

Amphibious Futures:
Rethinking Coastal Adaptation in Padilla Bay through Multispecies Design

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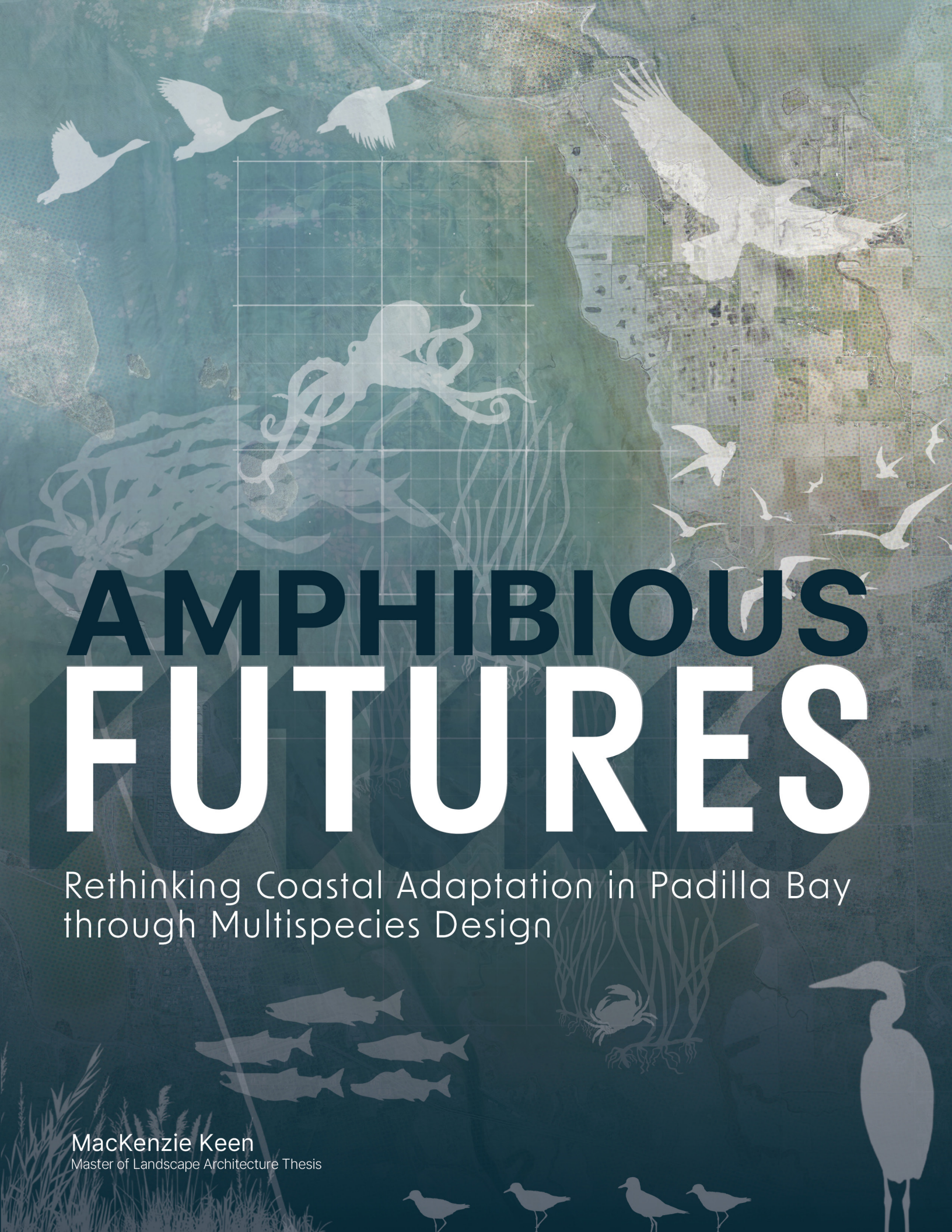
Abstract

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Climate change is transforming coastal environments and threatening human and ecological communities. Conventional coastal planning overlooks the dynamic nature of these landscapes, fixes boundaries between land and water in place, and prioritizes human interests over ecological health. Coastal planning must shift away from anthropocentrism toward strategies that work with coastal dynamics and recognize the interdependence of human and non-human communities. This thesis takes a multi-scalar approach, using eelgrass as a lens to investigate the socio-ecological systems and coastal adaptations that shape the Padilla Bay Estuary, and to examine how environmental and anthropogenic stressors affect ecological health on a larger scale. Through this analysis, the project identifies opportunities for design intervention and develops design principles that rethink coastal adaptation through a multispecies perspective. These principles inform speculative design visions for the future of Padilla Bay, illustrating what futures could emerge when coastal adaptation strategies prioritize multispecies coexistence. Ultimately, this work aims to contribute to broader conversations around multispecies design and how coastal environments can adapt to climate change and continue to thrive in the future.



AMPHIBIOUS FUTURES

Rethinking Coastal Adaptation in Padilla Bay
through Multispecies Design

MacKenzie Keen
Master of Landscape Architecture Thesis

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INTRODUCTION

This chapter frames the problem of coastal adaptation in the context of climate change and situates the thesis within broader questions of ecological change, infrastructure, and multispecies coexistence. It introduces Padilla Bay as the study site, establishes the research questions, and presents the conceptual framework that guides the thesis.

CHANGING COASTS

Coastal landscapes are changing under accelerating climate pressures. Rising sea levels, shifting precipitation patterns, and increasing frequency of extreme events are reshaping how water, sediment, and ecological systems interact. These changes are uneven and difficult to predict, emerging differently across regions and shaped by both environmental processes and human decisions (Flower et al. 2025).

Many existing approaches to coastal adaptation were developed under assumptions of stability. Strategies such as shoreline armoring, flood control infrastructure, and fixed land uses attempt to manage or contain change by holding shorelines in place. Over time, this leads to the disruption of the ecological processes that sustain coastal systems (Nordenson, Seavitt, and Chapman 2018; Huber 2024). While these approaches can reduce short-term risk, they frequently contribute to long-term instability in complex estuarine environments (Mauger et al. 2015; Miller et al. 2018). As sea levels rise and coastal processes become less predictable, they are also becoming increasingly difficult to maintain.

This creates a challenge for coastal adaptation. In dynamic estuarine environments, the line between land and water is not fixed. Yet many adaptation strategies continue to reinforce that divide, often prioritizing the protection of human infrastructure while doing little to support the surrounding ecosystem. In estuaries where human and ecological systems are deeply intertwined, this raises the question of how coastal landscapes might need to adapt differently to be more resilient to climate change.

PADILLA BAY AS A CASE STUDY

Padilla Bay is a large, shallow estuary located in Skagit County, Washington. It sits at the intersection of multiple competing land uses and management systems, including agricultural drainage, flood-control infrastructure, industrial activity, recreational use, and ecological conservation. These overlapping pressures make it a useful site for examining how coastal adaptation decisions are made, and what values and assumptions shape them. Figure 1.1 summarizes the overlapping characteristics that make Padilla Bay an interesting and complex place to study.

The bay's physical form is the result of historic sediment deposition from the Skagit River. However, diking, river regulation, and agricultural drainage have largely severed the bay from that sediment source. Because of this, Padilla Bay is considered an orphaned estuary (Washington State Department of Ecology 2008). Despite this disconnection, Padilla Bay retains significant ecological value. It contains approximately 7,500 acres of eelgrass, one of the largest contiguous eelgrass meadows in the United States (Washington State Department of Ecology 2008). This meadow supports sediment stabilization, nutrient cycling, carbon storage, and habitat for a wide range of species (Washington State Department of Ecology 2008). The Padilla Bay National Estuarine Research Reserve (NERR) supports ongoing monitoring, education, and stewardship of these resources. At the same time, the eelgrass and the broader estuary remain vulnerable to water quality degradation, altered sediment dynamics, and the cumulative effects of surrounding land use.

Management of Padilla Bay is shaped by decisions made across multiple scales, on adjacent farmland, along drainage channels, and through the infrastructure that governs water movement across the watershed. These decisions affect water quality, sediment movement, and habitat conditions, and their effects accumulate over time.

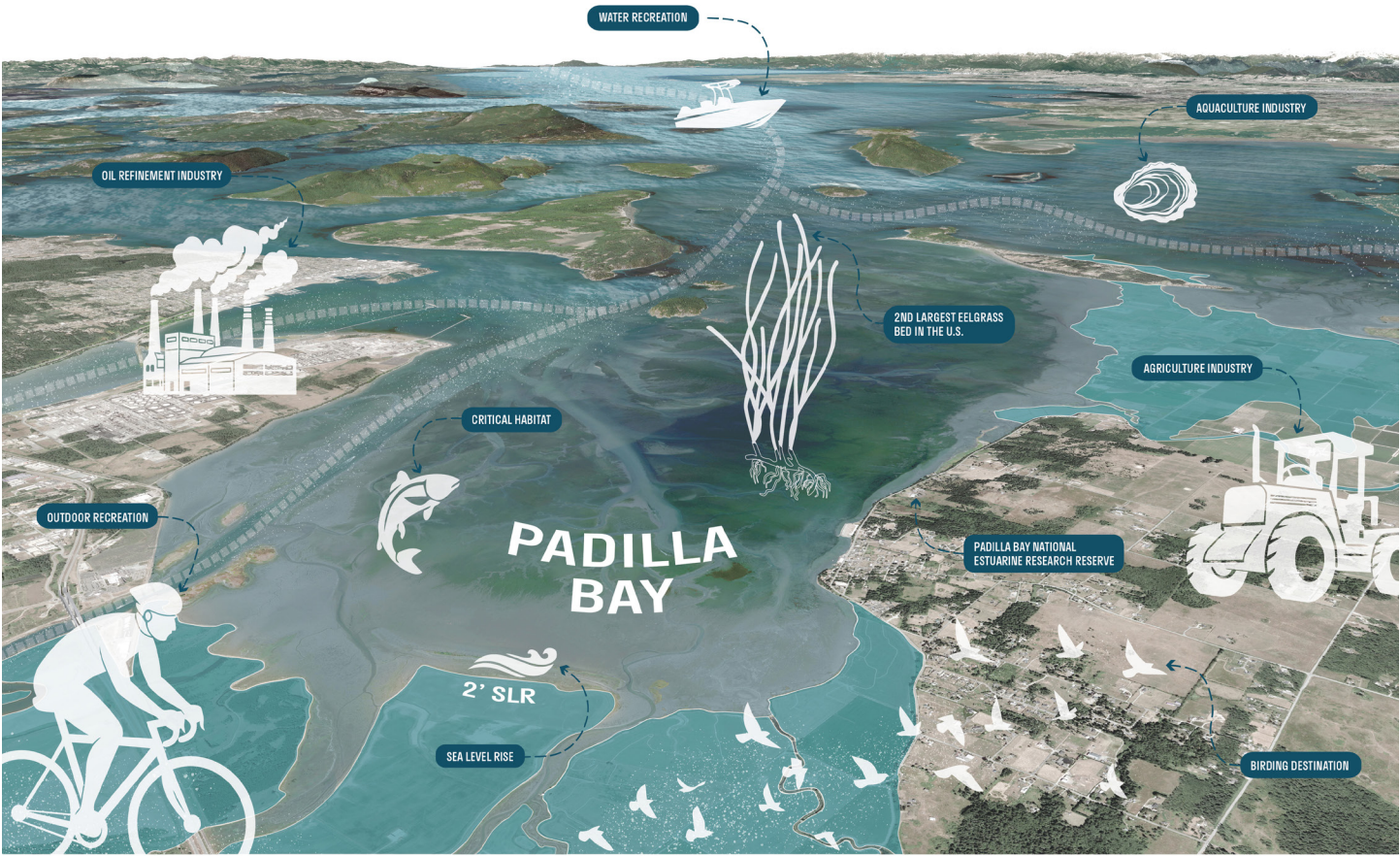


Figure 1.1: Conceptual site context diagram of Padilla Bay. Image by author.

This combination of ecological significance, physical alteration, and multi-stakeholder management makes Padilla Bay a productive site for examining coastal adaptation. As sea level rise and increased flooding place greater stress on the estuary and surrounding landscape, the tensions between agricultural, ecological, and community interests will become more difficult to manage. This thesis uses Padilla Bay as a lens to examine how those tensions are currently navigated, and what frameworks might better support adaptation decisions going forward.

THESIS OVERVIEW

This thesis investigates coastal adaptation in Padilla Bay by examining the socio-ecological systems that shape the estuary and influence ecological health. The project focuses

on eelgrass as a way to understand how environmental and human-driven stressors affect these systems over time. A multiscale approach traces these stressors across the region. This includes hydrological systems, agricultural practices, and infrastructure that produce conditions within the bay. By working across several scales, the project connects larger regional processes to site-specific conditions.

The analysis in this thesis forms the basis for a set of design interventions. The project identifies opportunities for intervention and develops design principles that address coastal adaptation through a multispecies perspective. These principles are tested through speculative design scenarios that examine how different strategies affect both human and more-than-human systems. The goal is not to produce a single design outcome, but to develop a series of possible futures for Padilla Bay.

CONCEPTUAL FRAMEWORK

The overlapping ecological, social, and political dynamics shaping Padilla Bay challenge conventional approaches to coastal adaptation, which often prioritize single objectives such as flood control or land protection. In a system defined by uncertainty, interdependence, and ongoing change, design approaches that seek to stabilize or optimize for one outcome risk reinforcing existing tensions rather than addressing them. This project adopts a conceptual framework centered on relationships, more-than-human agency, and temporal change to understand and engage with Padilla Bay as a dynamic and complex estuarine landscape.

The framework draws on three interrelated concepts: coastal adaptation, multispecies theory, and speculative design. These provide the foundation for the research and the organizational structure for the literature review. Figure 1.2 illustrates how these concepts are

defined individually and how they relate to one another. The areas of strongest overlap are where this research draws most significantly. The figure also reflects the multiscalar nature of the project and suggests that these concepts can be applied across the different scales it addresses.

The research is guided by three questions that structure the project’s progression from understanding socio-ecological systems of Padilla Bay to exploring design opportunities and speculative futures:

What broader socio-ecological systems influence eelgrass in Padilla Bay?

How can multispecies perspectives inform coastal adaptation strategies in Padilla Bay?

What futures for Padilla Bay emerge when coastal adaptation strategies center multispecies perspectives?

These questions establish a process that moves from understanding ecological relationships, to developing design strategies, to testing those strategies through speculative futures. The objective is to produce design visions that support the ongoing work of the Padilla Bay National Estuarine Research Reserve and contribute to broader discussions on coastal adaptation.

incorporating those perspectives into the overall design process. It examines the socio-ecological systems that influence the health and persistence of the estuary, identifies environmental and human-driven stressors, and considers how human systems are directly connected to ecological processes. The project then develops speculative scenarios to test how different approaches to coastal adaptation affect both human and more-than-human systems over time.

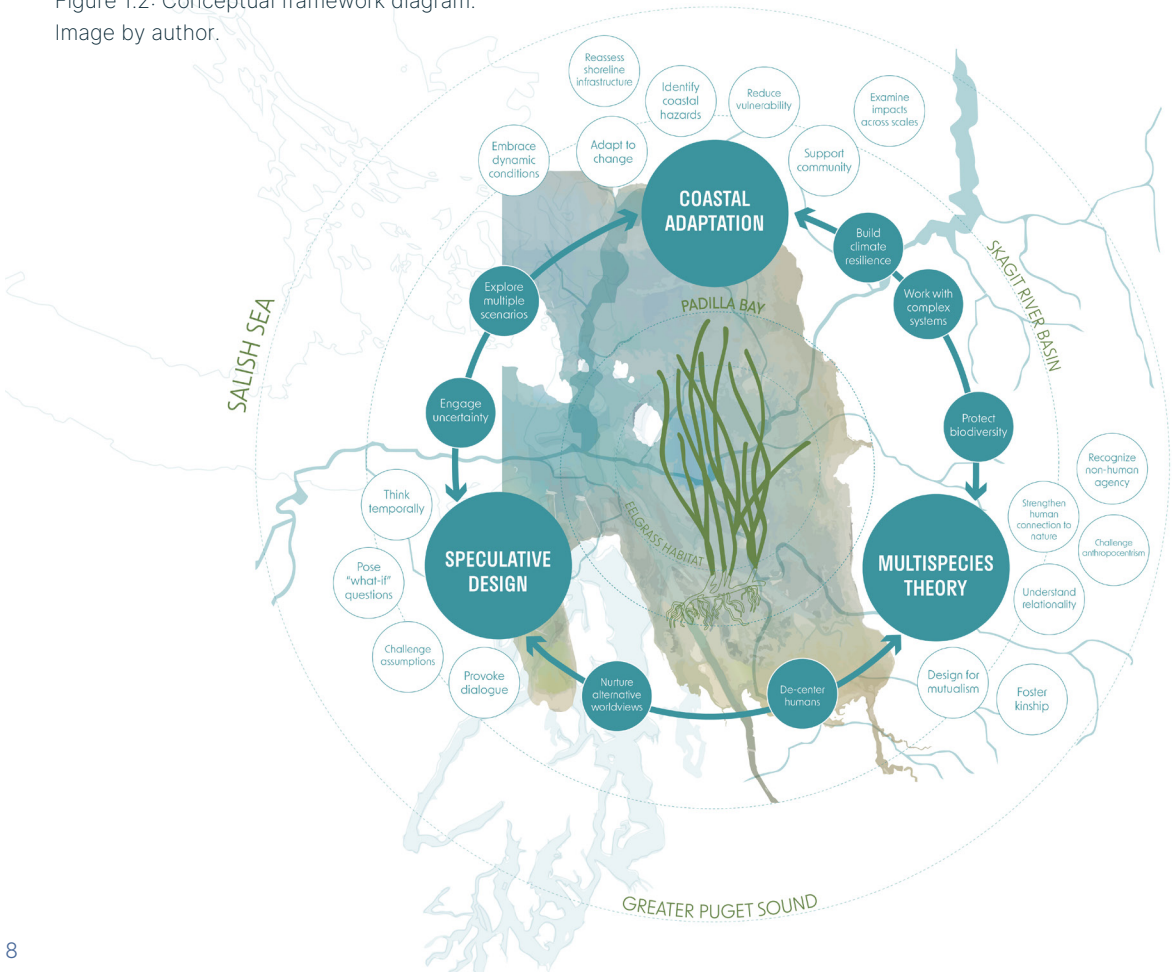
As designers of both natural and built environments, landscape architects shape the conditions that affect multiple species. The impacts of past decisions that have prioritized human needs while degrading ecological systems are visible in coastal landscapes through increasing flooding, habitat loss, and failing infrastructure. Expanding design practice to account for more-than-human systems is one way to begin addressing these conditions. This project contributes a framework for doing so that can be applied and adapted in future work integrating multispecies perspectives into coastal design.

RELEVANCE TO THE FIELD OF LANDSCAPE ARCHITECTURE

As a master’s degree student in Landscape Architecture, I am interested in how multispecies theory can be applied to coastal adaptation projects. I am motivated by the increasing frequency of climate-related impacts in coastal landscapes and the need to understand how communities and ecosystems may respond to these changing conditions. This research expands my understanding of the challenges facing coastal environments and tests how new perspectives can inform design. Multispecies theory offers a way to reframe how landscapes are understood and designed, but its application in landscape architecture practice remains limited. This project responds to that limitation by exploring how multispecies perspectives might inform coastal adaptation.

While multispecies theory is well established in disciplines such as geography, anthropology, and environmental humanities, there is limited guidance on how to apply it in design practice. This thesis addresses the gap between theory and practice by testing how multispecies perspectives can inform design decisions in a specific coastal adaptation project. By working through a particular site and species, it develops methods for understanding landscapes from the perspective of other forms of life and for

Figure 1.2: Conceptual framework diagram.
Image by author.



LITERATURE REVIEW

This chapter examines literature on coastal adaptation, multispecies theory, and speculative design as the conceptual foundation for the thesis. Together, these areas of scholarship help frame how coastal futures might be reimaged beyond conventional human-centered approaches.

PART 1: COASTAL ADAPTATION

EFFECTS OF CLIMATE CHANGE ON COASTS

Climate change is altering water systems and reshaping coastal environments (Cipriani 2024). Rising sea levels, stronger storms, and shifting precipitation patterns are changing how water moves through landscapes (Cipriani 2024; Newman and Qiao 2022). These processes affect flooding, erosion, and sediment distribution across coastal regions. These changes increase variability and unpredictability in coastal conditions, leading to more frequent flooding and altered sediment and salinity patterns (Mathur and da Cunha 2009; Cipriani 2024). Together, these changes reshape the structure and function of coastal systems.

Coastal environments operate through interactions among water, land, and living systems. These interactions are not fixed. They change over time as water moves through the landscape (Mathur and da Cunha 2009). Shorelines migrate, wetlands expand or contract, and zones of inundation shift in response to these processes (Nordenson, Seavitt, and Chapman 2018). These dynamics are inherent to coastal landscapes, yet they are often constrained by management approaches that treat shorelines as fixed boundaries.

These evolving conditions highlight a clear contrast: traditional planning and design often assumes that land and water can be separated by fixed boundaries; new climate realities expose the limitations of this assumption. Traditional control-based strategies rely on static boundaries to manage water, but increasing dynamism in water systems makes it difficult to maintain them.

As these fixed approaches lose effectiveness, emerging methods highlight the benefits of embracing variability and working with water’s natural processes. Recognizing variability as fundamental marks a significant strategic shift from controlling water to adapting with it.

LIMITS OF CONVENTIONAL COASTAL ADAPTATION

Coastal adaptation has historically relied on control-based strategies. Seawalls, levees, and dikes are used to stabilize shorelines and protect human settlements by fixing in place the artificial boundary between land and water (Huber 2024; Newman and Qiao 2022). These approaches assume that coastal systems can be controlled and that environmental conditions will remain relatively stable over time. Accordingly, infrastructure is typically designed using historical data, including past storm events, tidal ranges, and sediment patterns (Newman and Qiao 2022).

Under current conditions, these historic assumptions are no longer reliable. Sea-level rise and increased storm intensity are changing coastal dynamics, making infrastructure designed for past conditions less effective (Newman and Qiao 2022). In addition, control-based interventions also alter the systems they are intended to manage. For example, seawalls and similar structures redirect wave energy, change patterns of erosion, and disrupt sediment flows

that sustain beaches and wetlands (Nordenson, Seavitt, and Chapman 2018). These impacts often extend beyond the immediate site and can increase vulnerability in adjacent areas.

Many of these effects develop gradually. Changes in sediment distribution, habitat conditions, and shoreline form may not be immediately visible, making it difficult to trace cause and effect. This allows control-based strategies to persist even as they undermine long-term system function (Holmes 2020; Nordenson, Seavitt, and Chapman 2018). More broadly, this reflects a tendency to reduce complex environmental dynamics to discrete problems that can be addressed through technical intervention, a pattern described as *landscape solutionism* (Holmes 2020). This approach prioritizes clear design outcomes but does not account for the dynamic and interconnected processes that shape coastal systems. Consequently, control-based strategies can increase long-term risk. While they may provide short-term protection, they disrupt the processes that sustain coastal landscapes and can lead to greater instability over time (Nordenson, Seavitt, and Chapman 2018; Huber 2024).

RETHINKING COASTAL SYSTEMS

In response to the limitations of control-based adaptation, coastal systems are increasingly understood as dynamic and interconnected. Coasts are shaped by tidal movement, flooding, erosion, sediment transport and deposition, habitat distribution, and human land management decisions (Mathur and da Cunha 2009). These processes shape coastal landscapes over time and produce conditions that change across space and season.

This understanding questions the idea that land and water are completely separate. Instead, coastal environments are defined by varying degrees of wetness, with conditions shifting between wet and dry rather than being clearly divided (Mathur and da Cunha 2009). Shorelines move, wetlands grow or shrink, and flood zones change over time (Nordenson, Seavitt, and Chapman 2018). These shifting patterns are a natural part of how coasts work, both physically and from a design perspective. These dynamics also affect how people live in coastal areas. In many coastal areas, wet conditions are not rare events, but a normal and organizing part of life. People must adapt to water levels that change frequently, which makes stability temporary and requires constant adjustment through everyday habits (Camargo, Cortesi, and Krause 2025). This perspective challenges the idea of a strict divide between land and water, both physically and culturally. It shows that people experience coastal environments through uncertainty, ongoing change, and the need for flexibility.

Under conditions of climate change, shifting patterns of wetness and dryness are becoming more widespread. Environments that were once considered stable are increasingly characterized by periodic flooding, shifting shorelines, and changing hydrological regimes. As a result, living with unpredictable wetness is no longer confined to specific geographies, but is becoming a broader condition that coastal adaptation frameworks must address (Camargo, Cortesi, and Krause 2025).

At a broader scale, coastal systems can be understood as interconnected social, ecological, and physical systems, in which environmental processes and human decisions interact over time to shape coastal landscapes (Spencer et al. 2023). Coastal change results from external forces, such as sea-level rise, and from decisions about land development, infrastructure, and resource management. Coastal futures are

produced through these ongoing relationships, rather than determined by any single factor.

In response to the limits of fixed, control-based approaches, there is growing interest in flexible, hybrid, and nature-based strategies that accommodate the movement of water (Nordenson, Seavitt, and Chapman 2018; Huber 2024). Examples include restoring coastal wetlands, nourishing marshes with sediment, and building infrastructure designed to withstand or adapt to flooding. By working with the natural dynamics of the coast, these methods shift the focus from holding shorelines in place with hard structures to adapting to changing environmental conditions. Living shorelines, such as marshes and seagrass beds, help stabilize the coast by absorbing wave energy, trapping sediment, and gradually increasing elevation (Nordenson, Seavitt, and Chapman 2018). Because these systems are dynamic, they can continue to function as climate conditions change, provided they are supported and not overly restricted.

Realizing the adaptive benefits of flexible, hybrid, and nature-based strategies requires a shift in how coastal systems are understood and managed. Living infrastructure must be cultivated, monitored, and allowed to respond to environmental change rather than fixed in place through static design (Nordenson, Seavitt, and Chapman 2018; Huber 2024). This introduces a more process-based approach to design, where outcomes are shaped through ongoing interactions rather than being fully predetermined.

This shift to a more process-based approach also underscores the need for collaboration across disciplines and knowledge systems. Coastal adaptation involves interactions among physical processes, ecological dynamics, governance structures, and cultural practices, which cannot be addressed through technical expertise alone (Spencer et al. 2023). There is growing emphasis on integrating scientific, local, and Indigenous

knowledge to guide adaptation strategies, reflecting a broader recognition that the way coastal environments are understood is a product of both who is doing the understanding, and from what position (Nordenson, Seavitt, and Chapman 2018; Spencer et al. 2023). This has significant implications; not only for whose knowledge counts, but for what kinds of relationships with coastal environments are considered possible.

Despite these conceptual and practical shifts, coastal adaptation frameworks remain largely oriented toward human priorities. Strategies continue to focus on protecting settlements, infrastructure, and economic systems, with more-than-human systems treated primarily as instrumental resources (Newman and Qiao 2022; Huber 2024). Even as coastal systems are understood as dynamic and interconnected, this shift often does not extend to how value is assigned. Nature-based approaches are frequently justified in terms of ecosystem services, in which ecological systems are evaluated based on the benefits they provide to human populations.

The continued focus on human benefit reveals a tension within coastal adaptation literature. Coastal systems are increasingly understood as complex environments shaped through interactions between human decisions and ecological processes (Spencer et al. 2023; Wahl 2022). Yet many adaptation frameworks still treat ecological systems as passive settings to be managed or manipulated for human purposes.

This human-centered framing has important implications. Considering that coastal environments are shaped by both human and more-than-human processes, focusing only on human outcomes gives an incomplete picture of how these systems work together. As a result, environmental changes may be misinterpreted, key ecological processes can be overlooked, and interventions may fail to address the full complexity of coastal conditions.

Addressing the limits of human-centered coastal adaptation requires rethinking not just the techniques of coastal adaptation, but the assumptions that make those techniques seem sufficient in the first place. If coastal environments are co-produced through interactions between human and more-than-human processes, then frameworks organized around human benefit alone are incomplete and fundamentally misread the systems they claim to manage. What is needed is a different set of tools and a different way of understanding what coastal environments are and what relationships within them are worth sustaining.

