

From the Flyway to Urban Landings

Hexiang Wang

A thesis

submitted in partial fulfillment of the
requirements for the degree of

Master of Landscape Architecture

University of Washington

2021

Committee:

Ken Yocom

Jeff Hou

Program Authorized to Offer Degree:
Department of Landscape Architecture

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Abstract

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Chair of the Supervisory Committee:

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This is my honor to work with Dr. Ken Yocom and Dr. Jeff Hou in the Landscape Architecture Department at the University of Washington.

Dr. Ken Yocom encourages me to explore what I want to learn and help to envision the future of landscape architecture. He has been teaching me the critical foundations of ecological design since December 20th, 2019. These fundamental knowledge structures shaped my interests and passion later when I started thinking about my thesis. This has been a process for me to make the transition from a focus on design forms to the understanding of engaging processes that facilitate ecosystem functions in a landscape architectural approach. Also, Dr. Ken Yocom really takes care of my wellbeing during the COVID-19 pandemic, which fills my life with love and hope.

I started getting access to Dr. Jeff Hou's research on January 10th, 2020, when he gave a presentation on community design in the Urban Informality Studio. Dr. Jeff Hou's works inspired me to think about the value of place-making and the new meanings of urban public spaces. Sincerely, I wish to show my appreciation to Dr. Jeff Hou's encouragement and patience on my thesis. Almost every week, he generously gives me suggestions on structuring my work and ways of moving forward. Furthermore, I want to thank him for organizing the Thesis Studio for two quarters. Thank him for building this community that is full of engagement.

I am thankful for Dr. Brooke Sullivan and Prof. Nancy Rottle. I had learned a lot from them before the thesis, and later their wisdom assisted me to narrow down the scope of the research and find a clear path after the mid-term review.

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Finally, I, as a Chinese citizen (中國人), acknowledge that I studied at the University of Washington that is located in the Coast Salish peoples' land. The land where I studied touches the shared waters of the Duwamish (Dkhw'Duw'Absh) people and all the tribes and bands of the Muckleshoot (bəqəlšuʔucid), Suquamish (suq'wabšucid), and Tulalip (dxwlilap) nations. In this foreign land, I tried my best to respect the history, culture and tradition of this place.

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Figure 0.1 A city of ecological design inspiration

Chapter 1

Introduction

This thesis aims to study ecological design through the exploration of migratory bird habitat expansion in cities in the context of climate change. My project is conceptually guided by biodiversity planning and design (Ahern, Leduc, & York, 2006), ecological landscapes design (Steiner, 2008; Rottle & Yocom, 2010; Beck, 2013), and biophilic urbanism (Beatley, 2016), and knowledge from the study of bird migration ecology, ornithology, urban hydrology, planting design, community ecology, and urban design. I hypothesize that introduction of new ecological systems in urban waterfront open spaces enhances the capacity to support migratory birds that are dependent upon or closely related to urban aquatic environments. Improved habitat quality for these migratory birds by constructed ecosystems strengthens biophilic urbanism and builds resilient biodiversity of the Pacific Flyway at the highest scale of my thesis. To test the hypothesis in an exploratory approach, I organize my research exploration based on four primary questions:

1. What factors are impacting the target bird species along their migration routes, and what are their limiting factors?
2. What are the potentials of a city in supporting the lifecycle of these species?
3. What are different types of urban environments that can offer opportunities to introduce more efficient and effective ecological systems to support migratory bird habitat?
4. What design strategies at the site and city scale can be employed to negotiate over possible tradeoffs while modifying existing landscape features?

In other words, the four questions explore 1) what impacts the migration of the target bird species; 2) what design potentials are able to support parts of their lifecycle in a city; and, 3) how we can develop design strategies for each type of urban landscapes and enhance their ecosystem functioning to support migratory bird species.

The thesis begins with a literature review of basic understanding of the Pacific Flyway and widely accepted theories and landscape

architectural principles, and then selects three target species as examples of analyzing the missing ecosystem functions in the city, as well as urban landscapes that can be upgraded depending on typological studies of urban environments.

Inspiration

Montrose-Point Bird Sanctuary (figure 1.1) in Chicago along the shoreline of Lake Michigan is a highly functional urban habitat providing migratory birds with stopover spaces and food supplies. At Montrose Point Bird Sanctuary, as well as Montrose Beach Dunes Natural Area, there were more than 300 bird species recorded, and bird abundance is high (Chicago Park District, n.d.). From the design perspective, the aerial view created by Moss Design shows the ecological design characteristics of habitat enhancement. The proposed improvements include the translocation of sand volleyball courts, barrier islands, permeable pavement for the driveway, bird lookouts, a nature center, raised trails, and other features (Torem, 2020). The multifunctional urban open space requires the balance of human activities and bird habitat. For example, the sand



Figure 1.1 Montrose-Point Bird Sanctuary, image from Moss Design

volleyball courts were proposed to be translocated to the center of the natural area (Torem, 2020), so the beach area where more natural processes are occurring would be more available to sustain a more sustainable ecosystem. The whole site can be roughly divided into a human-dominated park and a wildlife-dominant natural area. The boat marina, the driveway, the golf course, and fields for other sports are preserved, and so are the ecosystem functions for birds. The bird sanctuary is a large site in the city, but it is not comparable to the really large-scale natural areas that are far away from cities. Similarly, Tommy Thompson Park in Toronto

along the shoreline of Lake Ontario is another example of an urban habitat designed to be ecologically significant for birds. Landscape architect Walter Kehm believes that the most important thing they need to do in Tommy Thompson Park is the preservation of ecosystem diversity including wetland edges, semi-wet areas, and areas with less moisture (Beatley, 2020). Kehm also suggested that



Figure 1.2 Lingang Bird Airport, image from McGregor Coxall

the city should possess a “diverse ecology” in spaces ranging from streets to bikeways to small parks (Beatley, 2020). The key point is that urban landscapes need to have diverse plant communities in a variety of ecosystems to maximize ecological efficiency in a city, and

in a relatively limited space.

The second source of inspiration is a project called Tianjin Lingang Bird Sanctuary Wetland Park (figure 1.2), a “bird airport” for migratory bird species along with the East Asian—Australasian Flyway (McGregor Coxall, n.d.). This project is located in Tianjin, China, a city in the Bohai Sea region. This design project proposes redevelopment of a previous landfill site and transformation to a large-scale constructed wetland. This 60-hectare wetland park and bird sanctuary is a large open space in an urban context and because of its size, it is expected to be a very important stopover for the birds migrating along the flyway. Educational purposes, stormwater management, and a research center are additional values of this design project.

The third image of inspiration is from Scape Studio (figure 1.3). This design is a competition proposal that focuses on coastal habitat enhancement techniques integrating marine protective interventions, on-shore resilience, and community engagement (Scape Studio, 2017). The proposed breakwater necklace protects

local neighborhoods from the negative impacts of wave action while creating additional habitats for multiple marine organisms (Scape Studio, 2017). I was inspired by this fascinating design of breakwaters conveying the idea that humans can positively alter the hydrologic system and biological system of the marine environment through ecological design, in this case, the aquatic environment, to build resilience and bring in more niches for wildlife.

I am further inspired by the City of Seattle, Washington (figure 1.4) where I lived for more than one year, and I hope my thesis to be a

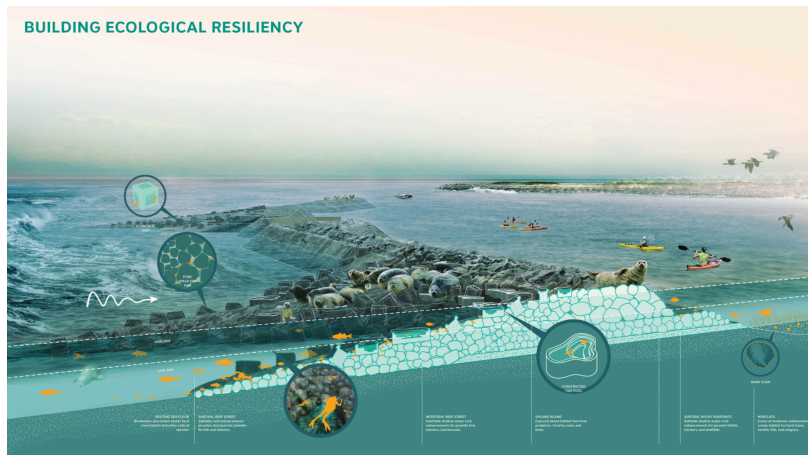


Figure 1.3 Living Breakwaters, image from Scape Studio

reflection of my perception of the natural resources in and around



Figure 1.4 Marsh Island, Seattle

the city and metropolitan region.

The Pacific Flyway

The Pacific Flyway covers a sequence of geographical regions from the Chukchi Peninsula in Northeast Siberia to the southern tip of Chile, Cape Horn. Along the Pacific coast of the Chukchi Peninsula



Figure 1.5 Ecoregions and threats along the Pacific Flyway

and American continents, the migration process of the flyway crosses approximately 19 countries, and climatic zones vary due to the variation in latitude, temperatures, prevailing winds, ocean currents, geography, and precipitations. Terrestrial biomes are determined by climate, and within each terrestrial biome, there are vegetation formation classes (Strahler, 2013). However, the complexity of the Pacific Flyway does not stop at the distribution of climatic zones and terrestrial biomes along Pacific coasts. Bird migration breaks the boundary between each theoretically and biogeographically defined biome. The overall bird migration patterns of the Pacific Flyway reflect characteristics of the Nearctic-Neotropical system. The distribution of tropical and temperate biomes results in an obvious dichotomy in breeding and wintering ranges of avian migration (Rappole, 2013). As

a result, large-scale migration has been necessary for some bird species. The flyway is not a clearly defined linear pathway (Benedict, Hammerson, & Butler, 2020) in that bird migration strategies can be classified into plenty of types. According to Rappole (2013), the typology of bird migration includes local seasonal movements, facultative migration, partial migration, short-distance migration, long-distance migration, and bird species do not always exclusively adopt one strategy over others. Thus, some bird species use small parts of the flyway for migration when necessary, while other species may migrate as whole groups and travel long distances. The long-distance migration leads to an obvious concern. The wintering population limitation caused by a variety of potential factors may limit the population of breeding, and vice versa (Newton, 2008) due to the connectedness of a series of habitats that support different periods of migratory birds' lifecycle. Similarly, population limitation also exists in stopovers because some species rely on these habitats for nutrient intake (Newton, 2008) to fuel the journey (Benedict et al., 2020).

On the hemispheric scale, there are some examples of threats in

different ecoregions along the Pacific Flyway (figure 1.5). Increasing wildfires are altering the original landscape mosaics; changing annual temperature could influence the timing of migration and habitat distribution of birds; growing urban populations might consume more resources including land, forest biomass, and other factors. Potential risks of sea-level rise could lead to habitat loss, and finally, overfishing is making food sources less available.

Why do I look into urban environments?

"Many cities, such as San Francisco, Chicago, New York, and Toronto, Ontario, lie on important bird migration routes, with millions of birds passing through these urban environments" — Timothy Beatley (2020)

"Cities are often located in critical habitat areas, such as river estuaries, and are part of larger environmental systems, such as riparian corridors, and the flyways of migratory birds. Thus, the habitat system can increase local urban biodiversity while also supporting regional and global wildlife populations" —Rottle &

Yocom (2010)

I am interested in urban ecosystems and urban biodiversity. Acknowledging that suburban and rural landscapes may be better suited to support bird migration, I would primarily explore opportunities for bird conservation in urban environments because the urban ecosystem has been impacted by human disturbances to a large extent, and the level of complexity in an urban environment is higher when we consider social agents and societal dynamics to be a part of the urban ecosystem. Also, there may be more spatial limitations when designing for wildlife. However, improving urban ecosystem services is mentally and biophysically beneficial for human residents. When we are providing premium habitats for bird species, we simultaneously provide human residents with accessibility to wildlife. Better ecosystem functioning supports overall wildlife communities when urban habitat meets the requirement of target bird species.

According to the quotes provided, many cities lie on important bird migration routes, and many cities are located in critical habitat

areas. I am very interested in exploring urban complexity, and uncovering some of the primitive ecosystem functions in nowadays cities, especially after I learned the environmental history of Seattle and of the Pacific Northwest.

Conceptual framework

Generally speaking, the methodology of this research-design thesis derives from the Ecological Systems Studio engaging cogitation of species relations, scenarios, and phasing. The methods for this research explore the species relations in the analysis of species needs and ecological characteristics of focal landscapes. Rather than directly frame this research by scenario planning, this research emphasizes more of the analog of the scenarios, and this analog is actually the typological studies. Phasing is included in the design characteristics of each proposed ecological design prototype. With these methods confirmed, the conceptual framework visualizes the whole structure in a simplified way (figure 1.6). From top to bottom, I have theories that I adopt, the values of my work, 3 target species, 5 urban waterfront typologies, and multiple design

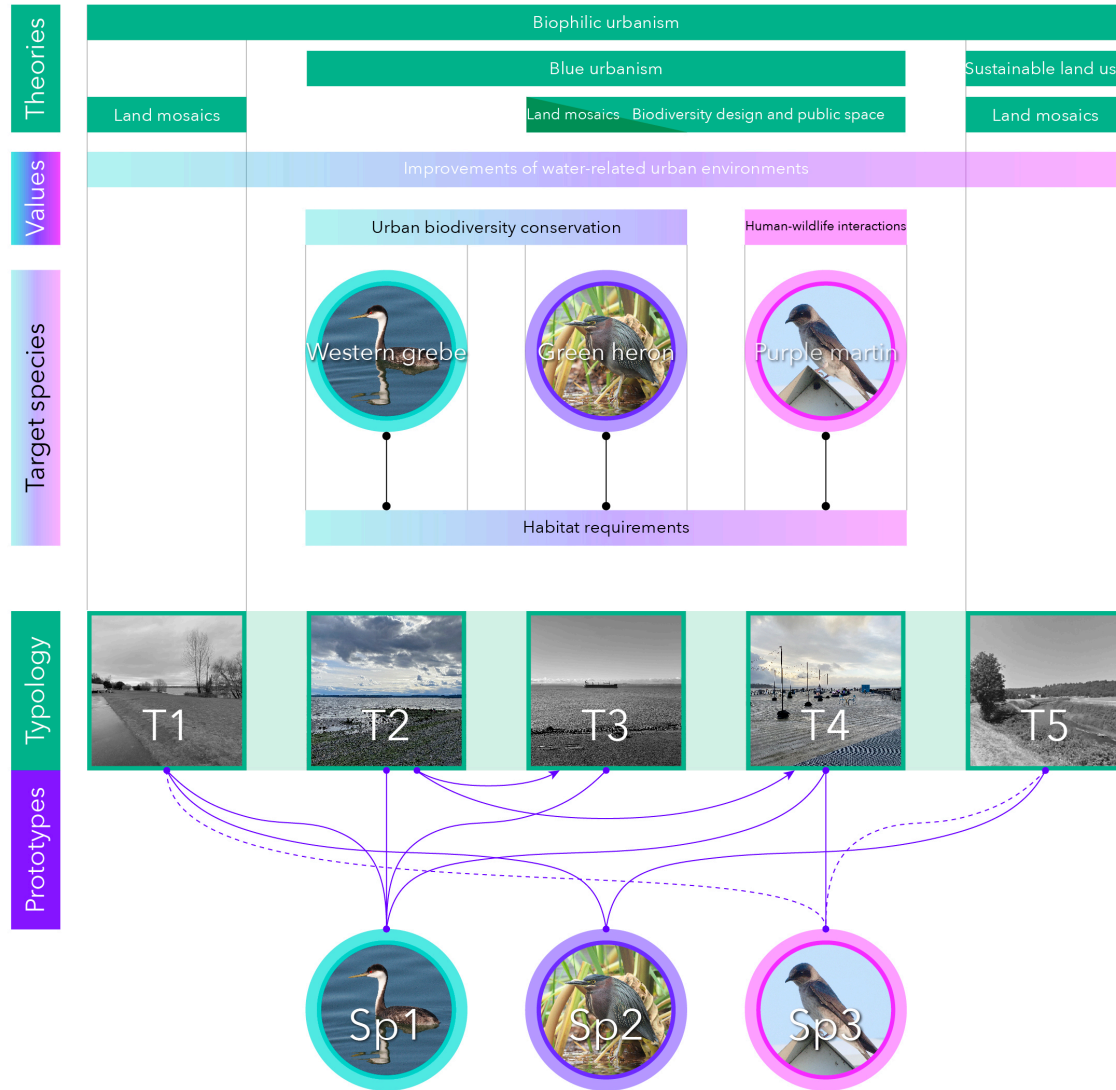


Figure 1.6 Conceptual framework

prototypes (shown by purple lines connecting typologies and target species). These sections are interactive. The habitat requirements of target species influence the way we think about prototypical solutions for different landscape typologies, and the theories are closely related to the desired conditions of different landscape typologies, and together, the target species and landscape typologies, they both contribute to the value of my thesis.

