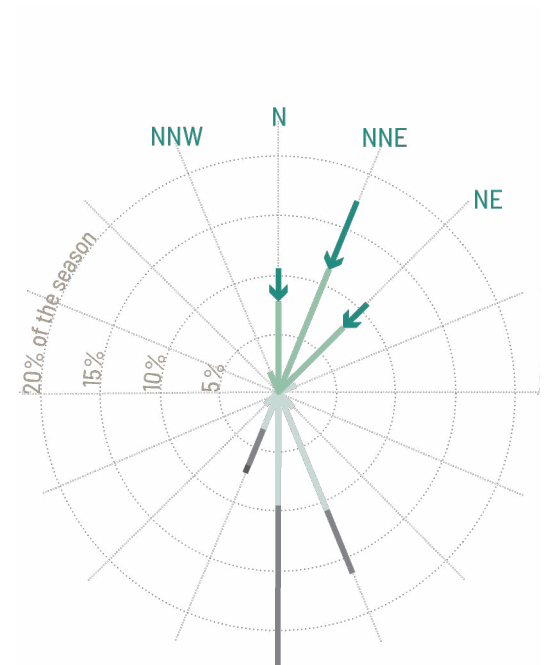




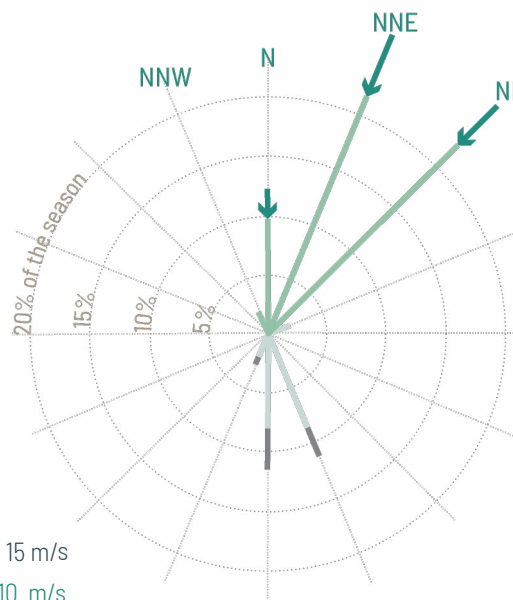
**above:** Fetch is greatest directly to the north of North Beach, suggesting that the largest waves are likely to come from the North.



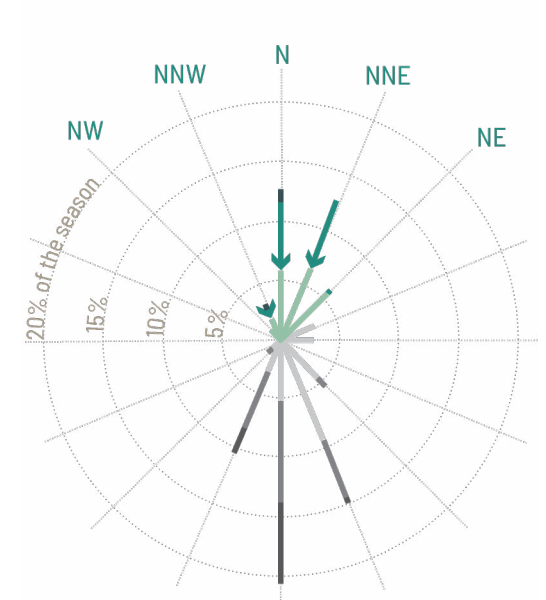
WINTER



SPRING



SUMMER



AUTUMN



## ***WIND, FETCH, WAVES and SEASONALITY***

Because central Puget Sound is sheltered from ocean waves by complex landforms that baffle and disrupt their transmission, the waves that reach North Beach are completely wind generated and are a function of the rate and direction of the wind over the distance of open water that wind travels, also known as fetch. Given the shape of the landforms bounding Central Puget Sound, Most waves reaching North Beach are generated by winds coming from: NE, NNE, N, NNW, NW.

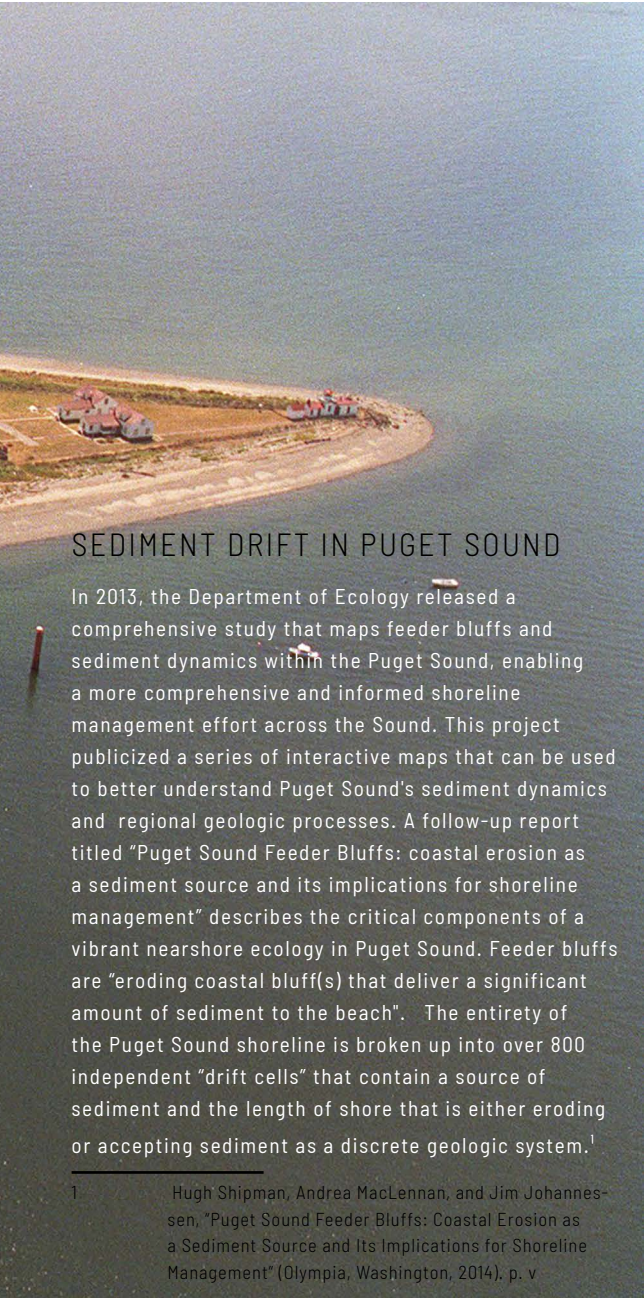
Having analyzed wind data collected from West Point at 10 minute intervals over a one-year period, I was able to plot the direction, speed and relative duration of sustained wind at this site.

In the autumn, winter and spring, Puget Sound experiences winds coming primarily from the South, SSE and some from the SSW, wind and waves from which North Beach is well sheltered. Overall, winds from the North and NW are uncommon, but they do pick up in the spring and summer, when winds at rates of 5-15 meters per second take place approximately 5% of the time from the NNE direction.

At North Beach, the greatest fetch is to the North, meaning that the potential for the largest waves comes from Northerly winds. Strong northerly winds are uncommon though northerly winds of 5-10 meters/second take place about 7% of the time in the winter months. While there are more Northerly and Northeasterly winds in the summer and spring, these are fairly gentle ranging at 0-5 m/s and consequently don't generate significant waves, especially given the limited fetch in the NNE and NE directions.

Overall, North Beach is protected from some of the strongest and most frequent winds in Puget Sound on the merit of its northwestern aspect. However, given filled and over-steepened form, North Beach is armored to prevent erosion of the fill supporting West Point Treatment Plant. The design scenarios in the following section explore potential configurations of mariculture and sediment interventions to provide shoreline protection while also expanding intertidal habitat.





## SEDIMENT DRIFT IN PUGET SOUND

In 2013, the Department of Ecology released a comprehensive study that maps feeder bluffs and sediment dynamics within the Puget Sound, enabling a more comprehensive and informed shoreline management effort across the Sound. This project publicized a series of interactive maps that can be used to better understand Puget Sound's sediment dynamics and regional geologic processes. A follow-up report titled "Puget Sound Feeder Bluffs: coastal erosion as a sediment source and its implications for shoreline management" describes the critical components of a vibrant nearshore ecology in Puget Sound. Feeder bluffs are "eroding coastal bluff(s) that deliver a significant amount of sediment to the beach". The entirety of the Puget Sound shoreline is broken up into over 800 independent "drift cells" that contain a source of sediment and the length of shore that is either eroding or accepting sediment as a discrete geologic system.<sup>1</sup>

<sup>1</sup> Hugh Shipman, Andrea MacLennan, and Jim Johannesen, "Puget Sound Feeder Bluffs: Coastal Erosion as a Sediment Source and Its Implications for Shoreline Management" (Olympia, Washington, 2014), p. v

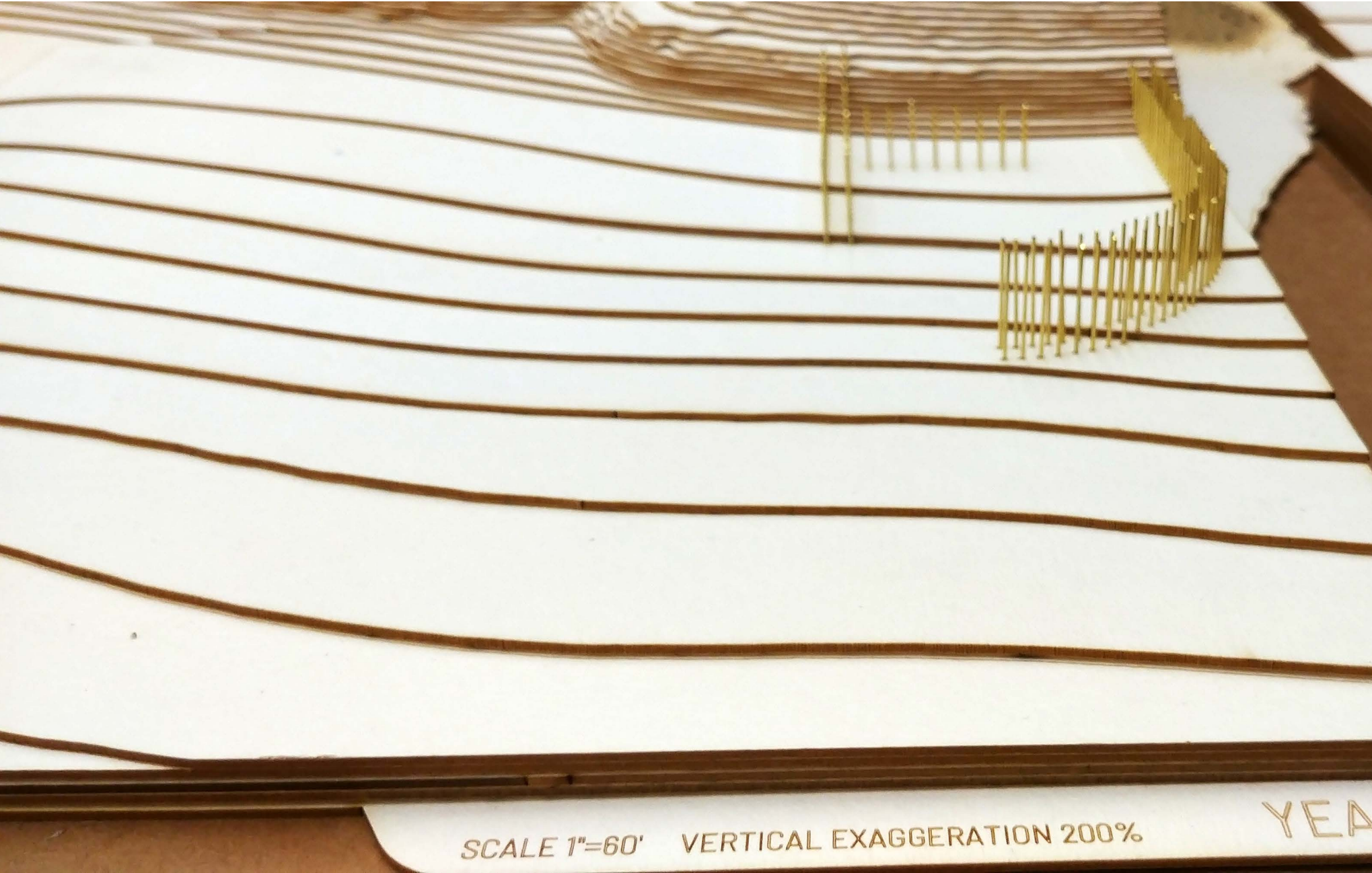
Image courtesy of King County Archives

## ASPECT AND SEDIMENT DRIFT

Sediment drift at North Beach is driven primarily by the angle at which waves impact the shore. If the wave hits the shore at a roughly perpendicular angle, it generates minimal drift of sediment, though there may be potential for scour if the waves are impacting a hard surface such as rip-rap or a wall. On the other hand, if waves meet the shore at a more oblique angle, medium and coarser sediments will bounce along the shore in the turbulence of the waves' swash.

North Beach is segmented into several parts. Near West Point's apex, the shore is more or less perpendicular to wave impact. However, further to the northwest, the shoreline angles to promote sediment drift towards the Point. Consequently, sediment drift is more active in the northeastern reach of the beach than at its southwestern apex.

A design intervention that leverages the site's sediment drift potential is more appropriate in the northeast stretch of the site than in the southwest. In the southwest reach of the site, shoreform interventions that minimize scour and retain sediment will remain relatively resilient to typical wave and wind conditions.