PART 2: MULTISPECIES THEORY

THE ANTHROPOCENE LANDSCAPE

Contemporary socio-ecological challenges are often described as part of the Anthropocene, a proposed geological epoch defined by human activity as the dominant driver of global environmental change, including climate change, habitat loss, and pollution from greenhouse gas emissions and other contaminants (Haraway 2016; Tsing 2015). Within this framing, humans are positioned as the primary force shaping environmental systems. However, the effects of the Anthropocene do not unfold evenly. Environmental change is uneven and situated, resulting in patchy systems shaped by specific histories, ecologies, and human interventions (Tsing, Mathews, and Bubandt 2019).

To understand how the uneven conditions of the Anthropocene persist, work in multispecies theory examines how ecological systems continue within environments shaped by disturbance and loss. Present-day landscapes are influenced by past ecological and social processes, including colonization, extraction, and environmental destruction. These processes leave lingering effects even when they are no longer occurring or directly visible (Tsing et al. 2017). These ongoing effects can be understood as “hauntings,” where past human actions continue to shape present ecological conditions (Tsing et al. 2017). For design, this requires engaging with the historical processes that have produced the conditions of a site. At the same time, disturbance also generates new,

MULTISPECIES ENTANGLEMENT

often unexpected, multispecies interactions, and recognizing these emergent conditions presents opportunities to find new ways of working with landscapes in transition.

Understanding these conditions requires attention to past actions and the new interactions that emerge from them. Tsing (2015) describes this as the “art of noticing,” a practice of paying careful attention to the relationships that structure ecological systems. This process involves recognizing ecological interdependence and observing how different forms of life shape one another over time, particularly in damaged or disturbed environments. For designers, this suggests expanding site analysis beyond what is immediately visible or contained within a site. It requires understanding how larger systems, as well as historical and ecological processes, have unfolded over time to shape a place.

This way of reading Anthropocene landscapes suggests that ecological systems cannot be fully understood through generalizations, but must be examined through the specific conditions in which they occur (Tsing, Mathews, and Bubandt 2019). What appears to be a single system is made up of distinct patches shaped by different species, materials, and past actions. Some changes are highly visible, such as shoreline erosion or flooding. Others develop gradually or remain difficult to detect, including shifts in species composition, sediment movement, or water quality. Not all processes are legible at the same scale, and what is visible in one context may be imperceptible in another. Multispecies relationships are therefore always situated, emerging from specific histories and conditions (Tsing, Mathews, and Bubandt 2019). For design, this means engaging with the layered and entangled relationships that shape a site, rather than treating it as a stable or generalizable system. Understanding these relationships requires a focus on how species are entangled and how landscapes are co-produced.

Most conventional coastal planning focuses on protecting human safety, property, and economic interests. More-than-human life is often considered only in terms of its ecological value to people, such as habitat or ecosystem “services”. This framing reduces other beings to supporting roles and overlooks their agency and active role in shaping the landscape. It also assumes a degree of separation between humans and nature. Multispecies theory challenges this assumption by showing that landscapes are shaped through interactions between many forms of life that cannot be separated from one another (Haraway 2016; Tsing et al. 2017). In doing so, it decenters humans as the primary agent and positions humans as one participant in a broader network of interdependent species. Environmental crises are not problems that can be resolved through discrete interventions. They reflect ongoing conditions that require sustained engagement with human and more-than-human systems.

Ecological systems are described within this framework as *sympoietic*, or collectively produced (Haraway 2016). No organism or system operates independently. Each species affects others and is affected in turn, and environmental conditions emerge through these interactions over time. Environments are shaped by shared histories and relationships between human and more-than-human life. This framing emphasizes relationality as the basis of how landscapes function.

The concept of making kin builds on this understanding. It describes the formation of relationships across human and more-than-human life based on sustained attention and care (Haraway 2016). Haraway uses the idea of making kin to argue that responding to contemporary ecological conditions requires cultivating new kinds of relationships: ones that cross species boundaries and are based on mutual dependency. This is not limited to biological kinship, but extends to the broader

affiliations formed through shared environments and ongoing cohabitation (Haraway 2016). For design, this reorients practice away from managing systems and toward building and sustaining the conditions under which these relationships can persist. It also involves fostering kinship between humans and more-than-humans by strengthening human connection to ecological systems through ongoing engagement and stewardship, shifting the emphasis from controlling outcomes to supporting the processes that produce and maintain multispecies life.

Multispecies theory overlaps with ecological design by focusing on environmental processes, but it goes further by emphasizing how organisms encounter, inhabit, and change their environments. In this way, multispecies theories recognize the agency of all species as co-inhabitants. In contrast, ecological design often looks at system-level processes like hydrology, nutrient flows, and habitat function. While these are important, they can overlook the relational dynamics that actually produce and sustain these systems.

Engaging with multispecies complexity in practice requires tools that can make these relationships legible at the scale of design. Because multispecies relationships are often too complex to map all at once, focusing on a key species can provide a practical way to explore broader multispecies entanglements. Certain species play a disproportionate role in structuring ecological communities by creating conditions that support other forms of life (Bruno, Stachowicz, and Bertness 2003). These are known as *foundation species*. Oysters, kelp, and cordgrass are examples: each one modifies physical conditions in ways that make the surrounding environment more habitable for a wide range of other organisms. Since many ecological relationships are organized around foundation species, they can help make broader multispecies networks more visible. Focusing on a single foundation species in a design context does not reduce

the analysis to that species alone, but provides a specific point of entry for understanding the relationships that shape a landscape.

Methods for applying multispecies theory in design remain limited. Few established approaches exist for translating these ideas into spatial interventions, and most precedents are highly project-specific. Coastal environments are a productive context for examining this gap, as the proximity of ecological processes, physical dynamics, and human activity makes the question of how multispecies relationships are structured particularly relevant. Bridging this gap between theory and practice is a central concern of this research.

MULTISPECIES DESIGN IN COASTAL CONTEXTS

Coastal environments are among the most ecologically and culturally rich landscapes on the planet. They are shaped by the continuous interaction of tidal cycles, sediment movement, species activity, and human communities across multiple temporal and spatial scales (Uehara et al. 2019). This convergence of ecological, physical, and cultural forces makes coastal landscapes productive sites for examining how multispecies relationships are formed and transformed over time.

The concept of *satoumi* offers one framework for understanding what multispecies relationships look like in coastal environments. The term, which combines the Japanese words for ‘village’ and ‘sea’, refers to coastal areas where biological productivity and biodiversity are sustained through ongoing human interaction with marine ecosystems (Uehara et al. 2019). In these systems, fishing, restoration, and stewardship are woven into the rhythms

of the coast over generations, maintaining ecological health and human livelihood as part of the same continuous practice (Uehara et al. 2019). Biodiversity, ecosystem function, and human productivity develop together through this sustained engagement, rather than being managed as separate concerns (Uehara et al. 2019). This reflects a system of mutualism, in which human and more-than-human activities support one another, and where ongoing interaction strengthens ecological health and human livelihood over time. For design, satoumi is a useful point of reference because it grounds the relational thinking of multispecies theory in an actual place-based practice. It shows that sustained engagement between human communities and coastal ecosystems can be generative, producing conditions that support both ecological health and human livelihood over time. It provides a concrete example of what making kin looks like at the scale of a coastal community, and of what design might work toward in contexts where those relationships have been disrupted.

The kinds of relationships satoumi describes are not common in most contemporary coastal environments. Industrialization, large-scale infrastructure, and the separation of land from water have displaced the ongoing interactions between people and coastal ecologies that once structured life along the coasts (Orff 2016). The practices and knowledge that once sustained those relationships have, in many cases, been lost or permanently fragmented.

Multispecies theory provides a rich conceptual basis for understanding what those entanglements can look like and why they matter, but methods for translating these ideas into design practice remain limited. Few established approaches exist for organizing design processes around multispecies relationships from the outset, and most precedents are highly project-specific. Some contemporary design work attempts to bridge this gap by

reintroducing ecological relationships into coastal infrastructure. These projects do not fully resolve the tension between multispecies thinking and the demands of infrastructure design, but they offer useful precedents for understanding how far that translation has progressed and where its limitations lie.

MULTISPECIES DESIGN PRECEDENTS

The following two precedents are well-regarded design projects that illustrate how multispecies theory has begun to inform design practice. *Living Breakwaters* and *Buoyant Ecologies* both explore coastal infrastructure as a site for supporting ecological relationships and multispecies interaction. They are useful examples because they show how designers are beginning to incorporate more-than-human life into the design process for buildable coastal adaptation projects, while also revealing the limitations of translating multispecies perspectives into practice.

Living Breakwaters, a built project designed by SCAPE Landscape Architecture in the aftermath of Hurricane Sandy, uses eight partially submerged breakwaters built from stone and ecologically enhanced concrete to reduce wave energy in the waters off New York City, along Staten Island's Tottenville shoreline (Orff 2016). The structures (Figure 2.1) incorporate reef ridges and tidal pools to support oysters, fin fish, and other marine species. Educational programs developed in partnership with the Billion Oyster Project connect local residents and schools to the shoreline. These components reflect a genuine attempt to integrate ecological and social relationships into coastal infrastructure. However, Wakefield (2020) cautions that projects of this kind risk making nature function as infrastructure, using more-than-human species within predetermined human goals rather than engaging them on their own terms. The oysters

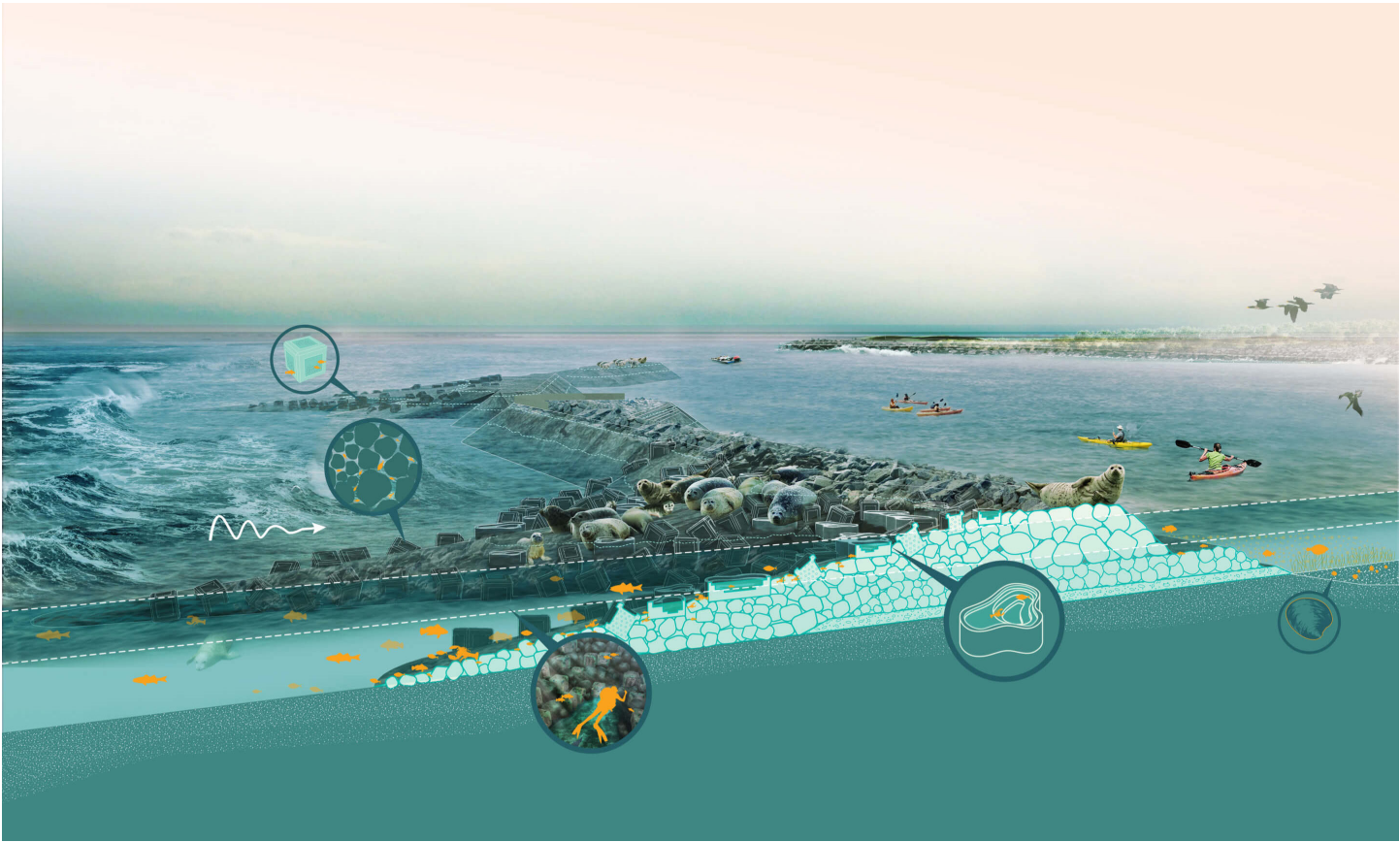


Figure 2.1: Living Breakwaters conceptual diagram. Source: Orff 2016.

in *Living Breakwaters* are components of a risk management system as much as they are participants in a shared environment. This is a limitation designers working within multispecies frameworks should remain attentive to.

Buoyant Ecologies began as a speculative research project and later developed into built prototypes that test how floating coastal infrastructure can support habitat formation and species colonization (Parr and Zaretsky 2024). Developed through collaboration between architects and marine ecologists at California College of the Arts and Moss Landing Marine Laboratories, the structure (Figure 2.2) consists of digitally fabricated substrates with variable surface topographies to encourage marine invertebrates to settle and interact according to their own ecological requirements. Variations in surface geometry on the structure create

distinct habitat conditions, allowing species to colonize the structure in their own ways. More-than-human species shape what the structure becomes over time. Even so, the project remains a prototype developed within a coastal infrastructure context, and the relationships it supports are still framed by the requirements of sea level rise adaptation.

These projects show that multispecies design is possible, but putting relational thinking into practice remains a challenge. Including ecological processes in design is not enough; what matters is whether more-than-human systems are treated as participants that shape the environment or as elements used to meet human goals (Wakefield 2020). When more-than-human life is engaged in this way, the ethical scope of design practice expands, and design becomes more adaptive and better able to support multispecies systems.

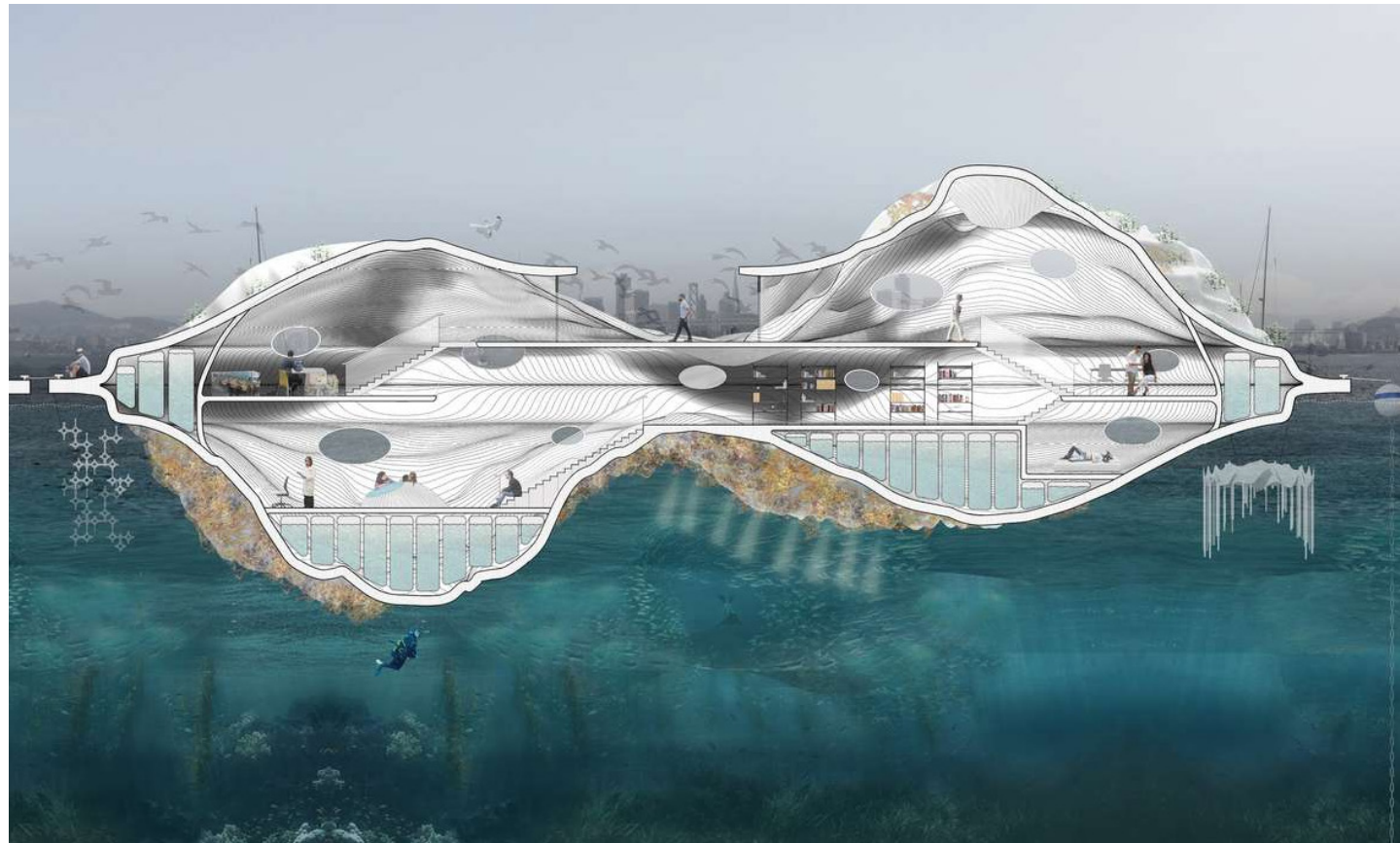


Figure 2.2: Buoyant Ecologies conceptual rendering. Source: Parr and Zaretsky 2024.

Although multispecies theory is still emerging in design and its applications to practice remain limited, its growing recognition comes at an important time. As climate pressures continue to reshape landscapes, multispecies thinking offers a way to move beyond conventional anthropocentric approaches toward more relational forms of practice that support the future flourishing of human and more-than-human life.

PART 3: SPECULATIVE DESIGN

WORLD-MAKING THROUGH DESIGN

Speculative design is a practice oriented toward imagining what futures might be possible, desirable, or worth pursuing (Dunne and Raby 2013). Rather than solving immediate problems within existing systems, speculative design is used to question the assumptions that make those systems seem inevitable, provoke dialogue about alternatives, and explore what else could be possible. Design decisions about space, infrastructure, materials, technologies, and relationships shape present conditions as well as the range of futures that become possible or foreclosed (Fry 2008; Escobar 2018). In this sense, design carries ethical and temporal responsibilities that extend well beyond the immediate project.

The ethical responsibility of the designer becomes especially important in the context of the global sustainability crisis. Conventional sustainable design often focuses on improving existing systems, but redirective practice asks design to address the deeper patterns that make those systems unsustainable in the first place (Fry 2008). Redirective practice positions design as a way to identify harmful patterns and move them toward more desirable futures. This requires designers to think beyond the immediate result of a project and consider the longer-term consequences of what their work supports.

The concept of *defuturing* extends this critique. Defuturing describes how design can contribute to the loss of future possibilities by continuing systems that are socially and ecologically harmful (Fry 2008). These systems may appear functional

in the present, but they can make it harder for human and more-than-human communities to persist over time. Defuturing helps shift the question from how design can solve a problem within existing systems to whether those systems should continue at all.

Within speculative thinking, design can also be understood as a practice of world-making. It produces more than just objects or spaces; it also shapes ways of living, relating, and imagining what futures are possible (Escobar 2018). Modern design has often reinforced systems that prioritize growth, efficiency, and development. Autonomous design offers a different framework, emphasizing community autonomy, place-based knowledge, and ways of being that are not driven by modernization alone (Escobar 2018). The idea of the pluriverse expands this argument by recognizing that many worlds and many ways of living can exist at once (Escobar 2018). This challenges the assumption that there is one universal path toward progress or development. It also suggests that design should not impose a single vision of the future, but support the conditions where different ways of living and relating can persist. While this idea is often discussed in relation to human communities, it also has implications for more-than-human life. If design helps produce worlds, then it also shapes the conditions in which other species live, adapt, and persist. These frameworks — redirective practice, defuturing, world-making, and the pluriverse — share a common implication: that design needs to incorporate methods of engaging with multiple possible futures rather than optimizing for a single predetermined outcome.

IMAGINING FUTURES

Speculative design asks what could happen under different future conditions, using scenarios and imaginative proposals to reveal how current systems shape expectations about what is possible (Dunne and Raby 2013). By imagining different trajectories, speculative design exposes the limits of existing approaches and opens space for alternatives that conventional practice tends to foreclose. Speculative design operates as a form of critique, shifting focus from solving a single, predefined problem to questioning the conditions that produced it (Dunne and Raby 2013). Many design problems are not isolated technical issues — they are produced by larger systems, values, and assumptions. Speculative design creates opportunities to examine those systems before deciding what kinds of responses are most worth pursuing.

The cone of possibilities (Figure 2.3) provides useful structure for this exploration. Beginning in the present and expanding outward, the cone distinguishes between futures that are probable, plausible, possible, and preferred (Dunne and Raby 2013). Probable futures describe what is likely based on current trends. Plausible futures describe what could happen based on current knowledge and resources. Possible futures describe what might become imaginable through new knowledge or changing conditions. Preferred futures ask what kind of future is actually desired. The cone makes explicit that futures are not neutral or fixed. What appears likely is only one path among many, and different futures reflect different values and priorities. This is significant for design because it shows that futures are shaped not only by what is possible, but by what people choose to prioritize in the present. Speculative design uses scenarios to make different possible futures visible, and to provoke dialogue about which futures communities actually want and what decisions would be needed to move toward them.

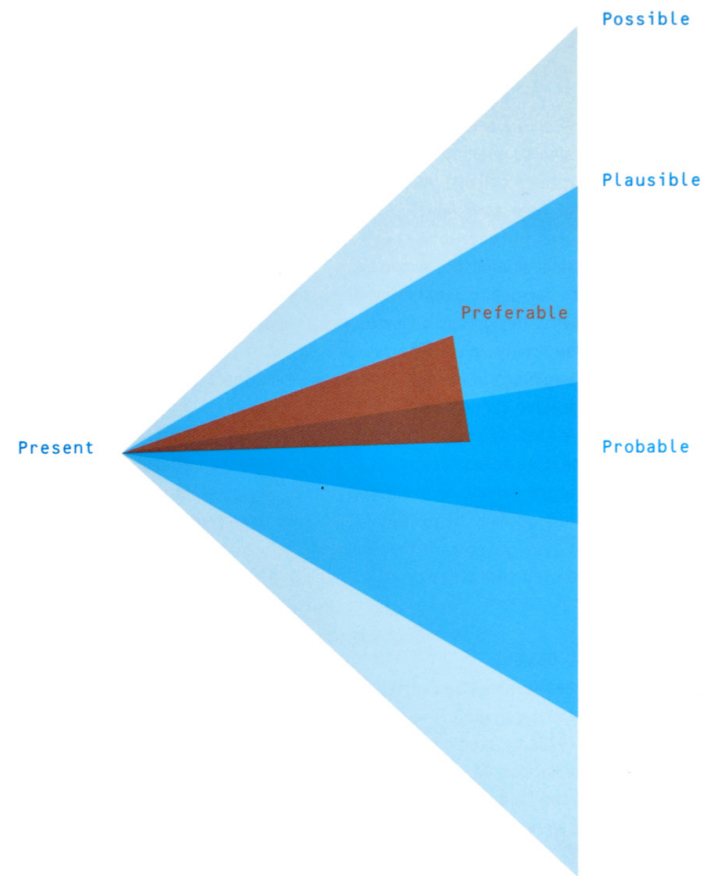


Figure 2.3: The cone of possibilities diagram.
Source: Dunne and Raby 2013.

“What-if” questions are one practical tool for generating those scenarios. A what-if question begins with an existing problem and asks how it could be reimagined if different goals or priorities guided the design. Instead of treating sea level rise only as a threat to infrastructure, a what-if question might ask how rising water could create new opportunities for intertidal habitat and coastal living. What-if questions do not point to clear design solutions or provide immediate resolution. Instead, they open a framework for testing values, challenging assumptions, and imagining alternative design outcomes (Dunne and Raby 2013). In design practice, what-if questions move a project beyond problem-solving and toward a more exploratory process of asking what else a place, system, or relationship could become.

Some speculative work deliberately operates outside the boundaries of what is currently considered feasible or realistic. Speculative design uses imagination and provocation to challenge the assumptions that narrow design thinking to what seems practical, buildable, or acceptable within current systems (Dunne and Raby 2025). This is especially important when those systems are shaped by capitalist and development-driven priorities. The value of this kind of work is that it makes familiar assumptions easier to question. It opens space to ask why things are designed the way they are, who benefits from those decisions, and what other approaches might be possible (Dunne and Raby 2025). In this way, speculative design functions as both a critical and creative practice, expanding what designers and communities can imagine before deciding what is worth pursuing.

Scenario-making is a speculative and participatory process in which futures are explored through narrative and storytelling (Tyszczyk 2021). In the context of climate change and the broader uncertainties of the Anthropocene, scenarios function as rehearsal spaces — ways of opening up civic space and preparing communities to respond to uncertain futures before those conditions fully arrive (Tyszczyk 2021). Scenario-making is a form of speculative improvisation, where collaborative exploration becomes a way of responding to uncertainty, global risk, and the collective action problems associated with climate futures. While the image or story produced by a scenario is valuable, the true importance is in the questions it prompts and the resulting conversations it can provoke.

One way to make these imagined futures more tangible is through narrative. Participatory scenarios translate speculative futures into forms that can be collectively understood and discussed with the community, connecting abstract possibilities to lived experience in ways that allow members of that community to engage with possible outcomes together (Wolff, Kaprielian, and Hamel 2025). The project *Adapting Waterfronts: Postcards from the Future, Singapore 2122* in Figure 2.4, demonstrates how this can work in a coastal context. Drawing on historic archives and scientific projections about sea level rise, the project constructed speculative narratives about the future of Singapore’s waterfront, presented through an exhibition, a virtual reality tour, and a public workshop (Wolff, Kaprielian, and Hamel 2025). By bringing together communities, scientists, and decision makers around imagined futures, the project showed how speculative design can foster new ways of thinking about coastal adaptation and reshape the relationship between research and public engagement. Visualizing the implications of future scenarios in a specific place made those futures feel tangible and debatable — real enough for diverse audiences to respond to.

What remains underexplored in speculative design literature is how speculative scenarios engage with more-than-human life. Scenarios tend to center human perspectives and human futures, even when the systems under consideration are ecological or multispecies. If design is a practice of world-making, then these imagined worlds cannot be limited to human communities alone. More-than-human life is also shaped by the futures design helps produce. This limitation is significant for design work in landscapes where human and more-than-human systems are deeply entangled, and where adaptation decisions affect a much wider range of species and relationships than conventional scenarios tend to account for.



Figure 2.4: Postcard from Adapting Waterfronts: Postcards from the Future, Singapore 2122.

Source: Wolff, Kaprielian, and Hamel 2025.

SUMMARY

This literature review has explored three interconnected areas of scholarship that together form the conceptual foundation for this design research project: coastal adaptation, multispecies theory, and speculative design. Together, these bodies of literature support the idea that coastal landscapes are changing in ways that conventional adaptation approaches cannot fully address. Many existing strategies continue to prioritize human protection, infrastructure, and land use, while overlooking the more-than-human relationships that also shape coastal systems. This creates a need for new approaches that can work with uncertainty, account for multispecies life, and imagine different coastal futures.