I identified five typologies of urban waterfront environments that are performing as interfaces for design interventions that support bird migration. Each type of urban environment has a different role to

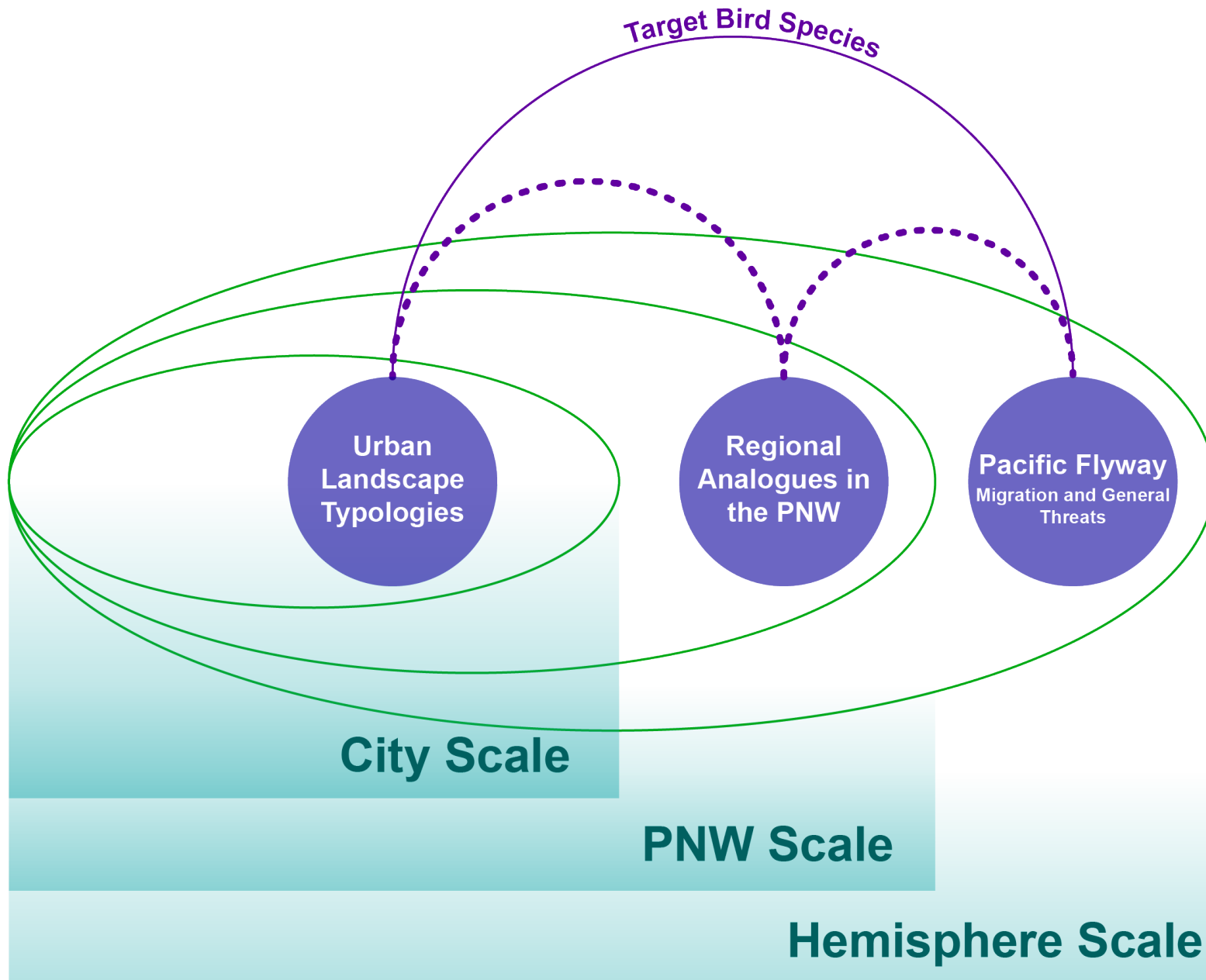


Figure 1.7 The three scales

play. For example, T1 has opportunities to provide Sp1 and Sp2 with better habitat, and Sp1 gets benefits from T1, T2, T3, and T4; Another example can be T2 which in ways serves other urban waterfront typologies. Thus, an interconnected web is produced between typologies of urban waterfront environments and target bird species. These connections themselves are potential design prototypes. Some prototypical solutions are explicit and directly related to specific target bird species (solid lines), while others have reserved extra options or a marginal benefit for the target species (dash lines). What are the meanings and values of this framework? The target bird species require a positive environmental change in the city, and therefore the change should be reflected through a series of landscape architectural design interventions. Prototypical design concepts of this thesis are grounded in public space design, sustainable land use, the perspective of land mosaics, as well as blue and biophilic urbanism. As a consequence, the values of these animal-aided design proposals are not limited to only urban biodiversity conservation and strengthened human-wildlife interactions, but are improving water-related urban environments at the city scale.

Scales

I am specifically examining three scales of bird migration (figure 1.7). The hemispheric scale explores the full extent of the flyway for bird migration along the west coast of the Americas. The Pacific Northwest scale is focused on regional patterns of urban landscapes in the Pacific Northwest of North America. And at the city scale, the urban landscape typologies provide a more tangible approach to engaging in design thinking.

The conceptual framework articulates these three scales of bird migration. Identification of these three scales conforms to the intersectionality of bird migration, and the hierarchy of natural environmental alteration by humans. On the hemispheric scale, the main focus is the dynamic and synthetic processes of the Pacific Flyway that extends to the Aleutian Islands in the north and to both sides of the Drake Passage in the south. This enormous crescent comprises a tremendous amount of ecosystem types and therefore an exceedingly large number of migratory bird species. On this

scale, the focal points are its ecological functions, climate change impacts, and general threats that are omnipresent in the Americas. The Pacific Northwest scale is more regionally defined by geography, annual temperatures, and precipitations (both sides of the Cascade Range). Growing cities and their conflicts with critical bird habitats in this region in a long-term prediction are the prime focus on this scale. Zooming into the city scale, the aggressive alteration of the natural environment over time has resulted in a remarkable degradation of wildlife habitats. The degenerated urban ecosystem functions, compared with their original status before the establishment of cities, prioritized the necessity of urban ecological design. Cities, one of the fundamental units of landscape hierarchy, are diverse compositions because of the existence of socio-ecological systems that are co-evolutionary, and whose potential futures are worth predicting. The city scale allows the exploration of integrating community participation in design projects for migratory birds.

The visual presentation of these three seemingly distinct scales is linked by both the nature of bird migration and by potential

geographical extension from one city to its peers in other regions. Ecological design interventions act like individual sparks that together can influence a larger system. This generalizability is conveyed by this conceptual framework diagram and directly contributes to the value of this thesis.

The theory basis

1) Animal-aided Design

Weisser & Hauck (2017) proposed an “Animal-Aided Design” methodology to use life-cycle analysis of a species to improve planning and conservation in open spaces in the city. This method assumes that 1) it is necessary to choose target animal species at the beginning of planning processes; 2) essential requirements of target animal species are ascertained by the species life-cycle which engenders a species portrait; 3) design inspirations can be gained from animal needs (Weisser & Hauck, 2017). Since biodiversity planning is most effective when other objectives, such as environmental education and environmental impact mitigation, are

consolidated in biodiversity planning (Ahern, Leduc, & York, 2006), animal-aided design stimulates considerable opportunities to combine biodiversity conservation and planning. Further, human-made resources, such as built structures in the ecosystem, and direct human participation, are one of the design options to enhance biodiversity in the urban setting (Forman, 2008), and this is another theoretical basis for actively connecting animals and design. My thesis discusses a quite similar topic, even though the scale and the framework are different. I adopt the method of target species portrait and use this as one of the guidelines to repeat and integrate to explore potential overlaps among multiple species. The overlapping needs of the target bird species may generate more design inspirations to support the novelty of urban landscapes and inform the change in thinking about landscape design to support bird habitat across distinct sites.

2) An intersection of the public space, biophilic design, and birds

In the book *Creating Vibrant Public Spaces*, Ned Crankshaw (2009) offers design guidelines for urban public space elements in

downtown areas. The guidelines include pedestrian paths, parking, lighting, trees, street furniture, and public art, graphics, and design (Crankshaw, 2009). Partially because the main focus of this book is on streetscapes in commercial and historic districts, the design guidelines are products of social interactions. However, I would expect future streetscape design and public space planning to articulate the narrative of human-wildlife relations. I also believe that the coexisting social and biological systems (of green infrastructure) (Rottle, 2013) can be adopted in public space design. In highly anthropogenic landscapes, biodiversity can be supported through a framework identifying the level of human-made environments' resemblance to their natural counterparts (Lundholm & Richardson, 2010). Diverse design elements in public space can be re-organized to weave ecological networks that are suitable for native bird species who have adapted to human existence.

Biophilic design attributes that contribute to the direct experience of nature include light, air, water, plants, animals, weather, etc., and these factors together create desirable habitats for people to give rise to health, fitness, and well-being (Kellert and Calabrese, 2015).

A bird-friendly built environment brings forth a direct and strong biophilic experience of nature in that compound public spaces that integrate bird habitat possess more than one element of biophilic design. Besides birds as the most important biophilic components in the city, vegetation and outdoor water accessibility are also providing human residents with biophilic and restorative values when people are engaged in activities associated with bird habitat maintenance and recreational birding. Bird inhabitants are an energetic component in urban environments. They are a part of urban soundscapes (Beatley, 2016), and bird songs render an atmosphere of well-being and relaxation (Farina, 2014). Moreover, the installation of bird nesting features may be an opportunity for environmental education, or a physical manifestation conveying a sense that birds should and can be an integral part of our lived experiences in the city.

The theory of "Blue Biophilic Cities" is Beatley's later integration of biophilic urbanism and blue urbanism (Beatley, 2018). This series of theories emphasizes "blue-urban connections" and "marine nature" being a source of wildness, healing, and a profound sense of place.

In addition to a leadership role in marine conservation and climate change mitigation, the Blue Biophilic Cities theory also mentions humans' emotional connections to the sea (Beatley, 2018), so I believe that interactive human-nature open spaces/habitat along the marine shoreline of a city would contribute to an insightful perception of the sea. The edge of the urban environment and the sea can be blurred by stronger attention to our landscape architectural interventions that stress the importance of critical habitat on the edge of the terrestrial and marine interface in the city. This can also be translated to other types of water-related urban environments so that similar emotional connections can be built on urban-lake and urban-river relationships.

3) Ecological frameworks for birds

The conceptual model of the urban structure proposed by Kevin Lynch (1964) including path, landmark, edge, node, and district, has spatial similarity to Forman's model of landscape ecology (1995) which articulates the importance of landscape patterns to support wildlife habitats such as patch, corridor, and matrix. The prototype

design of bird habitats should undoubtedly adopt the patch-corridor-matrix model for the arrangement of landscape architectural interventions to evaluate if the primary goal, such as sufficient edge habitat, conditions for plant growth, and food sources, will be achieved spatially. Additionally, one of the more important concerns is to contemplate the evolution that will occur in designed ecosystems. In different types of urban environments, ecosystem functions generated by three-dimensional spatial patterns vary and are depending on goals of bird conservation, or objectives for creating bird-friendly public spaces. Two prototypes grounded in different urban waterfront typologies and focusing on different species may share similar patterns according to, for example, the arrangement of patches and corridors, but their socio-ecological flows may be quite different, and this is one of the reasons why typological studies are critical to urban biodiversity design with a concentration on migratory birds. Another possibility can be two or more prototypes aimed to target a single priority species. In this case, the function and migration flow of these two prototypes are the same, but spatial features within each are distinct because ecological design interventions should always

conform to the capacity and limitations of the site to generate a proper patch-corridor-matrix layout in different scenarios and ecological settings.

Sustainable land use is a broader scope envisioning this ecological framework. I recognize that the land used for housing, manufacturing industries, commercial services, and transportation takes the majority of the urban space. Moreover, it is widely accepted that urban sprawl with a considerable amount of low-density development causes worse water quality, air pollution, public health issues, and severe income and racial segregation (Frumkin, Frank, & Jackson, 2004; O'Sullivan, 2019). In this context, especially in most cities in the United States, sustainable land use is an opportunity to spatially concentrate and condense the distribution of social-economic functions and services in the city and gradually return a small portion of land back to nature. Because the concentration is built upon the existing urban grid, what I can anticipate, at the city scale, is an urban grid with a larger amount of properly distributed green spaces for urban wildlife. Anticipated urban grids with an increasing number of green spaces may

promote additional access from each neighborhood unit to urban wildlife including urban migratory birds.

Values

The values of this thesis begin with my personal perception of nature, urban nature, and urban communities. There are four specific values that I ascribe to this research:

Firstly, the nature of this research is an urban bird conservation-oriented narrative, so it directly contributes to the value of urban biodiversity conservation. The abundance of the three target bird species is expected to keep growing if the proposed prototypes are realized.

Secondly, in the urban environment, this research also explores interactions between human communities and spirited birds. All of the target bird species reflect this value, and species 3, the purple martin is a primary contributor to this value. By building the connections to birds, connections to bird habitat are consequently enhanced.

Thirdly, another value lies in the attempts to improve ecosystem diversity and general environmental quality in urban waterfronts through the process of meeting the bird needs. This value is an indirect byproduct of the first two values, but it informs a discipline-level long-term expectation of landscape architecture.

Lastly, the research as a whole presents a framework of landscape architectural thinking to support bird conservation, and landscape typology-based methods for ecological design in a larger urban system, rather than focusing on an individual site in the city. This echoes the deliberation of habitat foundations of meta-population dynamics.

Chapter 2

Target Species

Along the Pacific Flyway, and through a close analysis of migratory species assessing prioritization for conservation and life history, I have selected three that I think could be most benefited from thoughtful design changes to the urban environment. This group of target species is a result of several iterations to compare and narrow down the research scope from a more extensive list of potential target species. In particular, I focus on species that migrate through the Puget Lowlands and the Seattle Metropolitan region. These species are the Western grebe (Sp1), green heron (Sp2), and purple martin (Sp3). Figure 2.1 is a spatial representation of the distribution of their

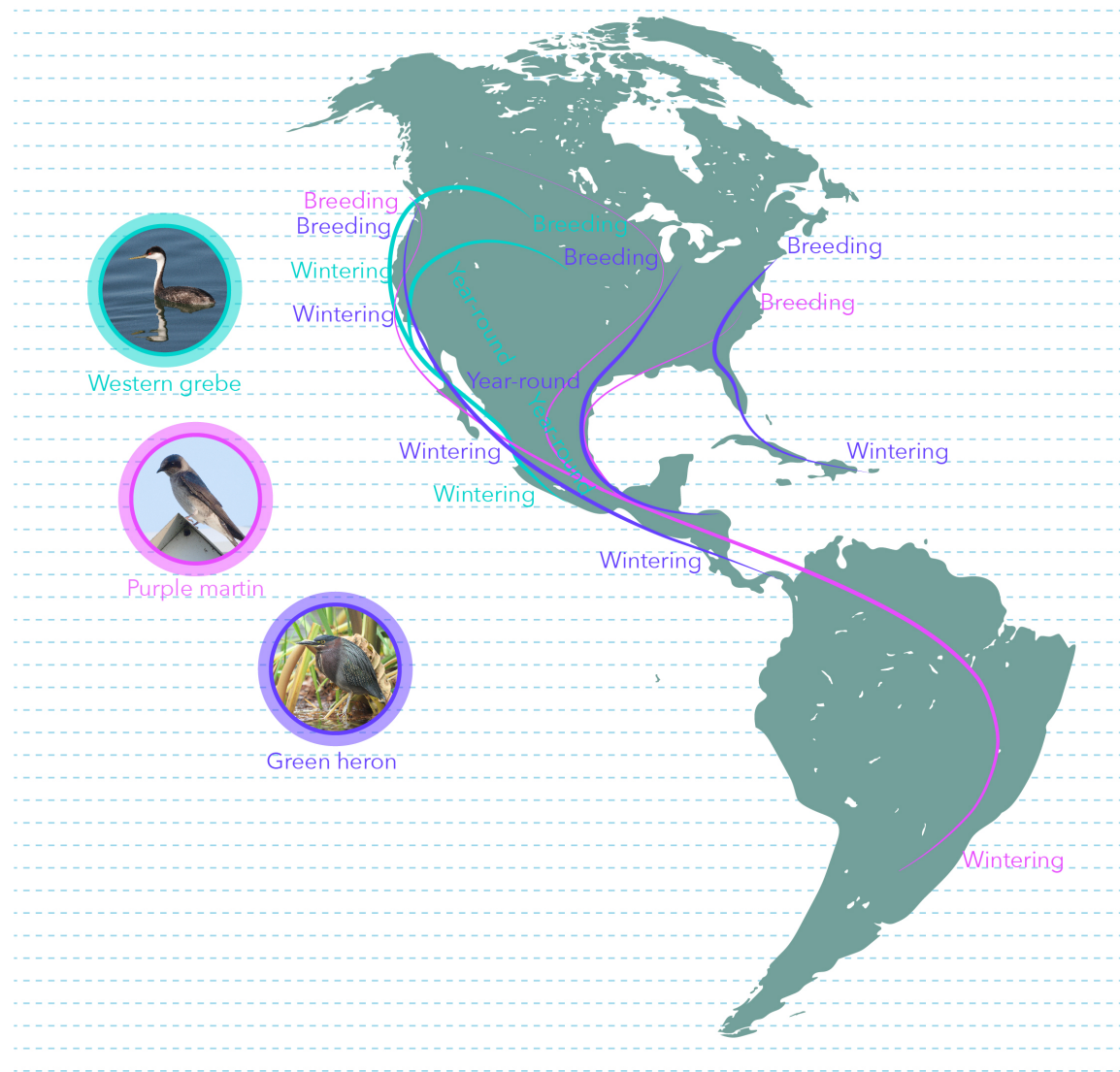


Figure 2.1 Distribution of the target species

breeding and wintering extents, as well as year-round habitat.

The target species are selected from the list of species of concern in the Salish Sea (Zier, and Gaydos, 2016). Each one of the target species represents a unique guild in order to cover as many aspects of consideration as possible. The aspects of consideration are related to both what the bird species require and what the city can provide.

For each target species, the provided species portrait contains the habitat for the bird during the breeding and non-breeding period, the major food sources, the body size, seasonal distribution of the bird, and places where people can find the particular bird species in and around the city of Seattle. Finally, the basic needs of the target species generate a primary theme of conservation, which is labeled on the bottom right in each species portrait. After each species portrait, several critical design elements are listed according to the behavior of the species.