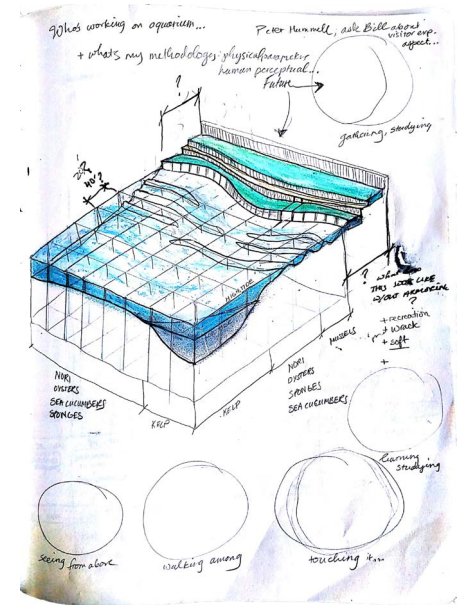
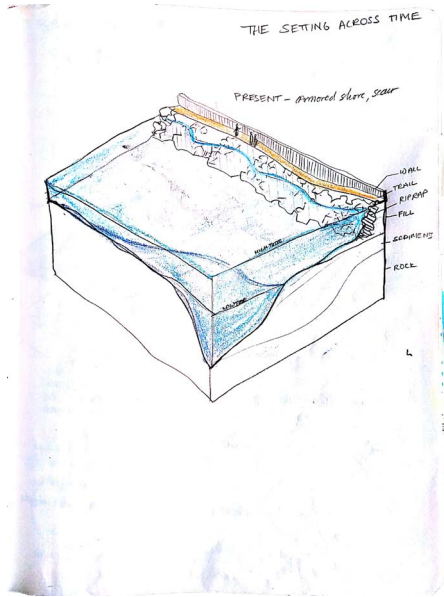
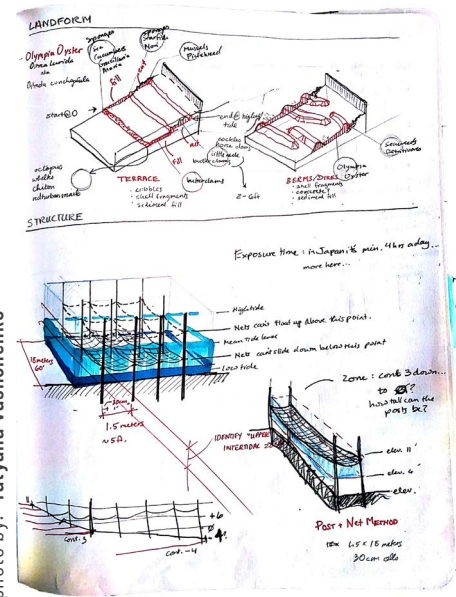


# SCENARIOS

In an environment as dynamic as the intertidal, any intervention, no matter how simple is open-ended. As sea level rises, sediment supply wanes and weather patterns change, a given intervention may morph in entirely unexpected ways. In exploring different approaches to expanding the intertidal gradient at North Beach, I cycled through numerous

iterations of sediment retention and accretion infrastructures. The primary forms explored consist of variants of terraces and groins. Each scenario is coupled with a high-level analysis of the interventions effect on wave energy and sediment drift.

photo by: Tatyana Vashchenko





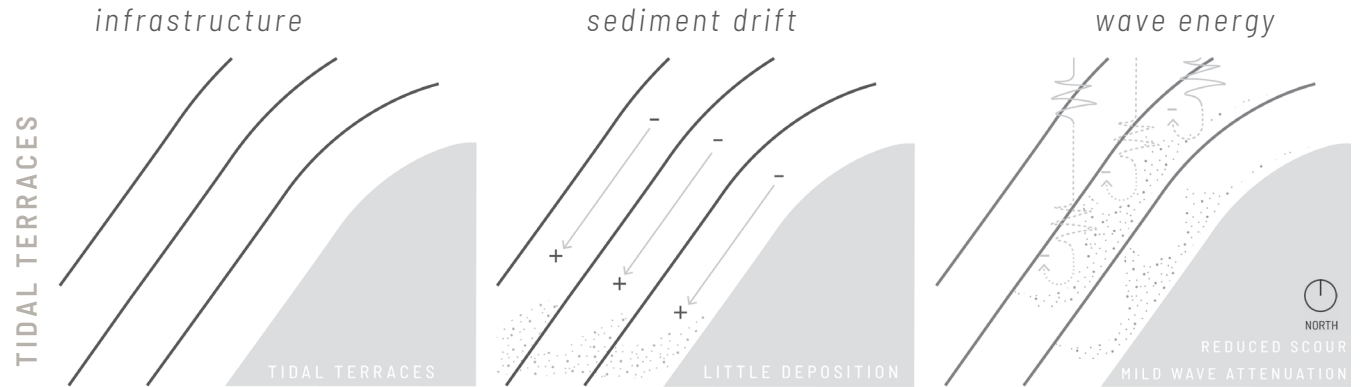
SCENARIO EXTENTS



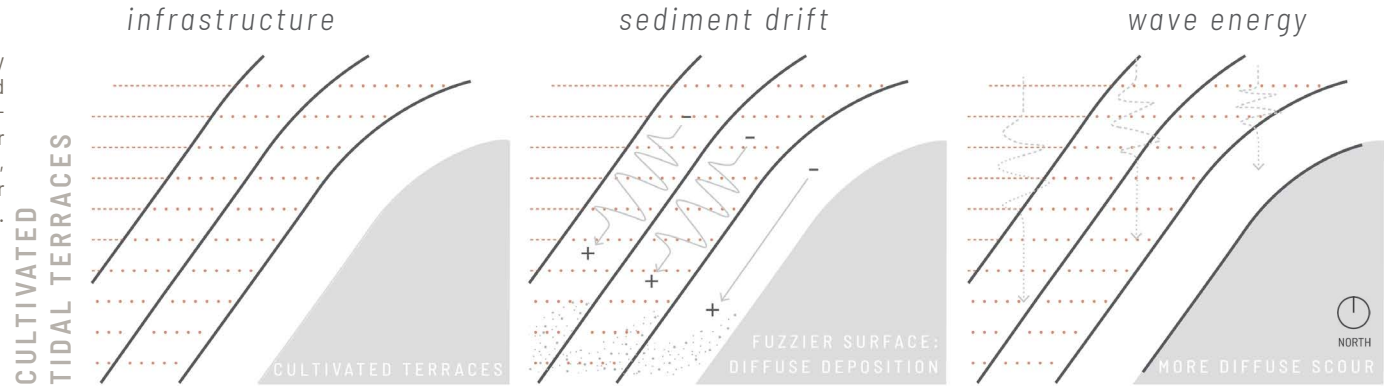
NORTH



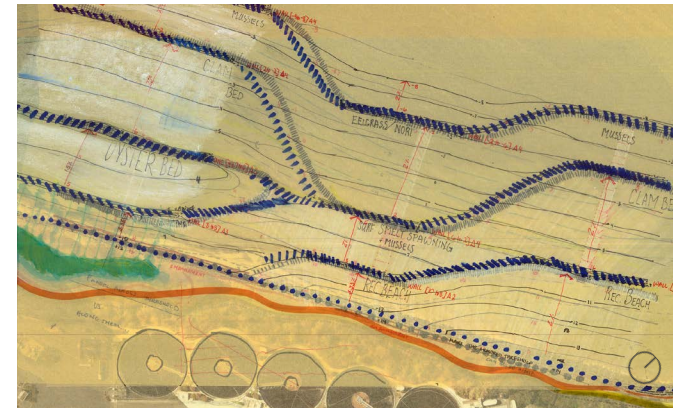
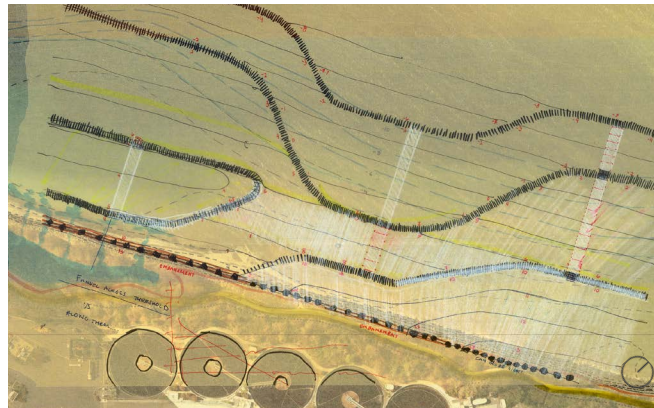
**Tidal terraces** allow for an extension of gently sloping substrate in topographically constrained conditions. Multiple low walls replace one monolithic wall. This strategy does create an upper intertidal zone that can support sediment drift, however, the terrace walls face potential for scour at their base.

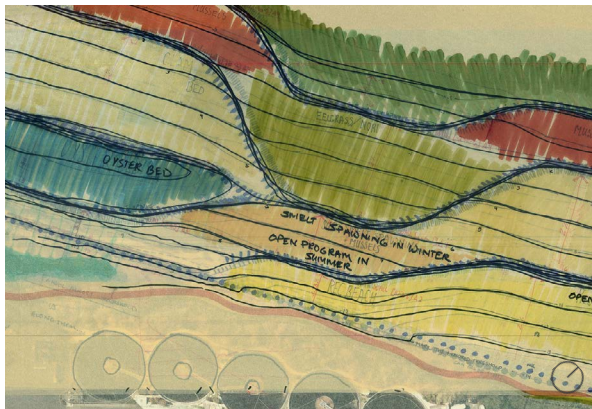
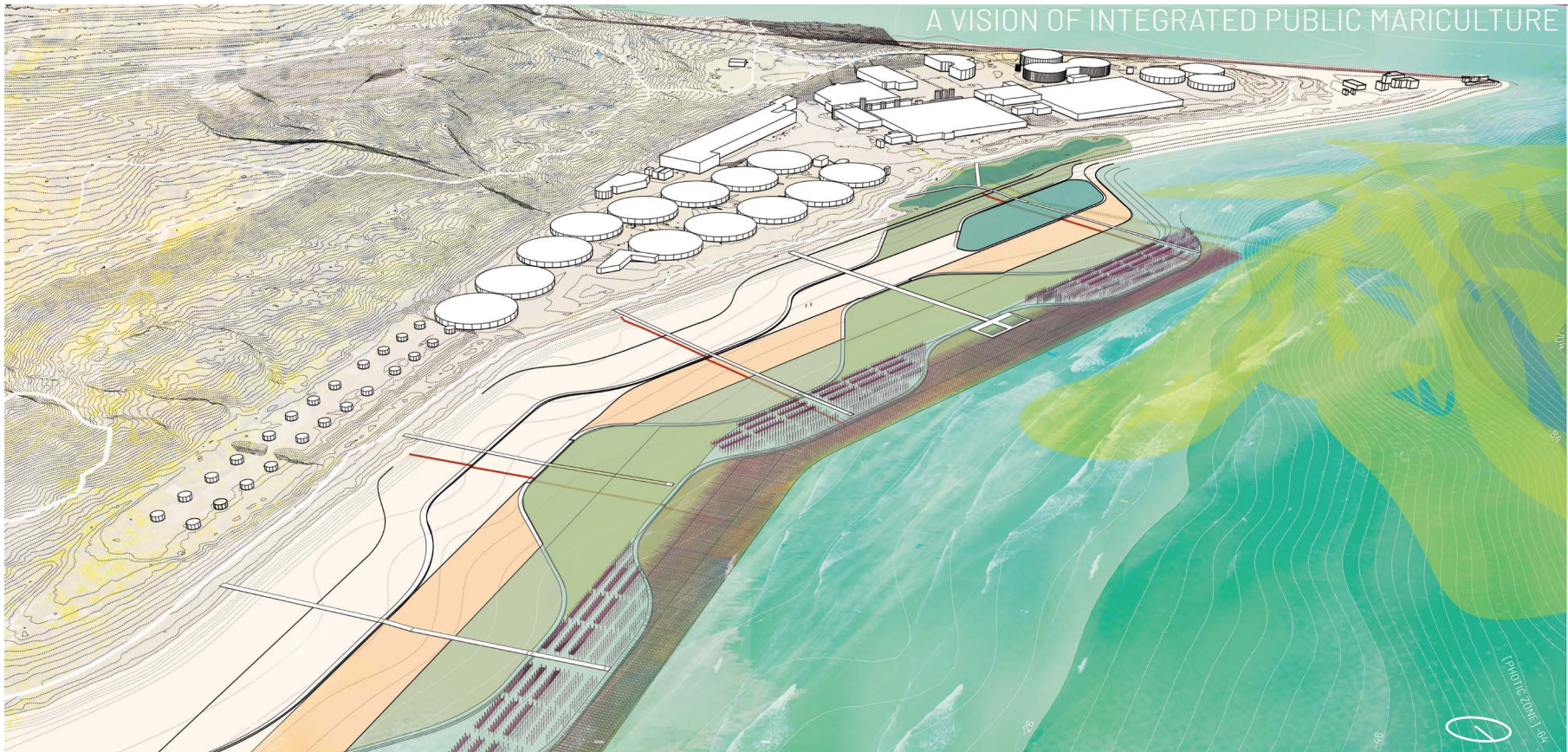


**Cultivated tidal terraces** extend gently sloping substrate in topographically constrained conditions. Multiple low walls replace one monolithic wall. This strategy does create an upper intertidal zone that can support sediment drift, however, the terrace walls face potential for scour at their base.



**right:** Iterative grading studies revealed that a series of terraces running at a constant width along the shoreline, would not provide optimal sediment substrate to shellfish and other sand/gravel loving organisms. Rather, alternating the compression and release of terraces in a scalloped pattern would allow there to be both sandy, flat sediments and vertical cobble substrate at every intertidal elevation.