Part 1 examined how coastal systems are rapidly changing and how conventional adaptation strategies are struggling to keep up with climate change. Control-based approaches such as seawalls and fixed infrastructure were designed for stable conditions that no longer exist, and in many cases they actively undermine the ecological processes they are meant to protect. Coastal environments cannot be understood only as places to protect human land uses and infrastructure. They are dynamic systems shaped by water, sediment, species, infrastructure, and human decisions. When adaptation frameworks focus only on human benefit, they overlook the ecological relationships and processes that make these environments function.

Part 2 introduced multispecies theory as a way of reframing who and what coastal adaptation is designed for. Multispecies perspectives challenge the idea that more-than-human life is only a resource, service, or type of habitat within a human-managed landscape. A multispecies perspective shows that landscapes are shaped through the relationships among overlapping ecological, social, and physical systems that affect one another. Projects such as Living Breakwaters and Buoyant Ecologies show how these ideas are beginning to influence design practice by integrating habitat, species interaction, and ecological processes into coastal infrastructure. At the same time, these examples also reveal a limitation: multispecies theory offers a strong way to understand ecological relationships, but design methods for applying those relationships are still developing.

Part 3 introduced speculative design as a way to imagine futures beyond the limits of current adaptation thinking. Instead of predicting one likely outcome, speculative design asks what could happen if different values, priorities, or relationships guided design. Scenario thinking, what-if questions, participatory narrative, and collective storytelling offer ways to make those possible futures visible and discussable. These methods are useful because they allow designers to test ideas, question assumptions, and consider the consequences of different futures. However, much of the speculative design literature still centers human experience and human decision-making.

These three areas of scholarship are closely interrelated, and each one helps address a limitation in the others. Coastal adaptation establishes the conditions that need to be reconsidered, but it often remains focused on human protection, infrastructure, and land use. Multispecies theory provides a relational framework for reimagining those conditions, but its translation into design practice is still developing. Speculative design offers tools for

exploring alternative futures, but those futures often remain centered on human experience. Bringing these bodies of literature together situates this thesis within an emerging area of work that connects coastal adaptation, multispecies relationships, and speculative futures. It also provides a framework for questioning conventional adaptation approaches and imagining coastal futures that account for more-than-human life.

SITE CONTEXT

This chapter provides background on Padilla Bay and the larger regional systems that shape the estuary. It describes the environmental, cultural, social, and infrastructural conditions that inform the thesis and establish the context for the design work.

SALISH SEA

The Salish Sea (Figure 3.1) is an expansive inland sea spanning the Canadian province of British Columbia and the U.S. state of Washington. It encompasses the Strait of Georgia, the Strait of Juan de Fuca, Puget Sound, and a complex network of channels and waterways that constitute some of North America’s most productive estuarine systems. The name recognizes the Coast Salish peoples, the Indigenous nations who have inhabited this region since time immemorial. Currently, the Salish Sea supports more than eight million people and thousands of marine species, many of which are threatened or endangered. The region is undergoing constant physical and ecological changes driven by climate processes, which place increasing pressure on both human and more-than-human communities to adapt (Flower et al. 2025).

Global climate models project continued warming throughout the twenty-first century, accompanied by changes in precipitation patterns (Flower et al. 2025). Although these trends are well understood at global scales, climate impacts are not distributed evenly across all regions. This variability complicates efforts to visualize and respond to climate change, especially in transboundary systems such as the Salish Sea. Climate data are frequently organized by political jurisdictions, whereas coastal and marine processes transcend borders. This misalignment complicates the understanding of how regional climate change affects interconnected estuarine and coastal systems (Flower et al. 2025).

Recent changes in climatic patterns are already evident: 2023 and 2024 ranked among the warmest years on record globally, illustrating how climate extremes are beginning to reshape both social and ecological landscapes (Flower et al. 2025). In the Salish Sea region, climate change is projected to continue altering temperature and precipitation patterns, sea levels, and ocean chemistry. These changes threaten ecosystem health, the productivity of fisheries

and agriculture, and the resilience of coastal communities. Both human and more-than-human populations will need to adapt to new conditions that vary across the region depending on local geography, land use, and historical management practices.

Future conditions remain uncertain, shaped by climate processes and by technological, economic, political, and demographic decisions that influence greenhouse gas emissions. This uncertainty underscores the need to plan for a range of possible futures and to develop strategies that support both human communities and the broader ecological networks of the Salish Sea.

Although these pressures affect the Salish Sea as a whole, their impacts are most pronounced in estuarine systems, where freshwater, marine processes, and human activity intersect. In Washington State, Puget Sound is a key subregion of the Salish Sea where these dynamics are particularly concentrated.



Figure 3.1: Map of the Salish Sea Bioregion. Source: National Centers for Environmental Information n.d.

PUGET SOUND

Climate uncertainties make planning especially difficult in Puget Sound, where dense urban development, armored shorelines, and sensitive nearshore ecosystems are closely connected. Puget Sound is a large inland estuarine system connected to the Pacific Ocean and it constitutes a major subregion of the Salish Sea within Washington State. Puget Sound encompasses approximately 1,330 miles of shoreline, nearly 30 percent of which is armored with bulkheads and other hard infrastructure (Mauger et al. 2015). Approximately four million people reside along its shores, with major urban centers including Seattle, Tacoma, Everett, Olympia, and Bremerton. Activities within these cities and their surrounding watersheds contribute pollutants that ultimately flow into Puget Sound, directly affecting marine and nearshore ecosystems (Mauger et al. 2015).

Human influence on the climate system is evident in Puget Sound, where the primary drivers of change are rising temperatures, altered precipitation patterns, increased frequency of heavy rainfall events, sea level rise, and ocean acidification (Mauger et al. 2015; Miller et al. 2018). Collectively, these forces are reshaping the region's water cycle, natural resources, and ecosystems. Warming temperatures are projected to increase the proportion of winter precipitation that falls as rain rather than snow. This will reduce snowpack and cause spring peak streamflows to occur earlier in the year, altering seasonal water availability for both human and ecological systems (Mauger et al. 2015). Changes in rainfall, snowpack, and streamflow are projected to increase the risk of landslides, erosion, and sediment transport during fall, winter, and spring, while reducing sediment movement in summer months (Mauger et al. 2015). These patterns are influenced by climate-driven changes as well as non-climatic factors such as development and land management, which complicates prediction and management. Both the extent and frequency of flooding are

projected to increase across Puget Sound watersheds. Heavy rainfall events are expected to intensify, increasing flood risk throughout the region (Mauger et al. 2015). Continued sea-level rise will extend the reach of storm surge, increasing the risk of coastal inundation (Miller et al. 2018).

Climate-driven changes also affect more-than-human communities. Warming temperatures and altered hydrologic patterns can shift the timing of biological events such as leaf emergence, plankton blooms, and salmon spawning runs. In addition, many species are expected to alter their geographic ranges, with some expanding and others contracting or migrating in response to changing climate conditions. These ecological responses are further shaped by non-climatic pressures, including habitat loss and shoreline development (Mauger et al. 2015).

Agricultural systems within Puget Sound watersheds are also affected. While warming temperatures may lengthen the growing season, higher heat stress and reduced water availability during summer months may limit productivity. Changes in the range and timing of pests pose additional challenges for crops and livestock (Mauger et al. 2015).

By the 2050s, the average yearly temperature in Puget Sound is projected to be approximately 4.2°F warmer under a low greenhouse gas scenario and 5.5°F warmer under a high scenario. By the 2080s, the number of wettest days is projected to increase by approximately 22 percent under a high scenario. By 2040, average snowpack is projected to decline by 23 percent under a low scenario and 29 percent under a moderate scenario (Mauger et al. 2015). Relative sea level rise, accounting for local subsidence, is projected to average approximately 0.6 feet under a low scenario and 0.7 feet under a high scenario by mid-century. By 2100, these estimates increase to approximately 1.6 feet and 2.0 feet, respectively, with projections for 2150

reaching 2.5 feet under a low scenario and 3.4 feet under a high scenario (Miller et al. 2018).

Impacts to Puget Sound's marine waters will further affect saltwater habitats by driving changes in currents, chemistry, and ecosystem structure. Sea-level rise is projected to expand some tidal wetlands while reducing others as water levels rise and areas become submerged. Rising seas will also accelerate wave-driven erosion, causing unprotected beaches and bluffs to recede more rapidly. Warmer water temperatures are expected to increase the frequency and severity of harmful algal blooms, and ocean acidification may increase the toxicity of some blooms (Miller et al. 2018). Together, these changes will affect marine ecosystems and their human and more-than-human inhabitants across Puget Sound.

Within Puget Sound, climate impacts are most concentrated in river basins and deltas, where freshwater inputs, estuarine habitats, and human land use intersect. These landscapes support both productive marine ecosystems and working agricultural systems, yet they are among the most vulnerable to flooding, sea-level rise, and hydrological changes. The Skagit Basin exemplifies these dynamics. As the largest river system feeding Puget Sound, it supports extensive estuarine resources and contains the largest agricultural center in western Washington, placing it at the center of increasing uncertainty as climate change reshapes both marine and terrestrial systems.

SKAGIT BASIN

The Skagit Basin (Figure 3.2) is one such area of particular interest. As the largest river system feeding Puget Sound, it supports extensive estuarine resources and contains the largest agricultural center in western Washington, placing it at the center of growing uncertainty as climate change reshapes both marine and terrestrial systems (Rybczyk et al. 2016). The Skagit Basin is located in the northwest portion of Washington State and extends into British Columbia, Canada. Water from the basin drains into the Skagit River directly or through approximately 3,000 tributaries. From forested uplands in the Cascade Mountains, water flows west through foothills and floodplains before reaching Puget Sound (Lee and Hamlet 2011).

The Skagit River is the largest river system feeding Puget Sound. Approximately ten billion gallons of water flow each day from the Skagit River into the Sound through the two forks that form Fir Island, contributing about twenty percent of all freshwater entering Puget Sound. This flow shapes the largest river delta in Puget Sound. Historically, this delta was a rich estuarine system larger than the 15 other major Puget Sound estuaries combined (Rybczyk et al. 2016).

Today, the Skagit Delta supports a diverse estuarine and intertidal landscape that remains critical to regional ecological productivity. These habitats support large wintering populations of snow geese, trumpeter and tundra swans, dabbling and diving ducks, shorebirds, and colonial waterbirds such as the great blue heron. The delta provides winter habitat for approximately eighty percent of western Washington's waterfowl and foraging habitat for nearly seventy percent of Puget Sound's shorebird population. Salmon, shellfish, and other marine species depend on the balance between freshwater input, sediment delivery, and tidal processes within this estuarine system. Commercial, subsistence, and cultural fisheries continue to rely on the health of these nearshore environments (Rybczyk et al. 2016).

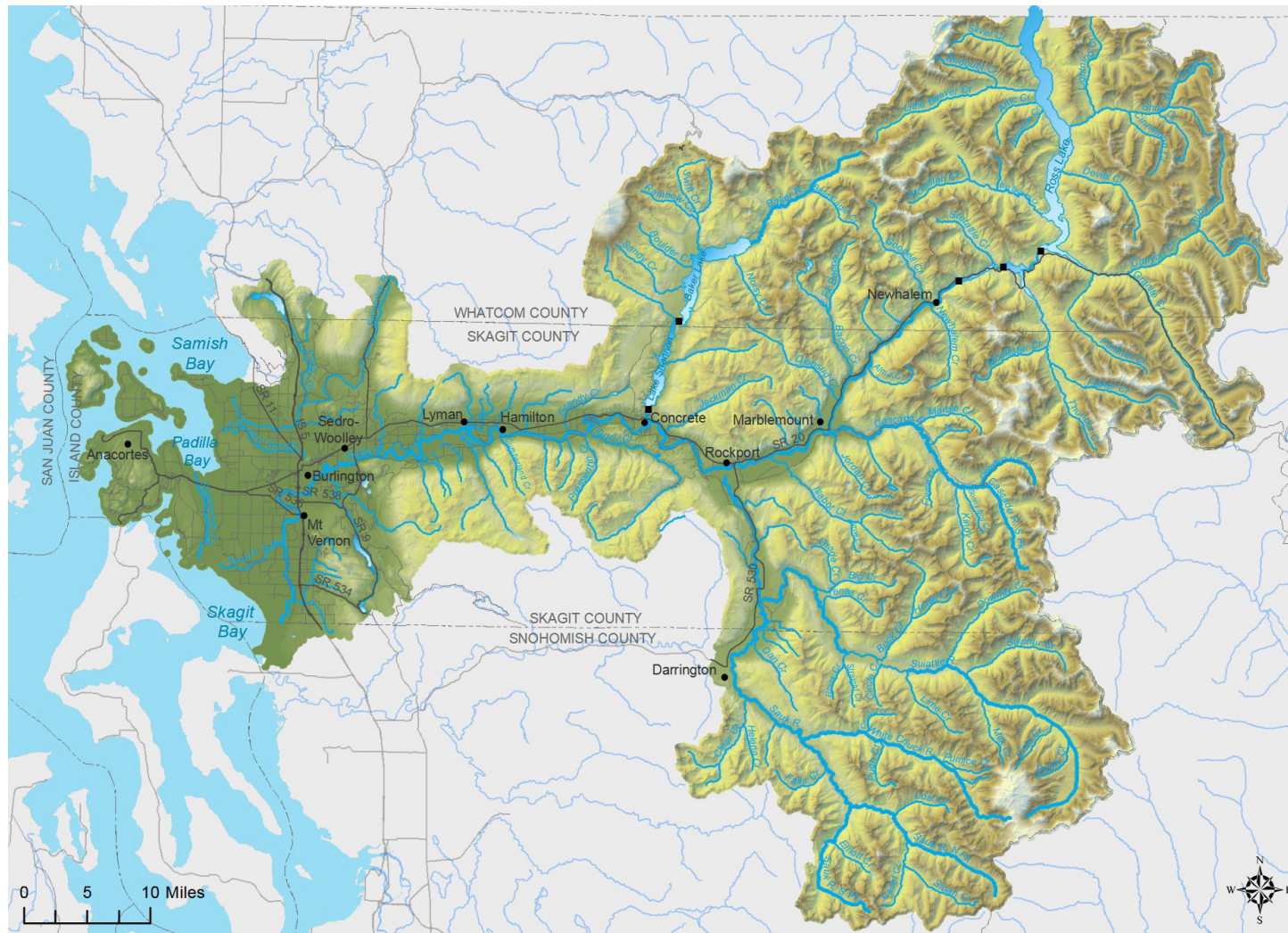


Figure 3.2: Map of the Skagit River Basin. Source: Ramsden 2014.

Beyond its ecological importance, the lower Skagit Valley is a highly managed working landscape. Eleven reservoirs throughout the basin temporarily store water, providing energy, drinking water, and irrigation to communities from Bellingham to Seattle. Extensive agricultural lands make the Skagit Basin the largest agricultural center in western Washington, producing key food products and supporting a vibrant tourism economy based on farming, wildlife viewing, and recreation.

This region is home to approximately 120,000 people, including the cities and towns of Anacortes, La Conner, Mount Vernon, Sedro-Woolley, Burlington, Lyman, Concrete,

Marblemount, Newhalem, Rockport, Darrington, and Hamilton. Interstate 5 connects the basin to metropolitan hubs such as Vancouver, BC, and Seattle. The Swinomish, Sauk-Suiattle, Upper Skagit, and Samish Indian Nations have called these lands and waters home since time immemorial. With population projections suggesting the basin may double in size by 2050, growth will continue to strain regional resources. In addition to agriculture and settlement, the county’s accessible ports and refineries support Washington State’s petroleum industry, adding further demands on land, water, and estuarine systems.

These intertwined ecological and economic systems are fundamentally shaped by the basin’s hydrology, making the region highly sensitive to climate-driven change. Alterations in freshwater flow, increased flooding, and sea-level rise directly affect farmland and estuarine habitats, both of which rely on precise balances of salinity, inundation, and sediment delivery. As climate conditions shift, managing the interplay among agricultural production, flood control,

and estuarine health becomes increasingly complex and uncertain. Figure 3.3 illustrates these climate change drivers in the Skagit Basin, showing how regional pressures play out through connected changes in temperature, precipitation, snowpack, streamflow, flooding, and sea level rise. Addressing these persistent challenges will require adaptation strategies that work with natural processes.

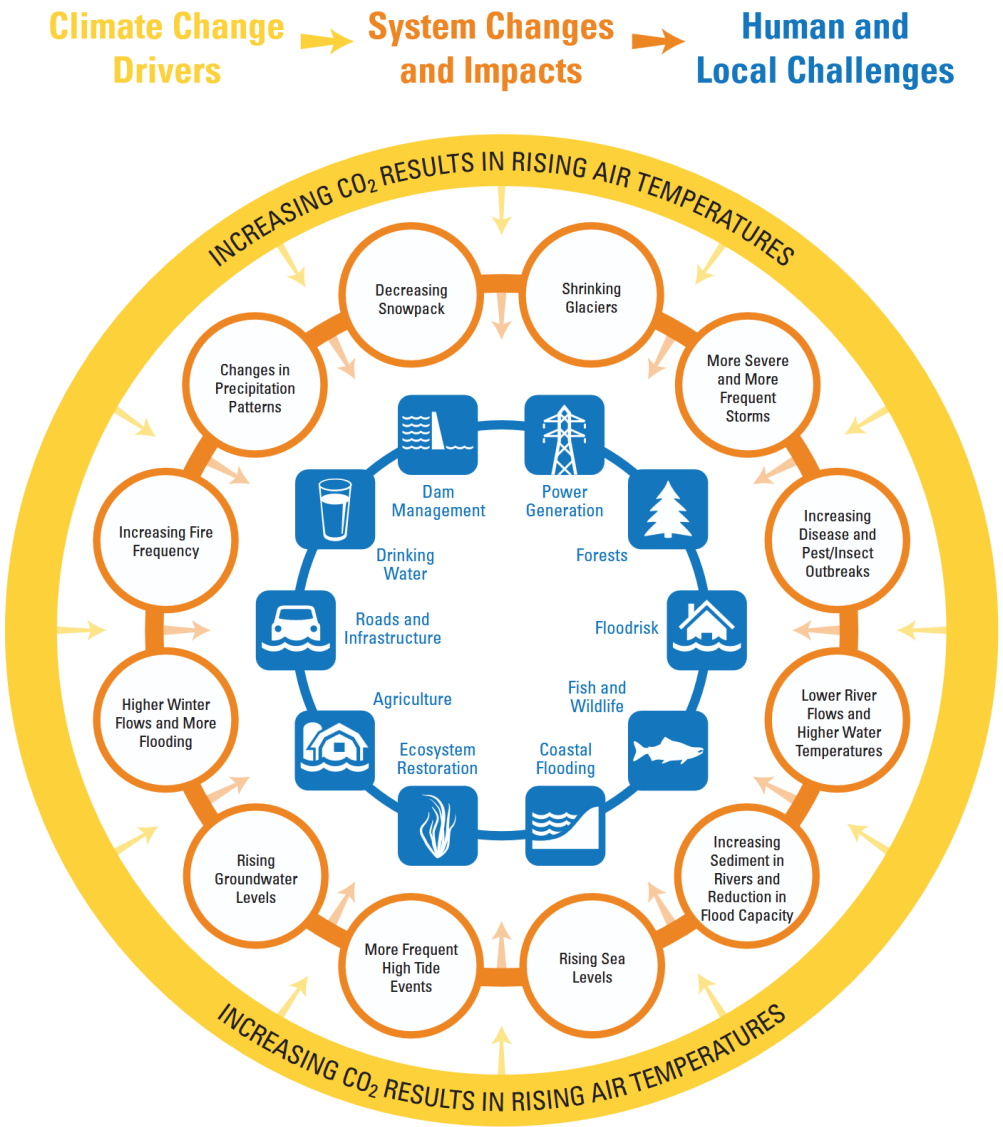


Figure 3.3: Infographic of climate drivers, system impacts, and human challenges. Source: Skagit Climate Science Consortium 2015.

PADILLA BAY

Padilla Bay is a large, shallow estuarine embayment located in Skagit County, Washington, along the northern reaches of Puget Sound. The bay lies within the Skagit Basin agricultural complex, a landscape shaped by thousands of years of sediment deposition from the Skagit River. Historic delta deposits formed by glacial erosion in the North Cascade Mountains underlie the fertile soils of the lower Skagit Valley and the bay itself. For millennia, seasonal flooding extended the river’s influence into the estuary, creating expansive mudflats and coastal marshes that supported dynamic estuarine processes.

Over the past century, these estuarine processes have been significantly altered through river regulation, diking, and agricultural drainage. With the completion of diking along the river and bay margins, normal river flow and sediment loads no longer enter Padilla Bay directly. As a result, the bay is often described as an orphaned estuary (Washington State Department of Ecology 2008). Despite this disconnection from a major sediment source, Padilla Bay still maintains many of the physical and ecological traits typical of an estuary in the broader Puget Sound estuarine system, including modified shorelines, meandering stream channels, and intertidal habitat shown in Figures 3.4, 3.5, and 3.6.

Padilla Bay encompasses more than 14,000 acres (Washington State Department of Ecology 2008). Its broad, flat intertidal basin fills and drains rapidly with twice-daily tidal cycles, exposing approximately 60–70 percent of the bay at a typical summer low tide. Average water depths are around 9 feet, with channels reaching 15–20 feet below mean lower low water. Adjacent marine waters exhibit varying salinity regimes: waters entering from the south via the Swinomish Channel and Skagit Bay are diluted by river input, with salinities ranging from 10–20 parts per thousand, while waters farther west reflect Puget Sound conditions of 25–35 parts per thousand. Average salinity within Padilla Bay ranges from

26 to 29 parts per thousand, and the system is generally well mixed with limited stratification (Washington State Department of Ecology 2008).

Water temperatures typically range from 40°F to 65°F, though shallow summer conditions can elevate temperatures significantly and stress intertidal habitats. These physical conditions support approximately 7,500 acres of eelgrass, making Padilla Bay home to the second largest eelgrass meadow in the contiguous United States (Washington State Department of Ecology 2008). This extensive eelgrass system provides critical habitat for fish, invertebrates, migratory birds, and marine mammals, while also supporting sediment stabilization, nutrient cycling, and carbon storage across the estuary.

The Padilla Bay watershed encompasses roughly 23,000 acres and receives freshwater inputs from several sources, including groundwater and surface runoff, the No-Name, Joe Leary, and Indian agricultural sloughs, the Fraser River in Canada, and the Skagit River via the Swinomish Channel. Land use within the watershed is dominated by agriculture, with approximately 52 percent cropland and 20 percent pasture, alongside forested lands and smaller areas of residential, commercial, industrial, and transportation infrastructure (Washington State Department of Ecology 2008). Residential development is concentrated in the eastern reaches of the watershed, while industrial activity, including the Port of Skagit County industrial park and airport, occurs nearby. The eastern half of March Point, home to oil refineries and chemical processing industries, drains directly into Padilla Bay, tightly coupling land-based activities to estuarine conditions.



Figure 3.4: Drone photograph of shoreline armoring along the northeastern shore of Padilla Bay. Image by author.



Figure 3.5: Drone photograph of intertidal habitat and bluff shoreline. Image by author.



Figure 3.6: Drone photograph of Joe Leary Slough at Padilla Bay. Image by author.

HUMAN DEVELOPMENT PRESSURES

Since the arrival of Euro-American settlers in the late nineteenth century, Padilla Bay has been shaped by extensive modification of its margins and surrounding lands. Logging, agriculture, and diking transformed thousands of acres of marsh and mudflats into farmland by constructing drainage systems and levees (Washington State Department of Ecology 2008). The formation of diking and drainage districts enabled coordinated construction and long-term maintenance of this infrastructure, and many of the dikes surrounding the eastern and southern shores of Padilla Bay remain largely unchanged from their early twentieth-century configurations, dating to approximately 1918.

Figure 3.8 shows several twentieth-century development proposals for Padilla Bay, including efforts to dike the entire bay and convert it to residential or industrial use. Some of these projects were partially initiated before being abandoned due to financial or engineering constraints, while others were halted due to evolving regulatory frameworks. The passage of the Washington State Shoreline Management Act in 1971 and Padilla Bay’s designation as a Shoreline of Statewide Significance rendered many of these proposals infeasible (Washington State Department of Ecology 2008).

Recognition of Padilla Bay’s ecological value intensified during the mid-twentieth century as development pressure along Washington’s coast increased. Beginning in the 1970s, State and Federal agencies evaluated estuarine sites across Washington for potential designation as research reserves (Washington State Department of Ecology 2008). Padilla Bay was ultimately selected due to its extensive intertidal mudflats, large eelgrass meadows, and relatively intact estuarine processes.

Community advocacy played a decisive role in this outcome. The Breazeale family, who settled on the shore of Padilla Bay in 1897, raised their children with a strong conservation ethic rooted in lived experience on the land. When plans emerged in the 1950s to convert the bay into an industrial park, Edna Breazeale (Figure 3.7) led a sustained grassroots campaign opposing development. Over more than two decades, she engaged civic groups, dike district commissioners, and state officials, challenging the prevailing assumption that economic development should take precedence over ecological function (Washington State Department of Ecology 2013). In 1980, Padilla Bay was designated a National Estuarine Research Reserve (NERR) under the Coastal Zone Management Act as a partnership between NOAA and the Washington State Department of Ecology. Breazeale later donated her family farm to serve as the Reserve’s interpretive center and research facilities, establishing a lasting legacy of stewardship, research, and public education.



Figure 3.7: Photograph of Edna Breazeale. Source: Washington State Department of Ecology 2013.

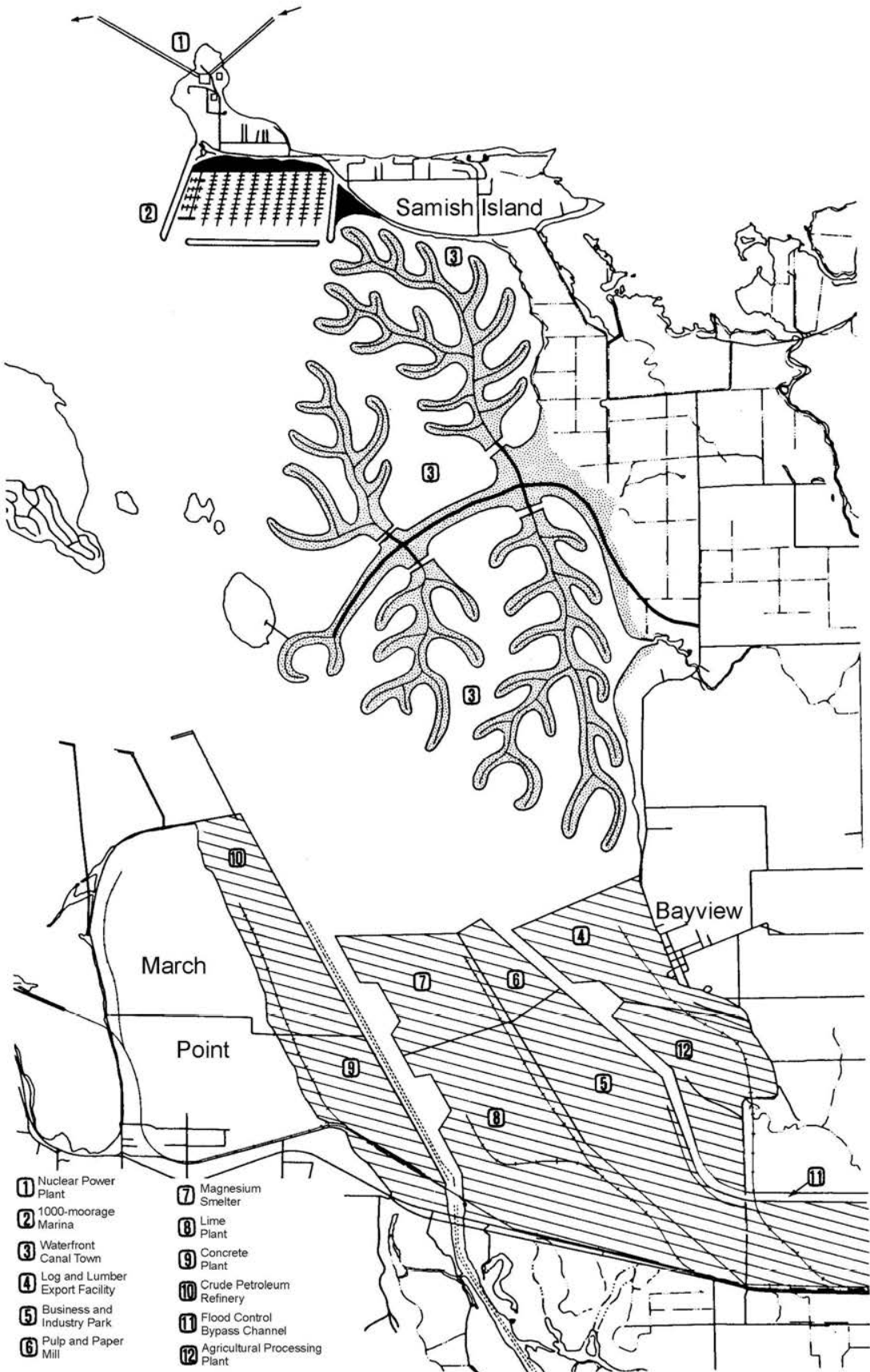


Figure 3.8: Historic development proposals for Padilla Bay. Source: Washington State Department of Ecology 2008.