Table 2.1 Guild of Target Species

	Breeding Period	Non-Breeding Period	Year-Round
Western Grebe	Piscivore: freshwater diver	Piscivore: water diver	
Green Heron			Insectivore: air screener
Purple Martin			Crustaceovore/ piscivore: water ambusher

Western Grebe

(*Aechmophorus occidentalis*)

The Western grebe (figure 2.2) is on the Red List in British Columbia (that have been legally designated as Endangered or Threatened under the provincial Wildlife Act, are extirpated, or are candidates for such designation), and it is a Candidate species in Washington State (which are those species that will be reviewed for possible listing as endangered, threatened, or sensitive) (Zier, and

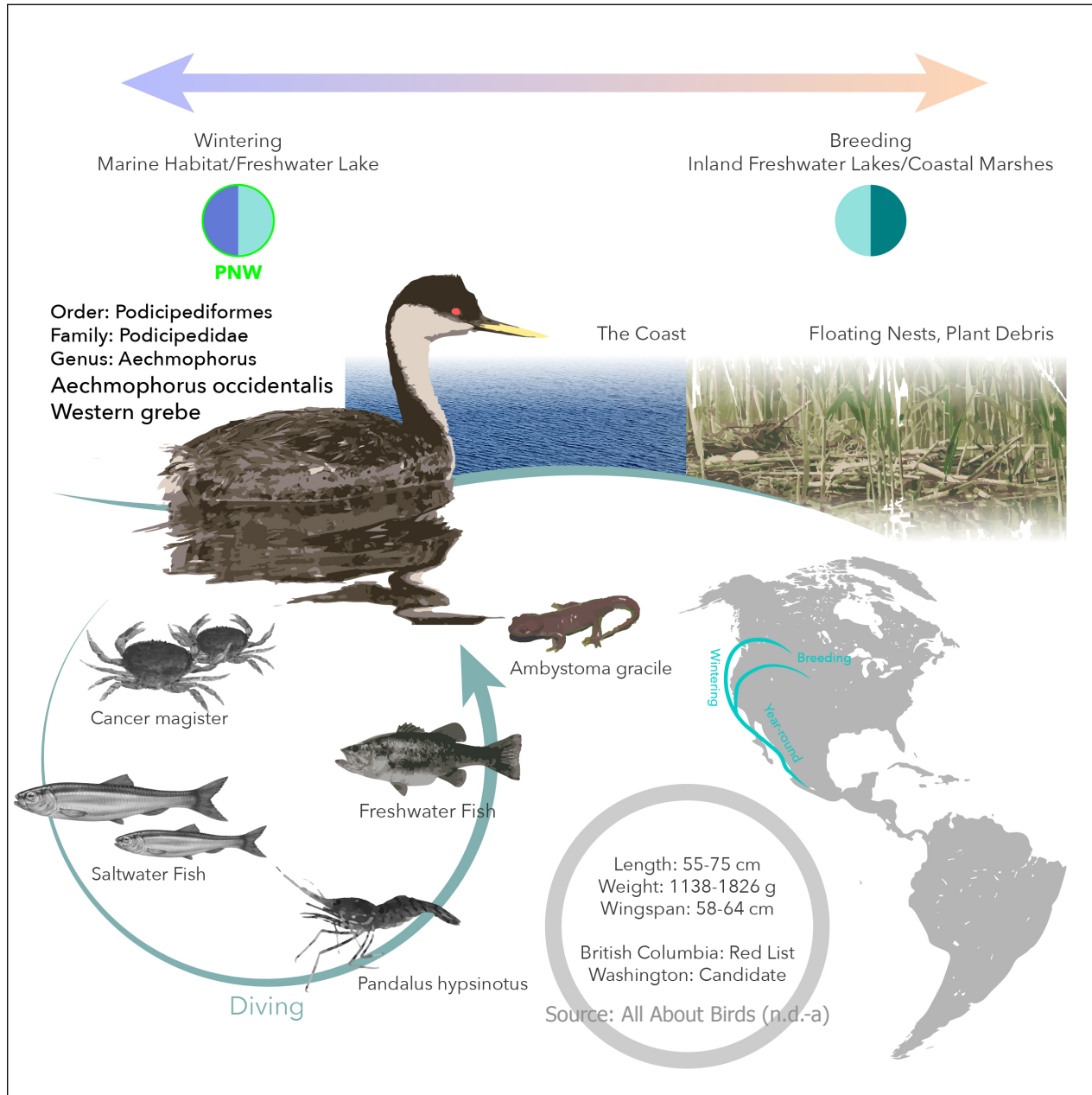
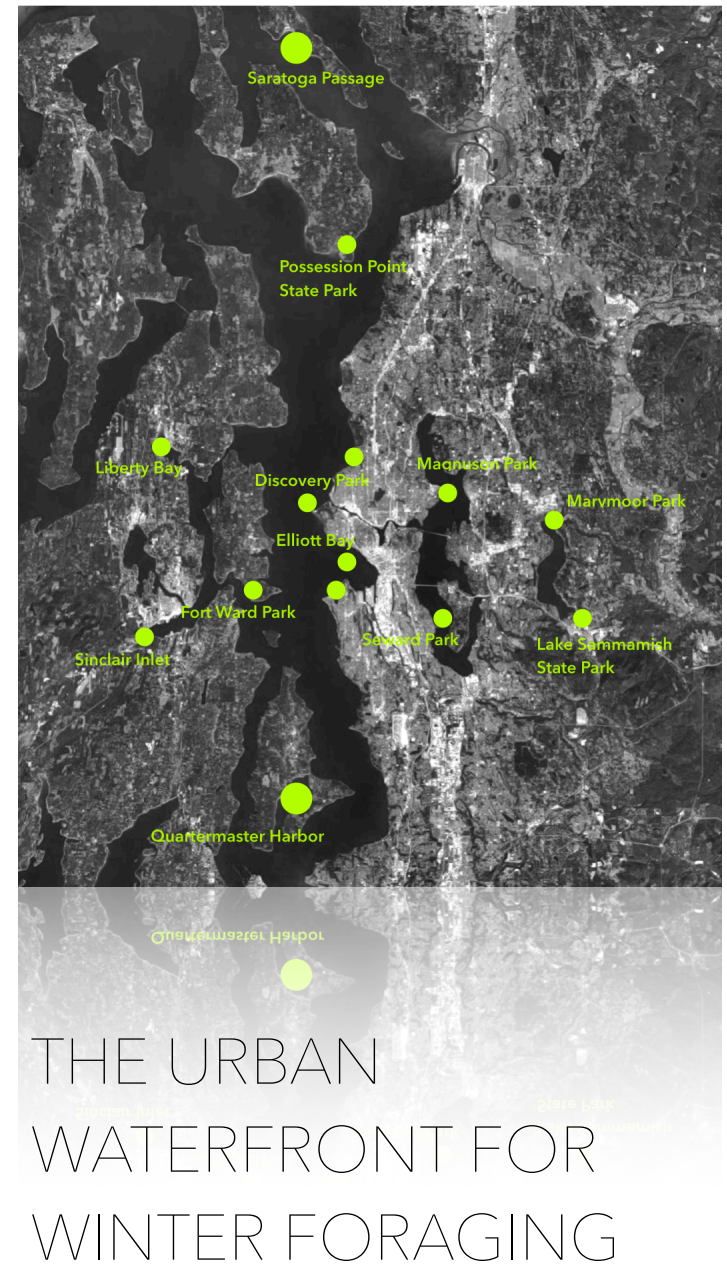


Figure 2.2 Species portrait of the Western grebe

From the Flyway to Urban Landings



Gaydos, 2016). From the migratory distribution, the Western grebe is a cross-flyway migrator that does not always follow the north-south migration. The northern population of Western grebe migrates from the Pacific coast to more inland areas of North America during the breeding season period, and before winter, they return to the Pacific coast. The Western grebe only colonizes freshwater habitat during the breeding period, and it forages in both saltwater and freshwater habitat during winter. They dive into the water and primarily feed on fish, and some other animals as well. The map on the right shows where people can observe them around Seattle (BirdWeb, n.d.-a.; Audubon Washington, 2011). Saratoga Passage and Quartermaster Harbor are two common locations to observe the Western grebe in winter (BirdWeb, n.d.-a). Western grebes can be also observed in Discovery Park, Elliott Bay, Seward Park, Magnuson Park, Marymoor Park, Lake Sammamish State Park, Fort Ward Park, Sinclair Park, Possession Point State Park, Liberty Bay Park, etc. (Audubon Washington, 2011) It is obvious that the Western grebe uses both marine and freshwater lake habitat, especially in protected habitat areas like bays and shallow shorelines.

Historically, there have been plenty of threats along their migration routes, including both breeding and wintering habitat. In the Salish Sea region, oil spills (Burger, 1997; Washington Department of Fish and Wildlife, 2013), gill nets (Burger, 1997), aquaculture (Burger, 1997), chemical pollution (Burger, 1997), marine traffic (Wilson et al., 2013), and herring deficiency (Wilson et al., 2013) threatened the abundance of the Western grebe across temporal scales. In the Pacific Northwest, algal blooms occurred in 2009 along the Southern Washington coast and the North Oregon coast significantly impacting local populations (Phillips et al., 2011). In the Pacific Southwest, a higher Mercury concentration was found in Western grebe populations in the Clear Lake watershed (Elbert & Anderson, 1998), and in Monterey Bay, there was also a harmful algal bloom that influenced the local population in 2007 (Phillips et al., 2011). On the west coast, in regions that are more interior, similar threats took place as well. Lake Wabamun oil spill in 2005 damaged a large nesting site for this species ("An Oil," 2005), and Burger and Eichhorst (2007) compared metal levels of four grebe species in Agassiz National Wildlife Refuge and they found that the Western



Figure 2.3 Growth trends of the Western grebe by bird conservation region, image from USGS

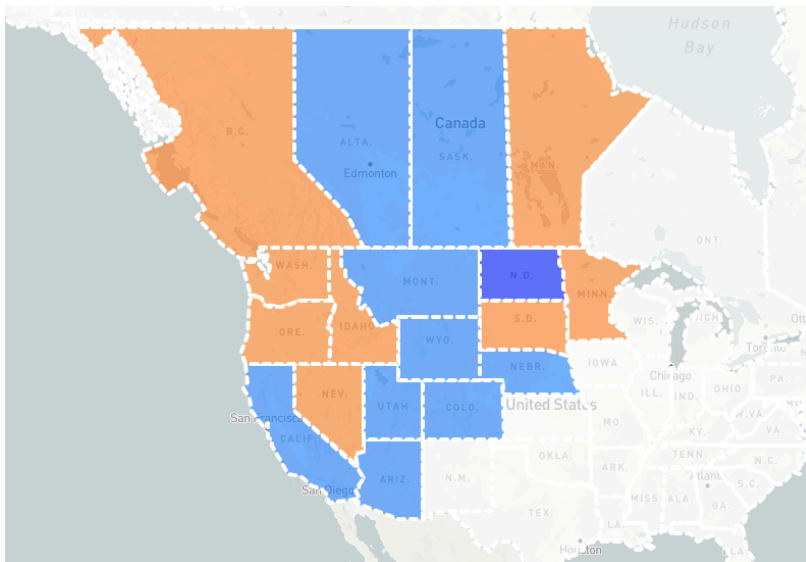


Figure 2.4 Growth trends of the Western grebe by state/province, image from USGS

grebe in this study site has a higher level of lead than other species. Further, the increased presence of common carp and invasive cattail hybrid may be responsible for a lower nest survival rate and the chick-adult ratio at Delta Marsh in Manitoba (Porte, Koper, & Leston, 2014). At Lake Christina, Minnesota, nests loss was caused by storm events in 2006, and the nesting success rate dropped by approximately 18 percent compared with the previous year (Allen, Nuechterlein, & Buitron, 2008).

Since the focal region of this research is the Puget Lowlands, conservation in this region would compensate for potential loss in other regions along their migration route. The decline of the Western grebe in the Pacific Northwest is primarily due to deficient food provision, especially herring (Clowater, 1998). On this map (figure 2.3), the population in the Pacific Northwest is in orange, which is declining (USGS, 2019a). On the state/province map (figure 2.4), the abundance of Western grebe has been declining in British Columbia, Washington, Oregon, Idaho, and Nevada, compared with a trend of increases in California, Montana, Wyoming, Utah, North Dakota (USGS, 2019a). The increasing abundance of Western &

Clark's grebe species in the Pacific Southwest coast is significant. This roughly coincides with a trend for Western grebe to migrate south in wintering seasons because of food insufficiency along the Pacific Northwest coast (WDFW, 2013), so their wintering habitat range is partially condensed to the Southwest.

How can we translate the needs of this species to a setting in which landscape architectural interventions can play a feasible role? Figure 2.5 is the conceptual framework starting with the Western grebe. Herrings are the primary food source of the resident Western grebe population in the Salish Sea region (Clowater, 1998; WDFW, 2013). Herring requires eelgrass meadows to reproduce. From a wider view, it's about the plant community composition supporting fish abundance, and thereby indirectly maintaining the population of Western grebe populations during winter in the Pacific Northwest. Thus, I came up with a connection from abiotic patterns and flows to plant community composition.

With the connection identified, the diagram further presents one example of opportunities to achieve the goal of conservation of

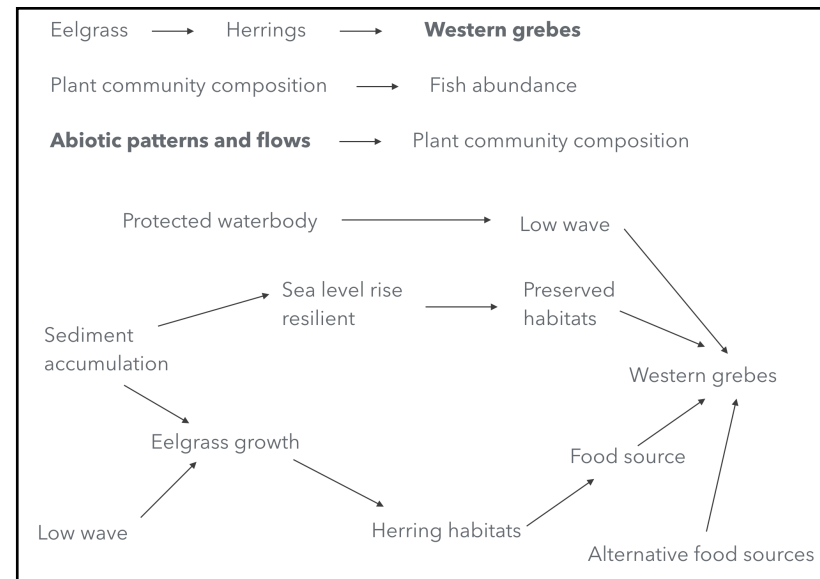


Figure 2.5 Design concepts for the Western grebe

wintering Western grebes. The ideas here are providing protected water bodies with sediment accumulation and protected water bodies. New areas with desirable sediment accumulation provide eelgrass growth for additional spaces. The extra area with seagrasses attracts fish species including herring. Also, accumulating sediments should be resilient to potential sea-level rise that may be worsening seagrass habitat loss. More shallow water areas are required for food provision. Seagrass growth desires a more protected water body. Reversely, the root system of

seagrasses stabilizes the substrate and reduces wave energy. The expectation of design elements in habitat for the Western grebe would be in mutually beneficial relations. Alternative food sources should also be considered because they make up about 20 percent of Western grebes' diet (WDFW, 2013). To summarize, the theme of ecological design for the Western grebe is defined as the urban waterfront for winter foraging. Ecological design prototypes can focus on different scenarios around the guiding theme.

Green Heron
(*Butorides virescens*)

The green heron (figure 2.6) is listed on the Blue List of the provincial Wildlife Act of British Columbia (Zier and Gaydos, 2016). The population of green herons gradually declined from 1966 to 2019, and the trend of green heron populations in the United States is estimated to be -1.35, and from 1993 to 2019, the trend is estimated to be -2.11 (USGS, 2019b). Green herons' habitat includes freshwater wetlands, ponds, densely vegetated riparian zones (BirdWeb, n.d.-b), human-constructed wetlands or ponds

(Heron Conservation Organization, n.d.). Green herons' nests are situated over water in vegetation including bushes and trees (Heron Conservation Organization, n.d.). Like other species, wetland loss is threatening green herons (BirdWeb, n.d.-b). Green herons primarily feed on small fish, though amphibians, crayfish, small rodents, and insects are also part of their regular diet.

I focus on the Pacific population of green heron. Along the Pacific coast, green herons breed in the north up to the Salish Sea area and to the south along the central Oregon coast. The northernmost end of green heron breeding is around Southwest British Columbia

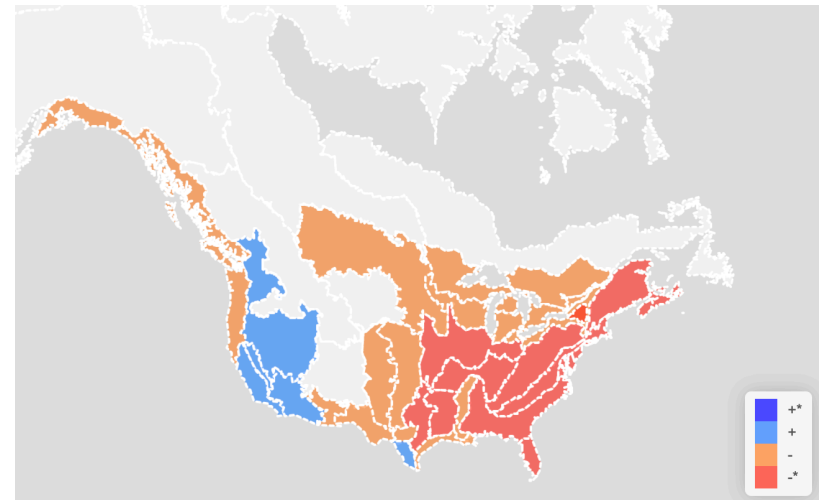
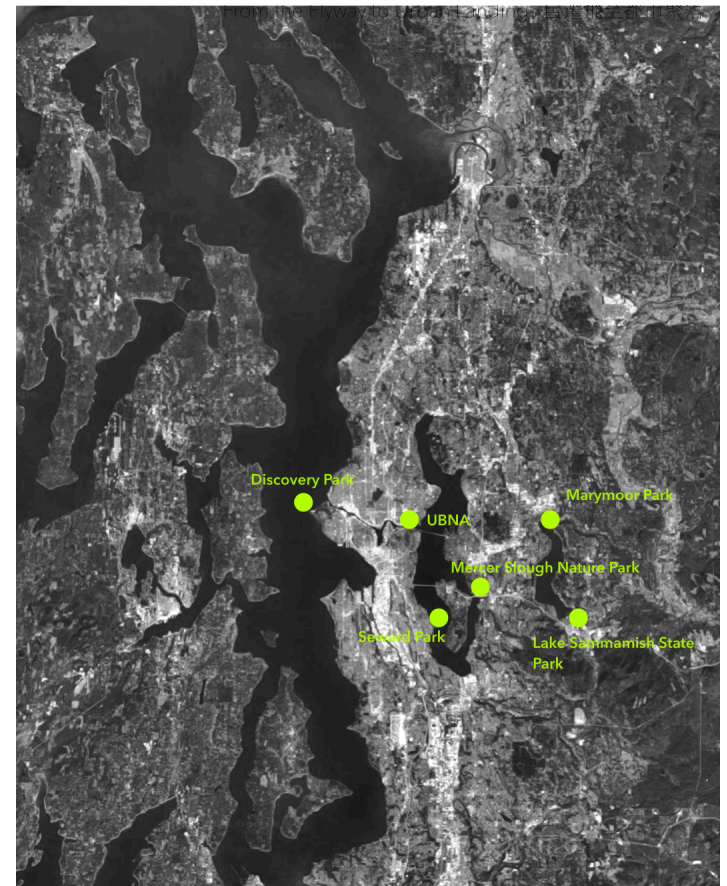
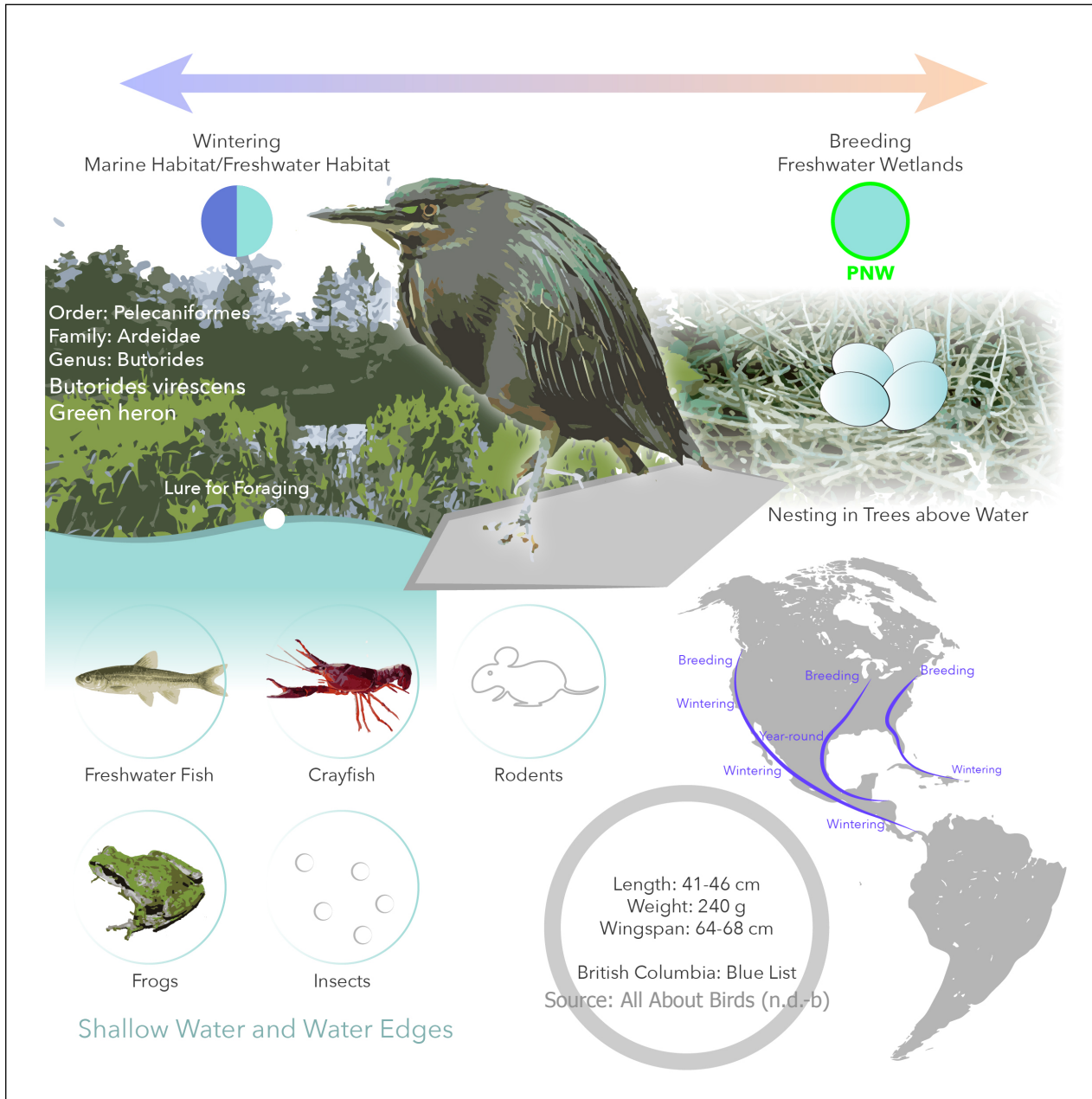