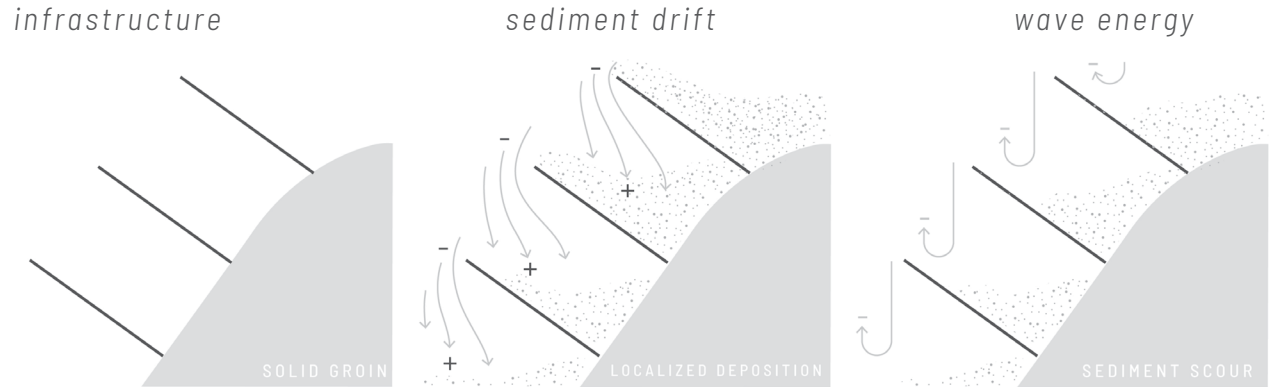


In intertidal ecosystems, every tidal elevation functions as a biological niche for some organism. Yet terraces, necessarily relegate certain elevations to rocky/wall habitat and others to gently sloping sediment. Adopting a scalloped pattern allowed me to alternate every intertidal elevation between tidal terrace and terrace wall, creating a mosaic of habitats in proximal juxtaposition. Upland, the existing trail, adjacent to the wastewater treatment plant, functioned as a control point at which to meet grade, and in the subtidal, starting at a

grade-brake near -14, served as the control point on the seaward side. The upper intertidal zone comprised the top two terraces which spanned elevations 14 to 8, mid-intertidal spanned two additional terraces, between elevations 8 to 2 and low intertidal spanned the bottom two terraces between elevations 2 to and -4. The base of the last terrace wall, meets grade and gives way to elevations ranging from -8 to -10 at which zone, a cultivated sugar kelp forests protects the first terrace wall from direct wave impact.

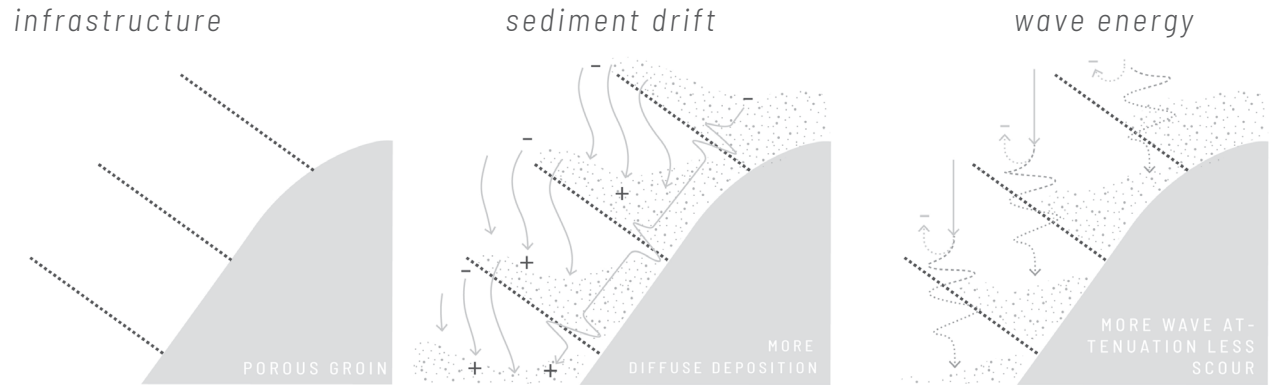
**Solid groins** are a shoreline armoring strategy used to either slow the erosion of sediment or to accrete sediment on their windward side. They are often made of concrete, though they can also be built of wood reinforced by piles or rock cobbles. When they are designed to allow for water to flow overtop of them, they also contribute to sediment scour and undercutting on their leeward side. As a result, this type of infrastructure often garners mixed results: patchy sediment accretion and scour and erosion in other areas. It can also lead to "terminal groin syndrome" in which the first groins in the series lock up sediment and prevent it from becoming more evenly distributed across subsequent groins.

**CONCRETE GROINS**



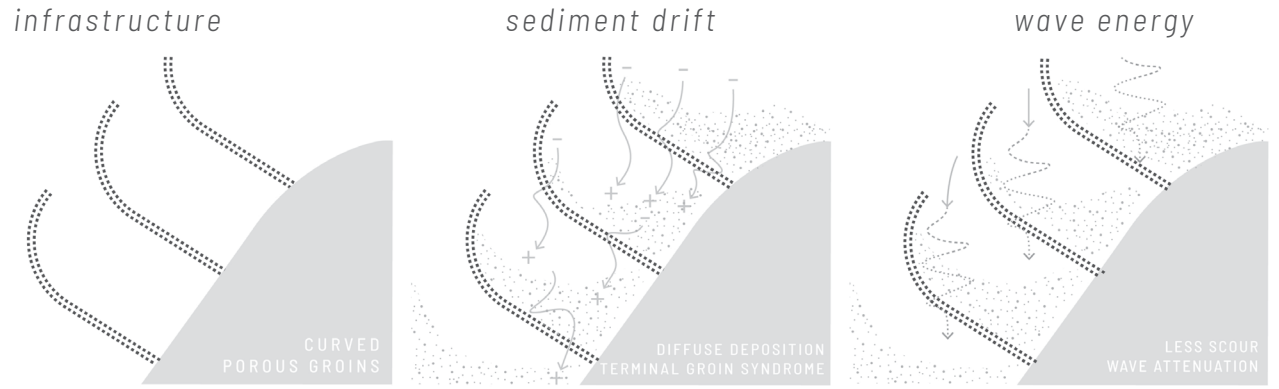
**Porous groins** can be designed in a variety of ways, however they all allow water and sediment to move through them, albeit slowing and agitating the water movement. Consequently, they diffuse wave energy at their deeper end and more evenly distribute sediment through the entire system. A straight groin, angled perpendicularly to the direction of sediment drift, would accrete sediment in roughly triangular forms. As a maricultural intervention, a porous groin could take the form of a mussel cultivation pile, a surface treatment that would add surface roughness and contribute to further wave energy dissipation.

**POROUS GROINS**

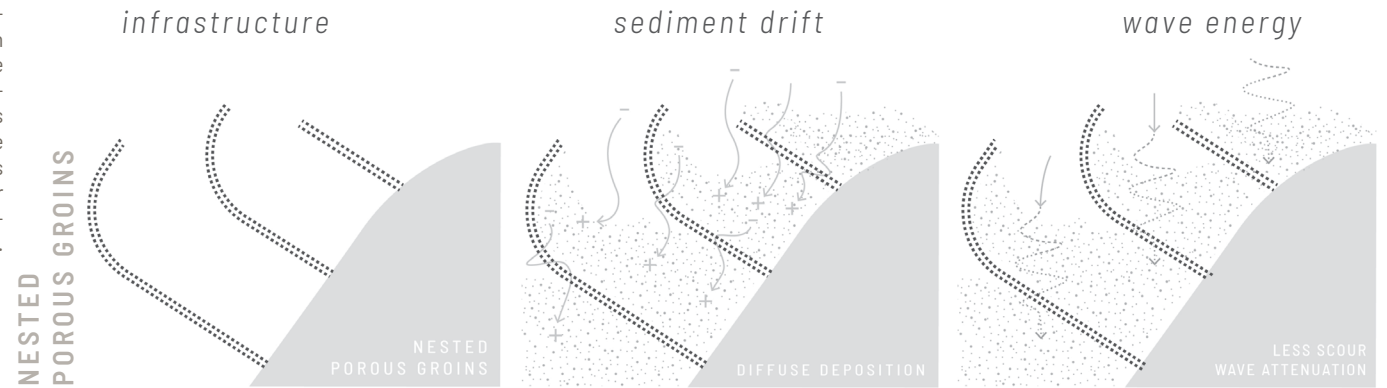


**Curved porous groins** are less common than their linear counterparts but could potentially create more protection from waves in between them. They could consequently contribute to a more continuous sediment accretion pattern. As piers, arched porous groins, could create an interesting user experience for visitors and a more varied spatial experience for kayakers at high tide.