FUTURE UNCERTAINTIES

Despite its protected status, Padilla Bay remains deeply influenced by activities within its watershed and along its shores. Industrial development on March Point, including oil refineries, marine shipping routes, shipping docks, and rail infrastructure, poses ongoing risks of spills, derailments, and pollution. Agricultural practices around the bay rely on fertilizers, herbicides, and drainage infrastructure, which directly affect water quality, turbidity, and nutrient loading in sloughs and eelgrass meadows. Excess sediment inputs, nutrient enrichment, and chemical exposure all pose risks to the delicate ecological balance of the eelgrass system.

Flood management has emerged as a persistent concern. Proposals such as the Avon Bypass, which would divert Skagit River floodwaters toward Padilla Bay or the Swinomish Channel, have raised significant ecological questions. Studies have identified more than twenty potential impacts associated with such projects, including the rapid introduction of large sediment loads that can smother eelgrass beds or reduce light availability to the point where photosynthesis cannot occur (Washington State Department of Ecology 2008). Although alternative flood management strategies are currently under evaluation, these debates underscore the bay’s vulnerability to upstream decisions and the challenge of balancing flood protection with ecological integrity.

Climate change is intensifying these existing land and water management pressures. Recent atmospheric river events, including severe flooding in December 2025 (Figures 3.9 and 3.10), illustrate the increasing frequency and magnitude of hydrologic extremes in the Skagit Basin. During this event, the entire 100-year floodplain was ordered to evacuate amid uncertainty about whether dikes and levees would hold. Roads were inundated, access to rural communities such as Samish Island was

cut off, and schools and facilities, including the Padilla Bay National Estuarine Research Reserve, were closed. Weeks later, many agricultural fields remained flooded as water levels slowly returned to typical winter conditions. These events reveal the interconnected vulnerability of ecological systems, infrastructure, agricultural lands, and human communities.

The future of Padilla Bay is shaped by many actors. Tribal nations, agricultural producers, industrial operators, local communities, and visitors are all entangled in decisions about flood protection, land management, and habitat conservation. More than human actors include thousands of species who depend on the bay’s intertidal and subtidal habitats for survival. As climate change amplifies flood risk and ecological stress, long-standing tensions among agricultural productivity, flood protection, habitat conservation, and recreation increasingly define debates about how the bay should adapt.



Figure 3.9: Photograph of Skagit River flooding in Mount Vernon, December 2025. Image by Kevin Clark. Source: Swanson, Conrad, and David Gutman 2025.



Figure 3.10: Photograph of flooded farmland near the Skagit River, December 2025. Image by Darrin Morrison. Source: Sowards 2026.

METHODS

This chapter explains the research and design process used throughout the thesis. It describes how different methods were used to understand Padilla Bay and translate that understanding into design work.

METHODS

For this thesis, I employed a mixed-methods framework that integrates archival research, geospatial mapping, field-based observation, expert consultation, design methods, and speculative design. Each method was selected to address specific aspects of my three research questions. Archival analysis established historical baselines and traced socio-ecological changes. Geospatial mapping enabled quantitative spatial analysis and modeling. Field-based observation provided grounded, experiential insight into the lived, multispecies realities of Padilla Bay, capturing localized phenomena that might otherwise be overlooked. Expert consultation incorporated practitioner and local stakeholder perspectives, grounding the broader research in local management practices and providing more nuanced insight. Design methods translated analytical findings into guiding principles and site-specific interventions through precedent analysis, iterative diagramming, and visual synthesis. Finally, speculative design facilitated the exploration of possible futures and the translation of those insights into adaptive, creative interventions.

These methods were selected for their capacity to engage simultaneously with quantitative ecological data and qualitative, experiential ways of knowing. Purely quantitative approaches can capture large-scale trends, but risk overlooking localized and situated knowledge. However, qualitative or participatory methods may lack the empirical grounding necessary for ecological modeling and scenario planning. By combining these approaches, this framework supports a more complete understanding of both environmental change and lived experience, and is especially well-suited to the more-than-human theoretical orientation guiding this thesis. Rather than prioritizing a single mode of inquiry, these methods work relationally, each informing and expanding the others across three research questions. The methodological framework is

outlined in Figure 4.1, which maps each method to its corresponding research question and illustrates how outputs from one phase inform the next.

ARCHIVAL METHODS

To establish a historical baseline for Padilla Bay and to trace how ecological, climatic, and land use conditions have changed over time, I conducted archival research. This method was foundational for building the background knowledge necessary to interpret my site observations, to contextualize the mapping layers compiled for Research Question 1, and to ground the design work in the region’s socio-ecological realities.

I organized archival sources by theme. To understand governance and management priorities, I reviewed the Padilla Bay National Estuarine Research Reserve Management Plan, the Skagit County Shoreline Master Program, and the Skagit County Comprehensive Plan. These documents clarified the regulatory and planning frameworks that shape conservation and land use in the region. Engineering reports for specific sites, such as the Samish Conservation Site in northern Padilla Bay, provided more detailed information on ongoing restoration and management at the local level.

For climate data at local and regional levels, I used the Skagit Climate Science Report for watershed-specific conditions and consulted broader regional models, including the Salish Sea Model, which provided detailed projections of oceanographic and atmospheric conditions across the wider region. Sea level rise projections were sourced from the Washington State Sea Level Rise Assessment, which offered more granular, locally calibrated data than national-



Figure 4.1: Methodological framework diagram. Image by author.

scale models could provide. These sources informed the climate and sea level rise mappings referenced in the multiscalar analysis graphics in Chapter 5.

Eelgrass was a primary focus of the archival research, given its role as the key ecological indicator for Research Question 1. The bulk of this research came from the Washington Department of Natural Resources Eelgrass Recovery Strategy, which provided comprehensive data on distribution, decline trends, and restoration priorities across the state. This was supplemented with a seagrass monitoring report and accompanying storymap, communications from local conservation organizations, and academic research studies focused specifically on Padilla Bay that investigate the future of seagrass restoration and projected climate

impacts on eelgrass persistence. These sources were integral to the mapping of eelgrass stressors outlined in Chapter 5. I also reviewed educational materials produced by the Padilla Bay National Estuarine Research Reserve (NERR) to understand how the reserve communicates ecological information to diverse public audiences, which informed my approach to representation and communication of the speculative visions discussed in Chapter 7.

FIELD VISITS

Between December 2025 and March 2026, I conducted repeated site visits to Padilla Bay to develop an embodied and place-based understanding that quantitative data alone cannot provide. These visits included several locations around the shoreline of Padilla Bay, such as the March Point peninsula, the Padilla Bay Shore Trailhead - South, Bayview State Park, the Padilla Bay National Estuarine Research Reserve, the Skagit Wildlife Area - Samish Unit, and Samish Island. I also visited nearby communities including Edison, Bow, Bay View, Burlington, Mount Vernon, Anacortes, and La Conner, to better understand the broader spatial and ecological context of the bay and its surrounding systems. I intentionally tried to visit across varying tidal stages, weather conditions, and times of day to capture the temporal and littoral variability that defines the estuarine environment. During each visit, I recorded field notes documenting observed species, site users, atmospheric conditions, and tidal state. During winter and early spring, I conducted five site visits encountering a range of conditions including extreme low tides, storms, and fog, which revealed the dynamic character of Padilla Bay. Each visit contributed new observations and insights that would not have emerged from remote analysis alone.

All fieldwork was conducted outside the summer and fall seasons. As a result, this research does not capture seasonal events such as species migration, vegetation changes, or patterns of human use that may be more prominent at other times of the year. Additional fieldwork across all seasons would provide a more complete understanding of the site's year-round dynamics.

PHOTOGRAPHY

Throughout the field visits I used photography as both a documentation tool and an analytical method. Ground-level photography captured variations in tides, vegetation, wildlife activity, and human use, creating a visual archive of site conditions over time. This visual record supported comparison across visits and helped identify spatial and ecological patterns.

I also used drone photography to capture aerial perspectives not accessible from the ground. Given the limited public access points along Padilla Bay's shoreline, aerial imagery was essential for developing a comprehensive spatial understanding of the bay's extent, habitat distribution, and edge conditions. Before conducting drone flights, I obtained the necessary permissions for operation in the area and complied with FAA regulations for unmanned aerial vehicle use. I took care to avoid disturbing sensitive wildlife and to respect the privacy of adjacent landowners.

Flying the drone over the water and mudflats was methodologically significant. The aerial perspective challenged a strictly ground-based, human-centered viewpoint and allowed the landscape to be understood in a manner consistent with the multispecies framework of this research. These images revealed spatial relationships not visible from the ground (See Chapter 3, page 35 for images). Aerial imagery also informed the identification of locations for the speculative visions developed later in the project.

EXPERT CONSULTATIONS

Expert consultation was a critical method for grounding my archival and field-based research in practitioner knowledge and locally situated expertise. I consulted primarily with the Stewardship and Coastal Training Program teams at the Padilla Bay National Estuarine Research Reserve through a studio course partnership. The Stewardship team, composed of ecologists and natural resource managers, provided insight into monitoring practices, invasive species management, water quality conditions, and key habitat dynamics. Because this team works closely with a range of stakeholders including tribal nations, shellfish growers, oil refineries, farmers, and environmental organizations, these conversations also highlighted the social and political dimensions that shape ecological management in the region.

I also attended lectures from engineers, ecologists, and land managers working in the Padilla Bay area. These sessions provided detailed technical information about river and coastal processes, as well as insight into the challenges of working within a complex network of stakeholders with differing priorities. These interactions contributed current and practice-based knowledge not always available in published literature and helped deepen the multiscale understanding developed through other methods.

MAPPING ANALYSIS

To synthesize spatial data across multiple temporal periods and geographic scales, I conducted geospatial analysis using ArcGIS Pro. The mapping analysis served two primary functions: establishing the current ecological and climatic conditions at Padilla Bay, and visualizing change over time by layering historic and contemporary datasets.

Geospatial data were organized into two categories: base layers that establish the geographic and administrative framework of the study area, and analytical layers that contain ecological, climatic, and infrastructural information relevant to the research questions. Base layers were sourced from Skagit County and the Washington State Geospatial Open Data Portal and included parcel boundaries, city limits, road networks, and hydrographic features such as rivers and watershed boundaries. These layers provided the foundational geographic context for all mapping work in Chapter 5 and were essential for situating the site within its broader administrative and hydrological setting.

Analytical data layers were drawn from multiple state and federal agency sources and selected for their relevance to understanding the ecological conditions and human land use pressures shaping the estuary. The Washington State Department of Ecology provided land-use classifications, shoreline type classifications, habitat and vegetation maps, and the locations of ports, dams, and current and historic landfill sites. I used these layers to identify where human infrastructure and land use intersect with sensitive estuarine habitats, and to trace how development patterns have historically encroached on the bay. Dike and levee locations were sourced from the Washington Department of Fish and Wildlife and were particularly significant for understanding how historic efforts to reclaim tidal land for agriculture have altered the hydrological connectivity of the estuary and continue to constrain ecological function today. Elevation and bathymetric data were derived

DESIGN METHODS

from LIDAR datasets provided by the Washington Department of Natural Resources at 2-foot and 10-foot contour intervals, which were essential for identifying low-lying areas most vulnerable to sea level rise. Sea level rise projections were sourced from NOAA and modeled across multiple scenarios to represent a range of plausible future conditions through the year 2150, providing the climate foundation for the speculative visions developed in the later phase of the thesis.

I structured the mapping analysis across four nested scales: the Salish Sea for broad regional biogeographic context, Puget Sound and the Skagit River Basin at sub-regional scales to capture both the saltwater and freshwater systems feeding into the estuary, and Padilla Bay as the primary site scale, with a focus on eelgrass distribution within the bay. This multiscale approach was necessary to trace how stressors operating at the watershed or regional level, such as changes in freshwater input, sediment load, and ocean acidification, manifest at the scale of a specific estuarine habitat. Integrating these layers across scales allowed me to construct complex composite maps that convey a multidimensional narrative of the bay's ecological condition, its history of human modification, and its vulnerability to projected climate change. These maps constitute the primary output for Research Question 1 (See page 8 for research questions), and directly inform the development of design principles and speculative scenarios in subsequent phases.

In the second phase of the project, I used several design methods to respond to Research Question 2. These methods were guided by a multispecies conceptual framework with the goal of generating coastal landscape design approaches that move beyond conventional anthropocentric practice, ultimately producing a multispecies coastal adaptation framework of guiding design principles and site-specific interventions for Padilla Bay.

I began with precedent analysis of built and speculative projects in coastal and estuarine landscapes, focusing on work related to ecological restoration, climate adaptation, and more-than-human cohabitation. These precedents, discussed in Chapter 2, helped identify possible transferable design strategies while also revealing where past approaches have fallen short ecologically. I also paid attention to the site-specific and cultural conditions that shape whether a given intervention can be meaningfully applied in a different context. This step clarified how a multispecies approach to coastal adaptation differs from conventional practice and established a critical foundation for the design work that followed.

Then, to synthesize analytical findings and develop design concepts, I used iterative diagramming and sketching. Diagrams helped organize insights from archival research, field observations, and geospatial analysis into spatial and relational frameworks, making it possible to explore connections among ecological systems, species, and human uses and to translate complex socio-ecological dynamics into a visual language accessible to multiple audiences. This process also helped identify patterns, overlaps, and points of stress across scales in Padilla Bay, reframing observed conditions as opportunities for design intervention.

This iterative process led to a design framework composed of guiding design principles grounded in the analysis of Padilla Bay. While these design principles (See Chapter 6) are intended to be adaptable to other coastal contexts with similar ecological characteristics, their application is shaped by the unique ecological, cultural, and regulatory conditions of this place, including differences in species assemblages, governance structures, and community priorities. Recognizing these limits is important for encouraging context-specific, adaptive application rather than treating the framework as a universal model. Early design concepts were developed through sketching and systems diagramming before being refined into the speculative visions described in the following section.

SPECULATIVE DESIGN

To address Research Question 3, I used speculative design methods by developing multiple plausible future scenarios for Padilla Bay under projected climate conditions. In this phase, scenario building served as both a method and a strategy for design inquiry. I structured the work around a series of “what if” questions (See Chapter 7), using these as starting points for world-building exercises that explored different directions the bay could take.

Each scenario branches from current climate trends and applies a distinct set of design interventions to explore how specific decisions might shape ecological conditions and lived experience over time. This approach is particularly useful in a system as complex and dynamic as Padilla Bay, where linear planning tools are often insufficient. Scenario planning engages uncertainty directly, exposing tradeoffs and expanding the range of possible outcomes.

The scenarios are not intended to prescribe a single solution. Instead, they provide a framework for discussion among designers, land managers, tribal nations, ecologists, and community members. By visualizing several alternative futures, this method encourages dialogue about priorities, values, and aspirations for Padilla Bay across both human and more-than-human communities.

Together, these methods allowed me to triangulate a range of data across historical, current, and projected future conditions. Technical reports and spatial data helped clarify the bay's ecological pressures, land use history, and climate risks, while field observations supplemented by local knowledge added a more grounded understanding of the bay. Applying these mixed methods provided a richer understanding of Padilla Bay and supported the design explorations that follow.

MULTISCALAR ANALYSIS

This chapter introduces eelgrass as a lens for understanding the socio-ecological systems that influence Padilla Bay. By tracing eelgrass stressors across multiple scales, the analysis reveals relationships between regional systems, local conditions, and potential leverage points for design.

MULTISCALAR ANALYSIS

This chapter addresses the first research question: *What broader socio-ecological systems influence eelgrass in Padilla Bay?* It establishes the ecological and spatial foundation for the project by showing how larger systems shape conditions in Padilla Bay. I examine eelgrass in order to take a multispecies lens to explore climate change and other stressors at both regional and site-specific scales. I use a multiscalar approach to analyze influences on eelgrass across multiple, interconnected spatial scales, ranging from the regional Salish Sea and Puget Sound context, through the watershed and bay, down to specific site characteristics in Padilla Bay. This approach shows how processes and stressors at each scale interact, and in doing so, reveals patterns not visible at a single scale. By outlining where stressors emerge and interact, I lay a foundation for coastal adaptation design. I also identify intervention points where design can reduce harm and support multispecies thriving.

SIGNIFICANCE OF EELGRASS

Multispecies inquiry studies interactions among species within an ecosystem and serves to decenter the human perspective. This approach is challenging because, while humans can attempt to communicate with other species, most cannot respond in ways we comprehend. The complexity of multispecies worlds makes it difficult and time-consuming to study all species simultaneously. Given these challenges, it became clear that a narrower focus would allow for deeper insights. For this reason, I focused my inquiry on one key species: eelgrass. This focus enables a more thorough analysis while still considering broader ecological relationships.

Throughout this thesis, I use eelgrass as both a focal species and a way of referring to a broader web of relationships. I frame this as ‘eelgrass+’: not just eelgrass, but also the species, habitats,

people, processes, and infrastructures connected to it. This framing allows the project to stay grounded in one species while recognizing that eelgrass is never isolated from the broader socio-ecological system around it.

Eelgrass (*Zostera marina*) is a type of marine, flowering seagrass found in temperate regions worldwide. It forms dense underwater meadows that are highly productive habitats for marine species (U.S. Geological Survey n.d.). It is common in the intertidal and subtidal zones along the shorelines of the greater Puget Sound region (Washington State Department of Natural Resources 2015). Padilla Bay has the second-largest contiguous eelgrass bed in the United States. This is a major reason I chose eelgrass as the focal species for this thesis.

Beyond its abundance in Padilla Bay, eelgrass plays a key role in the Pacific Northwest ecosystem (Puget Sound Partnership n.d.). The Puget Sound Partnership names eelgrass as a health indicator, recognizing its ecosystem value and its sensitivity to environmental changes (Washington State Department of Natural Resources 2015). Figure 5.1 summarizes these vital signs. These indicators measure ecological and social well-being in the region, including Padilla Bay. They also set important goals for this thesis. The vital signs cover ecological and human factors: functioning habitat, thriving species and food web, healthy water, healthy people, and vibrant quality of life. Many connect directly to the benefits eelgrass provides.

The positive effects of important species like eelgrass are often called ‘ecosystem services’, but I will use the term ‘ecosystem benefits’ in this thesis to avoid the exploitative tone of ‘services.’ Eelgrass forms critical habitat for other species, serving as a nursery and feeding ground for culturally and ecologically important species. These include Dungeness crab, Pacific salmon, Pacific herring, and waterbirds. By providing habitat for diverse species, eelgrass increases

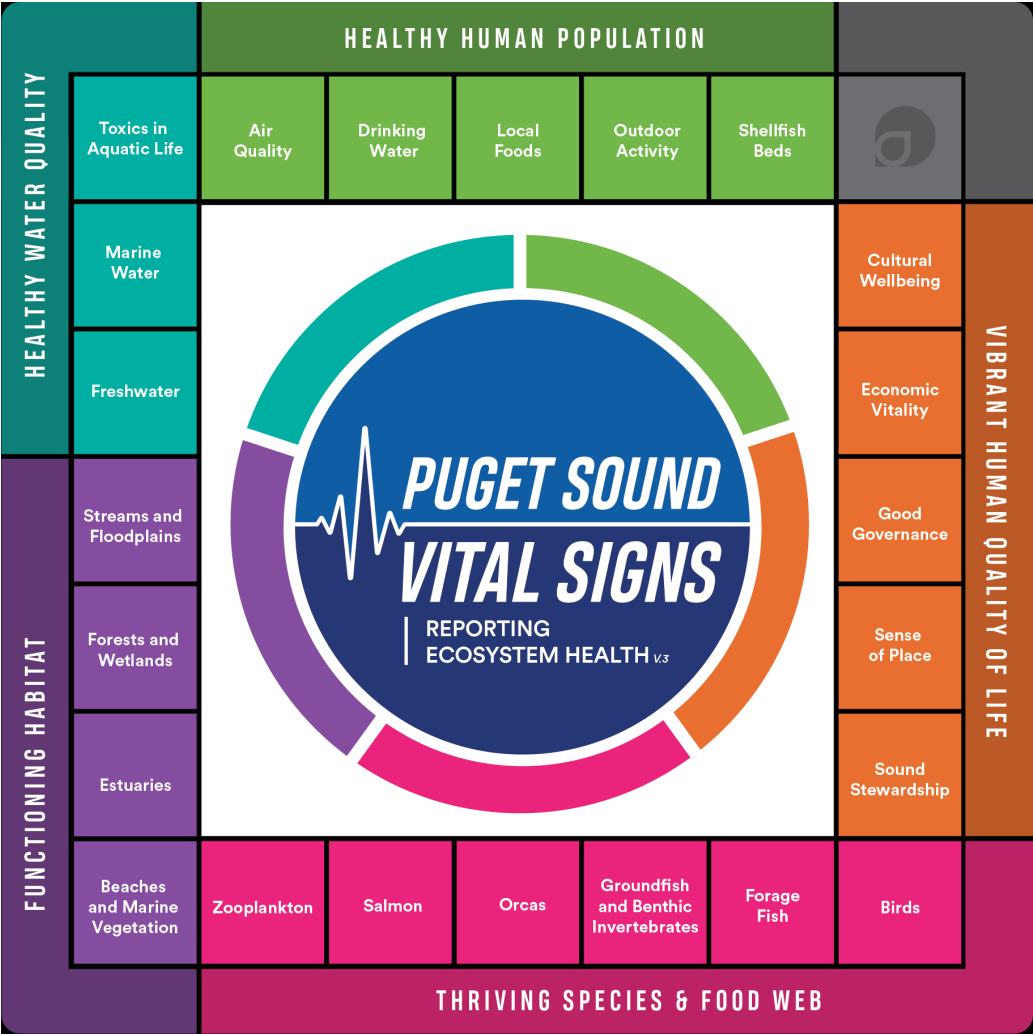


Figure 5.1: Infographic of Puget Sound Partnership's vital signs of ecosystem health. Source: Puget Sound Partnership n.d.

local biodiversity. Because many species depend on eelgrass, it may be a keystone species — that is, a species whose impact on its ecosystem is disproportionately large relative to its abundance, and whose loss would fundamentally alter ecological function. Eelgrass also has deep cultural value in the Pacific Northwest. Many related species support regional food webs, Indigenous ways of life, recreational activities such as birding and fishing, and economic activities such as diving and tourism (Habitat Strategic Initiative 2026). People have strong ties to these species. The presence of these species shapes the area’s identity and sense of place.

In addition to cultural and ecosystem benefits, eelgrass regulates the environment. It improves water quality by filtering seawater, removing excess nutrients, and trapping sediment. This filtering controls disease by reducing the number of pathogens. Eelgrass stores atmospheric carbon in its biomass and sediments, helping buffer the impacts of climate change. It protects coasts from storm surges by breaking waves and preventing flooding. Eelgrass absorbs carbon dioxide and oxygenates water, buffering ocean acidification through photosynthesis.

THREATS TO EELGRASS HEALTH

Eelgrass is an indicator species. Its presence, absence, or population reflects specific environmental conditions or changes (National Marine Fisheries Service 2017). Because it is sensitive to human impacts and widely distributed, eelgrass serves as an indicator of ecosystem health. Declining eelgrass signals broader ecological changes and the loss of key benefits in Puget Sound.

All of these benefits have significant ecological, cultural, and economic value, yet many people are unaware of the importance of eelgrass. This gap in awareness underscores the importance of the Padilla Bay National Estuarine Research Reserve’s work in protecting and educating people about eelgrass. Inspiring public concern and stewardship is vital for effective species protection. This thesis aims to contribute to those efforts by analyzing threats to eelgrass in Padilla Bay and discussing the broader implications of potential losses to ecosystem integrity and human well-being.

Before examining the stressors and threats to eelgrass and how they could be exacerbated by climate change, it is important to first understand the conditions that allow eelgrass to thrive and what indicators of health look like. Eelgrass is typically found in shallow, sheltered coastal waters, bays, and estuaries within temperate climates (Cleveland 2024). It requires soft, sandy, or muddy seafloors where it can anchor its rhizomatic root system. Eelgrass prefers calm or moderately active currents over high-energy, storm-driven environments. It requires high-light conditions for photosynthesis, which restricts it to relatively shallow depths, generally around 6 to 10 meters. However, it can grow deeper in clear water conditions. Eelgrass tolerates a wide range of salinities and is often found near river mouths, but it cannot survive in freshwater alone (Cleveland 2024).

Eelgrass structure and health can be assessed through several characteristics, as shown in Figure 5.2. Growth rate shows how well the meadow responds to current conditions. Above- and below-ground biomass indicate the

Figure 5.2: Eelgrass health indicators. Image by author.