Figure 2.7 Growth trends of the green heron, image from USGS



WETLAND EDGING

Figure 2.6 Species portrait of the green heron



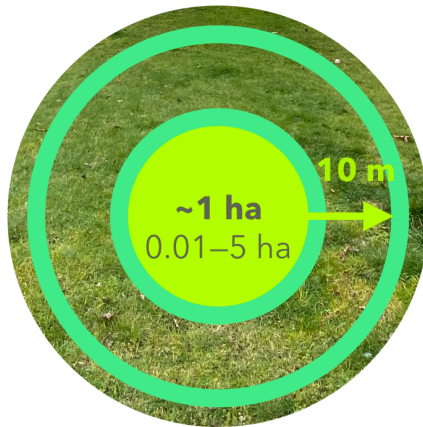
Vegetated banks

(Hoy, 2017; Photos by Steve Hillebrand, USFWS)



Slow-moving or shallow water for foraging

(Fraser and Ramsay, 1996)



Wetland patch and buffer

(Fraser and Ramsay, 1996)



Dense vegetations

(Fraser and Ramsay, 1996)

(Fraser, Ramsay, & BC Environment, 1996). The majority of green herons in Washington are migratory (BirdWeb, n.d.-b). In Western Washington, green herons appear from April through October, and they are rare during winter (BirdWeb, n.d.-b). There is a trend of migrating to further north recorded in the twentieth century, but severe winters are one of the factors that limit the wintering range of this species (Fraser et al., 1996). Since there is a trend for this species to migrate further north, in which case, the Salish Sea area in the Pacific Northwest is becoming more important with this observed trend. Moreover, potential global warming might facilitate expanding the distribution range of green herons as well. Thus, it is beneficial for this species to have an increased abundance of shelter and habitat that the urban environment can provide.

Figure 2.8 Critical needs of the green heron

Similar to the Western grebe, the map of bird

survey (figure 2.7) reveals that the population in the Pacific Northwest coast has been declining, compared with slightly inland areas east to the Cascade Mountains in the Pacific Northwest (USGS, 2019a).

The green heron specifically prefers (figure 2.8) a wetland edge habitat for nesting and foraging during the breeding period. Some important criteria for successful breeding should be considered when designing for green herons. Vegetated banks (Hoy, 2017) are one such feature benefiting herons. Slow-moving or shallow water for foraging and dense vegetation around water bodies for nesting are two relatively important components if green herons are going to successfully breed in suburban and urban environments (Fraser et al., 1996). During the breeding period, they also prefer oxbows and sloughs (Fraser et al., 1996). A patch for a green heron colony is typically larger than 1 hectare, but smaller patches also exist, and the buffer width should be at least 10 meters (Fraser et al., 1996).

Green herons typically tolerate to human-dominated areas, and their foraging behavior was influenced less by human disturbance

events than by habitat in the field experiments in San Marcos River in Texas (Moore, Green, Huffman, & Simpson, 2016). Therefore, this result would allow more flexibility to ecological urban design with human disturbance events in open spaces.

Based on research of this species, the ecological design theme focuses on enhancing wetland edge habitat to fulfill green herons' desire for more edge habitat that is adjacent to aquatic environments during the breeding period along the coast in the Pacific Northwest.

Purple Martin (*Progne subis*)

The purple martin (figure 2.9) is on the Blue List in British Columbia, and it is a Candidate species in Washington State. Purple martins are highly adaptive to human existence, and human-made structures often present desirable nesting locations when there is a lack of available tree cavities. The purple martin is a long-distance migration bird ranging from the Amazon Basin to Western

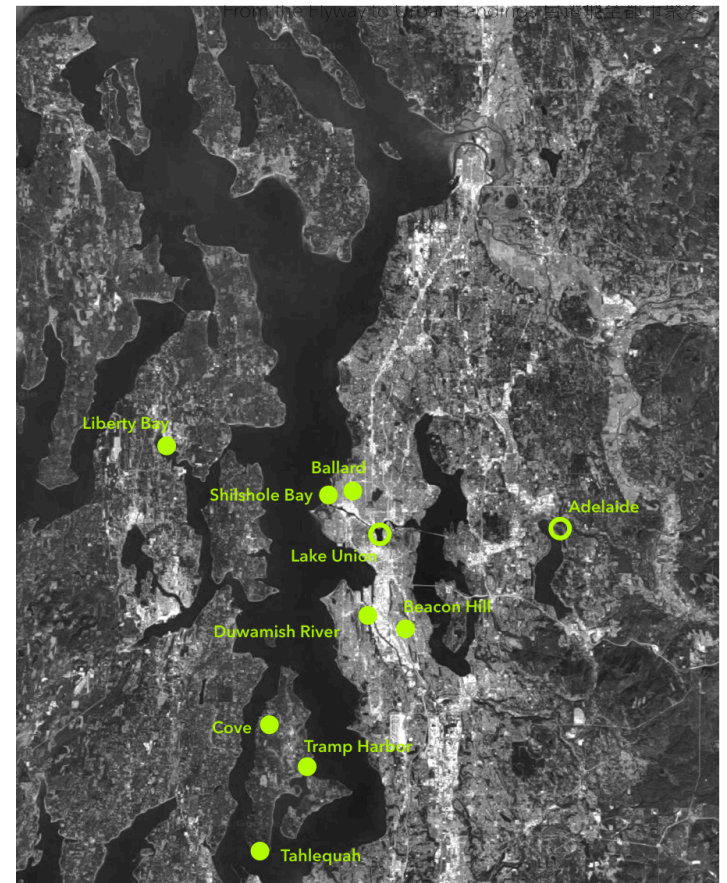
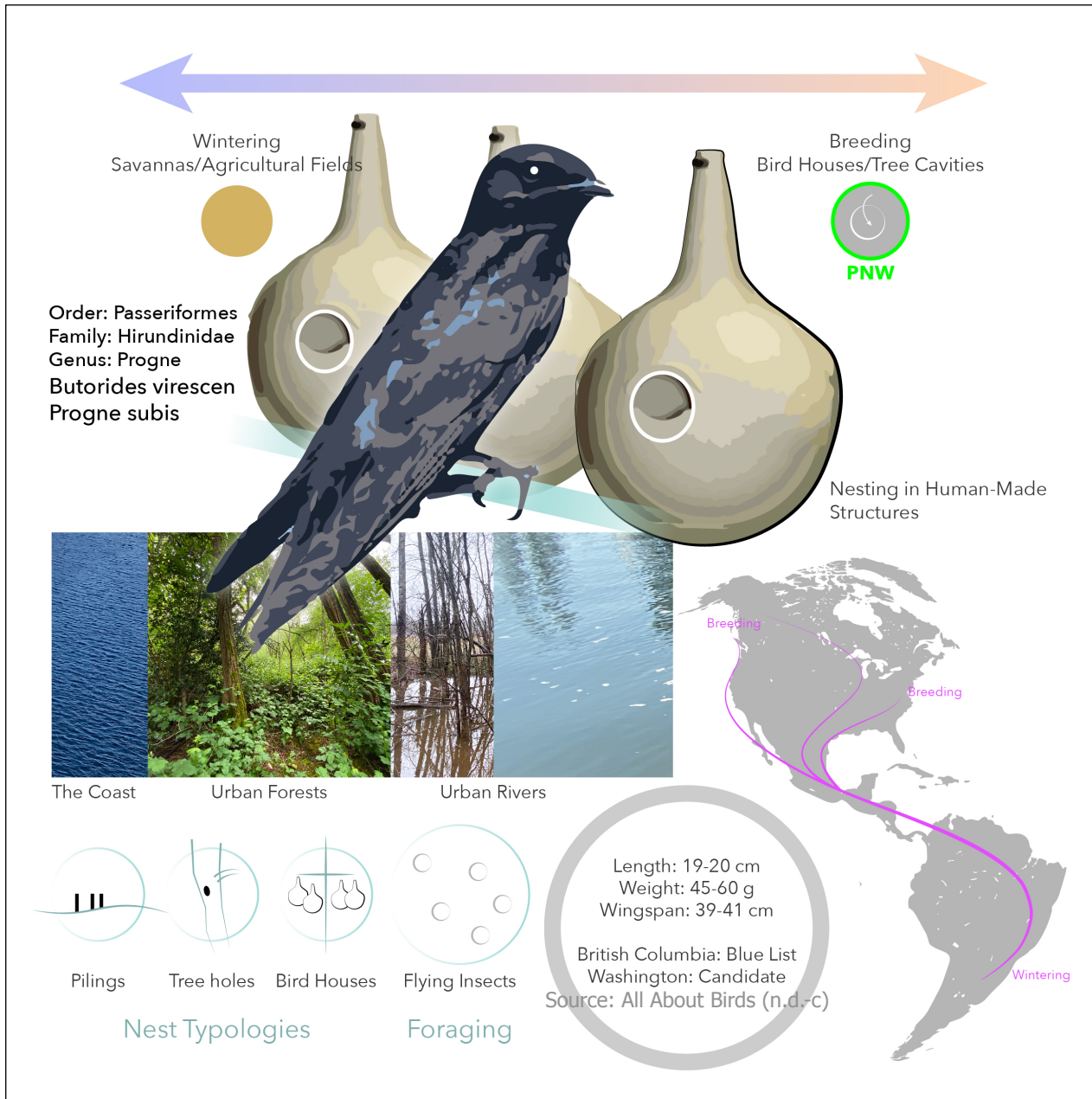
Washington in mid-April to May. In late summer, they group together and migrate to the south (BirdWeb, n.d.-c). Its population in the Pacific Northwest has been continuously increasing (USGS, 2019a). During the breeding period, purple martins use open land near water (BirdWeb, n.d.-c), colonizing tree cavities, abandoned woodpecker holes, pilings in the sea, birdhouses, etc. They are air screeners who feed on flying insects high above the ground.

In British Columbia, purple martins were restricted to birdhouses and human-made holes in pilings in river estuaries, bays, and harbors (Fraser, Siddle, Copley, Walters, & BC Environment, 1997). The threats comprise nest competition, insufficiency of nest sites, temperatures that are too low or too high, parasites, diseases, and pesticides (Fraser et al., 1997). Primary nesting competitors include starlings and house sparrows (*Passer domesticus*) (Hays & Milner, 2004; Fraser et al., 1997). Ecological design in the urban setting makes human maintenance possible to keep the birdhouses available for only purple martins if the total number of birdhouses or the number of food sources is limited. In terms of the temperature, the Salish Sea region can be a gift to purple martins because

extreme heat is less likely to happen in summer when purple martins are breeding.

In Washington, by 2014, there had been some efforts to conserve purple martins in King County through volunteer stewardship, but there are no formal conservation programs (Power, Stark, Siegrist, Anderson, & WDFW, 2014). By 2014, there had been 10 active nest sites in the Seattle metropolitan region; they are located at Sylvan Beach, Fern Cove, Cove, Lisabeula, Ellisport, Tramp Harbor, Dockton, Shilshole Bay, Terminal 105, and Kellogg Island (Power et al., 2014). The abundance of nesting pairs had increased by 2,200% between 1993 to 2013 due to the volunteer efforts.

The reason why this species is one of the target species of my research is that there are opportunities to adopt the theory of animal-aided design and integrate public space design methods to amplify the values of animal-aided design because of purple martins' adaptation to human existence. Instead of regarding purple martin conservation as the only objective of landscape architectural creation, the public space design process can be operated parallel to



DESIGNING PUBLIC SPACES WITH BIRDS

Figure 2.9 Species portrait of the purple martin

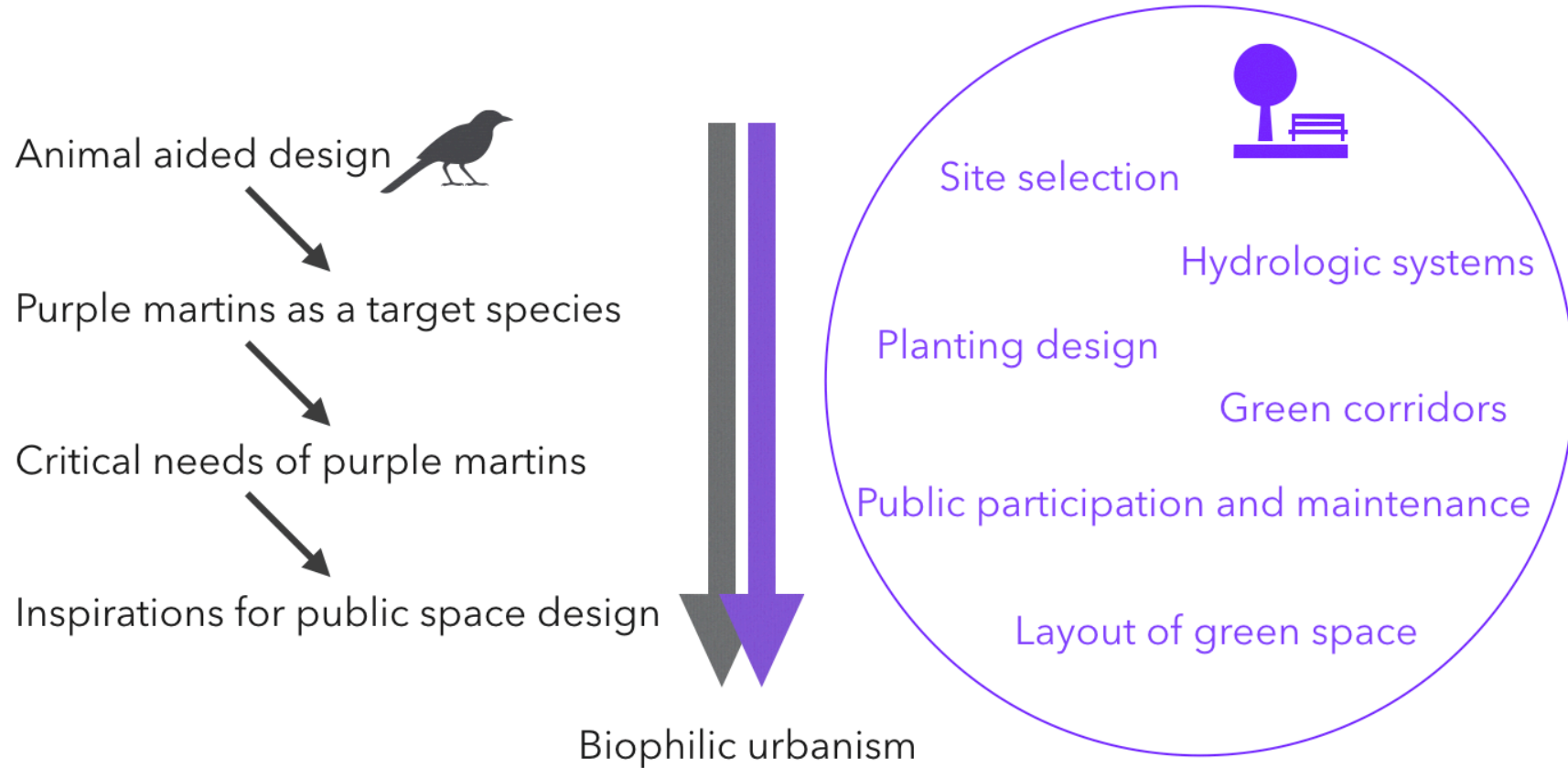
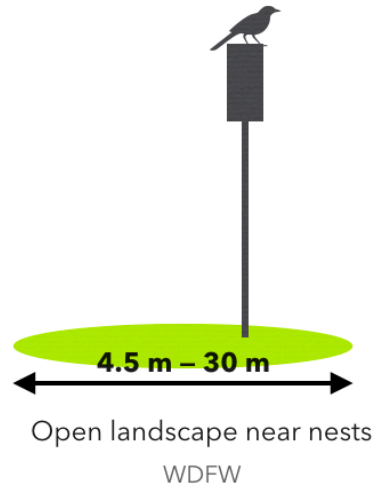


Figure 2.10 The purple Martin and animal-aided public space design

conservation (figure 2.10). The critical needs of purple martins generate design inspirations, and these inspirations influence site selection, hydrologic systems, planting design, green corridor-network analysis, public participation, maintenance, and the layout

of functions in public space design. The ecological design proposals are expected to be a unity of ecosystem functioning, and ecosystem services, depending on the priorities that landscape architectural interventions are aiming to achieve in the beneficiary spectrum.