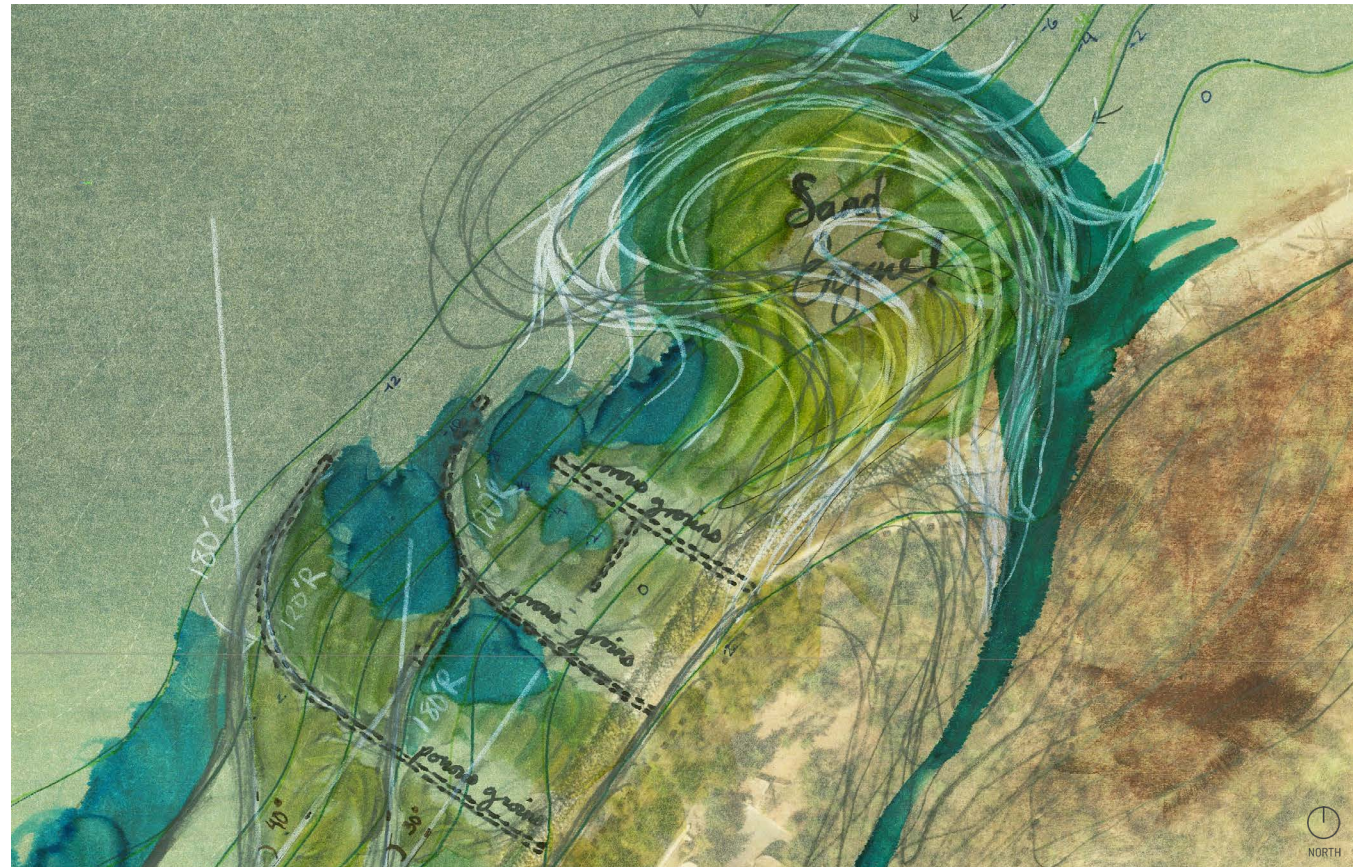
**CURVED POROUS GROINS**



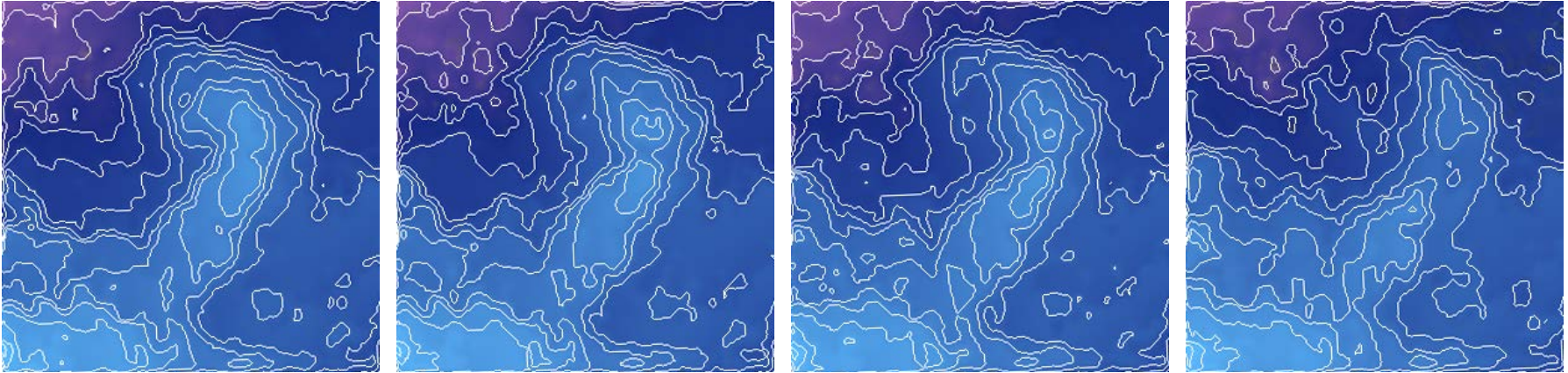
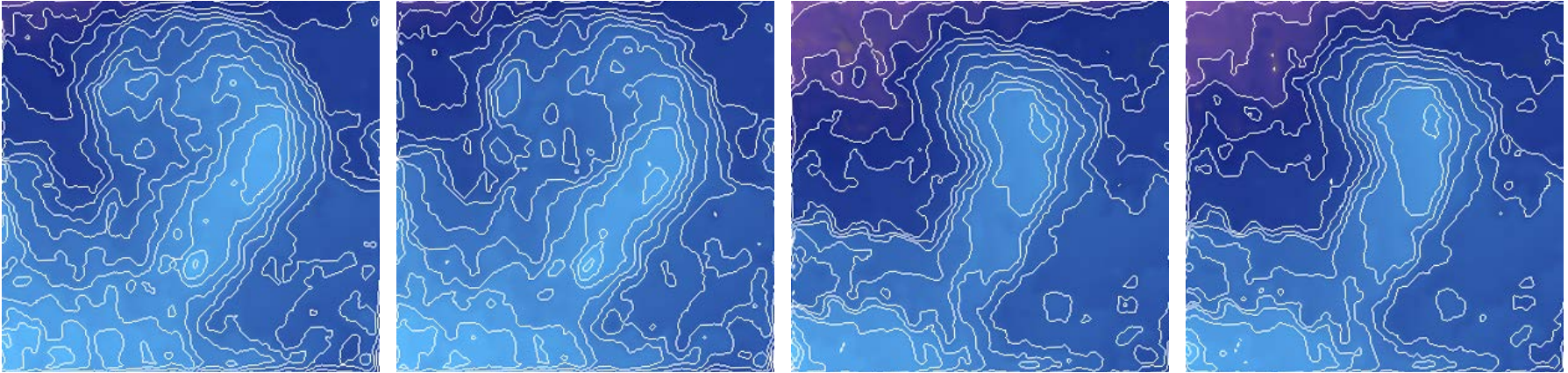
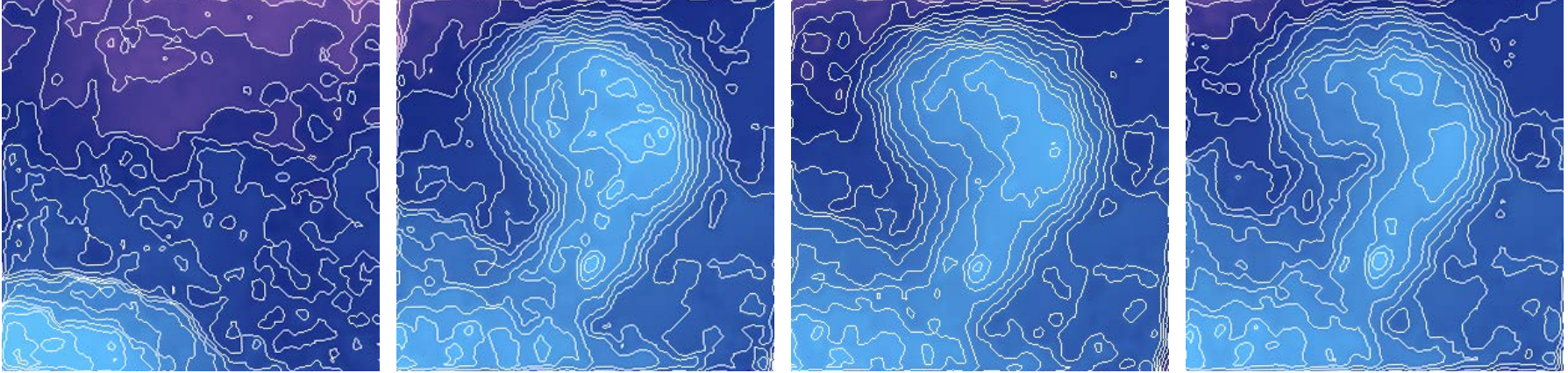
**Nested porous groins** would prevent or reduce terminal groin syndrome as the first groin is smallest and allows more sediment to move past it. Subsequent groins increase incrementally in size. However, because sediment drift takes place primarily in the swash zone of a wave, once a groin reaches a large enough size, and extends beyond the lowest reach of a swash zone, further increases in length will have less impact on sediment accretion patterns.



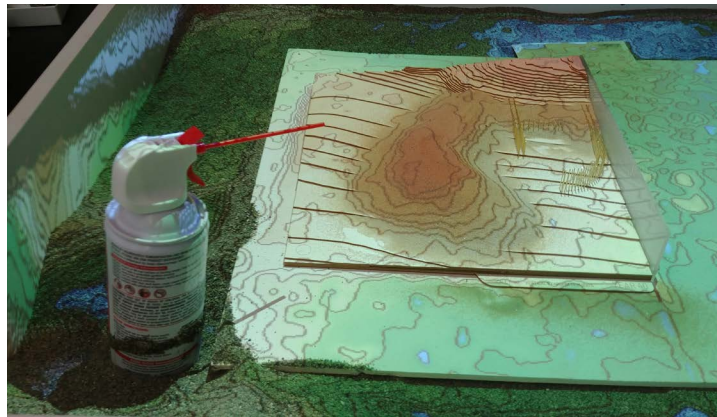
**Sand engine** refers to the deliberate massing of sediment with reference to waves, currents and drift patterns in order to leverage the drift cell's established dynamics to carry and deposit sediment. This strategy was most famously employed at the Netherlands' Zandmotor project, at a scale much larger than would be required at North Beach. North Beach's drift cell, had once contributed to the formation of West Point. However, today, a significant portion of the feeder bluffs up the drift cell are armored. There may no longer be enough sediment throughput in this system to build up an intertidal gradient even with armoring and sediment scour reduced along this beach. Consequently, I propose the location of a sandspit southwest of the Owl Creek's entry into the Sound.



EXISTING CONDITION



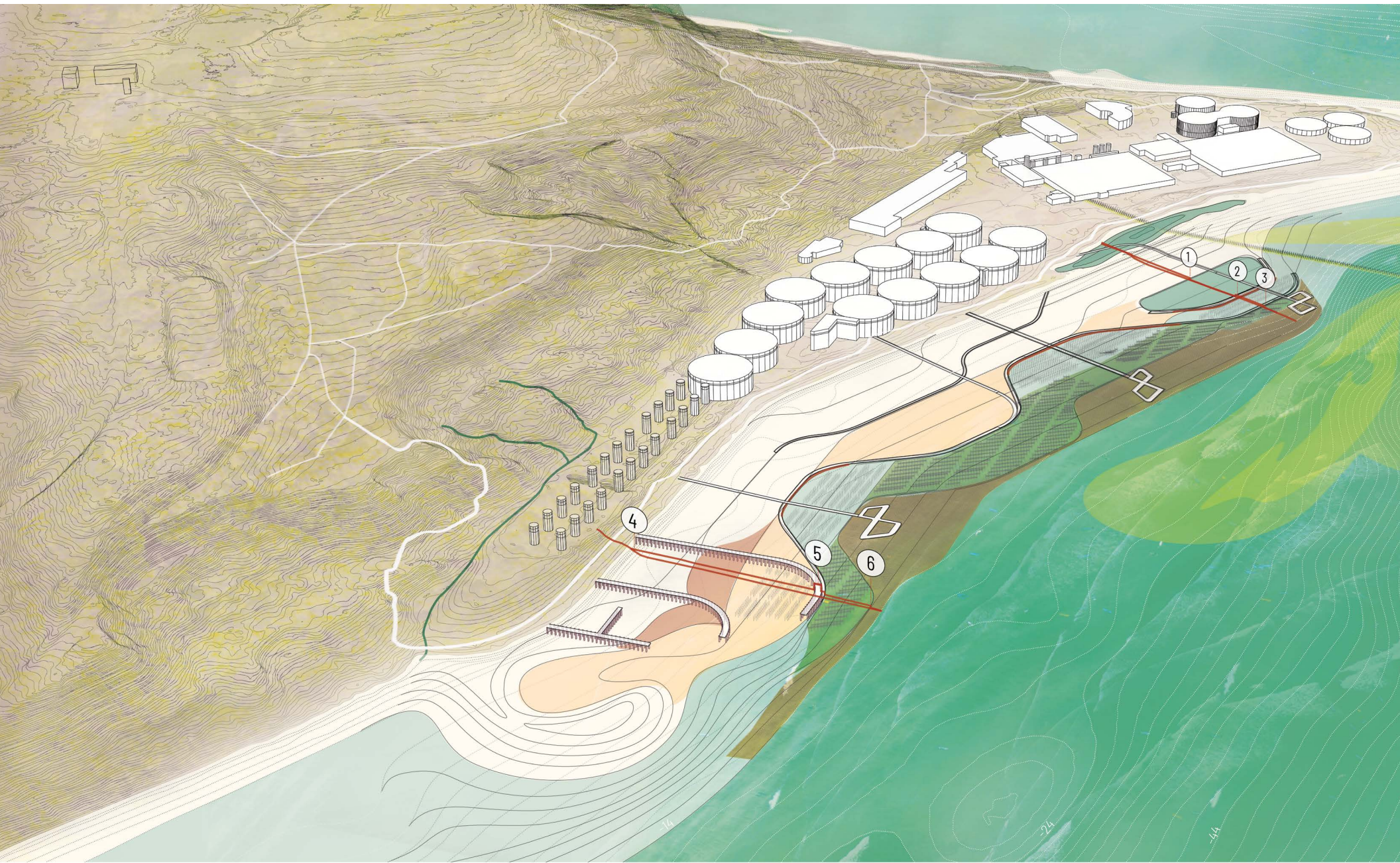
FUTURE CONDITION

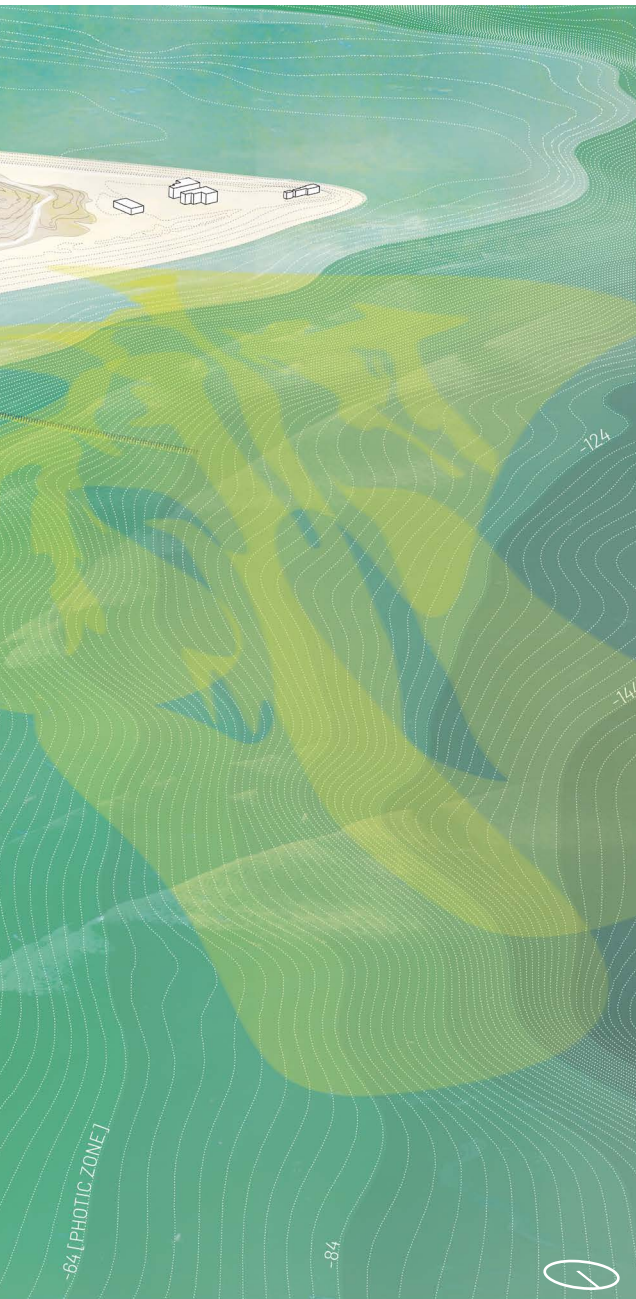


**opposite page:** Taken every 30 seconds as sand moves through the nested groin system model, these images represent how a sand engine might release sediment to drift through a series of groins to ultimately form a more resilient beach condition.

In order to test how sediment might accrete around a nested groin structure at North Beach, I built a model of the existing topography and used pressurized air and a fine-grained sand to document the resulting landform signatures using an augment reality sandbox. The pressurized air blew from the direction of the prevailing northerly wind and mimicked, though not entirely accurately, the effect that wind-generated waves might have on a sand engine. PhD candidate Susannah Morey, at the Earth at UW's Department

of Earth and Space Sciences, provided access to and assistance with the use of an augmented reality sandbox which projects contours onto 3D forms in realtime. By taking screenshots of the resulting landform signatures at 30 second intervals, I was able to map the progression of sediment migration from the sand engine, through the groin system. purposes of communicating this process, I built two additional models and stabilized the sediment at three different "phases" of drift to represent how the sand engine and beach would change over time.



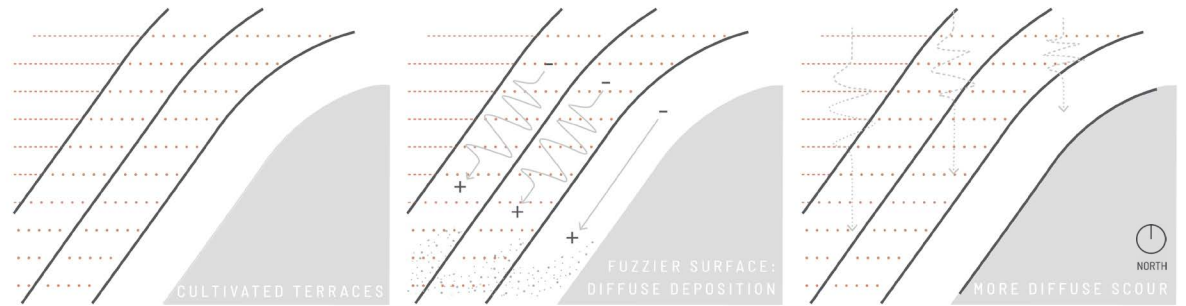


## ELABORATION

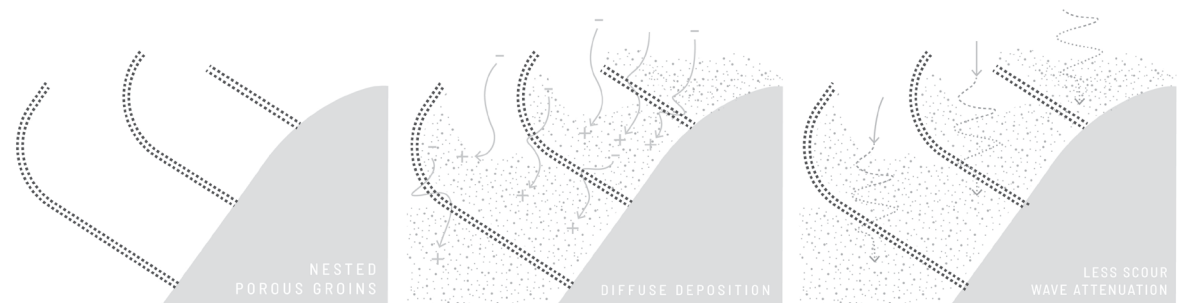
*A Vision of a Public Maricultural Waterfront*

Given the gradated influence of sediment drift across North Beach's drift cell, and the reduced throughput of sediment moving through this drift system, I chose to elaborate a scenario that hybridized a sand engine-groin approach with cultivated terraces.