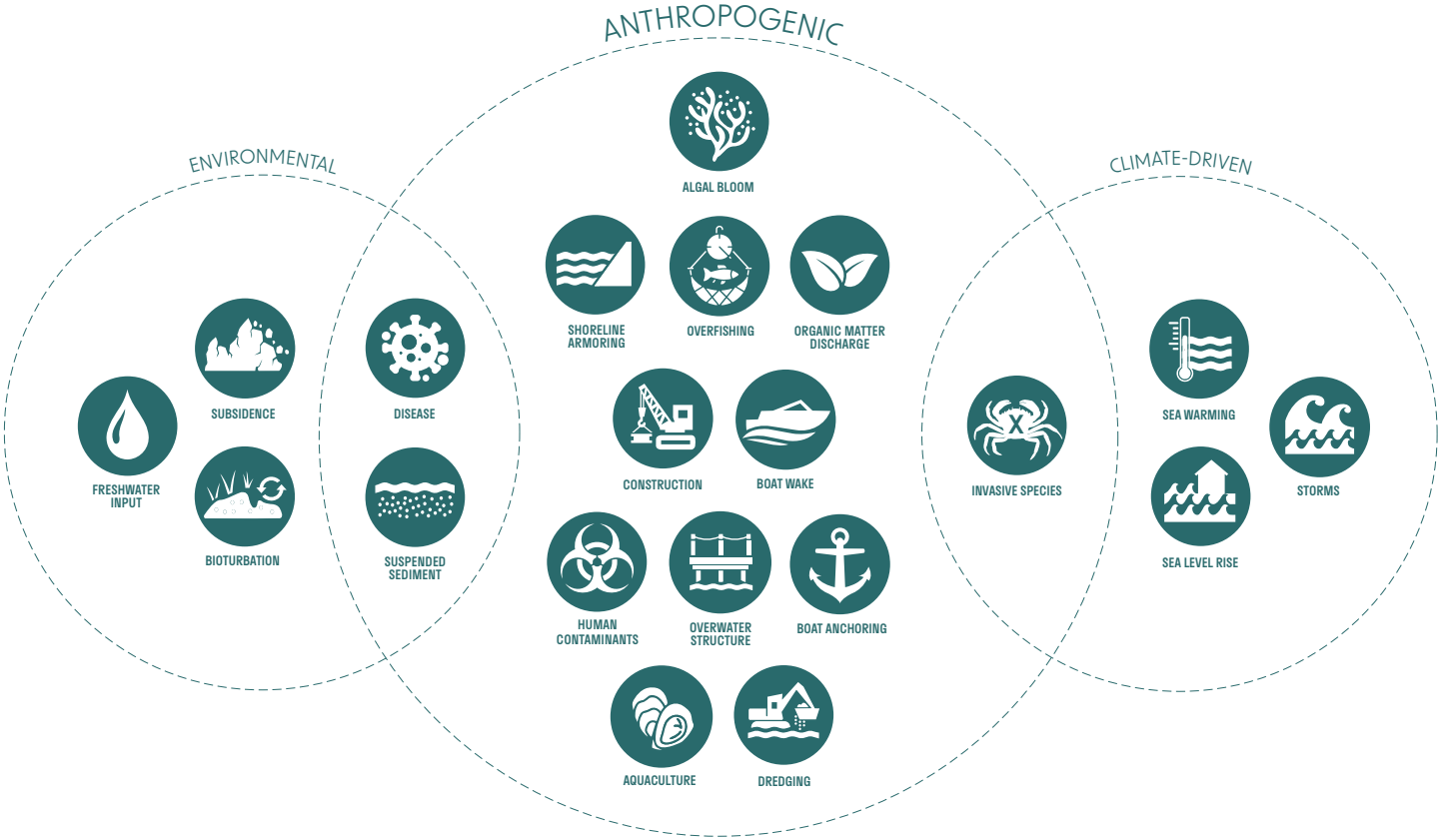
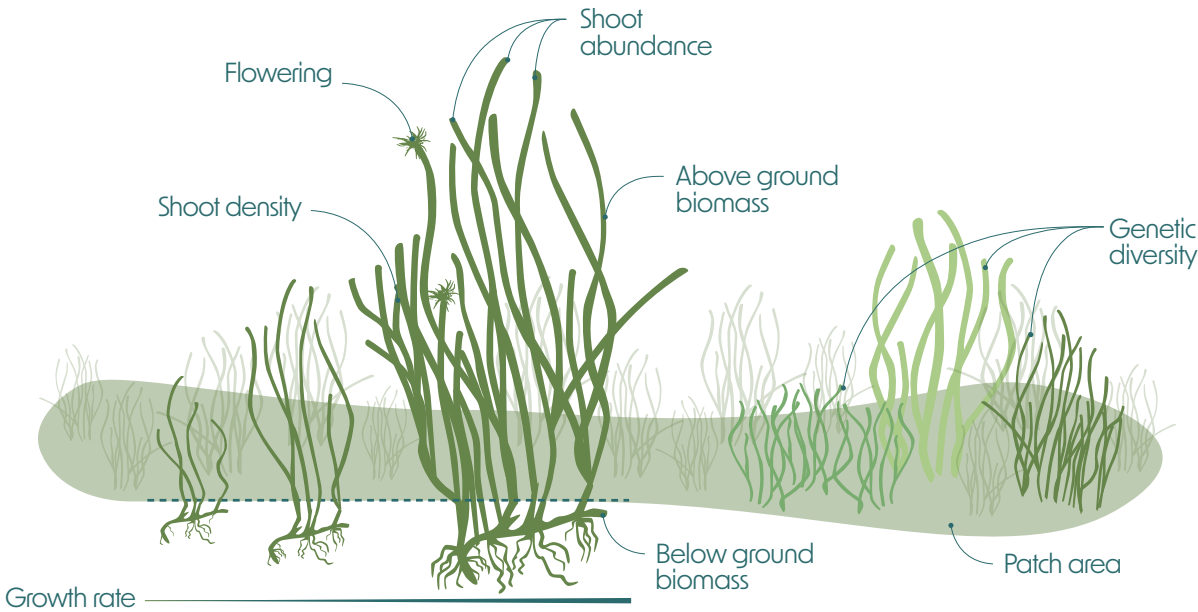


Figure 5.3: Eelgrass stressors categorized by environmental, anthropogenic, and climate drivers. Image by author.

distribution of energy between visible shoots and roots. Patch area highlights expansion or fragmentation. Shoot abundance and density describe how full and continuous the meadow is. Flowering signals reproductive capacity and persistence. Genetic diversity enables adaptation to changing conditions, supporting resilience. Together, these metrics clarify eelgrass health by linking its form to its capacity to persist over time.

These characteristics of health are shaped by a number of controlling factors that define a particular environmental setting: competition, light, substrata, energy, temperature, salinity, herbivory, and nutrients. Understanding these controlling factors makes it easier to identify how specific environmental stressors impact eelgrass health. It also helps to target interventions that could support its adaptive capacity once the conditions causing stress are better understood.

While this thesis does not address all of these stressors equally, it is worth surveying the main threats to eelgrass in the Greater Puget Sound region. This establishes a broader understanding of the systems that could impact eelgrass in Padilla Bay. After establishing these region-wide threats, it is important to consider how they manifest at the local level. What follows is a broad summary of stressors drawn from the Puget Sound Eelgrass Recovery Strategy. This section examines how, and to what extent, these stressors appear specifically in Padilla Bay.

Figure 5.3 summarizes sources of eelgrass decline, organizing these stressors into three categories: environmental, climate-driven, and anthropogenic. This organization was chosen to show that eelgrass health is not affected by a single pressure, but by overlapping forces that emerge from different systems. Some stressors

emerge from natural environmental conditions, while others are directly tied to human activity. Climate-driven stressors are difficult to isolate since they are often intensified by broader patterns of human-caused climate change. All of these stressors are projected to worsen over the coming decades, with significant consequences for eelgrass health (Magel et al. 2025). Model predictions, for example, show that eelgrass biomass in the Salish Sea could drop by nearly 50% by the end of the century. Understanding how these stressors interact, and where there may be opportunities to intervene, is essential to supporting eelgrass health into the future. The following describes each stressor in more detail and how it has the potential to impact eelgrass health in the broader region.

Aquaculture: Aquaculture can produce both positive and negative impacts on eelgrass. It can lead to competition for space on the muddy intertidal flats where eelgrass grows. Some mechanical harvesting techniques can have direct impacts on eelgrass beds. The magnitude of these impacts depends on the species being cultivated and the methods employed. Some studies show that shellfish and eelgrass can support one another (Washington State Department of Natural Resources 2015). Shellfish filter suspended particles and increase light penetration, which eelgrass needs for photosynthesis. Eelgrass stabilizes sediment and reduces suspended particles that would stress shellfish. However, these effects vary by location.

Climate Change: Rising sea temperatures and sea levels could significantly impact eelgrass in Puget Sound (Washington State Department of Natural Resources 2015). Higher water temperatures reduce eelgrass productivity, and extended warm periods could diminish its growth and survival. Rising sea levels increase water depths, which will likely result in the loss of eelgrass along the deeper edges of existing beds where light levels become insufficient. In the short term, eelgrass beds may expand toward the shore in response

to sea level rise. However, in many locations, shoreline armoring will restrict this inland migration, resulting in what is known as coastal squeeze.

Disease: Eelgrass wasting disease has caused significant population declines throughout the United States and has been confirmed in several locations in the San Juan Archipelago, adjacent to Padilla Bay (Washington State Department of Natural Resources 2015). The mechanisms and pathways underlying the spread of this disease remain unclear and warrant further research. Changes in salinity or temperature associated with climate change may increase eelgrass vulnerability to disease over time.

Dredging: Dredge-and-fill projects, primarily conducted to maintain the depths of shipping channels, can result in direct physical disturbance and mortality of eelgrass beds. Much of this maintenance occurs at regular intervals, producing recurring impacts. Modifications to nearshore depths and changes in wave energy following dredging can also prevent eelgrass from spreading and repopulating after a disturbance (Washington State Department of Natural Resources 2015). In the short term, dredging can reduce water quality by churning up sediment and reducing light availability. Historically, the dredging and filling of tidelands to support agriculture and land use development have contributed to the permanent loss of eelgrass beds (Washington State Department of Natural Resources 2015).

Construction: Construction activities around eelgrass beds, including the installation of pilings, overwater structures, underwater utilities, and breakwaters, can result in the direct removal, burial, or physical damage of plants. These activities can also temporarily increase water turbidity and reduce light availability. As regional population growth continues, these types of construction activities are likely to increase (Washington State Department of Natural Resources 2015).

Boat Anchoring and Wake: The mooring and anchoring of vessels can cause localized but meaningful damage to eelgrass beds. In high-use areas, these impacts can accumulate, contributing to a significant overall decline. Anchor chains dragging across the seafloor can damage substrate or uproot plants, and large vessels moored over eelgrass beds for extended periods can cause increased shading. These pressures are expected to grow as the population and recreational boating activity increase (Washington State Department of Natural Resources 2015).

Algal Blooms: Human-caused nutrient inputs transported into the nearshore environment from agricultural runoff, wastewater treatment facilities, fertilizer, and urban runoff can trigger phytoplankton and macroalgae blooms (Washington State Department of Natural Resources 2015). These blooms increase turbidity and reduce the light that reaches eelgrass beds. As excess algae die and decompose, oxygen is consumed, creating hypoxic or anoxic dead zones where other marine life cannot survive. Further research is needed in Puget Sound to fully understand the scale of these impacts on eelgrass (Washington State Department of Natural Resources 2015).

Organic Matter: Runoff from agricultural lands can carry excess organic material into nearshore waters, where it settles into the sediment and begins to decompose. Similar to algal blooms, this decomposition consumes oxygen and can create low-oxygen, or anaerobic, conditions in the sediment. It can also lead to the buildup of hydrogen sulfide, a compound harmful to eelgrass. Studies in the San Juan Islands have found hydrogen sulfide levels high enough to reduce eelgrass seedling survival, suggesting it may contribute to local declines and inhibit recovery once eelgrass is lost (Washington State Department of Natural Resources 2015).

Overwater Structures: The construction of overwater structures such as piers, docks, and boardwalks can directly impact eelgrass beds and contribute to long-term shading of nearshore habitats, reducing light transmission and inhibiting eelgrass growth. These structures can also contribute to habitat fragmentation in the areas surrounding them (Washington State Department of Natural Resources 2015). Design factors, including structure height, orientation, width, number of pilings, and the transparency of construction materials, all influence the magnitude of disturbance. As marina development and coastal economic activity expand with population growth, these structures are anticipated to become more common (Washington State Department of Natural Resources 2015).

Invasive Species: Non-native species can disrupt eelgrass meadows by competing for space, light, and nutrients. Some invasive algae grow quickly and form dense mats that shade eelgrass, while others alter sediment conditions in ways that make it harder for eelgrass meadows to persist and recover (Washington State Department of Natural Resources 2015).

Sediment and Freshwater Input: Sediment loading reduces water clarity and stresses eelgrass growth by limiting light availability. River discharge is a primary source of sediment, but stormwater runoff is another significant contributor. Historic channelization of rivers and deltas to support agriculture and land-use development has significantly modified sediment delivery patterns, concentrating inputs in some areas and eliminating them in others, altering historic eelgrass distribution over time (Washington State Department of Natural Resources 2015).

Bioturbation: Bioturbation occurs when sediments are stirred up by living organisms, including burrowing species such as crabs, worms, or shrimp. While this process is natural on seafloors, it can become disruptive when disturbance is too intense or occurs in already stressed eelgrass beds. Bioturbation can uproot eelgrass shoots or destabilize the substrate that supports them, and, in some cases, increase water turbidity, further reducing the light eelgrass needs to grow. Climate change can also shift species distributions, potentially introducing or increasing the abundance of sediment-disturbing species that intensify bioturbation and create more stressful growing conditions for eelgrass.

Subsidence: Subsidence, or the gradual sinking of land, can alter water depth in eelgrass habitats. Even small increases in depth can reduce the amount of light reaching the plants, making survival more difficult. Over time, this can lead to meadow decline or loss, especially in areas already close to the shallowest depth at which eelgrass can survive.

Storms: Storms can physically damage eelgrass through strong waves and currents that uproot plants or break apart meadows. They can also stir up sediments, reducing water clarity and limiting light availability for photosynthesis. Repeated storm disturbances can slow recovery and increase the fragmentation of existing beds (Washington State Department of Natural Resources 2015).

Overfishing: Overfishing can disrupt the balance of coastal ecosystems by removing key species that help maintain healthy eelgrass habitats. Declines in predator populations, for example, can lead to increases in grazing organisms that damage eelgrass directly or consume the invertebrates that keep eelgrass free of algae. These indirect effects can gradually weaken or degrade eelgrass meadows, potentially leading to long-term declines (Washington State Department of Natural Resources 2015).

Shoreline Armoring: Shoreline armoring methods, including bulkheads, riprap, dikes, and levees, are utilized to protect land from flooding and erosion. These structures can disrupt natural sediment delivery and transport within the nearshore ecosystem, thereby altering substrate composition (Washington State Department of Natural Resources 2015). They can also reflect wave energy from storms, increasing local erosion and elevating water turbidity. Critically, these structures can prevent habitats from migrating inland as sea levels rise, contributing to coastal squeeze. Additional research is needed to better understand the extent to which shoreline armoring influences eelgrass decline, particularly as these structures are being introduced and modified in response to sea level rise (Washington State Department of Natural Resources 2015).

Anthropogenic Contaminants: Human-sourced pollutants, including heavy metals, pesticides, and excess nutrients, can degrade water quality, directly affecting eelgrass. Some contaminants increase nutrient levels and trigger excess algal growth that blocks light, while others reduce water clarity. In more severe cases, certain contaminants can be toxic and harm or kill eelgrass outright. Because eelgrass depends on clear, clean water to survive, sustained declines in water quality can seriously harm its health and ability to recover. Further research is needed to better understand how different contaminants, individually and in combination, influence eelgrass decline and recovery over time (Washington State Department of Natural Resources 2015).

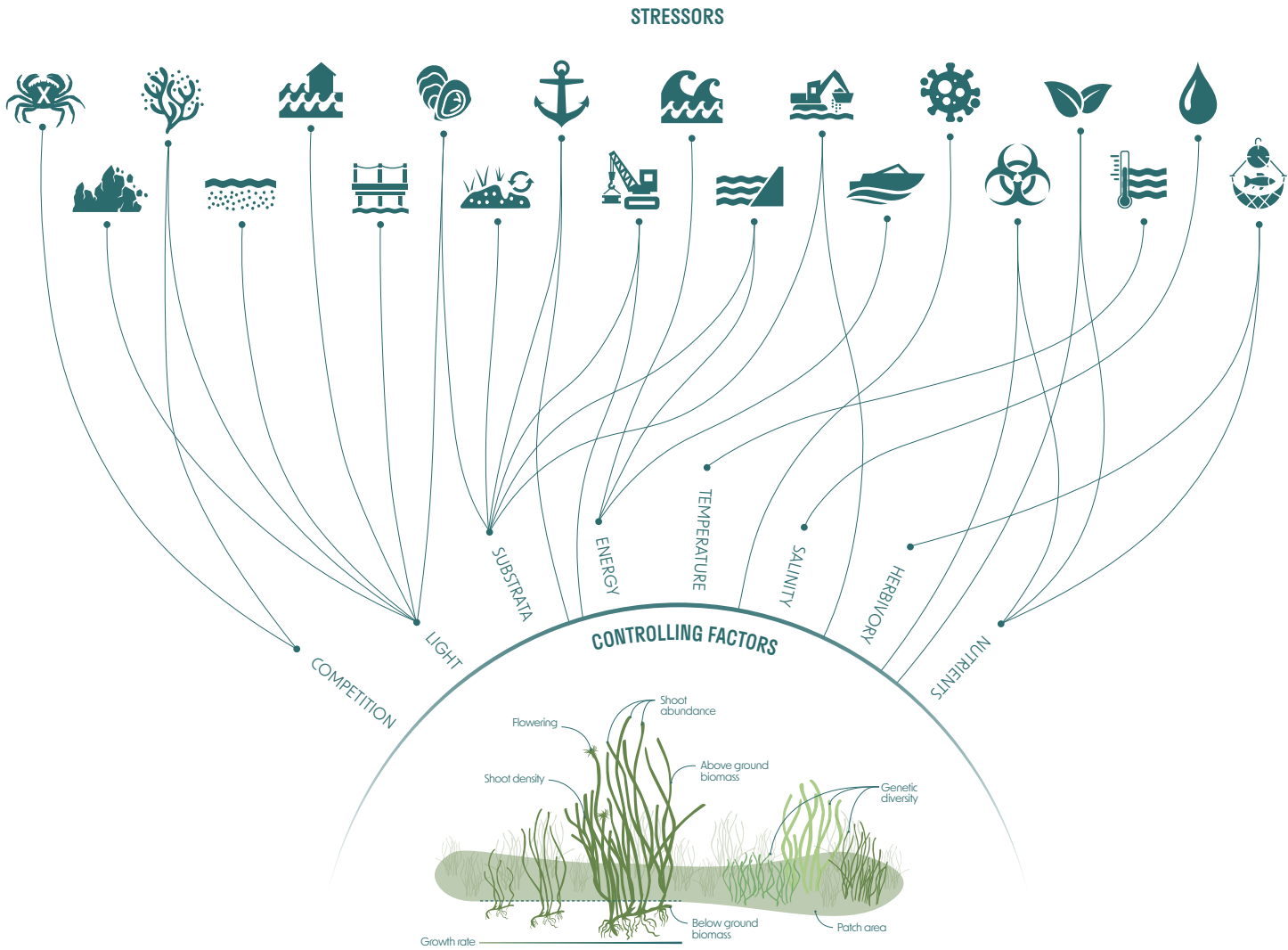


Figure 5.4: Diagram summarizing how eelgrass stressors influence eelgrass health. Image by author.

A summary of these stressors and their influence on the controlling factors of eelgrass health is shown in Figure 5.4. These controlling factors include light availability, substrate conditions, storm energy, temperature, salinity, nutrient availability, competition, herbivory, and direct physical disturbance. The following section examines how these stressors play out across multiple scales, from the broader region to Padilla Bay specifically. I draw on the background research to identify which stressors emerge as the most significant threats to eelgrass in Padilla Bay.

STRESSORS ACROSS SCALES

While the primary focus of this research question is the socio-ecological systems that influence eelgrass, this is not an eelgrass restoration project. By exploring the socio-ecological systems in Padilla Bay that impact eelgrass, this thesis aims to decenter humans and understand how climate change affects other species, and, in doing so, to recognize how deeply we are connected to these same systems. The conditions that will allow other species to thrive in the future will also benefit us. Conversely, if we do not recognize the needs of other species, there will be cascading impacts for all, including ourselves.

Not all of the stressors identified in the previous section are immediately visible in Padilla Bay because they operate across complex systems and across multiple scales. Some of these stressors have impacts far beyond Padilla Bay; though the bay is the primary area of study, many stressors affect more species than just eelgrass. Understanding the effects of these stressors on the ‘eelgrass+’ community required a multiscale approach. Rather than conducting a general site analysis across these scales, I used eelgrass as a multispecies lens to examine how these stressors directly play out within the context of Padilla Bay, as well as the broader systems in

which it is embedded. This approach reveals the relationality of eelgrass, where stressors appear and compound across multiple scales, and how deeply interconnected these systems are.

The analysis moves through five nested scales that impact Padilla Bay. The broadest scale explored is the Salish Sea, which then narrows to the Greater Puget Sound. It also explores the freshwater system of the Skagit River Basin and Padilla Bay itself, before zooming into the local micro-scale of eelgrass habitat within the bay. The scales are shown relative to one another, with Padilla Bay identified across all scales in Figure 5.5.

SALISH SEA SCALE

The Salish Sea encompasses 6,525 square miles in the Pacific Northwest region of the United States and British Columbia, Canada, with a coastline stretching 4,641 miles (Port Townsend Marine Science Center n.d.). It is a rich ecological region home to approximately 8 million people and a diverse array of more-than-human species, including 172 bird species, 252 fish species, and 113 threatened or endangered species, many of which are found in or around Padilla Bay (Port Townsend Marine Science Center n.d.). Figure 5.6 (see next page) depicts the range of socio-ecological systems at this scale, layering the eelgrass stressors across the region. Climate data are layered on Figure 5.6 in concentric rings, showing historical trends in seasonal precipitation, average annual precipitation, mean annual air temperature, and changes in sea surface temperature.

Average annual precipitation across the Salish Sea increased 5.3% between 1901 and 2012, establishing a long-term historical trend. More recent data from 1991 to 2020 shows a further 7.2% increase from that baseline, representing a growth of 6.3 inches. Climate projections from the Salish Sea Model project that precipitation will increase by 11.7 inches by 2100, or 15.6% above the 1901-to-2012 average (Flower n.d.). These changes are not uniform across seasons. Seasonal precipitation is projected to decrease in winter and increase in all other seasons (Flower n.d.), a pattern that will have significant implications for freshwater inputs, sediment delivery, and the salinity conditions on which eelgrass depends.

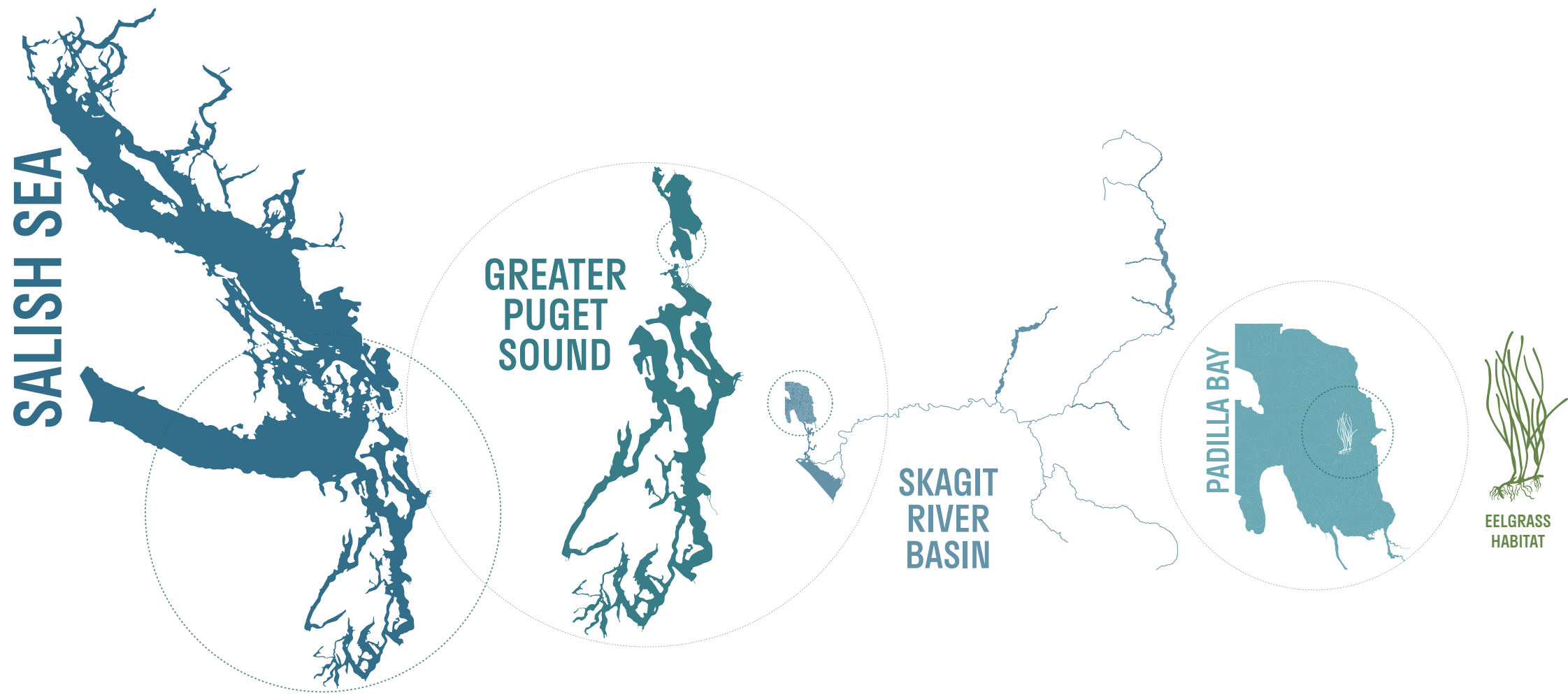
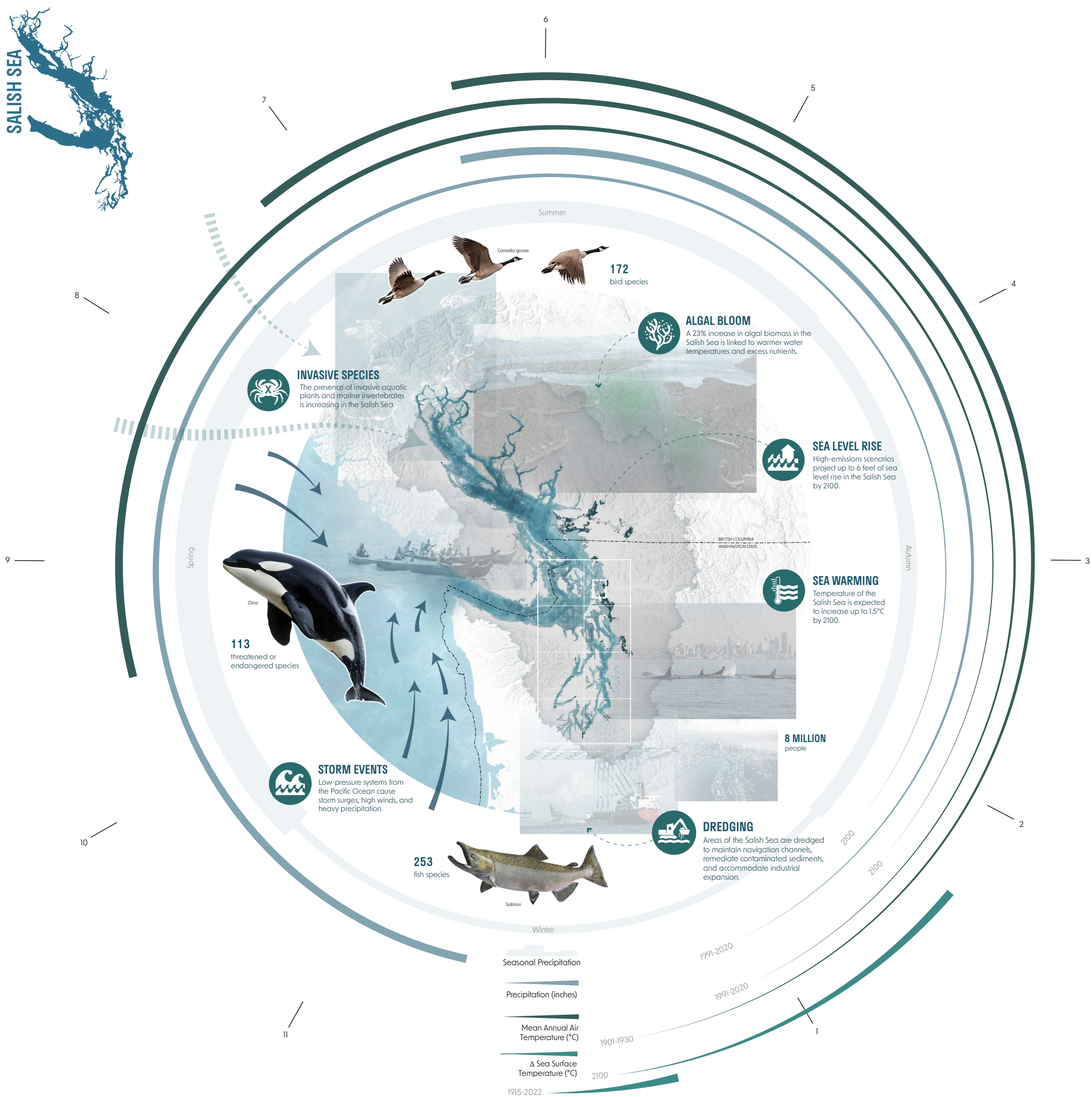


Figure 5.5: Diagram identifying the five scales of analysis. Image by author.