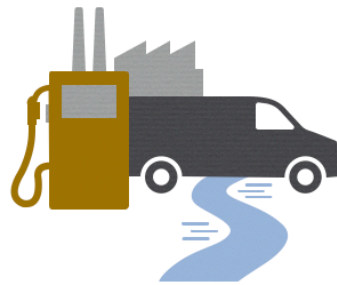
Highly urban environments
Photo by Bob Strahorn



Insect abundance



Public participation



Pollutants control



Predation control



Competition management

Figure 2.11 Design considerations of the breeding habitat of the purple martin

As the ecological design strategies are around public space design in the urban environment, criteria and considerations are also merged into some urban issues when setting up new nests for purple martins (figure 2.11). A new colony of purple martin should be located within 16 kilometers from an existing colony (Fraser et al., 1997). Open landscapes and clear spaces with a radius of 4.5 to 30 meters should surround the nest location to allow purple martins to circle and forage around the nest (Hays & Milner, 2004). Ecological design strategies need to place landscapes for human visitors to enjoy and for making sure that the insect abundance can meet the requirement of purple martins. The designed habitat for purple martins can potentially act multifunctionally to collect and retain urban stormwater runoff because the potential sites are always close to either the marine environment, lakes, or rivers, and thus ecological design strategies for purple martins block polluted runoff from directly flowing into these water bodies.

Table 2.2 Summary of habitat requirements of target species in PNW

Target Species	Season of Appearance	Stage of Lifecycle	Food Sources	Habitat	Nesting	Other Considerations
Western grebe (Sp1)	Winter	Wintering	Saltwater and freshwater fishes (especially herrings), salamanders, aquatic insects, crustaceans, etc.	Protected water bodies with good water quality and sufficient food supply	Floating nests in freshwater lakes (not considered)	Alternative food sources
Green heron (Sp2)	Summer	Breeding	Small fish, frogs, crustaceans, insects, etc.	Freshwater wetlands, ponds, and riparian zones with dense vegetation	Twig nests over water or near water, in trees	Existence of slow-moving or shallow water, dense vegetation
Purple martin (Sp3)	Summer	Breeding	Flying insects	Open landscapes near water	Tree cavities, abandoned woodpecker holes, birdhouses	Birdhouse management to control colonization of competitors

Chapter 3

Urban Waterfront Typologies

Typological studies

Most typologies of public open spaces are determined by categories like form, function, size, and dominant landcover (Wandl, Rooij, & Rocco, 2014). These morphological characteristics are contributing to the physical functions and place spirits of any urban landscape. Analysis of open space typologies helps assessment of potential sites for the introduction of new ecological systems in an urban environment. There have been multiple perspectives on the classification of urban public spaces including urban design perspectives, socio-cultural perspectives, and political-economy perspectives (Carmona, 2010). For example, the study of street edges may evaluate (1) scale and rhythm, (2) transparency, (3) appeal to many senses, (4) texture and details, (5) mixed functions, and (6) vertical façade rhythms (Gehl, Kaefer, & Reigstad, 2006; Gehl, 1964). The elements that form the city image, (1) paths, (2) edges, (3) districts, (4) nodes, and (5) landmarks (Lynch, 1964),

can also be perceived as a typological basis to analyze urban forms. In the field of ecological restoration and restoration ecology, it is even more obvious that scholars and professionals classify ecosystems into subcategories such as coastal rainforests, freshwater wetlands, and tropical savanna based on moisture, temperature, and vegetation cover so that precise restoration design strategies can be implemented respectively. Consequently, the spatial foundation of conservation biology is naturally dependent upon which types of habitats a certain species relies on.

In order to identify opportunities for improving urban habitat quality to support bird migration, typological studies in this research seek a combination of urban form typologies and their counterparts in ecological systems. Also, this typological analysis is specifically examining urban aquatic habitats along the waterfront of the Puget Sound, Lake Washington, the Salish Sea, rivers flowing through cities, as well as urban terrestrial environments that are closely associated with these aquatic ecosystems.

Table 3.1 Ecological characteristics of urban waterfront typologies

Urban landscape typology	Types of habitat (E1)	Water salinity (E2)	Biogeographic characteristics (E3)	Ecosystem diversity (E4)
Open spaces along freshwater lake shorelines (T1)	Grasslands, wetlands, forests, shrublands, the freshwater lake	Freshwater lake	Patches of grasslands along the shoreline	Rich in wetlands, homogeneous along grassy shores
Feeder bluffs/sediment-rich coastlines (T2)	Prairie, forest, coastal beach, bluff, intertidal/subtidal zone	Saltwater	Coastal gradient forming edge habitat, seagrass patches in shallow water	Diverse along the coastal gradient
Coastal open landscapes (T3)	Grassland, coastal beach, intertidal/subtidal zone	Saltwater	Linear shape along the shoreline	Less diverse along the coastal gradient
Overwater structures (T4)	Planting strips, sea walls, piles	Saltwater	Constructed edge that altered the natural shoreline	Habitats based on submerged built structures, streetscapes
Riverine zones (T5)	Parks, golf courses, commercial and industrial lands	River	Riparian corridor	Impervious paving dominated

Five urban waterfront typologies

I choose five common waterfront typologies in the Puget Lowland, and the Pacific Northwest (west to the Cascade) to discuss

opportunities for possible bird conservation interventions. They are (T1) open spaces along freshwater lake shorelines, (T2) feeder bluffs/sediment-rich coastlines, (T3) coastal open landscapes, (T4) overwater structures, and (T5) riverine zones (table 3.1). The intention of having these five urban waterfront typologies is to

Table 3.2 Examples of urban waterfront typologies

T1	Magnuson Park	Madison Park North Beach	Genesee Park and Playfield	Luther Burbank Park
T2	Discovery Park	Alki Beach	Golden Gardens Park	
T3	Centennial Park	Elliott Bay Park	Harbour Green Park	
T4	Pier 62/63	Waterfront Park in Seattle	Pier 48	Parking lots near the sea
T5	Duwamish/Green River in Tukwila	Puyallup River in Puyallup	Willamette River in University Park, Portland	Deschutes River at Tumwater, Olympia

identify some common features in multiple cities in the Pacific Northwest, and each chosen waterfront typology can be generalized to inform ecological design and bird conservation strategies in similar urban environments in other places in the Pacific Northwest (west to the Cascades).

If the five urban landscape typologies are too abstract, here are some real-world examples of these five urban waterfront typologies (table 3.2), even though this thesis does not focus on particular sites. For Typology 1, some prospective sites might be Magnuson Park, Madison Park North Beach, Genesee Park, Luther Burbank

Park, etc. For Typology 2, Discovery Park, Alki Beach, Golden Gardens Parks are sharing similar natural processes of longshore drift. For Typology 3, Centennial Park and Elliott Bay Park in Seattle, and Harbour Green Park in Vancouver are potential sites in different cities. For Typology 4, piers are good examples of overwater structures that were constructed based on landfills, and the feature of impervious surfaces of this typology makes the typology category also include some parking lots that are near the sea. Typology 5 contains the most common waterfront environment in cities in the Pacific Northwest since almost all the cities in this region were constructed along rivers. The maps reveal the distribution of

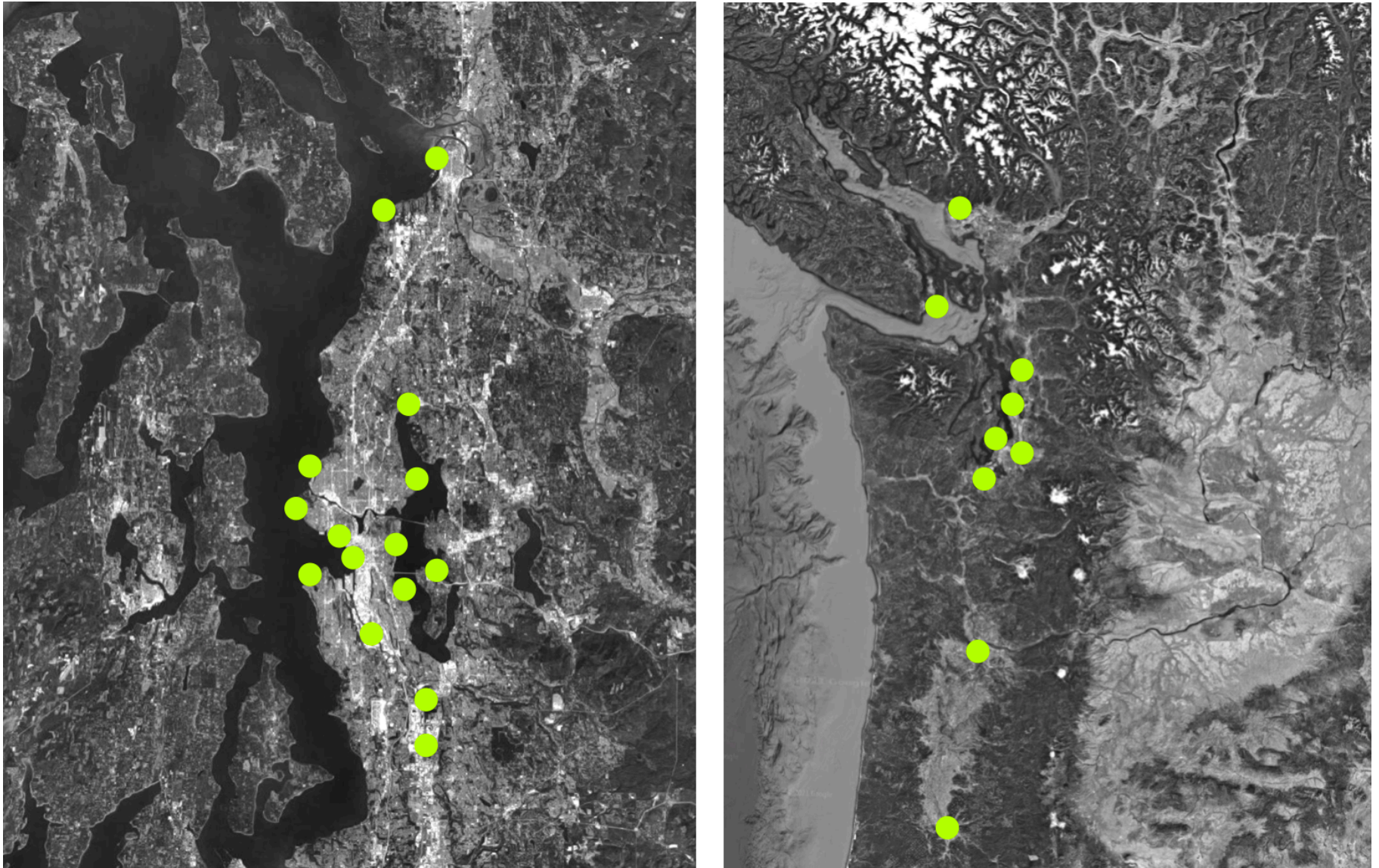


Figure 3.1 Distribution of potentially available sites; the left one is around the city of Seattle, Washington; the right one is from Eugene, Oregon to Vancouver, British Columbia; base maps from Google Maps

potentially available sites across the scale (figure 3.1). The map on the left provides some examples of urban waterfront typologies in and around the city of Seattle and the city of Everett, and the map on the right presents potential cities that possess these urban landscape typologies at the Pacific Northwest scale. These cities are Everett, Seattle, Tacoma, Puyallup, and Olympia in Washington, Portland, and Eugene in Oregon, and Victoria, and Vancouver in British Columbia.

Urban waterfront ecosystems need typological studies to evaluate urban landscapes with multiple criteria that reflect physical patterns, structural features, and ecological functions. Ecological functions contain (E1) types of habitat, (E2) water salinity, (E3) biogeographic characteristics, and (E4) ecosystem diversity (table 3.1). Correspondingly, Typology 1 could comprise grasslands, shrublands, forests, and wetlands around the freshwater lake. It is common that the open spaces are composed of a large portion of maintained grasslands along the shoreline to keep the open space open. In this typological group, ecosystem diversity is rich in areas getting access to moisture, while homogeneous in large patches of grassy areas.

Typology 2, feeder bluffs/sediment-rich coastlines, has an excellent capacity for sediment drift piled up along the coastline in the subtidal zone. In many cases, this typology of waterfront associates with other ecosystems ranging from urban prairies to beaches to forests. Thus, a coastal gradient comprises diverse habitat zones for bird species. For this typology, the ecological design attention is on further multiplying and spreading the benefits to support the target bird species, and assist other waterfront typologies that lack these merits. Typology 3, the coastal open landscapes, is usually maintained grasslands and coastal beaches that serve as urban waterfront parks with satisfactory views toward the sea. However, maintained grasslands are not always related to an exceedingly diverse ecosystem, particularly for waterbirds. Typology 5 often contains parks, golf courses, and commercial and industrial lands. The biogeographic characteristic of Typology 5 is essentially riparian corridors. Because of the imprecise perception of ecological functions of urban rivers, a considerable number of riverine spaces were designated for commercial and industrial uses. As a result, sometimes, impervious paving dominates the surrounding environment in the upland area of an urban river.

Table 3.3 Missing aspects and potential landscape architectural solutions

Urban landscape typology	What are missing?	Landscape architectural interventions	Potentials for bird species
Open spaces along freshwater lake shorelines (T1)	Ecosystem diversity along the shoreline	(1) Using freshwater for constructed wetland cells (2) Artificial habitat islands	Edge habitat for green heron breeding, alternative wintering habitats for Western grebes
Feeder bluffs/sediment-rich coastlines (T2)	N/A	Further enhancing the advantages by building subtidal breakwaters, eelgrass transplantation donor	More food sources for Western grebes
Coastal open landscapes (T3)	Low sediment accumulation, separate from aquatic environment	Eelgrass cultivation in constructed lagoons, public participation, public space design	New food sources for Western grebes
Overwater structures (T4)	Lack of vegetation cover, hard surfaces	Constructed micro-ecosystems with public space	Nests for purple martins in summer, additional food sources for Western grebes in winter
Riverine zones (T5)	Reduced riparian buffers by urbanization	Spatial expansion of hydrologic systems, long-term redevelopment of commercial zones	Edge habitats for green heron breeding, purple martins for mosquito control in summer

With these four indices identified, summarized, and described qualitatively (table 3.3), the feasibility of deploying landscape architectural interventions that aim to support target bird species are listed in table 3.2. For Typology 1, the missing point is ecosystem diversity in the open grassland along the shoreline of the lake. Solutions may be using constructed wetlands and artificial habitat islands to diversify the existing ecosystem. For Typology 2, as it has already been a habitat area with high quality, the landscape architectural interventions are aiming at further enhancing the advantages by building subtidal breakwaters for more eelgrass production. The potentials for Typology 3 are similar to Typology 1, but the ecological design for these two typologies differs due to water salinity. Typology 4 usually lacks vegetation cover, and thus adding vegetation and merging micro-ecosystems with public space design are the theme of this typology.

Indication on the cross-scale framework

To begin with, I was inspired by the species-area relation model

from the research of community ecology, which conceptualizes a relation between the area of the land, and the number of species that can be observed. Eventually, with the area increasing, the rate of finding new species gets decreases. However, observed new species rise rapidly when the area is expanded to a continental

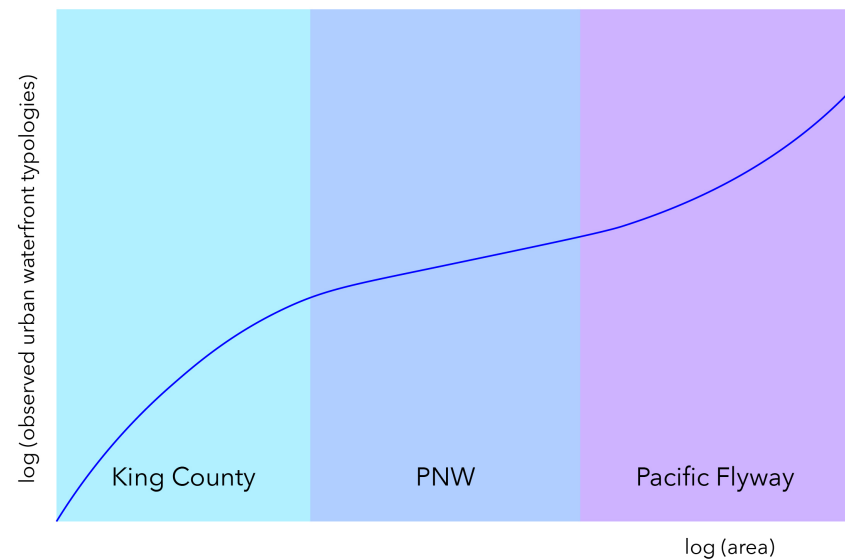


Figure 3.2 The Triphasic Typology-Area Relation

scale because an increasing number of biomes and ecoregions are involved in the process of species observation. This may also work in a typology-prototype exploration in ecological design in landscape architecture.

Then I propose a diagram which is called Triphasic Typology-Area Relation (figure 3.2). This diagram is a hypothesis that builds a log correlation between the size of the area, and the number of urban waterfront typologies that can be observed, and have the availability to support bird migration. I hypothesize that at the city scale, there is an increasing number of new typologies when getting into more districts, because some districts are next to the sea, while others could be located along a river. At the Pacific Northwest scale (west of the Cascades), the number of urban waterfront typologies observed does not increase rapidly, because there are many cities in this region sharing similar urban ecosystem features. For example, both Tukwila, Washington, and Eugene, Oregon predominantly contain Typology 5, and Seattle, Washington, and Victoria, British Columbia predominantly contain Typology 1. They are analogs, which means that the prototypes that this thesis will come up with in the next chapter can be generalized in this region. However, the number of urban waterfront typologies (log) may dramatically rise to a much higher level when the area gets to the hemispheric scale because the value of bird species richness is large, different ecoregions are defined by temperature and moisture, and distinct

methodology of urban design and planning in a different cultural and economic setting. It is obvious that the typologies and design prototypes in this research cannot cover all the cities along the flyway, so the goal is to acknowledge the importance of the existence of a larger system, and the smaller two scales with proper design prototypes on identified urban waterfront typologies will compensate the loss of target bird species along the whole flyway.