CULTIVATED  
TIDAL TERRACES



NESTED  
POROUS GROINS



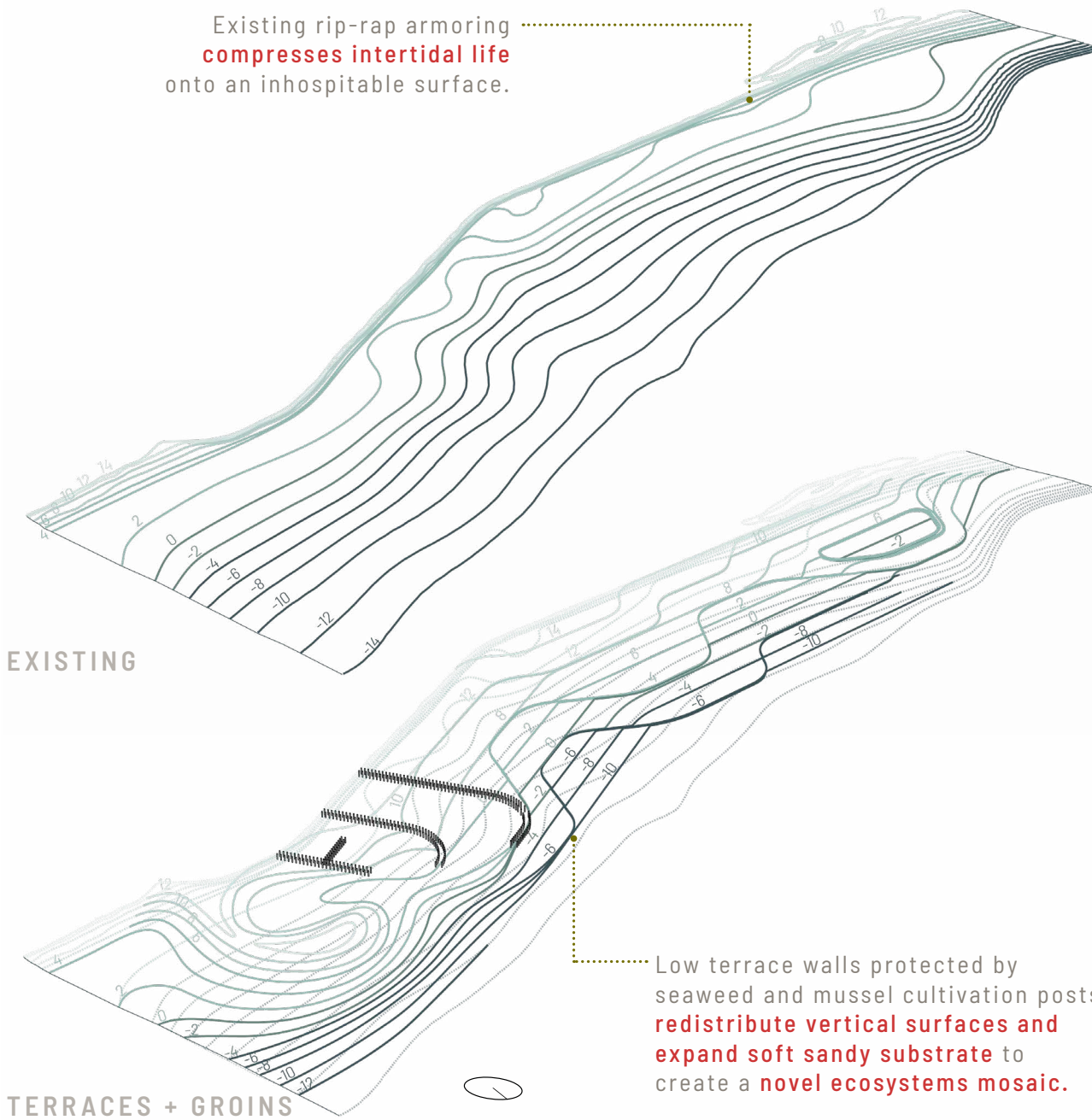
*infrastructure*

*sediment drift*

*wave energy*

**above:** The spatial design I chose to elaborate is composed of a hybrid between cultivated terraces and a sand-engine-fed nested groin system made of mussel posts.

Existing rip-rap armoring  
**compresses intertidal life**  
onto an inhospitable surface.



EXISTING

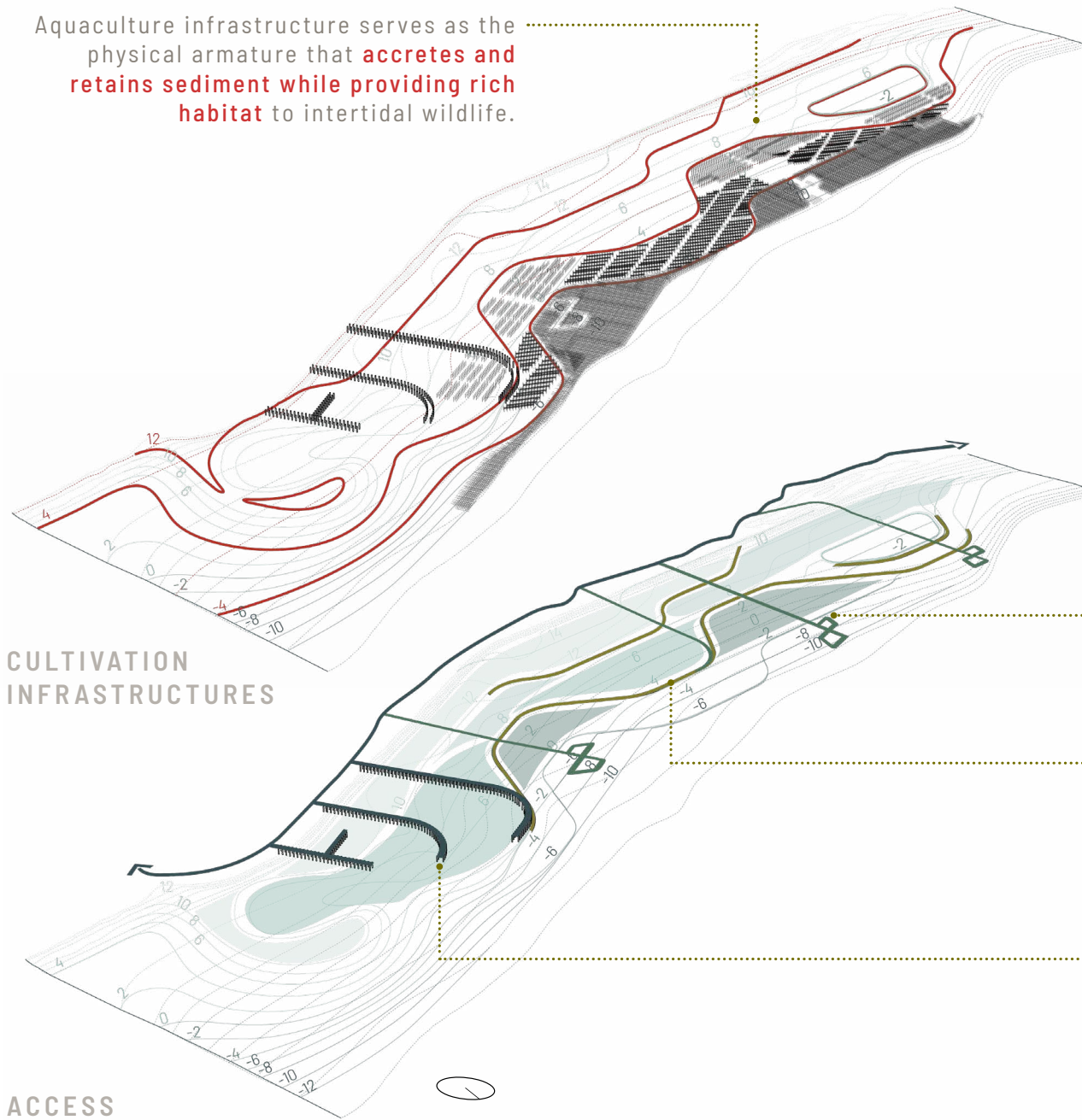
TERRACES + GROINS

Low terrace walls protected by seaweed and mussel cultivation posts  
**redistribute vertical surfaces and expand soft sandy substrate** to create a **novel ecosystems mosaic.**

At the southwesterly reach of the site, scalloped terraces retain a combination of imported and gradually accreted sediment behind four to six foot cobble walls. Towards the Northeasterly reach of the site, a sand engine made of imported sediment feeds into a system of nested porous groins, made of mussel cultivation piles supporting a walkway that affords views to the sand engine, over the amalgamation of North Beach's maricultural intertidal zone and across the Sound. As waves from the north and northeast gradually shift sediment from the sand engine down the drift cell, the coarsely textured mussel-encrusted piles slow and baffle the swash, inducing it to drop sand that had been bouncing along within its turbulent sweeps. Over the course of several decades, sediment will migrate from the sand engine onto the shoreline along the porous groins and across the terraces beyond. Utilizing the site's prevailing wind and waves coupled with the sand engine and groin system to reshape North Beach leverages the systems at play through the site's extents to create a more resilient shoreform than a more instantaneous fill operation could accomplish.

This approach also allows for cultivation and habitat enhancement to happen in a phased sequence. At the initial phase, the terrace walls can be built starting at the lowest terrace and moving up. The terrace walls and back-filled sediment will support shellfish, sea cucumber and macroalgae culture as the northeasterly portion of the Beach incrementally accretes sediment between groin structures. The

Aquaculture infrastructure serves as the physical armature that **accretes and retains sediment while providing rich habitat** to intertidal wildlife.



## CULTIVATION INFRASTRUCTURES

## ACCESS

processes of sediment accretion, habitat enhancement and water quality improvement on the site proceeds across the site at different rates. The terraces and the cultivation systems configured across them afford close encounters between park visitors and intertidal biological communities. The sand engine and groin structures make visible the process of sediment drift, spatializing the massive volume of sediment throughput that is no longer available to this drift cell as a result of shoreline armoring north of the Discovery Park. The location of this intervention at a well-loved public park, adjacent to county wastewater infrastructure, only intensifies the poignancy of this maricultural intervention on this site.

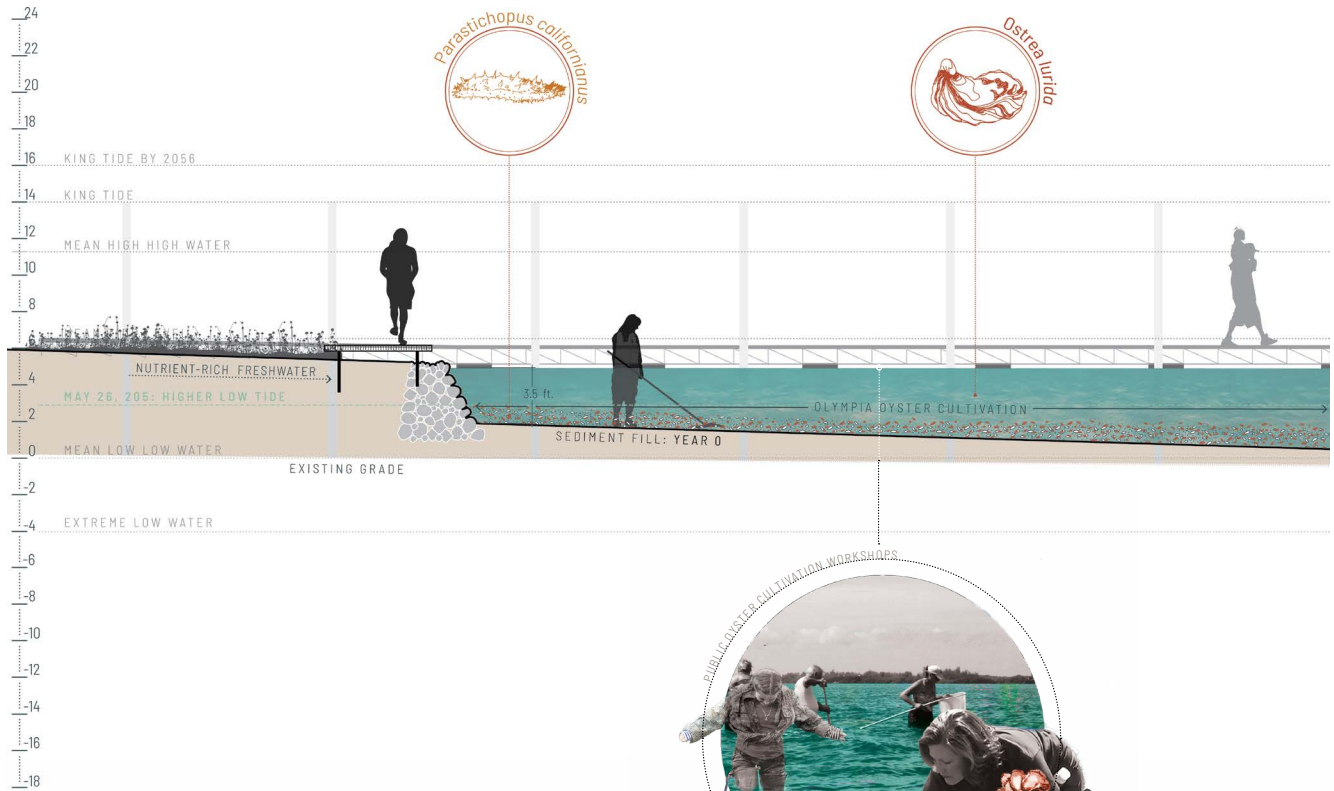
**Floating walkways** allow visitors to move across the intertidal mariculture system at both low and high tides.