Air temperature trends follow a similar trajectory. Average annual air temperature between 1901 and 1930 was 6.3°C, rising to 7.2°C between 1991 and 2020, an increase of 0.9°C. By 2100, climate projections expect average annual air temperature to reach approximately 9.5°C (Flower n.d.), representing an increase of 3.2°C from historic trends. Sea surface temperature has risen in parallel. Between 1915 and 2022, sea surface temperatures in the Salish Sea rose by 0.06-0.27°C, and by 2100 are projected to increase by a further 1.51°C (Flower n.d.). Given that sea warming is identified as one of the primary stressors of eelgrass, these temperature trends have direct, negative implications for the species at the center of this inquiry.

The ecological consequences of these changes are already becoming visible at the regional scale. Warming seas have contributed to a 23% increase in algal biomass in the Salish Sea, linked to higher temperatures and excess nutrients (Salish Sea Modeling Center n.d.). The region has also seen an increase in invasive aquatic plants and marine invertebrates, driven by human activity and warming seas. This allows non-native species to expand their ranges, threatening to outcompete native flora and fauna. Sea level rise compounds these pressures, with high-emissions scenarios projecting up to a 6-foot rise by 2100. More intense storm events from Pacific low-pressure systems are also anticipated, bringing storm surges, high winds, and heavy precipitation to the region. Although the Salish Sea is a broad region and the intensity of these impacts will vary locally, understanding conditions at this scale is essential for contextualizing the stressors operating in Padilla Bay and for appreciating what is at stake if these pressures compound across the region.

Figure 5.6: Graphic summarizing socio-ecological systems at the Salish Sea scale. Image by author.

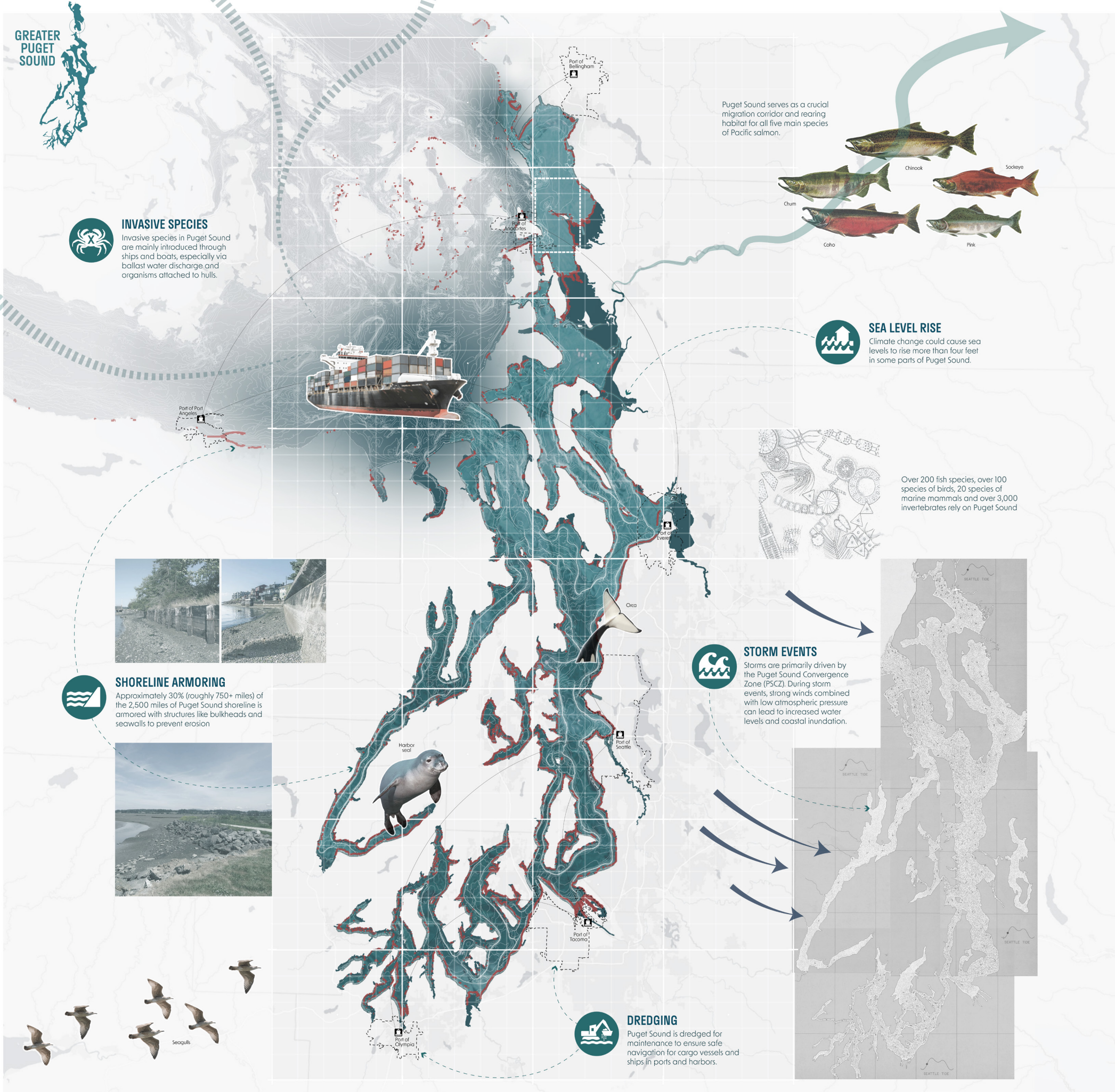


GREATER PUGET SOUND SCALE

The Greater Puget Sound is a major body of water in the Salish Sea, located in Washington State. It is a complex estuarine system of interconnected marine waterways with approximately 2,500 miles of coastline (Habitat Strategic Initiative 2021). Ecologically, Puget Sound is an extraordinarily important estuary for thousands of species, including all five main species of Pacific salmon. The waters of the Sound serve as a critical migration corridor and rearing habitat for salmon, a species of profound cultural, ecological, and economic significance to the human and more-than-human communities of the region.

Puget Sound is also a major commercial shipping corridor. Cargo vessels frequently visit major ports in Seattle, Tacoma, Olympia, Everett, Bellingham, Anacortes, and Port Angeles to transport goods, with Anacortes to the west and Bellingham to the north being the closest to Padilla Bay. To maintain the deep water shipping channels these vessels require, regular dredging occurs throughout Puget Sound; an activity that carries well-documented negative consequences for nearshore ecosystems, including eelgrass. Shipping traffic also poses a risk of invasive species transport, as vessels can inadvertently carry non-native organisms on their hulls or in ballast water tanks, potentially competing with or disrupting native eelgrass communities.

Figure 5.7: Graphic summarizing socio-ecological systems at the Greater Puget Sound scale. Image by author.



Although the Sound is an inland body of water, storm events can still have major impacts on its shorelines. Storms bring strong winds and low atmospheric pressure, which can raise water levels and cause coastal flooding, while high-energy waves accelerate shoreline erosion. To protect key infrastructure from these forces, approximately 29% of the Puget Sound shoreline has been armored (Habitat Strategic Initiative 2021). Shoreline armoring makes a dynamic shoreline static, disrupting the natural processes that replenish beaches and gravel with sand, and accelerating the loss of nearshore habitat. As sea levels rise, armored shorelines also prevent habitats from migrating inland, contributing to the coastal squeeze dynamic introduced in the previous section. Sea level rise in the region is projected to exceed 4 feet in some areas, with dramatic consequences for both habitat and coastal infrastructure. Figure 5.7 (see previous page) shows the socio-ecological systems operating at this scale and the locations of eelgrass stressors.



Figure 5.8: Graphic summarizing socio-ecological systems at the Skagit River Basin scale. Image by author.

SKAGIT RIVER BASIN SCALE

The Skagit River Basin is the freshwater system that feeds Padilla Bay, operating at a large regional scale from the mountains to Puget Sound. Historically, the Skagit River flowed into Padilla Bay, but through natural channel migration and decades of diking and converting the floodplain to farmland, the natural sediment supply to Padilla Bay has essentially been cut off (Lee and Hamlet 2011). Dams in the upper Skagit River Basin have further reduced the downstream sediment supply. The dikes and levees that now line much of the lower basin were constructed over the last century to maintain farmland and protect it from saltwater that would destroy crops. This land used to be covered in tidal mudflats, which create soil that is incredibly rich and productive for agriculture. Fertilizers and pesticides from agricultural land pose a risk of entering waterways and impacting water quality downstream in Padilla Bay.

The Skagit River Basin is also home to a range of other industries. Commercial shellfish aquaculture is a major coastal industry in the intertidal areas, providing economic and cultural benefits as a local food source. Although commercial shellfish operations are not located within Padilla Bay itself, many of the surrounding bays are home to major operators like Taylor Shellfish and Skagit Shellfish, which are among the largest in Washington State. The region is also Washington State's hub for crude oil refining, with major refineries located on March Point, a peninsula that forms the western shoreline of Padilla Bay. Crude oil is transported by rail from the shoreline to March Point, and then by water onto boats for regional distribution. These rail lines running along the coast pose a risk of toxic contamination of the waterways in the event of a spill.

Although the area supports many major industries, it also attracts significant wildlife, making activities such as birding, fishing, and hunting popular year-round. Other events, such as the annual tulip festival, attract thousands of visitors each year. Common wildlife found in the area includes bald eagles, peregrine falcons, otters, and trumpeter swans. Shorebirds are commonly found on the mudflats, and salmon species, including the endangered Chinook, can be found alongside Pacific herring, smelt, and shiner perch. The region's close proximity to King County's population centers and its easy access off Interstate 5 make it a popular destination for visitors.

The population of the Skagit River Basin is projected to double by 2050, placing significant development pressures on natural areas in the region, including Padilla Bay (Lee and Hamlet 2011). A large portion of the downstream areas are within the floodplain so this area is no stranger to flooding, which is another reason many waterways, including major rivers and the coast of Puget Sound, are armored to protect low-lying land. These issues will only intensify with sea level rise, with a 2-foot rise by 2100 increasing flood risk in this already vulnerable area. Much of the existing shoreline armoring is aging quickly without proper management, and is not designed to withstand the storms or higher sea levels projected in the future. Flooding in this region can result from snowmelt flowing down rivers, coastal flooding, storms, and intense rain events. Figure 5.8 (see previous page) depicts these socio-ecological systems, common species in the region, and how the eelgrass stressors play out at this scale.

PADILLA BAY SCALE

At the Padilla Bay scale, many of the same systems that appear in the Greater Puget Sound and Skagit River Basin are relevant, but many more start to emerge, as shown in Figure 5.9 (see next page). A large portion of the area surrounding Padilla Bay is at or below sea level, so shoreline armoring is used to protect homes from flooding during storm events and to protect agricultural lands from saltwater contamination that would damage crops. Hard armoring in Padilla Bay includes larger earthen dikes, concrete or wooden bulkheads in front of individual houses, and riprap along some trails. The dikes in the lower part of Padilla Bay have a trail on top, and are a popular recreational destination because they overlook extensive tidelands and agricultural fields.

Agricultural runoff carrying excess nutrients poses a risk of algal blooms in the watershed, which could make the water unsafe for recreation and harmful to life in the estuary. Other contaminants that pose a risk to water quality and ecosystem health include potential oil contamination from the March Point refineries, where pipelines that transport fuel stretch across the water to and from oil tankers. Any potential spills could pose serious risks to marine life. In addition, several historic landfills around Padilla Bay, including one at the refineries, pose a risk of contaminating the water with methane, heavy metals, benzene, and PCBs.

Because of the potential risks to Padilla Bay's protected habitat, ongoing monitoring is underway in the region, much of which is associated with the Padilla Bay National Estuarine Research Reserve. The Reserve's main facilities and interpretive center are located on the eastern shoreline, just north of the town of Bay View. The Reserve provides opportunities for research, monitoring, and stewardship, with a focus on water quality, habitat loss, climate change, impacts of invasive species, and loss of nearshore processes (Washington State Department of Ecology 2008). The site includes

an aquarium and exhibit space, an overlook and beach access point directly on Padilla Bay, an upland trail system, facilities for the stewardship team to manage lands and the new prairie restoration project, and space for community workshops, gatherings, and visiting researchers. Beyond the Reserve, other popular recreation areas include Bay View State Park just south of the Reserve and the Skagit Wildlife Area - Samish Unit to the north by Samish Island. These areas attract visitors for bicycling, bird watching, hiking, and boating or windsurfing, particularly in the warmer months, reflecting the broader cultural and recreational value this place holds for the region.

Commercial fishing boats and shipping barges are common year-round in Padilla Bay, and the wakes from these large ships can have an impact on eelgrass beds in the shallow waters of the bay. Evidence shows that the surface elevation in Padilla Bay is subsiding or eroding, likely due to the limited sediment supply, and it is uncertain whether the current rate of accretion is sufficient to offset the combined rate of subsidence and sea level rise (Kairis 2008). The Swinomish Channel connects Padilla Bay to Skagit Bay and requires dredging every three years to maintain navigable depths for ships, with dredge material deposited offsite (Kairis 2008). This boat activity has the potential to disrupt sensitive habitat, including eelgrass beds.

Much of the research in Padilla Bay focuses on eelgrass because its population size and spatial extent are comparatively healthy relative to other eelgrass populations in Puget Sound (Cleveland 2024). However, eelgrass is not the only important habitat in the area. Padilla Bay supports a range of other habitat types, each with their own plant and animal communities that are vulnerable to the stressors discussed in this chapter. Upland areas near the bluffs consist of Douglas fir, western red cedar, red alder, Pacific madrone, big-leaf maple, Oregon grape, stinging nettle, and salal. Freshwater sloughs near the

freshwater inputs include Lyngby's sedge and tufted hairgrass. Near the Swinomish Channel, dune wildrye, red fescue, cheat grass, and the invasive *Spartina* are present. Near agricultural dikes, red clover, English plantain, quack grass, and pearly everlasting are found alongside wild rose, red alder, black cottonwood, and willows (Washington State Department of Ecology 2008). Padilla Bay retains only around 3% of its original salt marsh (NOAA Office for Coastal Management n.d.), with remaining areas supporting salt-tolerant species including salt grass, pickleweed, gumweed, foxtail barley, Lyngby's sedge, orache, Canada sand spurry, seaside arrow grass, reed canary grass, bentgrass, and saltgrass. The maps in the bottom right of Figure 5.9 show changes in habitat and vegetation types in Padilla Bay over time. Invasive species like *Spartina* and blackberry pose an ongoing threat across many of these habitat types, as aggressive spreading plants that outcompete native vegetation and degrade nearshore habitat.

Sea level rise could have significant impacts on these nearshore habitats, including the eelgrass population in Padilla Bay. Although it is difficult to precisely predict sea level rise at the local scale due to factors such as subsidence, currents, and temperature patterns, local modeling for the Puget Sound subregions provides a clearer picture of local projections. Because these outcomes depend on greenhouse gas emissions scenarios, they vary considerably. The sea level rise matrix shown in Figure 5.9 presents data for high greenhouse gas scenarios based on 75%, 50%, 10%, and 1% probability thresholds.

Figure 5.9: Graphic summarizing socio-ecological systems at the Padilla Bay scale. Image by author.



Corresponding values for the year 2050 are 0.5, 0.7, 1.0, and 1.3 feet for those categories, respectively (Miller et al. 2018). These values do not seem extreme given that 2050 is in the near future; projections for the year 2100 become more significant, rising to 1.4, 2.0, 3.1, and 4.8 feet, respectively (Miller et al. 2018). Projections extending to 2150 are more difficult to predict, with values ranging from 2.3 to 10.0 feet at the extreme end (Miller et al. 2018). This scenario matrix helps distinguish the scenarios and understand the varying degrees of change tied to our own decisions as humans, signaling that a shift toward lower-carbon, more sustainable ways of living would lead to less extreme outcomes. Median estimates for relative sea level rise in Padilla Bay over the next 125 years range from 0.7 to 3.4 feet (Miller et al. 2018). Since Padilla Bay is the primary scale this thesis operates at, I examined these different sea-level rise scenarios to develop a more detailed understanding of the potential future impacts.



Figure 5.10: Graphic summarizing socio-ecological systems at the eelgrass habitat scale. Image by author.

EELGRASS HABITAT SCALE

At the eelgrass habitat scale, Figure 5.10 (see previous page) shows that many of the same stressors identified at the Padilla Bay scale are still present. At this finer scale, the localized impact of these stressors becomes clearer, revealing how they disrupt ‘eelgrass+’ habitat. Construction of structures along the waterfront, including shoreline armoring, buildings, and overwater structures, can have direct physical impacts on eelgrass and its substrate. Overwater structures like piers, docks, boat lifts, and boardwalks can block sunlight from penetrating the water, and their pilings can disturb the substrate, churning sediment and reducing water clarity. This reduction in light is particularly damaging in the deeper stretches of eelgrass territory, which are already operating closer to the lower limits of light availability. Bulkheads and other shoreline armoring disrupt the natural sediment movement that habitats like eelgrass and salt marshes rely on to maintain their elevation and protect against erosion. These structures also typically create steeper, narrower beaches, leaving less room for beach recreation and less space for habitat to migrate in response to sea level rise.

Sea level rise will raise water levels, increasing water depth and reducing light availability, altering habitat composition and forcing intertidal habitats to migrate landward into shallower areas within their suitable range. In the near term, with just a fraction of an inch of sea level rise predicted, eelgrass habitat might expand closer to shore while maintaining its deeper extents, as long as water remains clear and sunlight can reach it (Washington State Department of Natural Resources 2015). However, multiple feet of sea level rise would drown out much of the deeper extent of eelgrass habitat. Where shoreline armoring is present, it cuts off the tidal zone from migrating upland and prevents eelgrass from expanding into shallower range, eventually narrowing its extent to a ring around

the edge of the bay, as has already occurred in many other parts of Puget Sound (Puget Sound Science Review n.d.). These can be referred to as eelgrass fringe habitats, in contrast to the eelgrass flats found in Padilla Bay (Puget Sound Science Review n.d.).

Other impacts on eelgrass come from species interactions. Invasive European green crabs have been found in Padilla Bay in increasing numbers, though the Reserve is actively managing them and developing plans to protect eelgrass habitat. These crabs, and other invertebrates such as the Asian mudsnail, can devastate eelgrass beds through bioturbation — foraging and burrowing into the substrate as they search for prey, uprooting plants in the process. Disease is another concern. Eelgrass wasting disease is spread by a mold-like pathogen that causes black lesions on eelgrass leaf blades, limiting plant growth and reducing survival (Puget Sound Partnership 2025). Wasting disease is widespread in many areas of the adjacent San Juan Islands, and has been characterized by lower shoot density in affected areas. Higher-temperature days have been associated with increased disease prevalence and severity, whereas deeper eelgrass beds have experienced lower disease severity, suggesting they may offer some refuge and that temperature plays an important role in transmission (Puget Sound Partnership 2025). This is a concern under the effects of climate change, as warmer water temperatures can also shift the metabolic balance of eelgrass and increase its light requirements. If water temperatures and sea levels rise simultaneously, eelgrass may face compounded stress, requiring more light in conditions where light availability is increasingly limited.

Human activities also disturb eelgrass at this scale. Recreational boating, especially in shallow water, causes turbulence from boat wakes that can uproot eelgrass and smother beds with suspended sediment. Boat anchors dragged through eelgrass beds can damage them and leave scars where plants have died back. Boats anchoring in one spot for long periods, including oil tankers and fuel barges frequenting March Point, can shade eelgrass beds below. Overfishing is another concern. The removal of predatory fish, commonly targeted recreationally and commercially, allows small fish and crustacean populations to grow unchecked. These species overgraze the invertebrates that keep eelgrass free of algae, so with a reduction in predator levels, algae can thrive and smother eelgrass. Nutrient runoff from surrounding shore activities can trigger algal blooms that block sunlight from reaching the water and can also cause algae to overgrow directly on eelgrass blades, making it essential to maintain the invertebrate populations that feed on this algae (Mumford 2007).

KEY STRESSORS

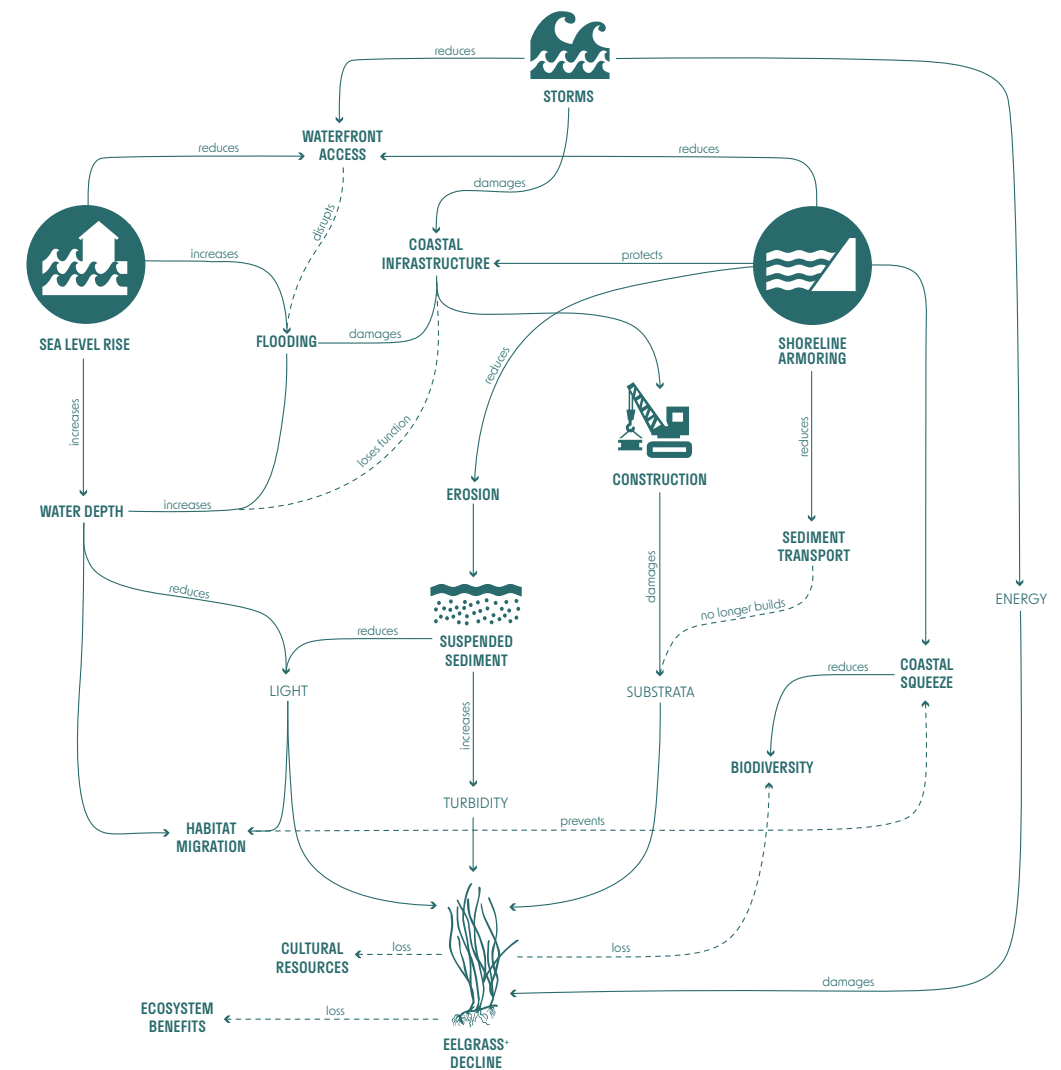
This multiscale analysis provided a broad summary of the socio-ecological systems that influence eelgrass, including humans, infrastructure, other species, and climate change. A multispecies perspective was explored by mapping the relationships between eelgrass and other species in the region. The stressors identified earlier were then traced across five nested scales, revealing where they appear, how they interact, and where they have the potential to compound one another throughout the system. By exploring these systems beyond the scale of Padilla Bay, a more complex picture emerged than would have been possible otherwise, as several of the broader dynamics at play in the region only become visible when you zoom out. Despite this, they still find their way into Padilla Bay through the larger systems they are part of.

Synthesizing this information across a variety of scales made it possible to see which stressors appeared most frequently and to get a better understanding of how impactful each one was within the context of a broader system. It also quickly became clear that this is an incredibly complex web that could not be fully explored within the scope of this thesis. To clarify the decision-making process, I established a set of criteria for prioritizing stressors for deeper analysis and design engagement. First, I considered the frequency and consistency with which each stressor appeared across multiple spatial scales, recognizing that stressors with a broader footprint are more likely to have cumulative or compounding effects. Second, I assessed the magnitude and significance of their ecological impact, especially regarding eelgrass and associated multispecies communities. Third, I evaluated the degree to which these stressors could potentially be addressed or transformed through design and adaptation strategies. Finally, I looked for stressors that were interrelated or synergistic, meaning their impacts were amplified when considered together.

Sea level rise leads to higher water levels, which ultimately reduce light availability for eelgrass and impact its ability to photosynthesize. Higher water levels also lead to flooding, which damages coastal infrastructure. When coastal infrastructure is damaged, it requires expensive reconstruction. The effects of this reconstruction, including the destruction of seafloor substrate and the creation of suspended sediment, increase water turbidity and further reduce light

While eelgrass was the focus of this background research, the goal of this project is not only to restore eelgrass. Using a foundational species like eelgrass as a lens allowed me to learn more about the interconnected web of relationships that eelgrass is a part of, and to understand the role that humans play in this system. Even though eelgrass is only one species, the multiscale analysis revealed how sea level rise and shoreline armoring move through the system, impacting eelgrass, other species, infrastructure, coastal communities, and humans. In this way, eelgrass

this analysis through a multispecies perspective made it clear that these impacts do not affect eelgrass alone. Even though this inquiry started by focusing on how these systems influence eelgrass, humans are deeply affected within this network as well. More desirable outcomes for eelgrass and its web of relations can also support more desirable outcomes for humans, because as Figure 5.11 shows, these systems are intertwined. Tracing the impacts of sea level rise and shoreline armoring through this context sets up the foundation for design and for the second research question of this thesis, which is discussed in the next chapter.



Multiscalar Analysis

DESIGN FRAMEWORK

This chapter translates findings from the background research and multiscalar analysis into a design framework. It introduces multispecies design principles that guide the approach to rethinking coastal adaptation.

INTRODUCTION

LITERATURE
REVIEW

SITE CONTEXT

METHODS

MULTISCALAR
ANALYSIS

DESIGN
FRAMEWORK

SPECULATIVE
VISIONS

CONCLUSION

DESIGN FRAMEWORK

This chapter addresses the second research question: *How can multispecies perspectives inform coastal adaptation strategies in Padilla Bay?* Building on the background research from previous chapters, here I develop a design framework for rethinking coastal adaptation from a multispecies perspective. This framework has two parts. The first part is the set of design leverage points identified through the systems analysis in the previous chapter, which help clarify where design might intervene in existing trajectories of eelgrass decline and related

socio-ecological impacts. The second part is a set of multispecies design principles that guide how design interventions might differ from conventional coastal adaptation approaches by expanding who and what adaptation is designed for. Together, these two parts translate the background research into a design approach for speculating on futures for Padilla Bay.

DESIGN LEVERAGE POINTS

Leverage points are places within a system where intervention has the potential to shift existing trajectories. In this thesis, they help translate the complexity of Padilla Bay into more focused opportunities for design. Rather than trying to respond to every stressor affecting the bay, I identified five leverage points where design can most meaningfully engage the interrelated impacts of sea level rise and shoreline armoring.

As shown in Figure 6.1, the five leverage points identified for this project are waterfront access, coastal infrastructure, flooding, coastal squeeze, and biodiversity. These were identified by synthesizing the socio-ecological systems diagram discussed in the previous chapter. The leverage points emerged by asking where the impacts of sea level rise and shoreline armoring are most concentrated, where multiple ecological, social, and infrastructural relationships overlap, and where design has a realistic possibility of intervening.