Concepts of waterfront typologies

Similar to concepts based on species needs, this section of concepts in the chapter on urban waterfront typologies starts from the environment, presenting the typical image of each typology, and envisioning future change that will be positive to bring more ecosystem functioning into play. These concepts are abstract at this point, but more feasible design features can be based on these foundations. Species needs and actual site conditions will generate easily perceptible variations of these concepts. In the first waterfront typology, a common problem is the homogeneity of plant communities, so the potential design concept for this typology can

be embedding more patches and corridors within the larger matrix of open landscapes (figure 3.3). The concept for Typology 2 is to further extend the assets that these types of environments possess and facilitate additional diverse habitats in the subtidal zone (figure 3.4). Similar to Typology 1, Typology 3 is also focused on diversification of the existing habitat zones but involves considerations of saltwater inundation (figure 3.5). Typology 4 induces two concepts (figure 3.6). The first concept is to replace the hardscape with more greenery to help build a foundation for any consumers in the food web, and the second concept is to think about the vertical habitat zonation in the deeper water. For Typology 5, the concept is to think about the geometry of the habitat pattern and expand the riparian corridor to a plain of highly functional waterfront habitat (figure 3.7).

TPOLOGY 1 OPEN SPACES ALONG FRESHWATER LAKE SHORELINES



Figure 3.3 A typical image of Typology 1 open spaces along freshwater lake shorelines

TPOLOGY 2 FEEDER BLUFFS/SEDIMENT-RICH COASTLINES

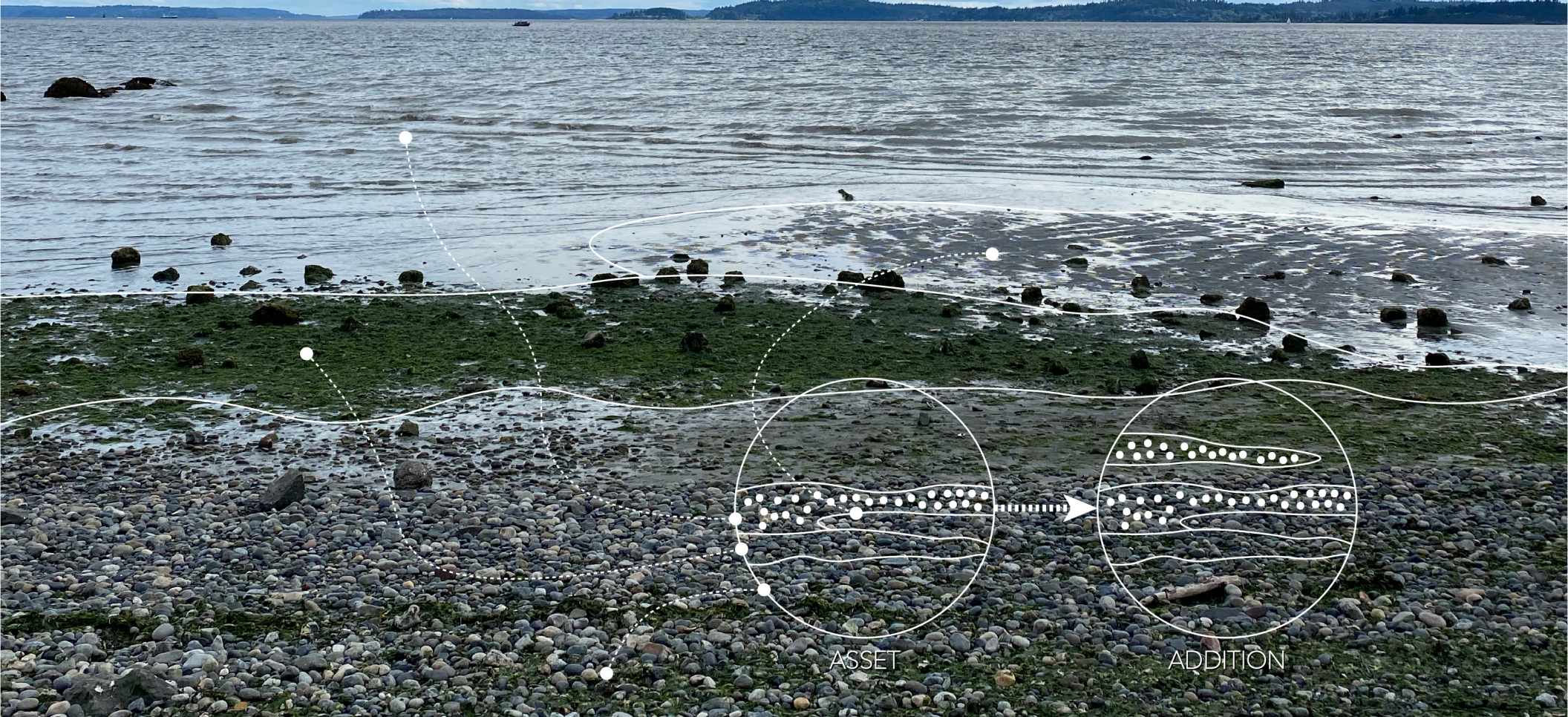


Figure 3.4 A typical image of Typology 2 feeder bluffs/sediment-rich coastlines

TYOLOGY 3 COASTAL OPEN LANDSCAPES

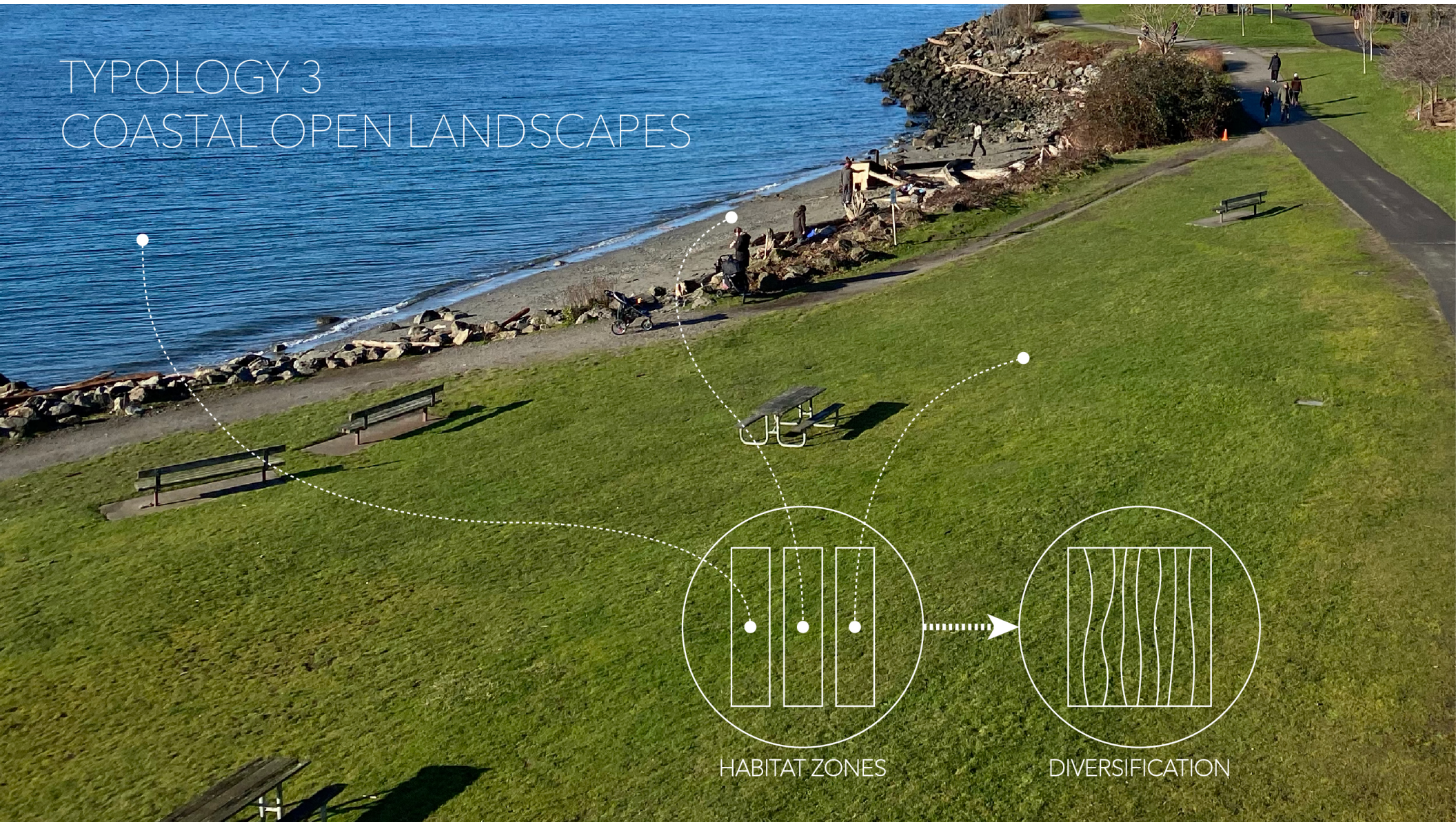


Figure 3.5 A typical image of Typology 3 coastal open landscapes

TYOLOGY 4 OVERWATER STRUCTURES

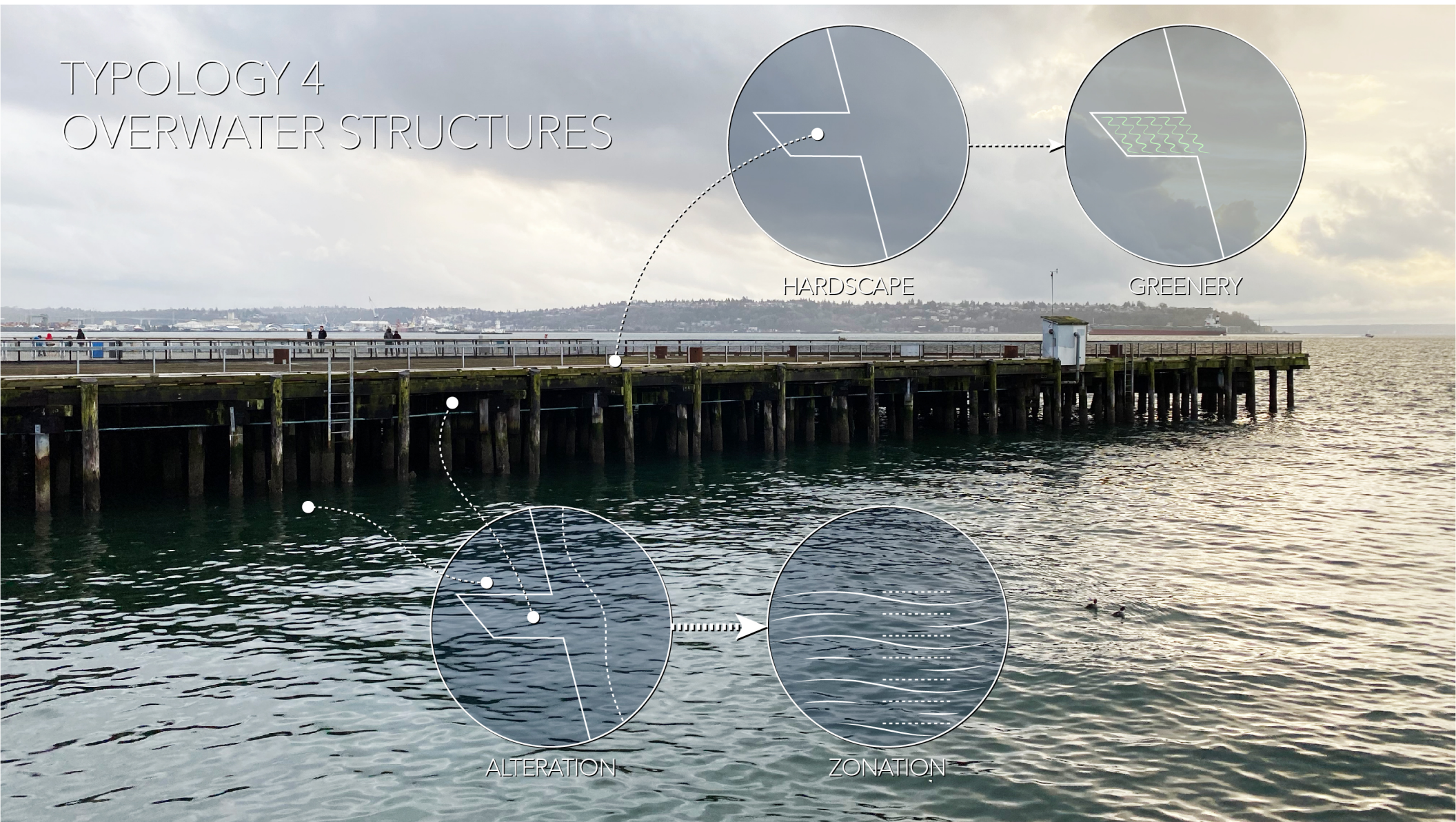


Figure 3.6 A typical image of Typology 4 overwater structures

TPOLOGY 5 RIVERINE ZONES

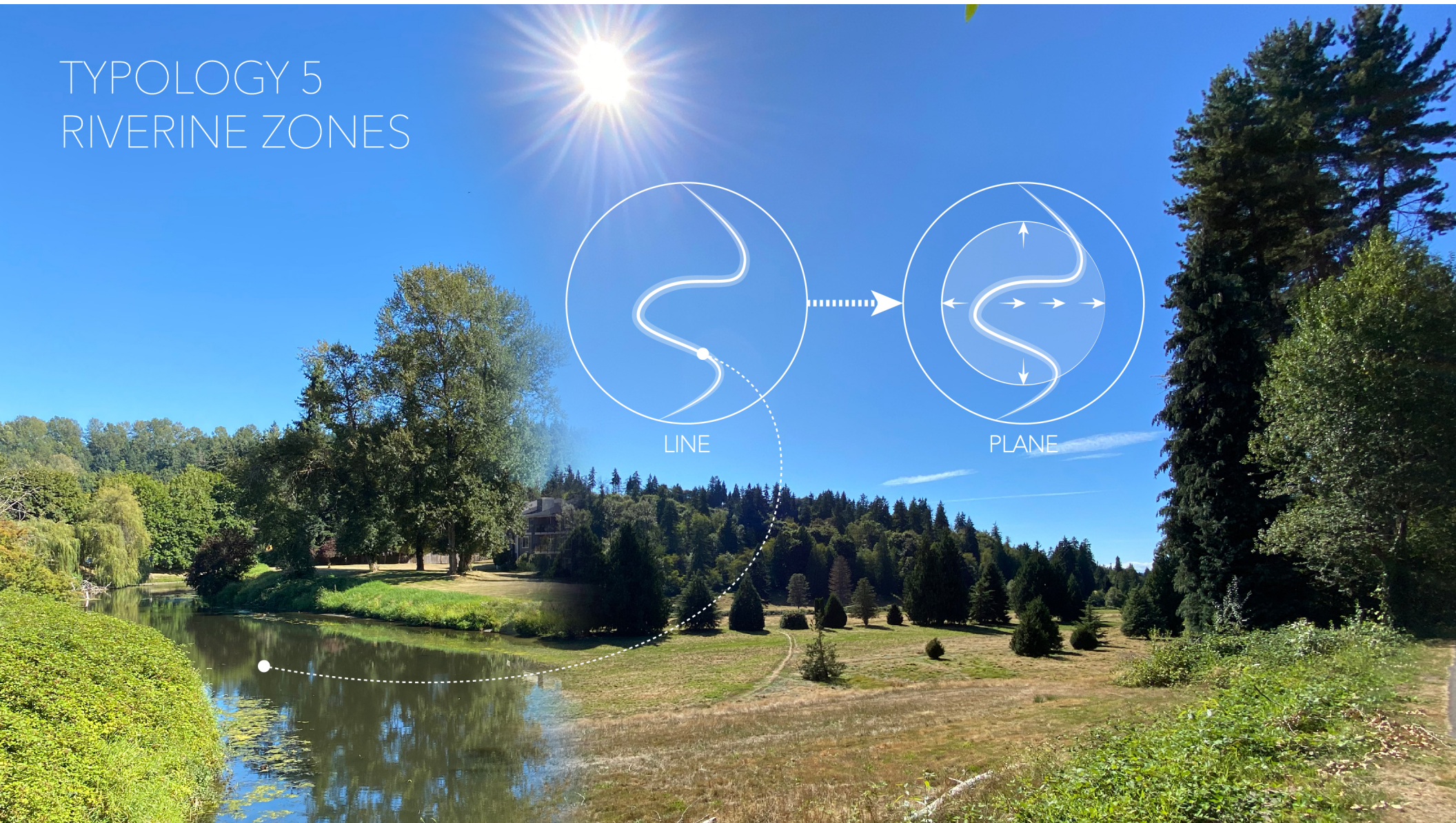


Figure 3.7 A typical image of Typology 5 riverine zones

Chapter 4 Prototypes

In Chapter 2, the identification of the 3 target species was summarized, while in Chapter 3, the potentials of each urban waterfront typology were collected. So far, this thesis has already organized some basic narratives for Chapter 4. The column names are urban landscape typologies, and the row names are primarily target species.

Target species intersect with urban waterfront typologies to generate ecological design prototypes. Matrix 4.1 presents some intersections of the needs of target species and the potentials of each urban waterfront typology. In this matrix, the intersections in the green area are ecological design prototypes. For example, when Typology 4, which is coastal open landscapes intersects with Species 3, which is purple martins, the result may be as the green box is showing, that is "constructed micro-ecosystems on overwater structures in public spaces." When Typology 1 intersects with Species 1, there will be two different design prototypes that are "backwater ponds" and "micro-habitat islands". There is a different

intersection in this matrix. Typology 2 can also interact with other urban waterfront typologies. These inter-typological prototypes are between Typology 2 and Typology 3, and between Typology 2 and Typology 4. Moreover, there can be almost the same prototypes when one species intersects with several different urban waterfront typologies. For example, when Species 3 intersects with Typology 1, Typology 3, and Typology 5, the prototypes remain the same.