Terrace walls double as **ephemeral pathways**. Depending on their elevation, they may only be accessible for a couple hours each day, offering a special opportunity to appreciate tidal flux.

Porous groins also function as **piers**, allowing for elevated views of Puget Sound, the sand engine and the maricultural system.

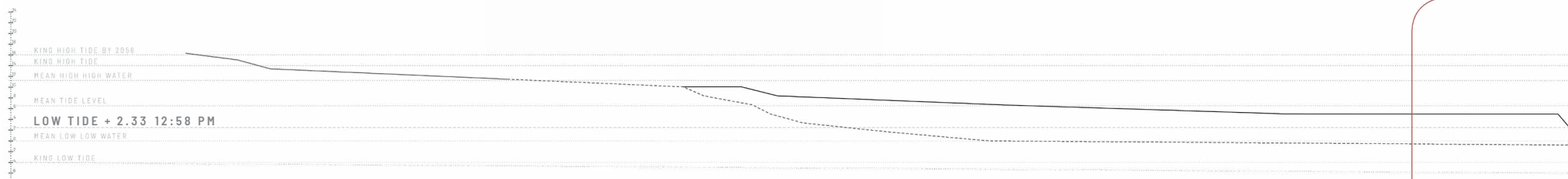
# 1 TIDAL MARSH TO BRACKISH BACKWATER

1" = 4' SCALE

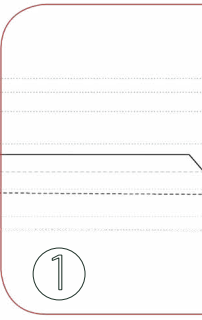


# 2 BRACKISH BACKWATER TO MUSSEL POND

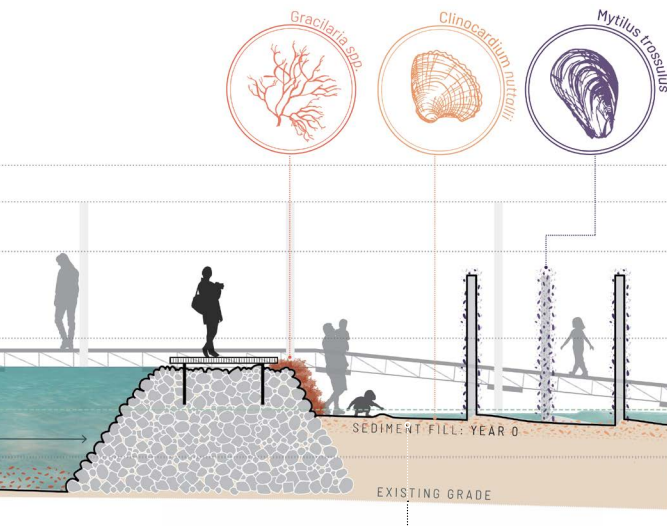
1" = 4' SCALE



TIDAL TERRACE SECTION: AUTUMN EQUINOX, 09-22-2028

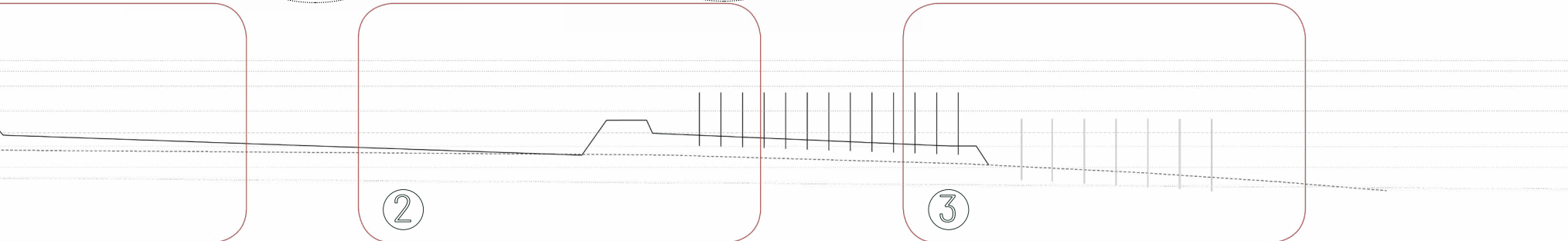
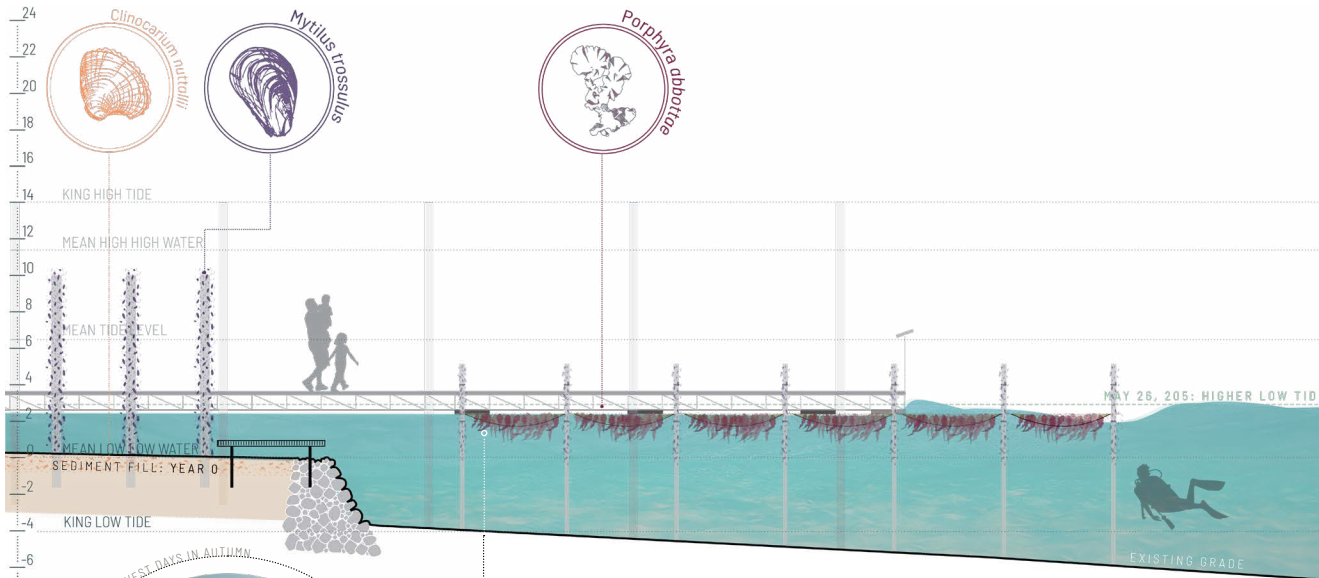


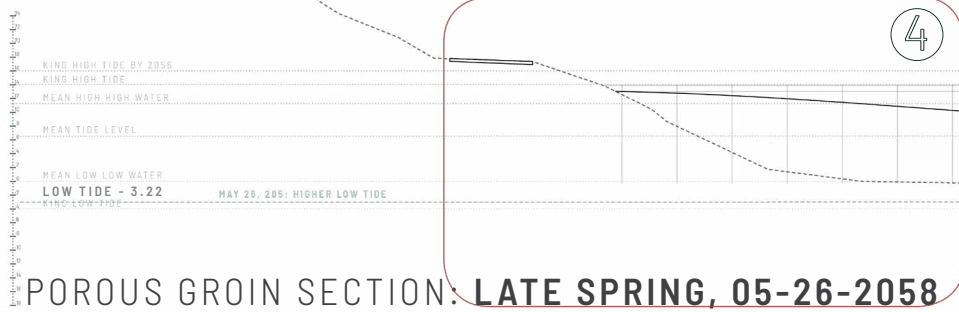
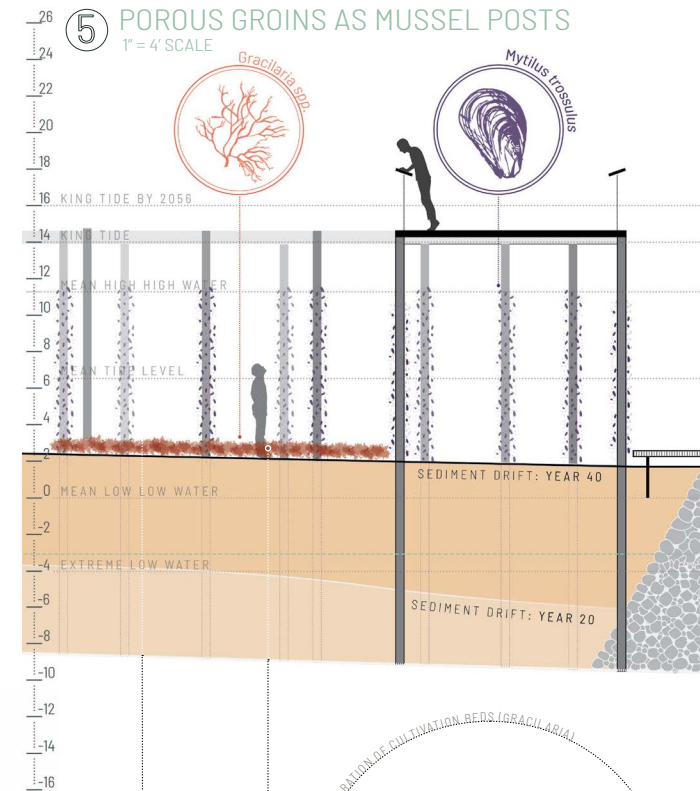
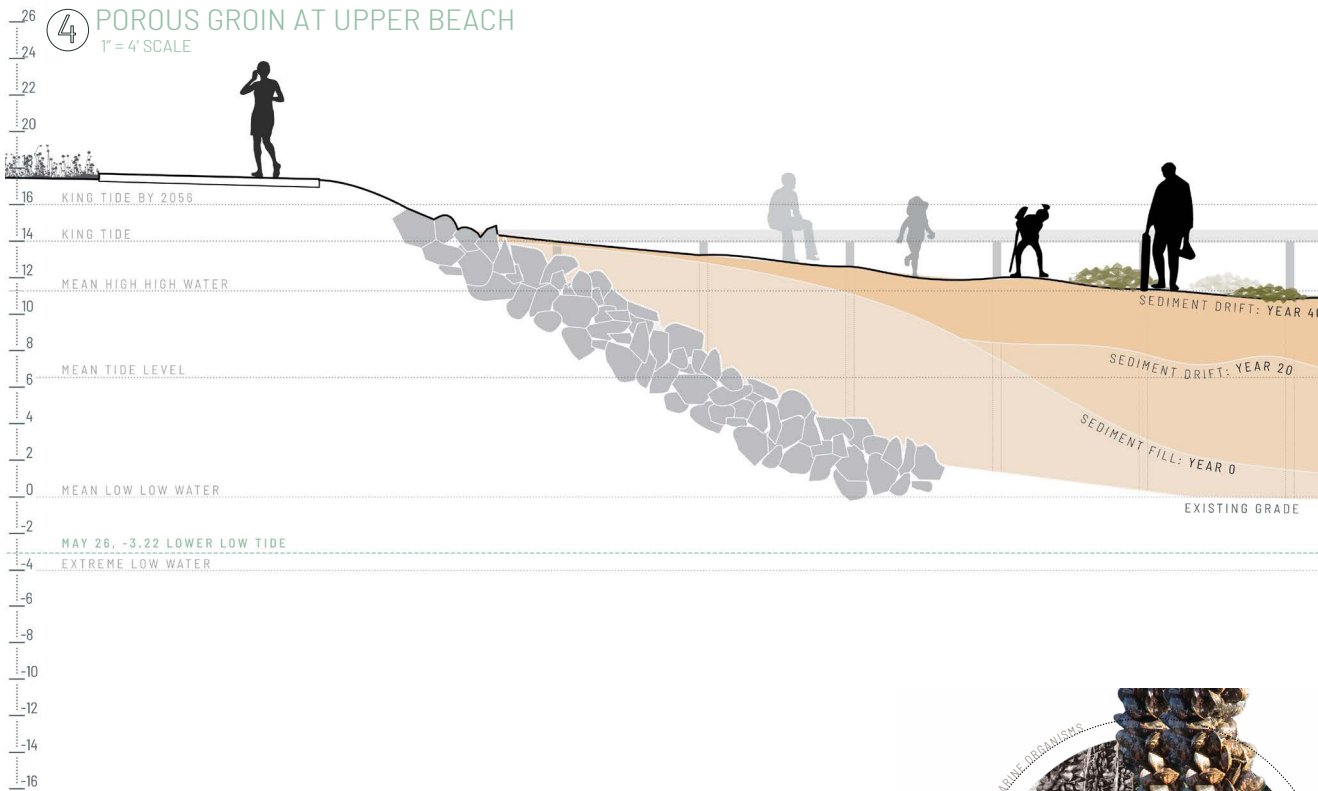
POSTS