Asking these questions helped clarify why these five leverage points were more directly useful for this design inquiry than other forces shaping Padilla Bay. While many conditions affect eelgrass and the broader coastal system, not all are equally suited to design intervention at the scale of this thesis. The leverage points identified here sit more clearly within the scope of coastal adaptation because they represent visible, spatial, and relational conditions that design can engage. Their value comes from their position within the system: each one is tied to multiple issues, which means working through them has greater potential to influence broader outcomes rather than addressing more isolated impacts.

These ecological relationships are visible across the five leverage points. For example, coastal infrastructure shapes how flooding is managed, how shoreline access is maintained, and whether habitats have space to migrate. Flooding affects infrastructure and access, but it can also become part of a more adaptive relationship between

land and water. Coastal squeeze connects sea level rise and shoreline armoring most directly, showing how fixed edges limit the movement of nearshore habitats as water levels change. Biodiversity is affected by all of these conditions, but it also reframes adaptation around the needs of eelgrass and the broader web of species connected to it. Waterfront access is tied to this same system because it shapes how people encounter the bay and how they might come to understand, value, or care for changing coastal relationships.

Together, these leverage points situate design within the complexity of Padilla Bay without reducing the project to a single issue or species. Because they are highly connected, they offer a way to think about coastal adaptation beyond smaller, targeted responses to individual problems. Their broader potential lies in their ability to shift relationships across the system, which is central to rethinking adaptation from a multispecies perspective.

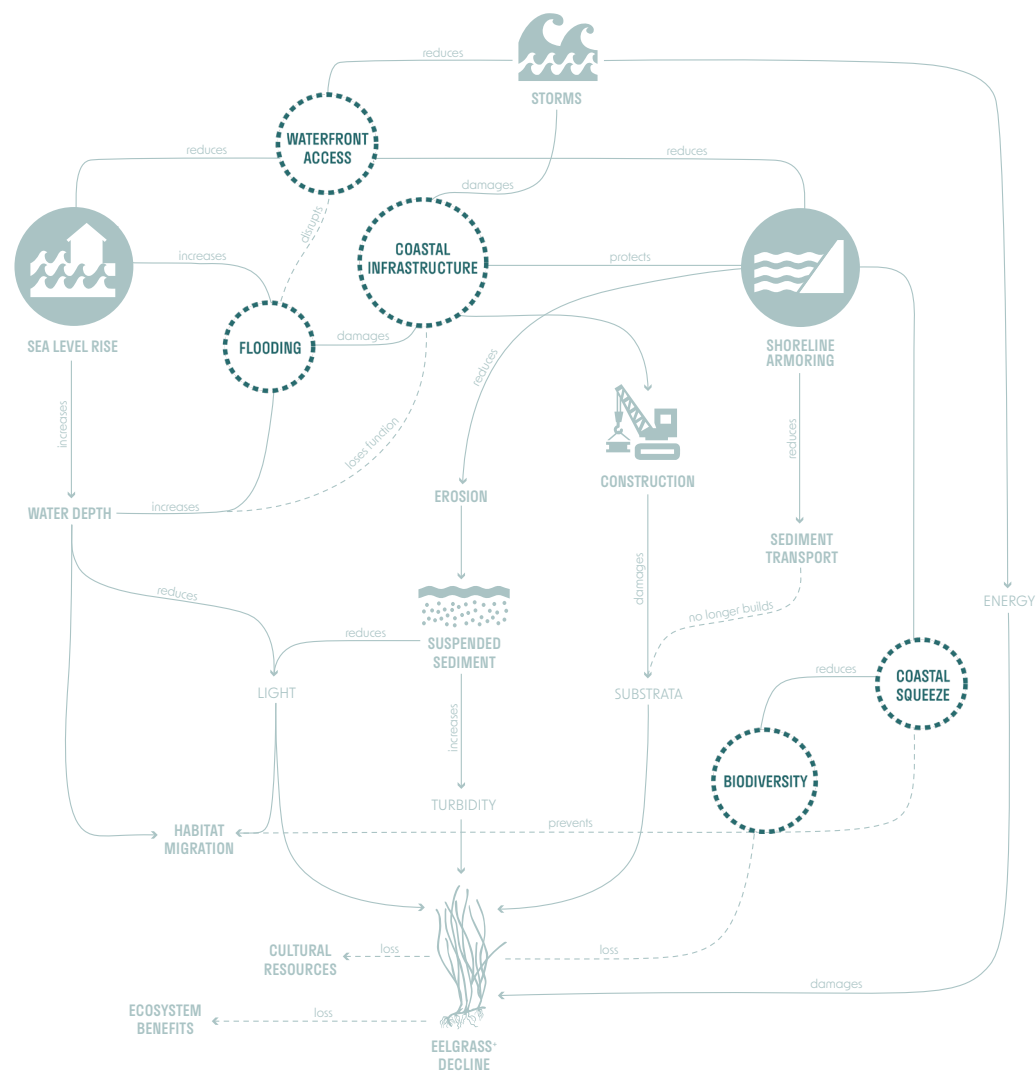


Figure 6.1: Systems diagram identifying leverage points for speculative design in Padilla Bay. Image by author.

MULTISPECIES DESIGN PRINCIPLES

Identifying design leverage points is a useful starting point because it grounds the work in the specific conditions of Padilla Bay. The five leverage points developed through the multiscalar analysis help locate where design might begin to engage the system, but they do not determine what a multispecies design response should look like. They show where design might intervene without explaining what values or relationships should guide that intervention.

To move from analysis into design, I used the leverage points to understand how design thinking around coastal adaptation would need to shift. Each leverage point revealed a particular tension that is typically difficult for conventional coastal adaptation to address. Waterfront access raised questions about how people might encounter the bay without disturbing sensitive habitats. Coastal infrastructure, flooding, and coastal squeeze pointed to a related conflict between fixed human systems and dynamic coastal processes. Dikes, roads, and hardened shorelines protect agriculture, settlement, and infrastructure, but they also restrict the movement of water, sediment, and intertidal habitats as sea levels rise. Biodiversity raised another tension between designing for the benefit of individual species and designing for the broader relationships among species.

Looking across these leverage points, multispecies design became a way to turn these tensions into opportunities to reimagine coastal adaptation and change the trajectory of eelgrass+ decline. I asked how design responses might change if the needs of eelgrass+ and other more-than-human communities were treated as central to the design process. This process revealed recurring themes that became the basis for the four design principles that follow.

Because this thesis takes a multispecies approach, these design principles also challenge some of the assumptions that tend to shape coastal adaptation and design practice. Adaptation is often framed around protecting human land uses, reducing risk to property, or maintaining existing infrastructure. Those concerns matter, but they do not capture the full range of relationships at stake in a place like Padilla Bay. A multispecies approach asks who else is affected by these decisions, what relationships are being supported or disrupted, and how design might create conditions for human and more-than-human communities to adapt together.

The four design principles shown in Figure 6.2 are Expand the Community of Stakeholders, Design for Multispecies Assemblages, Integrate Infrastructure with Ecological Systems, and Use Speculation to Reorient Relationships. These design principles draw from multispecies theory, speculative design, and the background research conducted through the multiscalar analysis. Together, these multispecies design principles provide a framework for approaching the leverage points through a multispecies perspective.

It is important to acknowledge that multispecies design is inherently speculative because humans cannot fully understand the experiences of another species. It also challenges many of the assumptions embedded in modern Western design traditions, where humans are treated as separate from nature and positioned as the primary subjects of design. However, we can observe, engage with, and learn from other species to build a clearer picture of what they need and how they are affected by human design decisions. This knowledge can be used to make the needs, behaviors, and relationships among other species more central to the design process, even if that understanding is partial.

A multispecies perspective affords a radical shift in conventional design thinking. It reframes coastal adaptation away from a purely human-centered project of managing risk and toward a more relational process of learning to adapt alongside the more-than-human world. The four design principles that follow describe how this reframing can begin to shape design practice.

EXPAND THE COMMUNITY OF STAKEHOLDERS

The first design principle is to expand the community of stakeholders. In most design projects, stakeholders are understood as human clients – users, agencies, property owners, or community members. Their needs guide decision-making because they can show up to meetings, fund projects, approve plans, and speak for themselves. This is true even in many ecologically motivated design projects, where the environment is treated instrumentally, as something to protect or restore for the ecological benefits it provides to humans, rather than something with its own stake in the outcome. More-than-human species are affected by design decisions too, but they are rarely treated as participants in the process.

Expanding the community of stakeholders requires designers to reconsider who the project is actually accountable to. When more-than-human life is understood as part of the community being designed with and for, the questions guiding the project begin to shift. It is no longer only about reducing flood risk for property owners or maintaining access to the waterfront. It also becomes about what conditions eelgrass needs to persist as water levels rise, or how shoreline modifications affect the species that depend on nearshore habitat. This does not mean every decision will benefit every species equally, or that human needs are removed from the process. Tradeoffs are real. What changes is the awareness of those tradeoffs, and the willingness to look for opportunities where human and more-than-human needs can be addressed together.

This principle of expanding stakeholders in a project also changes the role of the designer. Because other species cannot represent themselves in planning processes or design reviews, the designer has to act as their advocate. That role requires humility, but it also carries a risk of hubris: assuming humans can

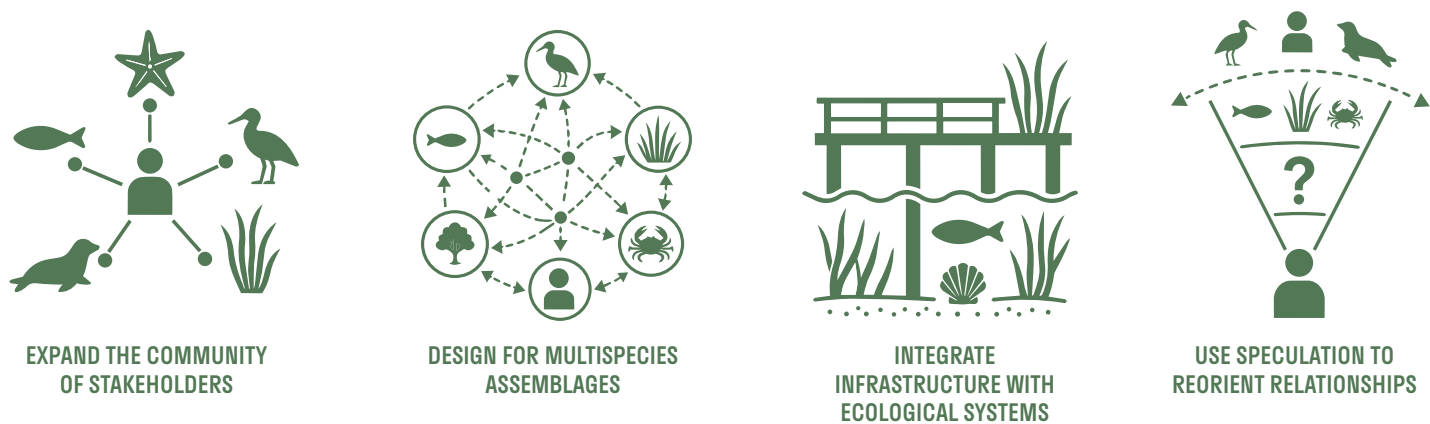


Figure 6.2: Multispecies design principles. Image by author.

fully understand or speak for another species may reproduce the same anthropocentric assumptions that the multispecies design framework is attempting to move beyond. Humans cannot fully understand the experiences of another species, and that uncertainty should not be resolved away but be acknowledged and kept present in the work. But by taking more-than-human needs seriously as a starting point, designers can begin to communicate those needs more clearly and make space for them in decisions that would otherwise be made without them.

DESIGN FOR MULTISPECIES ASSEMBLAGES

The second design principle is to design for multispecies assemblages. This means looking beyond individual species or isolated habitat improvements and paying attention to the entanglements between them. Eelgrass does not exist in isolation. It is part of a shifting, interconnected web of relationships with other species, from juvenile salmon and Dungeness crab to waterfowl and shellfish, as well as the humans who fish, manage, and live alongside the bay. Each of these species shapes the conditions that others depend on. Designing for assemblages means staying attentive to that web of mutual influence and resisting the tendency to treat any single species or habitat as something to design for in isolation.

This principle also recognizes that humans are part of these assemblages. Human communities are not separate from ecological systems, and ecological systems do not exist outside of social, cultural, and infrastructural contexts. In coastal adaptation, this matters because decisions made to protect human infrastructure or maintain

shoreline access can have direct consequences for habitat conditions and species survival. The reverse is also true. Healthier ecological systems can support more resilient human communities over time.

Designing for assemblages also means thinking across scales and embracing complexity. Design projects are usually defined by a site boundary, but ecological systems do not have distinct, static physical boundaries. A project in Padilla Bay is shaped by larger processes in the Salish Sea and the Skagit River Basin, while also affecting conditions at the scale of individual eelgrass beds and intertidal zones. This does not mean every project can respond to every scale with equal depth. It means the design process has to stay aware of the larger systems it is working within, and be honest about where its reach ends.

Where possible, designing for assemblages also asks designers to create conditions for multispecies interaction and coexistence. The goal is not only to reduce harm but to make relationships between humans and other species more visible and more lasting. This is where kinship becomes important. Much of the harm humans have caused to the natural world stems from a sense of separation, of human exceptionalism that approaches nature as something outside of us to be used or managed. Design can begin to challenge that by creating opportunities for people to encounter, observe, and share space with other species, and to learn from them. These experiences can cultivate a sense of kinship, rooted in the recognition that we are deeply embedded within ecological systems, and that we are as dependent on other species as they are on us.

INTEGRATE INFRASTRUCTURE WITH ECOLOGICAL SYSTEMS

The third design principle is to integrate infrastructure with ecological systems. This means recognizing that human-made systems can be part of ecological systems rather than disruptions to them. Conventional coastal infrastructure is typically designed to hold shorelines, property, and land-water boundaries in place. Seawalls, dikes, roads, and armored shorelines are built to protect land from water, and they often do that effectively in the short term. They do so by treating the boundary between land and water as something to be fixed and defended. In a changing coastal environment, that approach has significant ecological costs. Fixed infrastructure interrupts sediment movement, limits the ability of habitats to migrate as water levels rise, and contributes directly to coastal squeeze. Coastal squeeze occurs when rising sea levels force intertidal habitats to move landward to maintain a suitable elevation, but hardened shorelines prevent that movement, causing those habitats to narrow or disappear over time.

Ecological design has long recognized that built and natural systems are connected, and there is a growing body of practice around living shorelines, green infrastructure, and nature-based solutions that try to work with ecological processes rather than against them. This principle builds on that tradition, but asks a slightly different question. Rather than asking how infrastructure can be supplemented with ecological features, it asks whether the relationship between infrastructure and ecology can be rethought on a more fundamental level. Can infrastructure become adaptive rather than static? Can it make space for ecological processes to continue over time rather than constraining them?

Integrating infrastructure with ecological systems can happen at different scales. At the larger scale, decisions about where infrastructure is situated, how it is managed, and when it might be removed or relocated can reduce harm to habitat and create room for shorelines to shift as conditions change. At smaller scales, the materials, surfaces, and forms of built elements can be designed to support life by providing texture, shelter, substrate, or attachment points. In this way, infrastructure can become a scaffold for ecological processes rather than only a barrier or structure for human use.

This integration also means thinking about other species as collaborators in the design process. If built elements can be colonized, inhabited, or gradually reshaped by other species over time, then designers are not fully in control of the outcome. That is part of the point. Design creates the initial conditions, but ecological processes and species autonomy continue to act on them long after construction ends. That ongoing transformation is not a failure of the design. It is part of what the design is for.

USE SPECULATION TO REORIENT RELATIONSHIPS

The fourth principle is to use speculation to reorient relationships. Speculation is useful in a multispecies design approach because it creates space to imagine relationships and futures that look different from the present. That kind of imaginative work is necessary when the goal is not only to optimize existing conditions, but to ask whether those conditions could be fundamentally different. For speculation to do that work, it needs to be grounded in ecological and social realities rather than drifting into abstraction.

Conventional design practice tends to move toward resolution. The goal is usually to identify a problem and arrive at a preferred solution. Speculative design works differently. Rather than resolving toward a single answer, it opens up questions. It asks what else might be possible, what assumptions are embedded in current approaches, and what futures might look like if different values were guiding the process. Speculative scenarios are most effective when they are believable enough that people can project themselves into them and work backward to understand how that future might have come to be, even if it looks very different from the present.

Speculation also functions as a form of critique. By imagining alternatives, speculative design can make the assumptions embedded in current approaches more visible and harder to take for granted. Existing adaptation strategies tend to prioritize protecting property and maintaining infrastructure, and those priorities reflect particular values and particular understandings of what the coast is for. Speculation creates enough distance from those assumptions to ask whether they represent the full range of relationships worth caring for, and whose relationships are being left out.

This design principle of using speculation to reorient relationships also resists the idea that there is one correct future. Instead of producing a single solution, speculation can test multiple scenarios and possible pathways. These scenarios are not meant to be final answers. They are meant to make different futures visible and prompt dialogue about what kinds of adaptation are more desirable. In this way, speculation becomes a design method for reorienting relationships, not by predicting exactly what will happen, but by expanding what can be imagined and discussed.

FRAMEWORK FOR DESIGN

Together, the leverage points and design principles described in this chapter form the design framework for this thesis. The leverage points are specific to Padilla Bay and grounded in the multiscalar analysis. They identify where the impacts of sea level rise and shoreline armoring become visible and actionable through design, especially in places where ecological conditions, human use, and infrastructure are closely intertwined. The multispecies design principles shape how those leverage points are approached. They ask how adaptation might change when more-than-human lives, ecological interdependencies, and speculative futures become more central to the design process. While the principles could inform other design contexts within complex socio-ecological systems, here they are used to think specifically through the conditions of Padilla Bay.

This framework provides a way to move from context analysis into speculative design. It creates a structure for imagining alternatives to current coastal trajectories and conventional adaptation approaches. The next chapter develops this framework through a series of speculative visions, using the leverage points as points of departure and the design principles as lenses for imagining different relationships between humans, more-than-humans, infrastructure, and a changing coast.

SPECULATIVE VISIONS

This chapter presents speculative visions for Padilla Bay that explore how the bay might change over time. These visions imagine what futures could emerge when coastal adaptation is guided by multispecies relationships and new ways of living with a changing coast.

SPECULATIVE VISIONS

This chapter addresses the third research question: *What futures for Padilla Bay emerge when coastal adaptation strategies center multispecies perspectives?* I apply the design framework outlined in the previous chapter to develop speculative visions for Padilla Bay. These visions are built from a series of “what if” questions informed by the contextual research and guided by the design framework to rethink relationships and conditions within the bay. These “what if” questions are then refined into five speculative visions, each exploring how humans and more-than-humans might relate differently to water, infrastructure, and coastal change. Rather than proposing a single detailed design plan, these visions work together to form an interconnected set of design proposals that explore how coastal adaptation that is centered on multispecies thriving might open new ways of living with a changing coast.

WHAT-IF QUESTIONS AND DESIGN THEMES

The series of “what if” questions I developed were to help move from analysis into speculative design. These questions emerged from applying the design framework to findings from the multiscalar analysis. This exercise allowed me to explore a broad range of possible futures for Padilla Bay before narrowing the work into more developed speculative design visions.

At the beginning of this process, the “what if” questions were intentionally open-ended. The goal was to keep the design process generative and avoid limiting the work too early. Many of the systems shaping Padilla Bay, including shoreline armoring, agricultural drainage, fossil fuel infrastructure, and habitat fragmentation, are the result of long-term cultural and infrastructural

decisions. Recognizing these systems as designed conditions made it possible to ask how they could be changed. Some of the questions that shaped this process included:

- *What if shoreline armoring was removed and the landscape was allowed to flood, forming a mosaic of wetlands and island high points?*
- *What if shoreline armoring was removed and repurposed to construct wave-reducing habitat reefs?*
- *What if farmland was gradually surrendered to tidal wetlands as sea levels rise?*
- *What if land-based agriculture transitioned to aquaculture?*
- *What if Padilla Bay became a regional nursery for eelgrass and tidal wetland restoration?*
- *What if people became stewards of the expanding intertidal landscape through monitoring, education, and seasonal celebrations of eelgrass?*
- *What if dredged sediments were used to build new islands for habitat, farming, or housing rather than being transported away?*
- *What if agriculture adapted to rising water levels with floating farm modules?*
- *What if people lived in floating or elevated homes within the intertidal landscape?*
- *What if coastal infrastructure was designed to support life both above and below the water?*
- *What if shoreline roads were removed and waterways became the primary transportation routes?*
- *What if people didn’t rely on fossil fuels?*

As I refined these questions, they began to group into themes. Some focused on making space for the bay by removing shoreline armoring and allowing intertidal habitats to expand. Others explored how farming, housing, transportation, restoration, and infrastructure might shift in response to rising water. The strongest themes that emerged were: living with water, making way for the bay, farming the sea, inhabiting the intertidal, and designing infrastructure as habitat. These themes helped distill the set of questions into the final speculative visions, keeping them grounded in the context of Padilla Bay while still exploring larger shifts in coastal adaptation.

SPECULATIVE VISIONS FOR PADILLA BAY

The speculative visions translate the what-if questions and design themes into a spatial vision for Padilla Bay. It shows how different areas of the bay might change over time and serves as the larger context for the five visions that follow. The plan is not intended to be a master plan or phased implementation strategy. Instead, each speculative design shows one example of how the ideas generated through this design process could take spatial form in Padilla Bay.

Figure 7.1 (see next page) shows an overall vision for Padilla Bay shaped by living with water and adapting to wetness. As sea levels rise, the relationship between land and water changes. Shoreline armoring is removed in some areas, allowing intertidal habitat to expand inland. Former agricultural lands transition into tidal wetlands, restoration areas, and intertidal commons. Movement around the bay becomes more connected to water, with boats playing

a greater role in access and exchange. Some production shifts from land-based systems to intertidal and marine cultivation. The region relies less on fossil fuels, and some industrial remnants associated with oil infrastructure are removed or repurposed for new ecological and social functions.

Within this larger shift, five design interventions (noted in Figure 7.1) are distributed across different parts of the bay. These are: Eelgrass Embassy, Eelgrass Alliance Headquarters, Intertidal Commons, Sea Farm Hub, and Aquapelago Co-op. Near the Padilla Bay Reserve, the “Eelgrass Embassy” is built into the eroding bluff, creating a space connected to the Reserve where people can engage more directly with eelgrass habitat. At the southern end of the bay, the “Eelgrass Alliance Headquarters” occupies a former farmhouse in an area where dikes have been removed, allowing salt marsh and eelgrass restoration to expand inland through community stewardship. The “Intertidal Commons” occupies former agricultural land that has been reopened to the sea, creating a shared space for restoration, cultivation, and stewardship. In the deeper waters of the bay, the “Sea Farm Hub,” a repurposed oil tanker, supports new forms of marine farming, processing, and ecological monitoring. The “Aquapelago Co-op” is also imagined in deeper water as a mobile floating community that can sustainably farm the waters of Padilla Bay and potentially the broader Puget Sound. The visions are all speculative, but not in the same way. Some are closer to current restoration and stewardship practices, while others imagine much larger changes in housing, food production, transportation, and energy use. This range is intentional. The plural approach creates a spectrum of speculation, with some ideas that feel more immediately possible and others that would require broader cultural, political, and spatial shifts over time.

The visions explore different ways that coastal adaptation might take shape. Some focus on expanding habitat, supporting eelgrass restoration, and creating new forms of stewardship. Others imagine intertidal commons, water-based movement, sea farming, floating settlements, or the reuse of industrial infrastructure. Because of this, the visions should not be read as a single set of solutions that all happen the same way or on the same timeline. Instead, they show different levels of change within one possible future for Padilla Bay. The following sections describe each speculative vision in more detail.

Figure 7.1: Speculative vision plan for Padilla Bay. Image by author.



EELGRASS EMBASSY

Figure 7.2 shows the Eelgrass Embassy, built into an eroding bluff near the Padilla Bay Reserve. It is designed as a place to learn about eelgrass and develop a closer relationship with it through various forms of interaction, whether above the water, at the water’s edge, or below the surface. I begin with this vision because eelgrass is the central lens of the thesis, but it is also a habitat that often remains hidden beneath the surface. The embassy makes eelgrass more visible and gives people a way to understand its role in the bay’s larger ecosystem.

The structure is integrated into the bluff, providing immersive, low-impact access to eelgrass habitat. Because it sits within the intertidal zone, changing water levels create shifting experiences over time. People encounter the habitat differently depending on the tide, the season, and the conditions of the bluff’s changing edge. In this way, the building offers ever-changing experiences throughout the year, offering a unique view into ecological change.

Recycled riprap from the removal of shoreline armoring is also integrated into the structure. This is one of the main ways the vision traces a remnant of the past. Riprap, which once hardened the shoreline and reinforced the separation between land and water, is reworked into a rough underwater surface that can provide habitat for various marine life. It becomes a scaffold where marine life can attach, colonize, and form reef-like conditions over time. The human-built structure is still present, but its role changes. It becomes part of the ecosystem rather than an interruption to it.

This vision applies the design principles by treating eelgrass and its associated species as part of the project’s community of stakeholders. The facility is built for humans, but it is also built around eelgrass and the needs of the species that use nearshore habitat. To protect eelgrass and to promote engagement and scientific monitoring, human access to the embassy’s



Figure 7.2: Eelgrass Embassy speculative vision. Image by author.

surrounding waterways will be minimized by establishing no-wake and no-anchor zones. This vision explores a future in which people and their aquatic surroundings are more integrated. It imagines infrastructure as a way to support multispecies interaction, foster care, and help people recognize their connection to the species

and processes around them. As sea levels rise and the bluff retreats, eelgrass habitat will expand around the structure. On top, coastal prairie restoration mirrors the nearby rocky bluffs while providing habitat and views of the bay. Although the example in Figure 7.2 is located near the Padilla Bay Reserve, this idea could

be adapted to other shorelines with eelgrass habitat, allowing for public access and supporting education, habitat protection, and closer relationships with the water.

EELGRASS ALLIANCE HEADQUARTERS

Figure 7.3 shows the Eelgrass Alliance Headquarters at the site of an old farmhouse and dike that have been reimagined as a conservation center focused on community stewardship of intertidal habitat. This vision is connected to the Intertidal Commons, but it focuses more on the social and educational infrastructure needed to care for expanding habitat over time.

In this vision, the repurposed farmhouse becomes a headquarters for monitoring, education, and stewardship. The boardwalk follows the path of the former dike, maintaining public recreation while allowing salt marsh and eelgrass habitat to expand inland. The dike remains as a trace of the agricultural past, but it no longer functions as a hard barrier cutting habitat off from the upland. Its path is reused as a way for people to move through and observe an intertidal landscape that is changing around them.

Bivalve restoration also supports eelgrass growth. In this vision, eelgrass seeds are harvested and attached to clam shells before being placed in the intertidal zone. As clams burrow into the sediment, they help plant the seeds and create conditions for eelgrass to establish. Restoration is still supported by people, through harvesting, seeding, and monitoring, but the process does not depend on human labor alone. In this way, restoration is framed as a cooperative process, where human stewardship supports the relationships that allow eelgrass and other species to establish over time.

The Alliance Headquarters helps foster a sense of kinship by making restoration something the community can take part in together. It creates a place where people can learn about eelgrass, monitor changes in habitat, participate in seed planting, gather with others, and return over time. Having a place for these repeated encounters to take place is important because relationships, especially those with other species, are not built through a single encounter. Familiarity develops through ongoing interactions. Over time, that



Figure 7.3: Eelgrass Alliance Headquarters speculative vision. Image by author.

familiarity can grow into a deeper sense of responsibility for the bay and care for the many species that depend on it. This idea could be translated to other bays in the Skagit Valley, especially where former agricultural land, dikes, or farm buildings could be adapted to support habitat restoration and expansion. It suggests

that the remnants of agricultural infrastructure don't necessarily need to be removed or abandoned, but can become part of a new stewardship network for intertidal habitats. They can become part of a new stewardship network for intertidal habitats.