Design characteristics

Twelve prototypes with design characteristics are identified based on the typology-species matrix. To explain each ecological design prototype, there is a list of design characteristics of design prototypes in general. These prototypes are listed in tables 4.1, table 4.2, and table 4.3. Each row represents one prototype. Table 4.1 is explaining what urban waterfront typology, what target species, and what stage of lifecycle each prototype is focused on and designed for. The column names are what design characteristics each prototype has (table 4.2 and table 4.3). These indices are 1) structure, 2) hydrologic system, 3) water quality control, 4)

Matrix 4.1 Typology-species intersections

	T1	T2	T3	T4	T5
Sp1	(1) Backwater ponds (cut)	Expanding eelgrass habitat range by using submerged breakwaters to promote sediment accumulation	Constructed lagoons with eelgrass cultivation	Overwater structures for eelgrass cultivation in protected water bodies	
	(2) Micro-habitat islands (fill)				
Sp2	(1) Constructed wetland cells (cut)				(1) Creation of parallel but meandered water flow along the main current
	(2) Artificial habitat islands (fill)				(2) Land use change with T5-Sp2-1
Sp3	Birdhouses (AHP)		Birdhouses (AHP)	Constructed micro-ecosystems on overwater structures in public spaces	Birdhouses (AHP)
T3/T4		Eelgrass transplantation sources			

planting, 5) spatial patterns, 6) flow and change, 7) stability, 8) recreation.

Structure is the overall appearance of the proposed ecosystem of

each prototype. This column can include the type of ecosystem, such as a lagoon versus a watercourse, or a series of ponds versus birdhouses.

Hydrologic system refers to how water flow and the change of the water level would influence prototypical design, and what hydrologic system each prototype would result in. Some prototypes stress the dynamics of the hydrologic system, while some other prototypes emphasize a stable and calm water body.

Water quality control ensures that water touching the core habitat area is clean. There are only three interventions: aquatic phytoremediation, stormwater buffers, and sediment buffers. For prototypes with a more open hydrologic system, no specific water quality control intervention is available.

Planting design concepts hinge on the type of ecosystems that the prototype

Table 4.1 Prototypes

Prototype	Urban Waterfront Typology	Target Species	Lifecycle
T1-Sp1-1	Open spaces along freshwater lake shorelines	Western grebe	Wintering
T1-Sp1-2	Open spaces along freshwater lake shorelines	Western grebe	Wintering
T1-Sp2-1	Open spaces along freshwater lake shorelines	Green heron	Breeding
T1-Sp2-2	Open spaces along freshwater lake shorelines	Green heron	Breeding
T2-Sp1	Feeder bluffs/sediment-rich coastlines	Western grebe	Wintering
T3-Sp1	Coastal open landscapes	Western grebe	Wintering
T4-Sp1	Overwater structures	Western grebe	Wintering
T4-Sp3	Overwater structures	Purple martin	Breeding
T5-Sp2-1	Riverine zones	Green heron	Breeding
T5-Sp2-2	Riverine zones	Green heron	Breeding
T2→T3/T4	Feeder bluffs/sediment-rich coastlines	Western grebe	Wintering
Accessory habitat provision (AHP)	Flexible	Purple martin	Breeding

Table 4.2 Summary of design characteristics

Prototype	Structure	Hydrologic System	Water Quality Control	Planting	Spatial Patterns	Flow and Change	Stability	Recreation
T1-Sp1-1	Freshwater ponds in existing open landscapes; created by cut	Calm water flowing into ponds from the freshwater lake	Phytoremediation forebays and stormwater buffers	A natural ecotone around the ponds; plants in medium-intensity; aquatic phytoremediation plants applied	Wetland patches forming winding boundaries between the lake and terrestrial landscapes	Existence of beaver activities; organic matter cycle; attracting freshwater fish	Shoreline erosion control, beaver dam removal	Alternative pedestrian circulation and compensatory recreational facilities
T1-Sp1-2	Micro offshore artificial islands; created by fill	Highlighting littoral zones of the micro islands	No specific interventions	Plants for the marsh on the edge; ground covers and shrubs at the high point	A large number of vegetated patches surrounded by the water body	Insect colonization; food dispersal attracting freshwater fish	Erosion control along the edge of artificial islands	Piers for more water accessibility and better views
T1-Sp2-1	Watercourses in existing open landscapes; created by cut	Water flowing into watercourses from the freshwater lake; shallow water	Phytoremediation forebays and stormwater buffers	Dense trees, shrubs, and ground covers along the watercourse; aquatic plants for phytoremediation	A network of riparian corridors	Accumulation of organic matter, growing vegetation for more nesting options	Erosion control along banks of watercourses	Alternative pedestrian circulation and compensatory recreational facilities
T1-Sp2-2	Offshore artificial islands; created by fill; islands forming strips	Slow-moving water between the shoreline and new islands; shallow water	No specific interventions	Dense trees, shrubs, and ground covers on available artificial islands	An stripe pattern of alternating terrestrial vegetation and shallow water	Accumulation of organic matter and growing vegetation for more nesting options along with succession	Erosion control during primary succession	Piers for more water accessibility and better views
T2-Sp1	Subtidal breakwaters	Longshore drifts by prevailing winds	No specific interventions	Increasing eelgrass patches	Expansion of shallow water zones	Growing sediment terraces and emergence of new ecological niches	Height difference in terraces to imitate natural processes	Bird watching
T3-Sp1	Backwater lagoons	Marine inundation and protected water bodies	Stormwater buffers	Trees and shrubs surrounding eelgrass lagoons; limited ecotones	Aquatic habitat patch in backwater zones, connected to existing marine environment	Eelgrass cultivation and maintenance by humans, natural succession latter	Shoreline erosion control	Alternative pedestrian paths and trails, volunteer works

Table 4.3 Summary of design characteristics (continued)

Prototype	Structure	Hydrologic System	Water Quality Control	Planting	Spatial Patterns	Flow and Change	Stability	Recreation
T4-Sp1	Subtidal-overwater structures	Semi-enclosed water bodies on platforms	No specific interventions	Subtidal eelgrass cultivation	Built shallow water patch in deeper water	Eelgrass cultivation and maintenance by humans, natural succession latter	Highly constructed structures improving efficiency	Over-water structures opened to public in summer
T4-Sp3	Greenery on overwater structures	Marine moisture and irrigation	No specific interventions	Shrubs or mixed shrub-small tree micro-ecosystems; open lawns for purple martins' houses; wildflowers	Green patches embedded in a hard surface matrix	Irrigation in summer, regular landscaping, birdhouses maintained by humans; predator control	Predator control	Bird watching, volunteer works
T5-Sp2-1	Meandered streams	Gentle slopes slowing down water flow	Phytoremediation forebays, stormwater buffers, and sediment buffers	Alternating patches of dense trees and shrubs with the stream in cross-sections; aquatic phytoremediation plants	Meandering stream corridor forming a large patch of wetland edge habitat	Accumulation of organic matter, growing vegetation for more nesting options	Stream bank erosion control, water inlet armoring	Trails along the edge of habitat
T5-Sp2-2	Land restoration with meandered streams	Gentle slopes slowing down water flow with urban stormwater management	Phytoremediation forebays, stormwater filtration, and sediment buffers	Alternating patches of dense trees and shrubs with the stream in cross-sections; aquatic phytoremediation plants	Meandering stream corridor forming a large patch of wetland edge habitat; merging wildlife habitat with community greenery	Accumulation of organic matter, growing vegetation for more nesting options	Stream bank erosion control, water inlet armoring, policy supports	Trails along the edge of habitat, community green spaces
T2→T3/T4	Eelgrass cultivation beds	N/A	No specific interventions	Eelgrass transplantation	N/A	Eelgrass transplantation and monitor by humans	Organizational participation	Volunteer works
AHP	Birdhouses	Proximity to aquatic environments	N/A	Open landscapes	Scattered spots for nesting	Mosquito control near stagnant water	Moist environment and ecosystem diversity	Bird watching

intends to create, as well as the ecotone condition of those ecosystems. The common idea for each ecological design prototype is diversification of the existing plant communities to enhancing food production and sources for target bird species or the major prey of the target bird species.

Spatial patterns are identified on the basis of the patch-corridor-matrix model described earlier. This column is a complementary description, a synthesis, and a result of the structure, the hydrologic system, and planting. Also, spatial patterns guide the design of the plan view.

Flow and change are listing important natural processes, human interventions over time, and forces embarking on change. Ecological design strategies should contemplate how energy and resource flows will shape composition and function through annual community growth and long-term ecosystem succession.

Stability includes methods to keep the novel ecosystem stable. Different from flow and change, this column has one-time

interventions that do not require frequent management from humans.

Recreation is one of the social values that each prototype has. This design characteristic category mainly regards the approaches through which human visitors get to be engaged in these open spaces. Additionally, this section should analyze tradeoffs between urban bird conservation and ecosystem services for humans.

Prototype T3-Sp1

Coastal open landscapes for the Western grebe

Prototype T3-Sp1 is the coastal open landscape for the Western grebe during their wintering season. The ecosystem structure should be backwater lagoons. The hydrologic system is marine inundation and protected water bodies. Saltwater inundation can be a natural process if the lagoon structure is properly constructed, and the water bodies become protected and calm with the existence of the lagoon buffer. In order to separate the constructed ecosystem from urban hydrologic pollution, there can be stormwater buffers

between the constructed lagoon ecosystem and the inland urban environment, so stormwater runoff does not carry pollutants to the lagoon ecosystem. For the planting design concept, at the bottom of the lagoon, there is an eelgrass planting bed, and surrounding the water, trees, and shrubs form a loop of vegetation that keeps some space between critical Western grebe habitat and human activities in the coastal open space. Further, the spatial patterns are an aquatic habitat patch in the previous backwater zones, but the newly formed water body is connected to the existing marine environment by water inlets. Again, one advantage that urban landscapes can have is to integrate the active participation of social organizations. So in this prototype, humans can take care of eelgrass cultivation and maintenance through transplantation at the beginning of the new ecosystem formation. The source of eelgrass can be obtained from the successful development of Prototype T2→T3/T4, which is the inter-prototypical solution providing healthy eelgrass patches. Over time, the goal of Prototype T3-Sp1 will be self-sustaining and primarily dominated by natural processes because of the secondary succession after human interventions.

Taking one step further, this prototype suggests that the shoreline erosion control cannot be neglected because the land grading could make the substrate structure less stable right after construction. One potential method is to utilize stones that generate a noticeable amount of sediment brought by wave action. Embedding the stones along steep subtidal and intertidal slopes facing the sea helps to stabilize substrate, and over time, the slope would be solid and sediment rich. For the recreational purposes of the coastal open landscape, the existing typical function and main ecosystem service to human communities are urban parks and accessibility to water, so this prototype provides a solution to accommodate the coexistence of human activities and Western grebe foraging. To achieve this goal, some of the existing trails, especially the ones right next to the shoreline, can be elevated, so the plant communities and landscapes do not get interrupted, and the hydrologic flow can be ensured. Along the timeline of a novel self-sustaining ecosystem formation, in the first two years, the site may have an opportunity to engage organizational supports on ecosystem management, and after the ecosystem becomes more mature, it can be engaging birding activities and long-term public

Prototype T3-Sp1

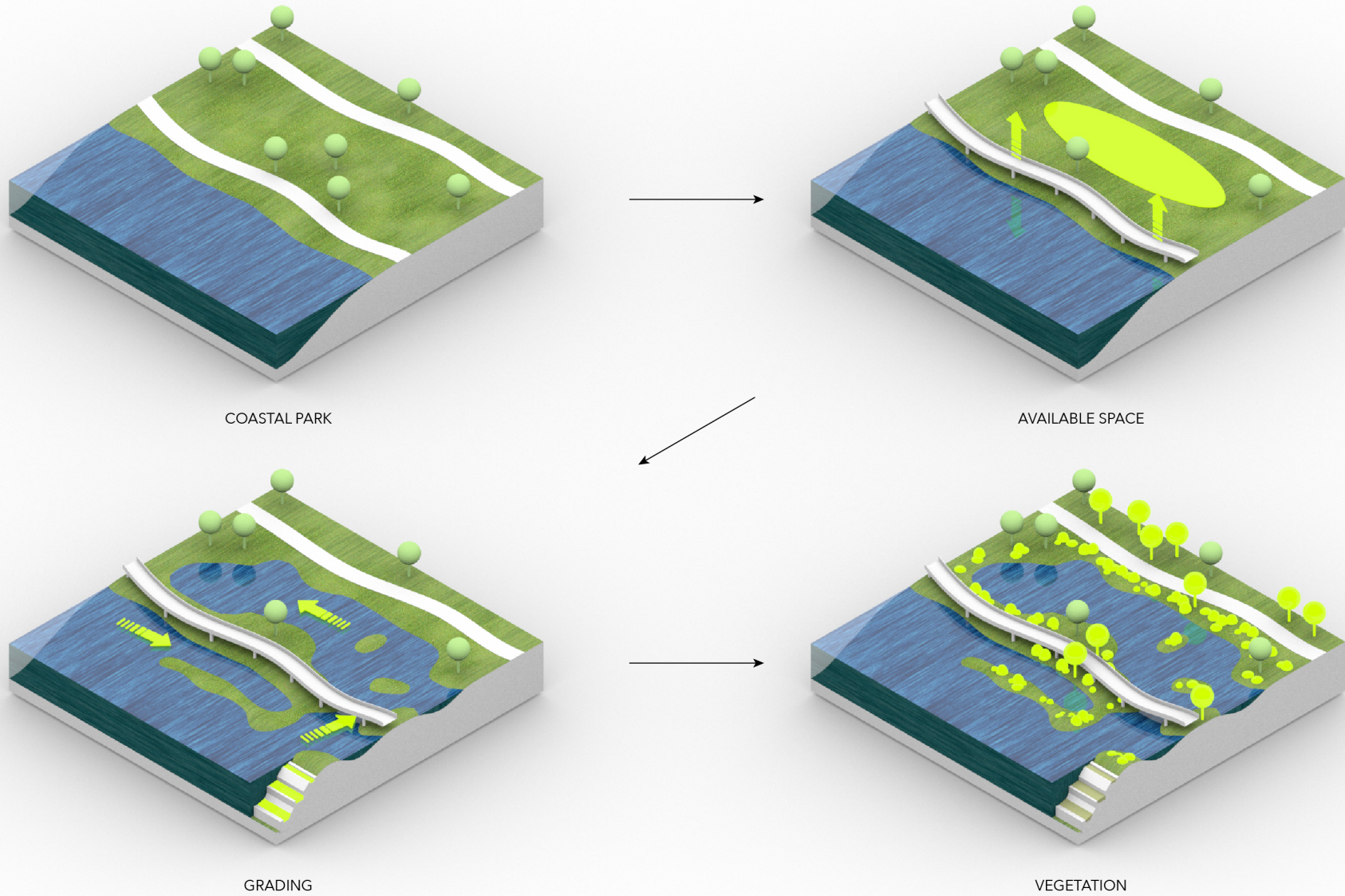


Figure 4.1 Steps of construction and spatial arrangement

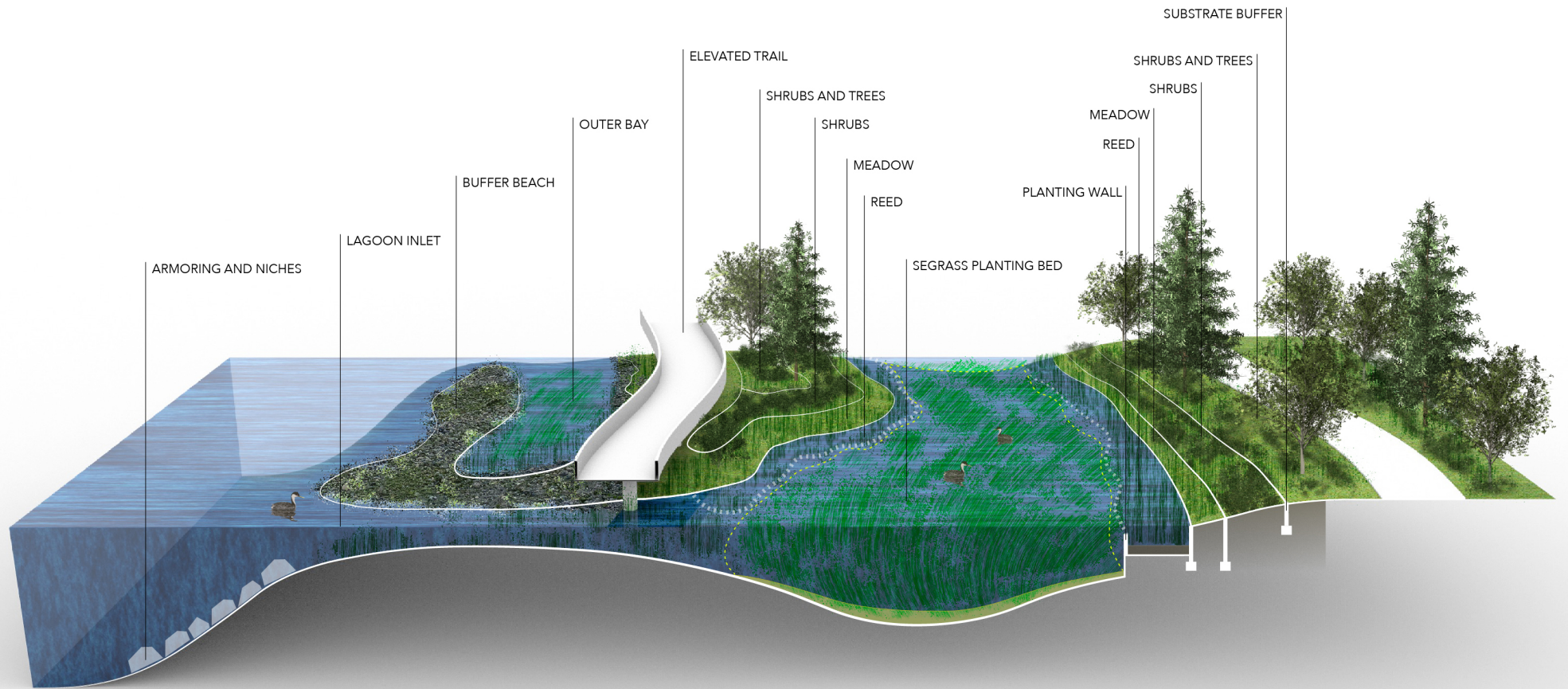
attention to environmental issues about urban bird conservation and urban wild nature.