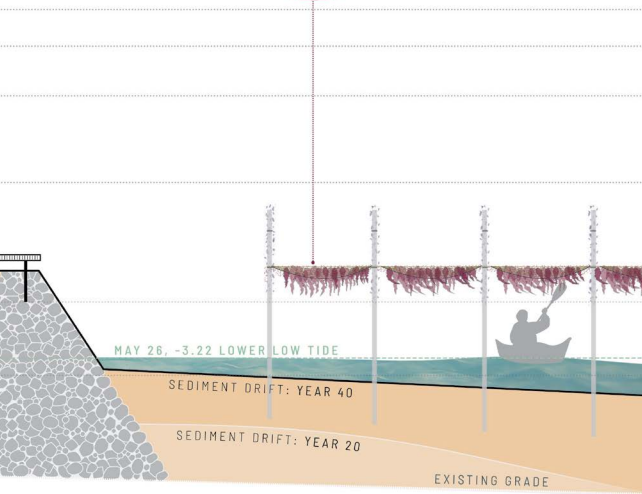


3 MUSSEL POSTS TO NORI CURTAINS

1" = 4' SCALE

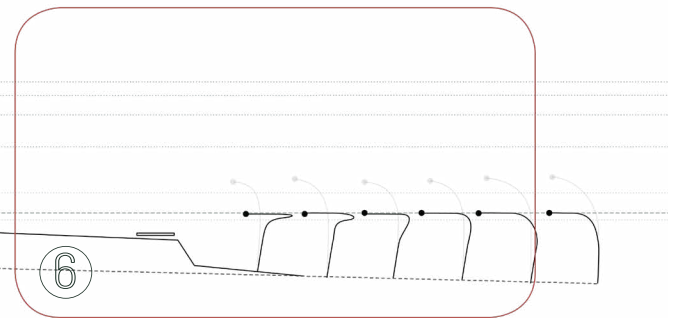
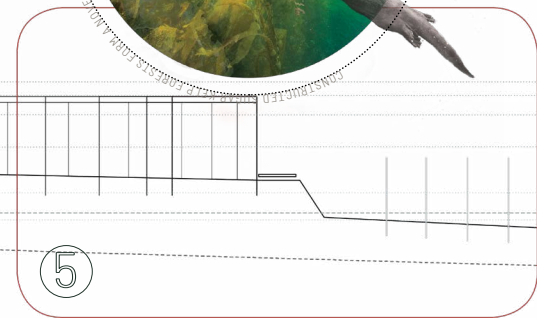
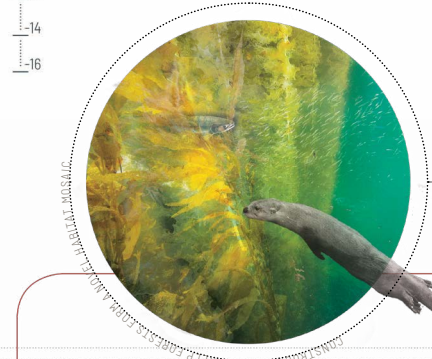
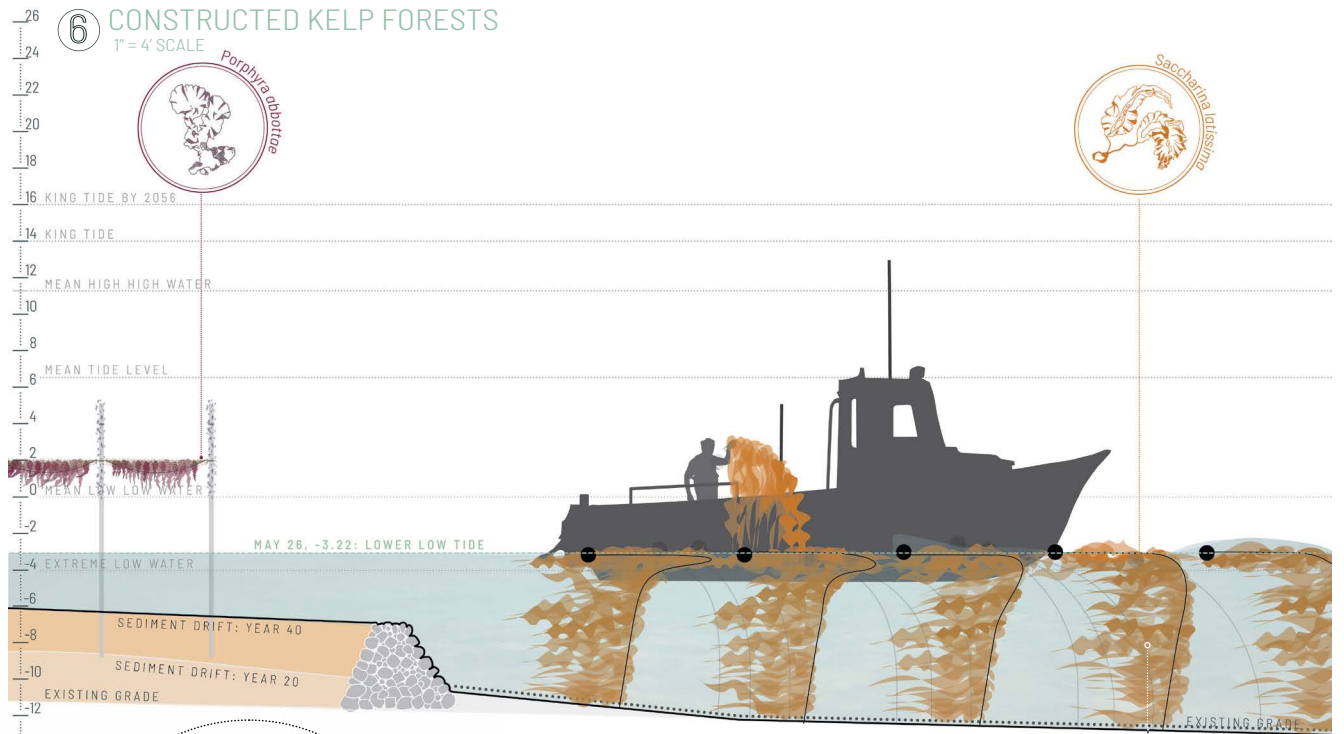


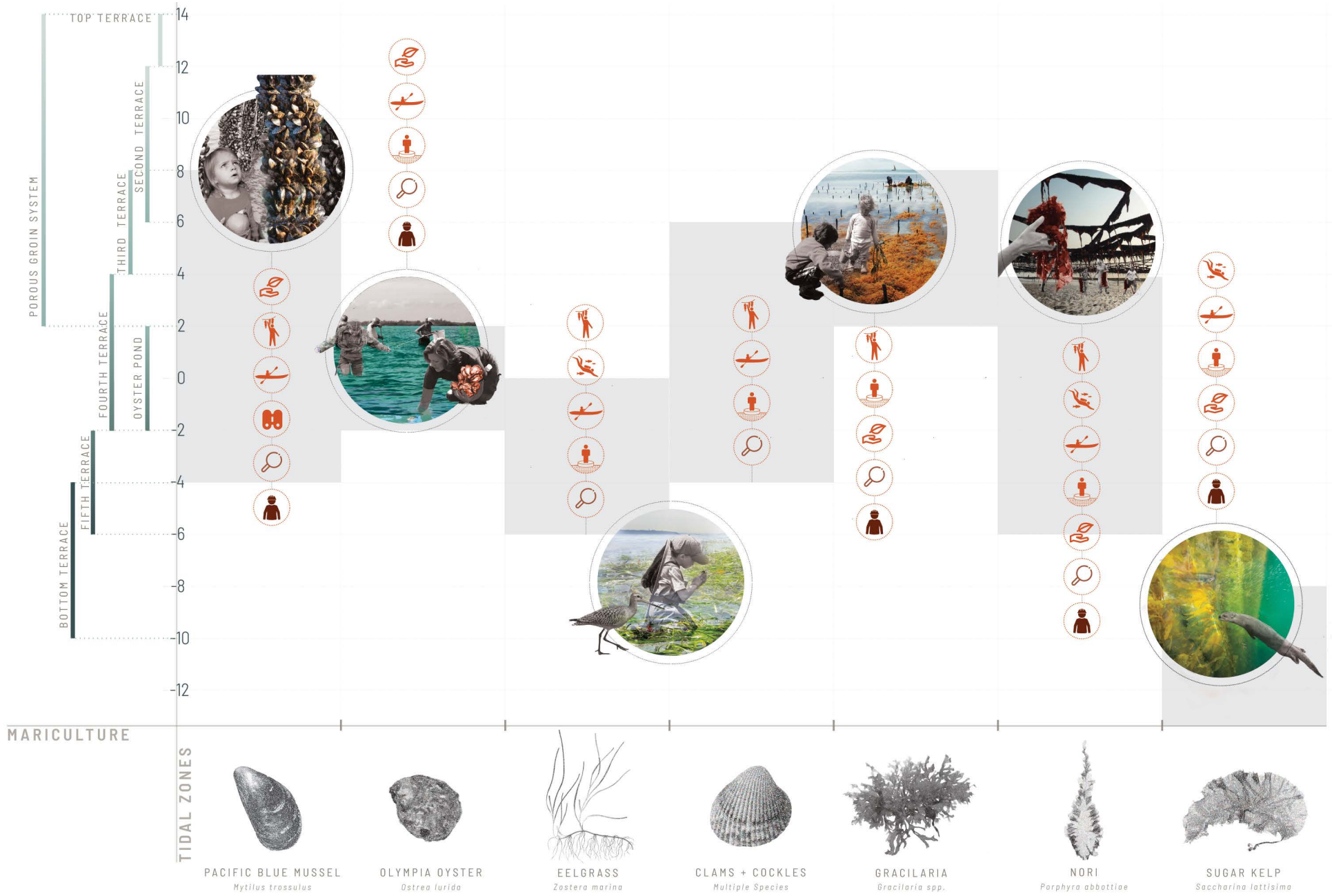




## 6 CONSTRUCTED KELP FORESTS

1" = 4' SCALE





## ICON LEGEND



OVERLOOK



DOG WALKING



DIRECT ACCESS TO PEDESTRIANS



DIVING



KAYAKING



ACCESS VIA FLOATING WALKWAY



PUBLIC HARVEST DAYS



MONITORING/EDUCATION



PERIODICALLY CLOSED FOR  
AQUACULTURAL OPERATIONS

Mariculture as a spatial design tool is morphologically and performatively plastic.

It is a model that changes as maricultural agents become established and form habitat for other non-cultivated creatures. An IMTA-based waterfront could go beyond retaining the land in spite of the sea. It could re-establish an interstitial space for the organisms that make the intertidal zone a living place and a living infrastructure for a terrestrial urban center. In this way, the inter-tidal zone is both a threshold and a place. In conventional waterfront design, the intertidal zone is summarily overlooked as it is rarely understood as valuable as recreational space for urbanites or performative valuable as a softer form of shore protection infrastructure. As a result, the urban intertidal has been designed as the thinnest of spaces: a contour, a line, an edge.

In an urban world that is pressed for public space and in need of multi-faceted approaches to mitigating the uncertainty and risk at the water's edge, mariculture as a design tool offers a medium with which to reconceptualize the threshold between city and sea as a place again.





photo by : Tatyana Vashchenko

## REFLECTION

### *Design and Investigation Process:*

The design scenarios I explored and developed for North Beach respond to conditions specific to that site. Consequently, the design configurations that emerged out of this research are not directly transferable to sites beyond the Puget Sound and may not be transferable to all coastal sites within the Puget Sound. The application of multi-trophic mariculture as an ecological design tool, on the other hand, holds exciting potential and flexibility for enhancing and expanding the intertidal zone where site conditions allow. The research and design process that emerged out of this thesis will continue to serve me as I continue to investigate the potential of living systems as a waterfront design medium. Though my research and design process felt anything but linear in the moment, my overarching method for exploring and defining a design as research method can be summed up as follows:

1. Pose one or two driving questions to motivate the inquiry.
2. Develop an outline of auxiliary questions to identify and gain a high-level understanding of related topics.

3. Define the dialectical and physical setting for the inquiry: what theoretical and scientific discourses frame the topic in question and what physical terrain the inquiry engages.

4. Define and explore the nature of the strategy in question. What are its components? How is it deployed? How does it work? Has it worked anywhere else?

5. Define site selection criteria and choose a site upon which to apply and test the strategy.

6. Identify and explore the biological, ecological, geological and political dynamics at play across the setting and site. How do these dynamics, individually or in agglomeration, shape hypothetical outcomes of the design strategy across a site?

7. Select one or preferably several design scenarios and elaborate them further, extrapolating possible spatial, ecological and morphological outcomes based on the best available science.

At each step, consult experts in allied fields, formulate and reformulate questions and reflect on outcomes and lessons learned.

**opposite page:** A father and son take a moment to reflect at on a short stretch of unarmored shore at North Beach, where a creek forms a small delta between rip-rap walls.

## *Personal Reflection*

Though I had no idea I would choose to pursue a design thesis focused on integrated multi-trophic mariculture until mid-October 2017, I discovered and maintained a strong interest in urban waterfront design and marine ecology from the very start of my graduate studies, taking every opportunity I could to write and research on related topics. By the summer of 2017, I was still struggling to identify a finer-grained topic or narrative to pursue within the vast dialogue surrounding urban waterfronts, infrastructure and climate adaptation. Each year, it seems that there are hundreds if not thousands of design theses investigating and expounding upon the topic of climate adaptation of urban waterfronts, and while I would have inevitably learned a tremendous amount by carving my own path through this monumental topic, I felt compelled to craft a thesis inquiry that might add some new insight or perspective to this larger conversation. Examining and exploring the topic of public intertidal mariculture presented me with the opportunity to investigate a cultivation and production strategy of which I had only superficial knowledge to that point.

The process of learning more about the marine environment within which I strove to design, consisted of a seemingly perpetual feedback loop in which I would: 1) assume I know enough, 2) begin to draw and design, 3) discover I know very

little, 4) read, research and meet with experts from other disciplines, return to # 1) and cycle through the rest of the phases over and over again. At this point, I know enough to know that I know very little. In fact, I know just enough to derive significant pleasure from the assurance that in practice, I would never approach a similar project without a team of ecologists, biologists, geomorphologists, engineers, artists and spatial designers with whom to collaborate throughout the inquiry and design process. If anything, this thesis has been a process of growing my appreciation of other disciplines and their discrete contributions to a more holistic understanding of complex processes and conditions in a shifting and fluid terrain.

Having decided that I would explore multi-trophic mariculture as a medium for waterfront design with the aim of enhancing and expanding an emaciated intertidal zone, I proceeded with little precedent for how to begin educating myself on the issues enmeshed within this topic. Consequently, I started by asking <sup>11</sup> what integrated multi-trophic aquaculture really is and how it is being implemented. However, before I could really begin answering this question, I realized that to make my thesis accessible to a broader audience, I would have to back up and define aquaculture: what it is, its many manifestations and quickly move beyond tangential questions about Atlantic salmon farming in the Northwest. Meanwhile, <sup>12</sup> I began to research the current state of Puget Sound's shorelines in

order to understand how IMTA might fit into the trajectory of coastal development and efforts at restoration. This inquiry uncovered for me, the conditions that made a maricultural intervention all the more compelling. The next motivating question that emerged was,<sup>13</sup> whether anyone had linked IMTA with ecosystem services and eco-revelatory experience for humans. I found that scientists are beginning to explore the ecosystem services afforded by IMTA and that one art photographer named Tugo Cheng had recently put on an exhibit titled Coastal Geometries, re-framing intertidal and nearshore aquaculture in Fujian, China, as abstracted, immersive and captivating spatial patterns that are both unfamiliar and evocative to the Western viewer, accustomed to admiring the beauty of land-based agriculture but new to such representations of aquaculture.