INTERTIDAL COMMONS

Figure 7.4 shows the Intertidal Commons on former agricultural land that has been reopened to the sea through the removal of shoreline armoring. The vision reimagines the remnants of land-based agriculture around Padilla Bay. Much of the land around the bay was once tidal habitat, but it was diked and drained for agriculture. In this future, some of that land is allowed to revert to intertidal conditions as sea levels rise.

The commons is community-owned and collectively stewarded by humans and more-than-humans. Farming shifts from a strictly land-based practice to a form of intertidal stewardship that incorporates water. The site focuses on the managed restoration and cultivation of Olympia oysters and native eelgrass. This is grounded in real restoration efforts for Olympia oysters, but it imagines those practices becoming part of a larger adaptation future for Padilla Bay.

The pairing of eelgrass and oysters is significant because it demonstrates how the proposed design principles can move beyond isolated species restoration. These species are sometimes understood as competing for space, but this vision cultivates them in a way that allows their relationships to support one another. Eelgrass absorbs carbon dioxide and can help reduce acidification, supporting oysters as they build their shells. Oysters filter particles from the water, improving water clarity and creating better growing conditions for eelgrass. This design encourages and takes advantage of the relationship between the two species, creating a habitat where they both can thrive.

The commons model also changes the social relationship to adaptation. It advocates for species such as Olympia oysters and eelgrass while also acknowledging human needs for food, livelihoods, and shared stewardship. It suggests that human economic activity and ecological restoration could be more closely integrated as coastal conditions change. In this vision, farming becomes less about keeping water out, and



Figure 7.4: Intertidal Commons speculative vision. Image by author.

more about working with tidal processes, native species, and the bay’s changing edge. This idea could be transferable throughout the region, especially in places where former tidelands or low-lying agricultural areas may need to transition over time. It offers one way to think about how communities in the Skagit Valley, Puget Sound,

or other coastal agricultural regions could adapt land-based practices into intertidal forms of cultivation and restoration.

SEA FARM HUB

Figure 7.5 shows the Sea Farm Hub, a repurposed oil tanker located in the deeper waters of Padilla Bay. In this future, the region is less reliant on oil, and the tanker remains a relic of that fossil-fuel past. This is one vision of how infrastructure from an extractive economy could be redirected toward more adaptive and ecological forms of production. Rather than continuing to support extraction and distribution, the ship becomes a decentralized hub for local sea farming operations.

This design choice is important because March Point, the peninsula in Padilla Bay that is home to two oil refineries and a major heron rookery, is already a major part of the regional context. The tanker in this design carries that history into the speculative future, but its purpose changes. It becomes a working platform for marine cultivation, processing, monitoring, and distribution. The repurposed ship supports onboard processing of eelgrass, seaweed, oysters, and other marine resources into food, fertilizer, and building materials. Longline systems attach directly to the boat, where kelp can be cultivated and harvested. Kelp also grows more freely in the surrounding waters, where it can be monitored and studied as an indicator of the bay's ecological health.

This vision is grounded in sea farming as a real practice, but it speculates on how this farming could become more central to Padilla Bay. It also shows how human-made infrastructure can support other species. The ship provides a platform for human labor and regional distribution, while the longlines, submerged surfaces, and surrounding cultivated waters create habitat and support ecological monitoring. Infrastructure becomes more than a tool for human production. It becomes a framework in which humans, kelp, eelgrass, oysters, boats, and other marine species coexist.



Figure 7.5: Sea farm hub speculative vision. Image by author.

The Sea Farm Hub could also be scaled up, especially in the Greater Puget Sound and Salish Sea, where tankers and working waterfronts already exist. In other regions with industrial marine infrastructure and shifting energy

economies, similar questions could be asked: what happens to these structures if the systems they were built for become unsustainable, and how might they be adapted to support ecological and social futures?

AQUAPELAGO CO-OP

Figure 7.6 shows the Aquapelago Co-op, a floating community that moves through the deeper waters of Padilla Bay and is capable of operating at the broader Puget Sound scale. This vision is more speculative; it shifts the focus to how people might someday live with water as an ever-present, everyday condition.

Floating homes already exist in many coastal cities around the world. This vision presents a speculative view of the way housing could be organized as a cooperative, mobile, multispecies structure in Padilla Bay. The co-op is imagined as a ring of floating homes that can relocate over time in response to changing water conditions and the seasonal locations of species like crab, shrimp, and sea cucumbers. It can also anchor in place to support rotational farming of mussels and sugar kelp. Rooftop farm plots provide supplemental food production, while submerged surfaces provide habitat for macroinvertebrates. Floating wetlands around the structure act as both landscaping and habitat, supporting species above and below the water.

The Aquapelago Co-op imagines housing as something that supports humans and more-than-humans together. The structure is designed for people to live in, but it also creates surfaces, sheltered areas, and planting zones that other species can colonize and use over time. In this way, the co-op acts as both housing and habitat. The built form becomes part of the ecological conditions that allow life to gather around it.

The cooperative model is also important because it imagines the community as more than a group of human residents. It includes kelp, mussels, wetlands, fish, birds, and invertebrates as co-inhabitants of the bay. These species are not in the distance, or only encountered through recreation; they become neighbors within daily life. By treating the cooperative as a shared living system, the vision suggests how repeated attention to other species could grow into care, responsibility, and kinship over time.

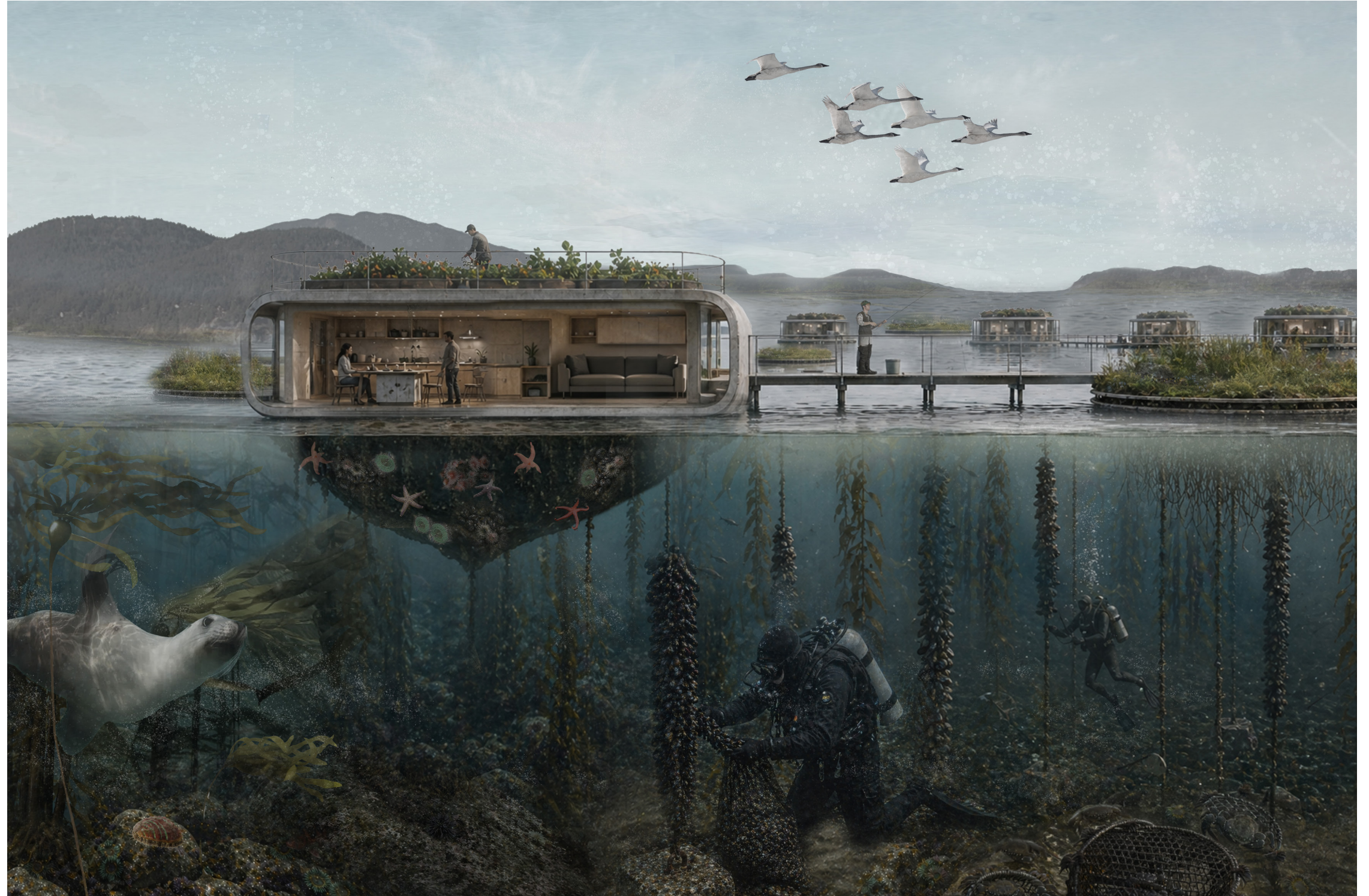


Figure 7.6: Aquapelago Co-op speculative vision. Image by author.

This vision would require major cultural, political, and technical shifts, including different expectations around housing, mobility, ownership, comfort, and water-based life. It is not meant to suggest that floating cooperatives are the solution for every coastal community. Its purpose is to make a more radical form of

coastal living visible and open to discussion. Because it operates through mobility, shared infrastructure, and marine cultivation, the idea could be considered at broader scales across the Puget Sound, or in other coastal regions where communities are beginning to rethink settlement in response to sea level rise.

POTENTIAL FUTURE TRAJECTORIES

Together, these five visions show how the design framework can be applied to imagine a different future for Padilla Bay. These visions are not meant to be specific design solutions or components of a master plan. Each one focuses on a different leverage point in the Systems Analysis and uses it as a lens to explore how multispecies coastal adaptation could take shape across the Bay if those leverage points were redirected toward positive outcomes.

Figure 7.7 connects these visions back to the systems diagram from Chapter 5, which showed how sea level rise and shoreline armoring contribute to eelgrass decline, habitat loss, and coastal squeeze. The visions begin from those same pressures, but imagine different trajectories. Waterfront access becomes a way to encounter and care for eelgrass habitat. Coastal infrastructure adapts to support life above and below the water rather than only

protecting land. Flooding is treated as a condition to which we must adapt, rather than only defend against. Coastal squeeze, the compression of intertidal habitats between rising seas and fixed landward barriers, is addressed in this design by giving intertidal habitats room to move inland. Across all of the visions, existing conditions are not erased but reworked. Riprap becomes habitat scaffold. Farmland becomes intertidal commons. An oil tanker becomes a

platform for sea farming. A farmhouse and dike become stewardship infrastructure. These transformations acknowledge the existing conditions, infrastructure, and industrial systems present in Padilla Bay, but redirect them into future scenarios with a more positive outcome.

Eelgrass runs through all of these visions as a connective element and species. The Eelgrass Embassy makes this most explicit, positioning eelgrass habitat as a place people come to encounter, study, and develop a relationship with one of the keystone species of Padilla Bay. However, the other visions are also organized around eelgrass in less direct ways, through the expansion of intertidal habitat, the development of stewardship infrastructure, and the reorganization of farming and settlement around conditions more favorable to eelgrass. Centering eelgrass in this way is not only about protecting one species. It showcases the entanglements among eelgrass, other species, water, land, infrastructure, and human communities; asking what it would mean to design with those relationships in mind.

The plurality of the visions was intentional. Rather than proposing a single answer, the visions explore a multitude of different possibilities. Some are similar to current restoration and stewardship practices. Others are more speculative, proposing dramatic repurposing of infrastructure, land use, and human settlement. These visions would have significant spatial and technical requirements, and would require changes to governance, land ownership, food systems, and public values. Before shoreline armoring could be removed, communities would need to decide which areas needed protection and which other areas would allow water to move and change the landscape. If farmland becomes tidal wetland, questions of livelihood and land tenure become part of adaptation. If oil infrastructure is repurposed for sea farming, coastal adaptation becomes

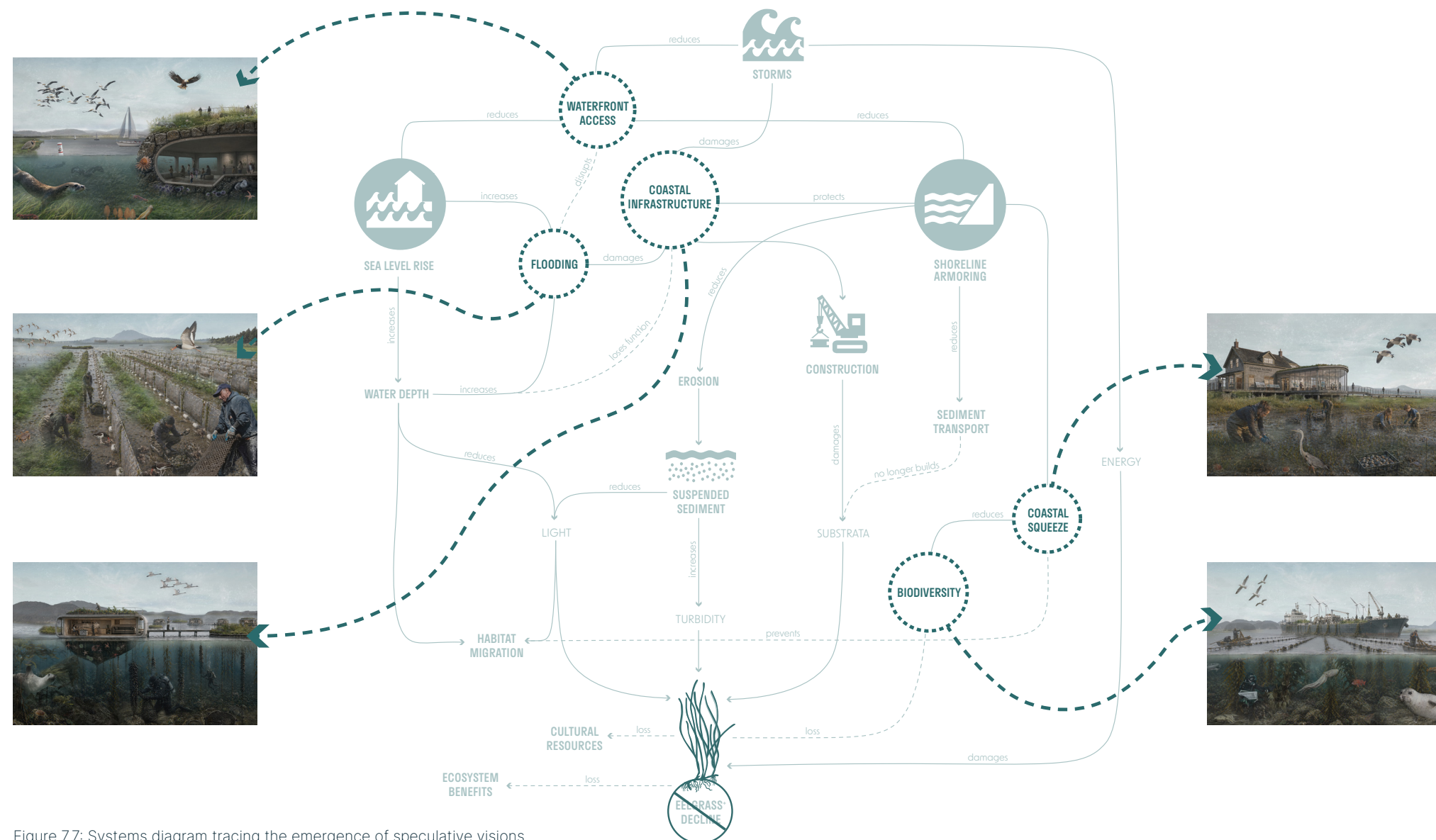


Figure 7.7: Systems diagram tracing the emergence of speculative visions from leverage points. Image by author.

tied to larger transitions away from fossil fuels. The visions do not intend to definitively resolve these questions, but they bring some of these relationships to light and make them better tools for discussion.

By presenting these speculative visions, my aim was not to prescribe concrete solutions but to envision possibilities and foster discussion. Arriving at futures like these would require major cultural, political, and spatial shifts. Some of those shifts might happen incrementally over time through smaller decisions and experiments. Others would require more fundamental changes in how coastal communities understand their relationships to the natural world. This thesis does not map that process. It uses imagination to open up the conversation about what that process could be working toward.

Figure 7.8 places the existing condition of Padilla Bay next to my speculative vision. This comparison is not meant to show a finished before and after. It is meant to illustrate one idea of the future of Padilla Bay, and to open that idea up to evaluation. Which ideas seem desirable? What changes would be needed to move toward them? What existing approaches might need to be challenged?

Although these designs are specific to Padilla Bay, the questions they raise and the lessons learned from them could be applied elsewhere. Other coastal regions are dealing with the same pressures: sea level rise, shoreline armoring, habitat loss, agricultural transition, and aging infrastructure. The value of the visions is not only in the specific forms they propose, but in the way they test a design approach that uses speculation to ask what futures become possible when more-than-human life is centered in adaptation. These are questions that coastal communities in many places are beginning to face, and design imagination is one way to start working through them.

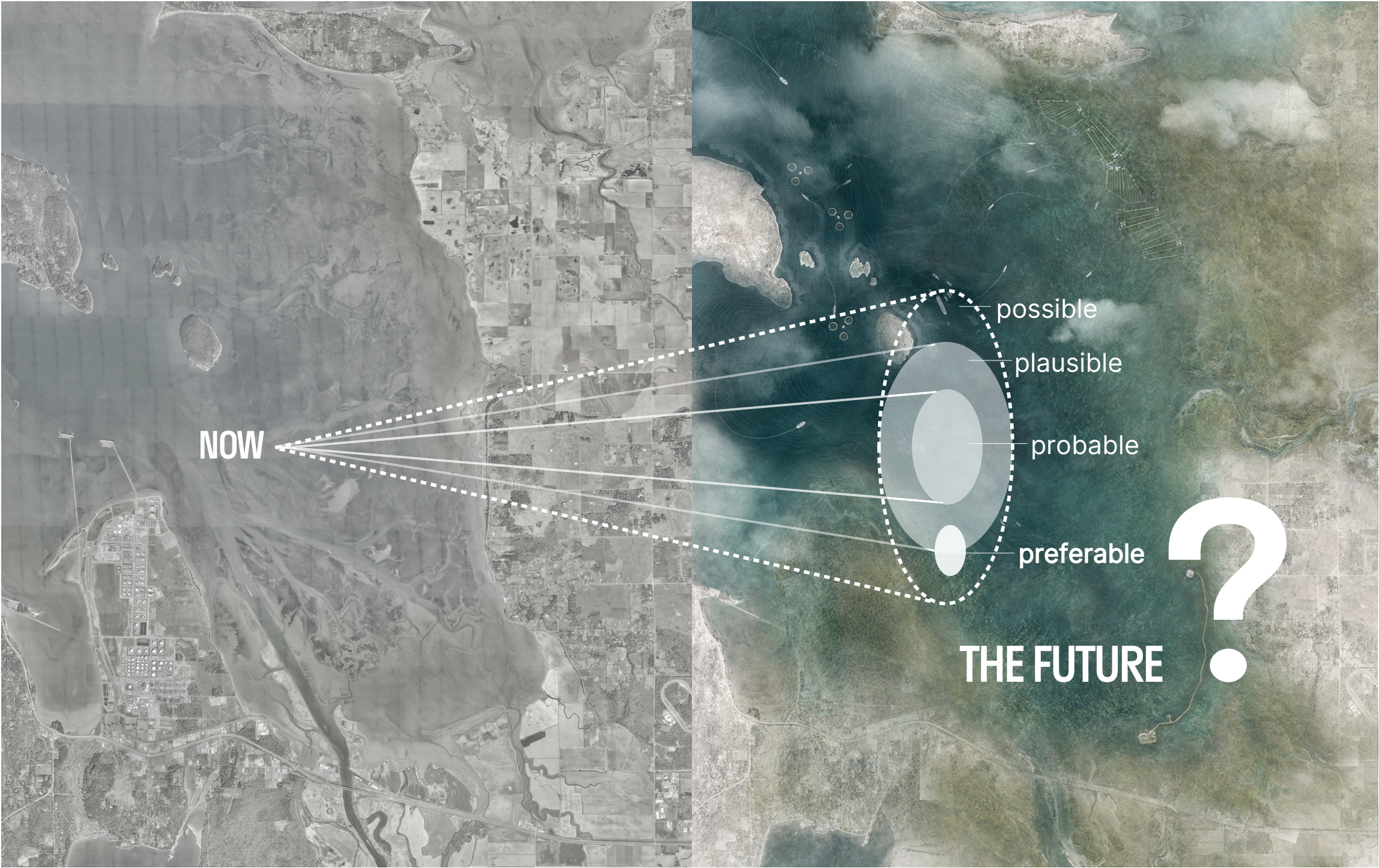


Figure 7.8: Graphic juxtaposing current conditions and the speculative vision for Padilla Bay. Image by author, adapted from Dunne and Raby 2013.

CONCLUSION

This chapter reflects on the thesis process, findings, and broader implications for landscape architecture. It considers how multispecies design can expand approaches to coastal adaptation and open new ways of thinking about future coastal landscapes.

CONCLUSION

Coastal adaptation is at a turning point. Sea level rise, shoreline armoring, and habitat loss are reshaping estuarine landscapes across the Pacific Northwest and beyond, and the approaches we have relied on to manage these changes are no longer sufficient. Most coastal adaptation strategies are designed around human needs: protecting infrastructure, reducing flood risk, and maintaining existing land uses, while doing little to support ecological systems. Their static, change-resistant design makes them increasingly problematic as dynamic coastal environments continue to change under accelerating climate pressures. This thesis proposes a different starting point. It used eelgrass as a lens to reveal how humans and ecological systems are bound together in ways that conventional coastal adaptation does not account for, and to reimagine what design could look like if it did.

Building this understanding required a layered research approach that looked across time and scale. Archival research traced the history of diking, agricultural land conversion, altered hydrology, and land use practices that have shaped Padilla Bay’s current conditions. This revealed how successive decisions about land and water have progressively disconnected the bay from its original sediment sources and tidal processes, negatively affecting habitat connectivity. Field visits, photographic documentation, mapping, and expert conversations provided a more place-based understanding of the bay today, while climate projections helped clarify how existing pressures may intensify over time.

Eelgrass research became central to the research process because studying its stressors revealed broader system impacts. Eelgrass decline is not the result of a single stressor or cause, but of overlapping pressures that show up at different scales and are shaped by human decisions made across the watershed and beyond. Studying eelgrass, then, became a way of studying the broader entanglements of Padilla Bay. This shifted the project from focusing on eelgrass alone to the idea of eelgrass+: the broader network of species, habitats, ecological processes, and human systems tied to eelgrass health.

The research traced eelgrass+ decline through the ways people have organized land, water, and infrastructure along the coast. Shoreline armoring prevents intertidal habitat from moving inland as water levels rise. Agricultural land sits on former tidal systems that eelgrass and other species once depended on. These entanglements reveal the inherent conflicts in coastal adaptation: between flood protection and habitat movement, between agricultural productivity and tidal restoration, between the infrastructure we have built and the ecological systems we have disrupted. There are no easy resolutions to these tensions. This thesis does not prescribe a single answer. Instead, it uses multispecies design as one way to understand and reimagine coastal adaptation in Padilla Bay. By centering eelgrass, it asks how adaptation might change when the needs of other species are considered alongside human needs, and what kinds of coastal futures might become possible through that reframing.

THESIS REFLECTIONS

Focusing my research on eelgrass pushed me to rethink what ecological design means. Most ecological design projects integrate human systems with living processes to minimize environmental impacts. Multispecies design asks something different. It treats more-than-human species as active stakeholders and asks designers to create conditions for coexistence. I understand that distinction more clearly through this project. The questions I was asking shifted from how to protect the shoreline to how to make room for habitat to move. My understanding of what a successful design outcome looks like shifted with them. Building conditions that allow other species to thrive became as essential as designing for people. During the process of learning about eelgrass, what it needs, what threatens it, and how much else depends on it, I developed a genuine sense of kinship that I hadn’t experienced before in a design project. Engaging with eelgrass and telling its story alongside the human story of Padilla Bay made it feel less like a subject of study and more like a collaborator in the work, and I don’t think I would have arrived there through a more conventional approach.

Spending time on site was essential to that shift in perspective. Walking the bay with Reserve staff and community members gave me a perspective I couldn’t have gained from maps and reports alone. Repeat visits across different seasons, tidal conditions, and weather helped me understand how dynamic and temporally complex coastal landscapes are. The bay I walked at low tide in one season felt very different from the one I visited at another time. That sense of the place as something always shifting, never static, felt important to carry into this design work. The more time I spent there, the more invested I felt in the bay’s future.

These visits also revealed the inherent complexity of this ecosystem. Padilla Bay is an eelgrass habitat, agricultural land, industrial shoreline, public access, and reserve land all at once, and many communities, species, histories, and forms of knowledge are tangled up in its future. That complexity required me to make concrete choices about the project scope. I focused on sea level rise and shoreline armoring because they are most directly connected to spatial change and design intervention. It was outside the scope of this project to consider other important stressors such as invasive species, water quality, eelgrass wasting disease, agricultural drainage, and industrial contamination as deeply. I acknowledge that, despite my efforts, I can never fully understand the perspective of eelgrass or any other more-than-human species. Trying to design with another species in mind is not the same as truly understanding what it needs. Still, engaging seriously with that question helped me step outside my own assumptions.

The speculative design process asked me to challenge something else entirely: the inherent purpose of design as a tool. I am used to producing design work that is more precise, feasible, and buildable. This project asked for something entirely different, something speculative and abstract. This was initially outside my comfort zone and forced me to face new challenges. It meant working beyond what feels immediately feasible, while staying grounded enough in the real-world conditions of Padilla Bay that the visions didn’t lose their footing. Over time, I came to value this uncertainty as part of the value of the method. These visions are tools for imagination and critique more than they are design proposals. They are a form of storytelling about what could be possible when we take other species seriously in our decisions about the coast.

FUTURE DIRECTIONS

Multispecies theory is a topic of frequent discussion in academic circles, but is not yet widely applied in landscape architecture practice. This project is one attempt to test what that application could look like, and to show that centering another species in the design process leads to different and worthwhile outcomes. The framework developed here is meant to be translatable. It could be applied to other coastal contexts facing similar pressures from sea level rise, shoreline armoring, habitat loss, and agricultural transition. While the designs are specific to Padilla Bay, the value of this work is in the processes it lays out, more so than the specific design ideas it proposes.

These visions are not specific design solutions or a blueprint for an ideal future. They are a form of storytelling grounded in real conflicts around coastal adaptation. The path toward any of these futures is uncertain, but imagination has a role to play that analysis and policy alone cannot fill. Before communities can work toward different futures, those futures need to be pictured. This is what design can do: make alternative futures visible and give momentum to ideas that are worth moving toward.

Continuing work in the future could build on this thesis in several ways. One next step would be to bring these speculative visions into community engagement sessions with tribal representatives, local residents, farmers, Reserve staff, scientists, and planners. These conversations could explore which futures feel desirable, which raise concerns, what tradeoffs they create, and what shifts in land use, policy, and governance would be needed to move toward more ecologically supportive adaptation. That kind of consensus-building in community priorities is something this thesis was not able to do, and that any next phase of work would need to address. Additional research could also take up the stressors left underexplored here. Invasive

species, water quality, eelgrass wasting disease, and industrial contamination all shape the future of Padilla Bay in significant ways, and each could shift the design framework and lead to different speculative futures. Finally, the framework itself could be tested in other coastal contexts, contributing to a growing body of practice around multispecies design that moves the conversation from theory into the work designers actually do.

Many of the human-made systems we rely on are harming other species and are starting to fail us, too. This project was one attempt to imagine what an alternative could look like. It is only one vision, but I hope it can be useful to others working in coastal landscapes, and that it contributes to a growing consensus that design can help communities address uncertainty about the future by making different possibilities feel real enough to work toward. Asking what might be possible, plausible, and ultimately preferable for all life on this planet is the right place to start.

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