Recognizing that I was unlikely to encounter an inquiry and precedent sufficiently analogous to my own, I began to meet with marine scientists, marine policy experts, marine ecologists, phycologists, an oceanographer, and a coastal geomorphologist, to ask them the questions I had, generate new ones, and run my design explorations by them. Everyone I encountered met me with curiosity and enthusiasm and shared their time generously, meeting with me on Skype, corresponding by e-mail and meeting with me time and time again. Through my conversations with Dr. Ryan Kelly and Professor Si Simenstad,<sup>14</sup> I hatched the intention to draw a trophic web that synthesizes prototypical interspecies metabolic flows within Puget Sound's intertidal zone. However, I soon

recognized why only one such web has ever been drawn (by Si Simenstad in 1979), and why no one since has attempted to advance this effort. That drawing alone would have taken many years of research and a robust expertise in intertidal ecology. However, this unsuccessful effort did give me a better understanding of the complexity of marine ecology, biological community dynamics and the extensive journey that seaweed takes through the many animals inhabiting the intertidal zone. Meanwhile,<sup>15</sup> I worked to attempted to apply my growing awareness of Puget Sound-wide coastal mapping and spatial analysis efforts by consolidating available geospatial data into a geodatabase that helped identify site selection criteria, potential sites and eventually to narrow down the list of sites for design exploration.<sup>16</sup> Perhaps the most pivotal phases of this exploration consisted of my conversations with Miles Logsdon, director of the UW School of Oceanography's Spatial Analysis Lab and Hugh Shipman, coastal geomorphologist with the Washington Department of Ecology. Though one of these conversations took place in the beginning of January and the other at the end of April, each helped to crystallize my understanding of which site conditions are formative and should/would shape and reshape any design interventions on a north-facing coastal site. Just as Miles had suggested at the outset of this project, an understanding of the tides, wind, fetch and bathymetry on a coastal site is requisite for any landform or structural intervention in Puget Sound's coastal environments. Hugh linked these site conditions to the play of sediment drift, accretion and erosion across the site in





photo by : Tatyana Vashchenko

**above:** Children repurpose driftwood in the upper intertidal reaches of an dearmored and "sediment nourished" segment of North Beach.

question, reviewing and revising the scenarios I had been developing for the previous month. In conversation with Hugh, I came to face the intrinsic indeterminacy of any intervention within an environment as fluid and understudied as Puget Sound's shores. The structure of a design thesis required that I choose a scenario and elaborate it more fully, extrapolating a trajectory and a possible outcome. An effort that turned into an instructive exercise in landform grading, visualization and communication. This thesis has not brought me to anything remotely resembling a resolved proposal for a site. Rather, it has offered me the opportunity to practice exploring design challenges involving academic territories I find foreign, employing tools and media with which I have no experience.

Though this thesis ended up focusing primarily on the *why, what, where and how* aspects of multi-trophic mariculture in an urban public waterfront, I was initially motivated by a desire to focus this thesis on exploring the rich experiential and phenomenological qualities of intertidal multi-trophic mariculture. I recognize now that in order to focus my thesis on these experiential and somatic qualities of maricultural places, I would have required the time and resources to travel, experience and document intertidal mariculture where it actually exists. This is something I hope to pursue through a travel grant or fellowship. The questions I would like to explore on this next stage of inquiry are numerous: how does it feel to walk among curtains of seaweed which just hours ago, had been drifting in the surf, or to wind between columns of mussels, their coarse violet mass vibrating with crustaceans. How does offering

access to a cultivated intertidal bring attention to the ongoing management and impact that humans exercise over marine environments? How does this place shape one's view and perception of the waterfront, drawing attention away from the horizon beyond, and down towards the living systems and processes at play beneath one's feet?

Additionally, diving deeper into an exploration of the experience of an intertidal maricultural park from other species' points of view poses an intriguing challenge. What does it take to design a living system with non-human interests as the primary priority? How would such a novel mosaic of habitats feel to a juvenile salmon or an octopus searching for a nook to occupy? How do these maricultural infrastructures and agents influence and reshape this place? How do the cultivated and propagated organisms host, attract or repel other organisms?

Some of these questions I started out with and some developed over the course of this research, many of which remain largely unanswered. Reflecting on my inquiry and thesis process, I recognize that it was necessary for me to take the time I did to learn more about Puget Sound's regional and temporal setting, the maricultural strategy and the dynamics that would shape and reshape spatial and structural interventions in the intertidal realm. Yet I also recognize that this came at the expense of exploring the spatial and somatic qualities of this place as I had originally intended to do. I look forward to exploring these questions as I move on to a different phase of my professional and academic career.



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## BIBLIOGRAPHY

- Beatley, Timothy. *Blue Urbanism: Exploring Connections Between Cities and Oceans*. Washington, DC: Island Press, 2014.
- Belanger, P. "Landscape As Infrastructure." *Landscape Journal* 28, no. 1 (2009): 79–95. <https://doi.org/10.3368/lj.28.1.79>.
- Bilhimer, Dustin. "Reducing Puget Sound Nutrients." Department of Ecology- Water & Shorelines, 2018. <https://ecology.wa.gov/Water-Shorelines/Puget-Sound/Helping-Puget-Sound/Reducing-Puget-Sound-nutrients>.
- Carman, Randy, Kathy Taylor, and Hugh Shipman. "Puget Sound Partnership – Setting Targets for Dashboard Indicators: Shoreline Armoring." Olympia, Washington, 2011.
- Costa-Pierce, Barry A, ed. *Ecological Aquaculture: The Evolution of the Blue Revolution*. Malden, MA: Blackwell Science Ltd, 2002.
- Cox, Jack, Keith Macdonald, Tom Rigert, Washington, Keith Mackdonald, and Tom Rigert. "Engineering and Geotechnical Techniques for Shoreline Erosion Management in Puget Sound." V. 4. Olympia, Washington, 1994.
- Davis, Joth, Betsy Peabody, Puget Sound, and Restoration Fund. "Using Seaweeds to Mitigate Ocean Acidification in the Salish Sea." Seattle, WA, 2017.
- Dethier, Megan N., Wendel W. Raymond, Aundrea N. McBride, Jason D. Toft, Jeffery R. Cordell, Andrea S. Ogston, Sarah M. Heerhartz, and Helen D. Berry. "Multiscale Impacts of Armoring on Salish Sea Shorelines: Evidence for Cumulative and Threshold Effects." *Estuarine, Coastal and Shelf Science* 175 (2016): 106–17. <https://doi.org/10.1016/j.ecss.2016.03.033>.
- Druehl, Louis D., and Bridgette Clarkston. *Pacific Seaweeds: A Guide to Common Seaweeds of the West Coast*. Second. Madeira Park, British Columbia: Harbour Publishing, 2016.
- Earle, Sylvia A. *The World Is Blue*. Washington, DC: National Geographic Society, 2009.
- EPA. "National Water Program: Best Practices and End of Year Performance Report." Washington, DC, 2013.

**left:** Mussels form striations along the surface of a boat ramp at Redondo Beach.

- Evans, La Kenya, and Matthew S. Edwards. "Bioaccumulation of Copper and Zinc by the Giant Kelp *Macrocystis Pyrifera*." *Algae* 26, no. 3 (2011): 265–75.
- Finlayson, David. "The Geomorphology of Puget Sound Beaches," 2006. <http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA477465>.
- Granada, Luana, Nádia Sousa, Sofia Lopes, and Marco F.L. Lemos. "Is Integrated Multitrophic Aquaculture the Solution to the Sectors' Major Challenges? – a Review." *Reviews in Aquaculture* 8, no. 3 (2016): 283–300. <https://doi.org/10.1111/raq.12093>.
- Hanley, M. E., S. P.G. Hoggart, D. J. Simmonds, A. Bichot, M. A. Colangelo, F. Bozzeda, H. Heurtefeux, et al. "Shifting Sands? Coastal Protection by Sand Banks, Beaches and Dunes." *Coastal Engineering* 87 (2014): 136–46. <https://doi.org/10.1016/j.coastaleng.2013.10.020>.
- Harrison, Ariane Lourie. "Animal Interfaces for a Post-Human Territory." In *ACSA 101: New Constellations New Ecologies*, edited by Ila Berman and Edward Mitchell, 352–61. ACSA Press, 2013.
- Hoek, Ronald E. Van den, Marcela Brugnach, Jan P.M. Mulder, and Arjen Y. Hoekstra. "Analyzing the Cascades of Uncertainty in Flood Defence Projects: How 'Not Knowing Enough' Is Related to 'Knowing Differently.'" *Global Environmental Change* 24, no. 1 (2014): 373–88. <https://doi.org/10.1016/j.gloenvcha.2013.11.008>.
- Hughes, Adam D, Richard A Corner, Maurizio Cocchi, Karen A Alexander, Shirra Freeman, Dror Angel, Mariachiara Chiantore, et al. "Beyond Fish Monoculture - Developing Integrated Multi-Trophic Aquaculture in Europe." Florence, Italy, 2016.
- Interstice Architects. "Bay Remediation Site: 1," 2009. <http://www.intersticearchitects.com/?project=bay-remediation-site-1>.
- Kroeker, Kristy J., Rebecca L. Kordas, Ryan Crim, Iris E. Hendriks, Laura Ramajo, Gerald S. Singh, Carlos M. Duarte, and Jean Pierre Gattuso. "Impacts of Ocean Acidification on Marine Organisms: Quantifying Sensitivities and Interaction with Warming." *Global Change Biology* 19, no. 6 (2013): 1884–96. <https://doi.org/10.1111/gcb.12179>.
- Kruckeberg, Arthur R. *The Natural History of Puget Sound Country*. Edited by Weyerhaeuser Environmental Book. 2nd Print. Seattle: University of Washington Press, 1995.
- Ma, Michelle. "First Salish Sea-Wide Shoreline Armoring Study Shows Cumulative Effects on Ecosystem." *UW News*. April 18, 2016.
- Neudorf, Christina M., Nicole Smith, Dana Lepofsky, Ginevra Toniello, and Olav B. Lian. "Between a Rock and a Soft Place: Using Optical Ages to Date Ancient Clam Gardens on the Pacific Northwest." *PLoS ONE* 12, no. 2 (2017): 1–21. <https://doi.org/10.1371/journal.pone.0171775>.
- NOAA. "What Is Aquaculture?," 2011. <http://www.noaa.gov/stories/what-is-aquaculture>.

- Nordenson, Guy, Catherine Seavitt, and Adam Yarinsky. *On the Water: Palisade Bay*. Edited by Hatje Cantz. 1st ed. New York, New York: Museum of Modern Art, 2010.
- Orff, Kate. *Toward an Urban Ecology*. New York, New York: Monacelli Press, 2016.
- Partnership, Puget Sound. "State of the Sound." Olympia, Washington, 2017. [www.psp.wa.gov/sos](http://www.psp.wa.gov/sos).
- "Process-Based Restoration." Puget Sound Nearshore Ecosystem Restoration Project, 2016. [http://www.pugetsoundnearshore.org/natural\\_processes.html](http://www.pugetsoundnearshore.org/natural_processes.html).
- Redmond, Sarah, Lindsay Green, Charles Yarish, Jang Kim, and Christopher Neefus. *New England Seaweed Culture Handbook-Nursery Systems*. Connecticut Sea Grant, 2014. <http://seagrant.uconn.edu/publications/aquaculture/handbook.pdf>.
- Ross, D.A. *Introduction to Oceanography*. New York, New York: HarperCollins, 1995.
- SeaChoice. "Aquaculture Methods." SeaChoice for Healthy Oceans. Accessed May 19, 2018. <http://www.seachoice.org/info-centre/aquaculture/aquaculture-methods/>.
- Shipman, Hugh. "A Geomorphic Classification of Puget Sound Nearshore Landforms," 2008. [http://pugetsoundnearshore.org/technical\\_papers/geomorphic\\_classification.pdf](http://pugetsoundnearshore.org/technical_papers/geomorphic_classification.pdf).
- Shipman, Hugh. "West Point, Seattle, Washington." Coastal Care, 2011. <http://coastalcare.org/2010/11/west-point-seattle-washington/>.
- Shipman, Hugh. "West Point February 20, 2012." Gravel Beach, 2012. <http://gravelbeach.blogspot.com/2012/02/west-point.html>.
- Shipman, Hugh. "West Point July 07, 2013." Gravel Beach, 2013. <http://gravelbeach.blogspot.com/2013/07/west-point.html>.
- Shipman, Hugh. "West Point November 12, 2009." Gravel Beach, 2009. <http://gravelbeach.blogspot.com/2009/11/west-point.html>.
- Shipman, Hugh, Andrea MacLennan, and Jim Johannessen. "Puget Sound Feeder Bluffs: Coastal Erosion as a Sediment Source and Its Implications for Shoreline Management." Olympia, Washington, 2014.
- State, Washington. *Shoreline Modifications (2004)*.
- The Burke Museum of Natural History and Culture. "The Archaeology of West Point." The Burke Museum, 2003. <http://www.burkemuseum.org/static/westpoint/>.
- Thomas, Susan A. "Integrated Multi-Trophic Aquaculture: A Workshop." edited by Susan Thomas, 1-46. Port Angeles, Washington: Peninsula College, 2011.

US Department of Commerce, National Oceanic and Atmospheric Administration. "NOAA National Ocean Service Education: Tides and Water Levels." NOAA Ocean Service Education, 2017. [https://oceanservice.noaa.gov/education/kits/tides/tideso2\\_cause.html](https://oceanservice.noaa.gov/education/kits/tides/tideso2_cause.html).

Washington Department of Fish and Wildlife. "Clams." Fishing and Shellfishing, 2018. <https://wdfw.wa.gov/fishing/shellfish/clams/>.

Washington Sea Grant. "Shellfish Aquaculture in Washington State: Final Report to Washington State Legislature," no. December (2015): 1-84.

Yarish, Charles, J K Kim, and G P Kraemer. "Seaweed Aquaculture for Nutrient Bioextraction in Long Island Sound and the Urbanized Bronx River Estuaries." Stamford, Connecticut, 2013.



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