The axonometric diagram explains the three steps of the primary construction and spatial design concept of this prototype (figure 4.1). In an existing coastal park, it is common to have trails along the shoreline, and scattered trees are distributed in the grassland setting. If the city is going to deploy this prototype for the Western grebe, the balance between the function as an urban park, and the value of Western grebe conservation is unavoidable. In this case, I assume that there is a trail going along the shoreline in this coastal park. In this case, there is very limited space between the two parallel trails, because the environmental setting is a linear terrestrial landscape, and so that the rest space for ecological design interventions is even more deficient. The strategy here is to raise the trail next to the shoreline, and move the trail towards the water so that the terrestrial landscape is larger to hold more ecosystem functions. Simultaneously, the removal of several trees can be considered after evaluating the tradeoff of space availability, but the preservation of trees is always more desired. The second

step is land grading. The soil excavated may be used for some landfills to form an outer landscape structure so that there are two types of protected water bodies. By cutting and filling the land, the hydrologic system will naturally be shaped. In the constructed lagoon, there can be several small islands to add to ecosystem diversity, and thereby plant and animal species richness, of the ecological design prototype. The last step of this primary construction and spatial design concept is to have sufficient vegetation around the critical habitat which is the central water body to serve as a human-wildlife buffer.

The perspective vignette (figure 4.2) reveals the spatial distribution of the selected design characteristics and considerations mentioned above. From left to right, the diagram presents a cross-sectional gradient of ecosystem diversity. Along the section, the ecosystems are 1) the marine environment, 2) the buffer beach formed by the base of the landfill, 3) the outer bay enclosed by the original shoreline and the buffer beach, 4) the original landscape, 5) the constructed lagoon, and 6) the inland portion of the original landscape. Since the substrate structure may be unstable because

Prototype T3-Sp1



ECOLOGICAL NICHES



CUT AND FILL



LOWER DISTURBANCE



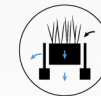
PROTECTION



FISH HABITAT



ECOTONE



RUNOFF CONTROL

Figure 4.2 Perspective vignette

Prototype T3-Sp1

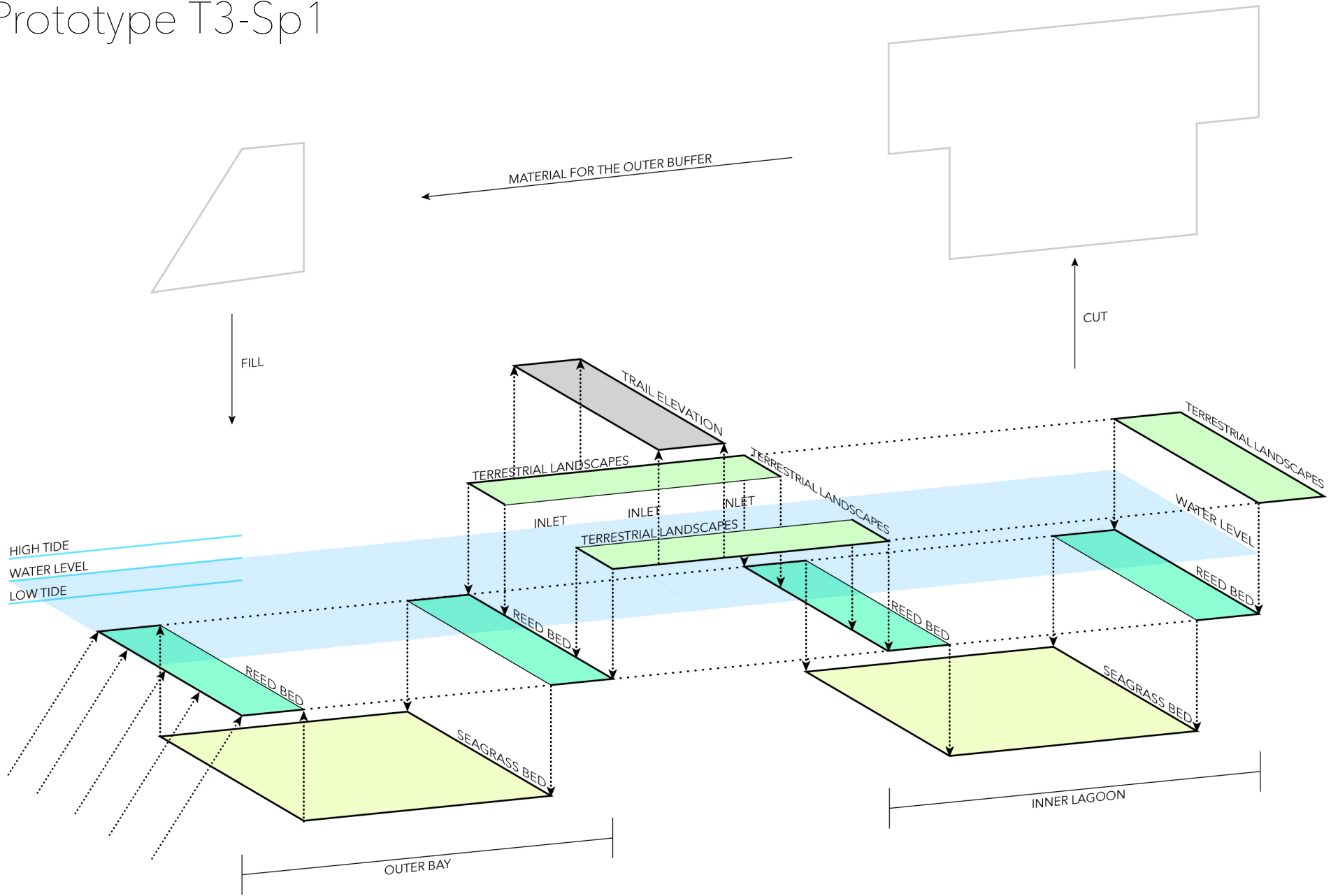


Figure 4.3 Zonation and land use efficiency concept

of land cut and fill, as well as potential steep slopes facing the sea, considerations of slope armoring by partially embedding stones in the substrate on the subtidal slope is a strategy to stabilize the new substrate layer while providing more ecological niches for some marine animals in the crevice. The buffer beach is an imitation of its natural analog by spreading gravel and woody debris on the top layer. The elevated trail allows flows underneath. Human visitors walking on the bridge-like trail would experience a variety of landscapes, not only the grassland, and have a better view of the sea. This would contribute to the cultural value of the site by highlighting the experiential quality. There are two types of water bodies that have the capacity to support eelgrass growth: the inner lagoon, and the outer bay. Here is a potential problem with the inner lagoon. In a resilient ecosystem, plant species richness is usually a foundation. However, it is obvious that the proposed lagoon is located in the original grassland, so as a consequence, salinity change would inevitably alter nearby plant community composition. Many existing and proposed plant species are not tolerant of high salinity. The design proposal for addressing this dilemma is shown by both the perspective drawing (figure 4.2) and

the diagrammatic concept (figure 4.3). The idea takes advantage of the construction aspect of ecological design, even though I acknowledge the natural processes to be the priority driver of ecosystem succession. The diagrammatic concept (figure 4.3) stresses a sense of cognitive deconstruction of the proposed ecological composition. The diagram presents a vertical distribution of multi-layered major plant communities and abiotic factors according to elevations. The seagrass bed layer at the bottom is for eelgrass meadows, the reed bed layer is located around the intertidal zone, the terrestrial landscape layer is always higher than the high tide, and the trail elevation layer is much higher than the terrestrial landscape. Grouping the plants based on this layered structure improves land-use efficiency in an urban setting. Transition zones, or ecotones, often take more space compared with a plant zonation that has clearly defined boundaries. This prototype can achieve this goal. With the substrate buffer illustrated in the perspective diagram (figure 4.2), the lagoon edge is divided into several semi-independent planting zones: reeds, saltwater meadows, shrubs, and trees. The substrate buffer is underground, indicating that the landscape appearance above ground is still

continuous, and the movement of small animals like amphibians and insects above ground is partially preserved, but unwanted salt does not penetrate the designated zones. Consequently, the site acquires both plant species richness, and accommodation to relatively limited areas of available land for ecological design in the precious urban waterfront. Moreover, the vegetated lagoon edge with substrate buffers absorbs stormwater runoff in winter when Western grebes come.

Thus, protected water bodies with high-quality eelgrass meadows attract fish, especially herring, to visit and even reproduce. As a result, more food sources for the Western grebe are available. Also, the diversified lagoon edge guarantees alternative food sources besides saltwater fish.

Prototype T4-Sp1

Overwater structures for the Western grebe

Prototype T4-Sp1 (figure 4.4) is the overwater structure for the Western grebe in their wintering season. This prototype proposes

vertical structures that will exist in both subtidal and overwater spaces in the urban waterfront in the sea. This prototype appears to be a highly constructed infrastructure when compared with other prototypes mentioned in this thesis.

In this kind of urban landscape with a lot of overwater structures like piers or a highly urban waterfront with remarkable historical landfills, Prototype T4-Sp1, a coupled public space and wildlife habitat structure is one potential. In the semi-enclosed water body, the water depth is much deeper than a natural shoreline. Urbanization in this category of urban waterfront typologies is intense so that a large number of social, economic, and recreational activities are usually busy. In this circumstance, it is more important to engage human visitors, and consider human needs when designing for birds.

The alteration of landfills shifted the primitive shoreline ecosystem to a condition that is difficult to implement ecological restoration or reclamation. In this scenario, this prototype proposes that continually building up overwater structures might be a better

Prototype T4-Sp1

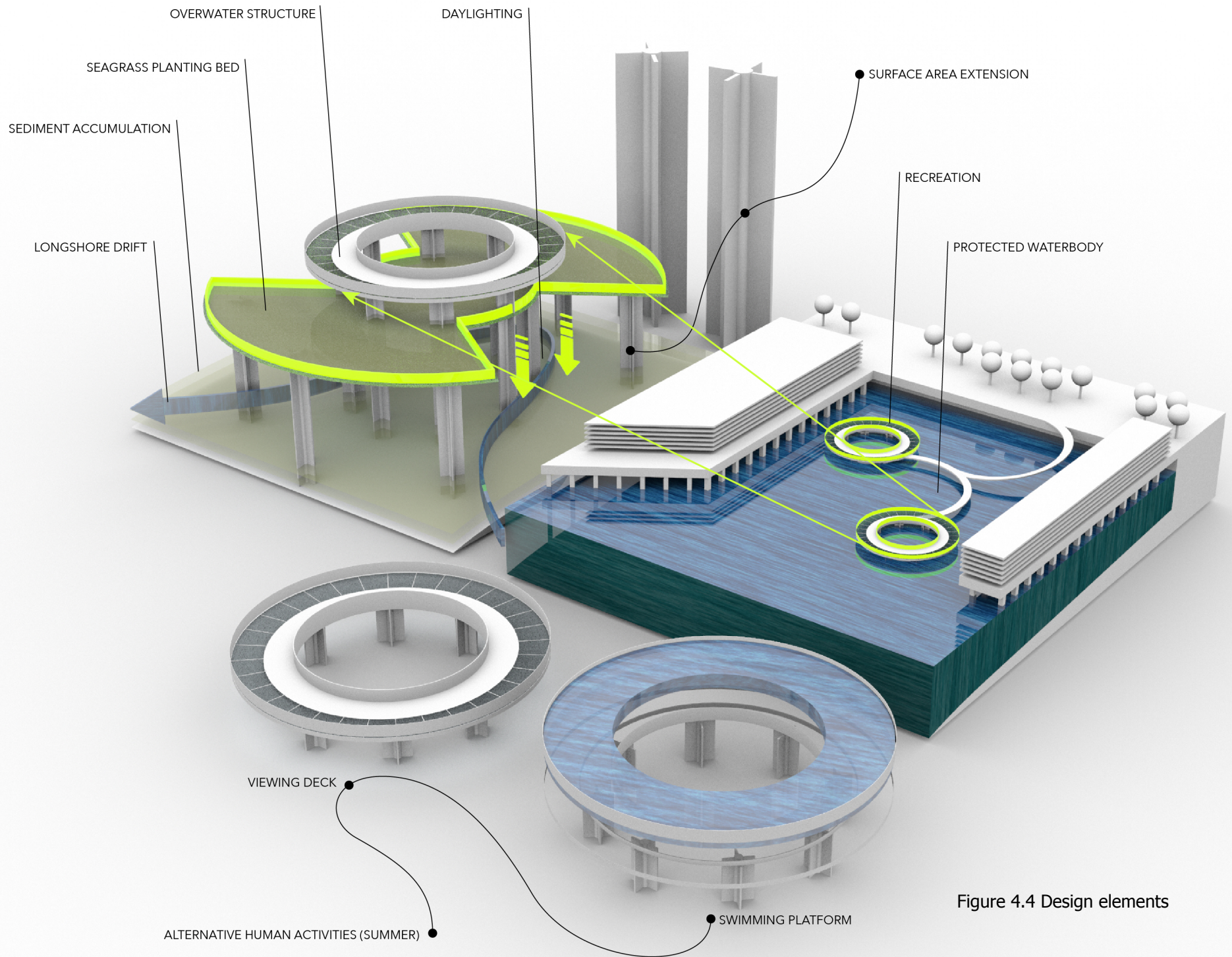


Figure 4.4 Design elements

Prototype T4-Sp1

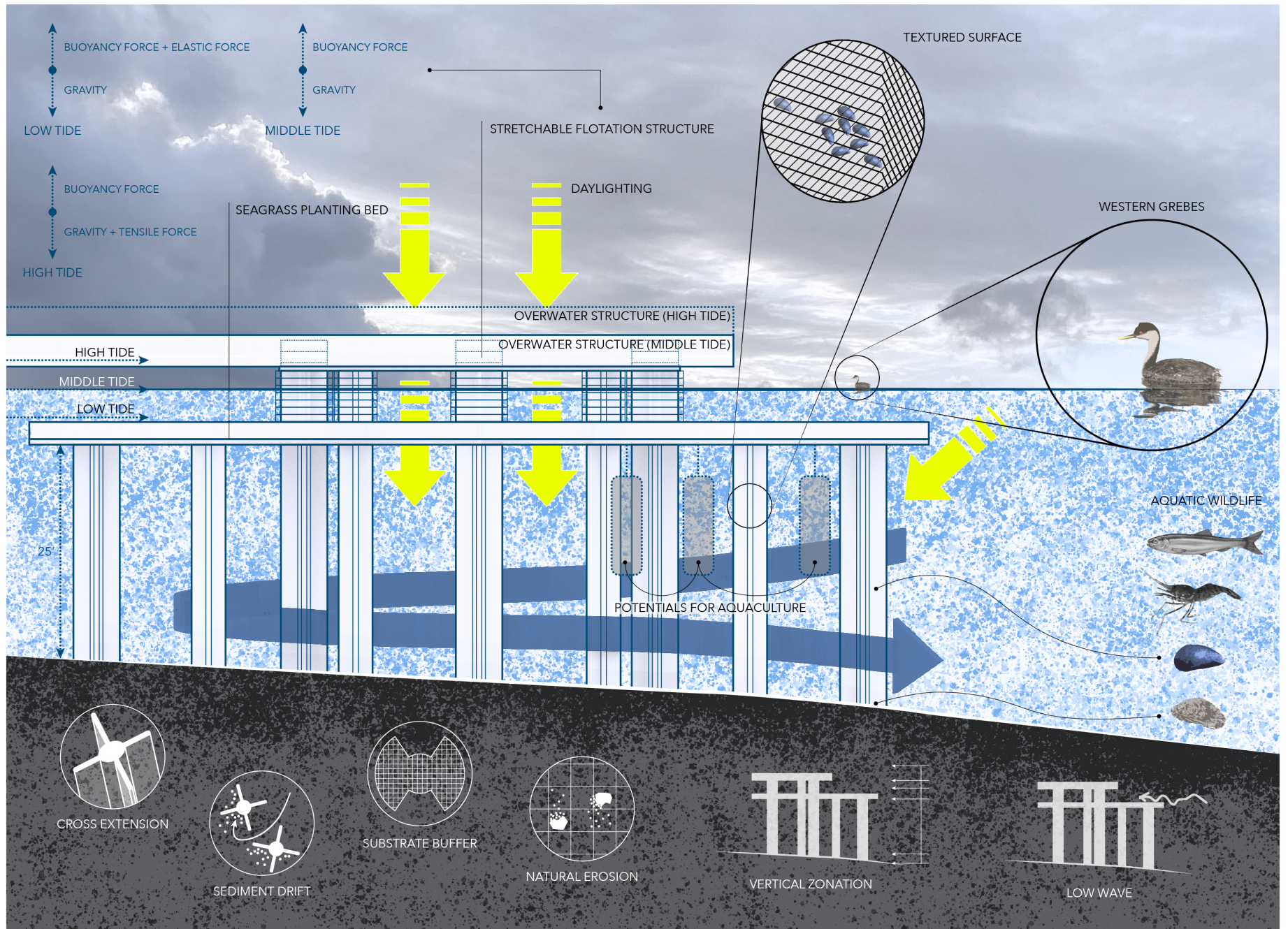


Figure 4.5 Functions and mechanism

solution to amplify some new ecosystem functions, but in an environmentally friendly way. The perspective drawing contains some of the design characteristics of this prototype. First, the overwater portion of the proposed structure is an extension of existing waterfront open spaces. Paths connect the coastline street or other existing overwater structures to the new structure. The new structures are just above the water level, so human visitors could get closer access to the sea while having an open view around the structures. The recreational activities are flexible on the proposed overwater structures. A very basic version is the viewing deck with tempered glass being a part of the paving materials to minimize shady areas under the water level. Also, the overwater portion of the proposed structure can be used as a swimming platform. A similar real-world example is Kastrup Søbad in Denmark where people are immersed in a distinct atmosphere of swimming. In addition to these two recreational functions, the structures would be able to host other facilities depending upon analyses of specific scenarios in different settings. In summer, these recreational facilities are open to human visitors when the weather is appealing in the Pacific Northwest, while in winter, it is better for these places

to be cleared out for Western grebes.

A seagrass planting bed, in the proposal of this prototype, is installed below the water level. Instead of having a round shape of the planting bed, some areas of the planting bed are subtracted from the circle to keep sufficient daylight reaching the sea bed. This prototype, which is similar to Prototype T3-Sp1, can utilize the eelgrass transplantation source from Prototype T2→T3/T4. At the bottom of the structure, the pilings slowly and gradually capture some sediment from longshore drift. The pilings are visually thick because of two-dimensional surface area extension, but in the digital model, the cross-section area is actually narrow. The design proposal of this prototype saves materials required for surface area extension of the pilings. The enlarged surface area of the pilings benefits some marine species attaching to the pilings.

Additionally, the section view (figure 4.5) illustrates more details of this prototype. The overwater part of the structure is a floating platform. The intention of having a segment of the structure float is

because of the attention to reducing the weight. Therefore, the pilings do not have to be inserted deeply into the sea bed to support very heavyweight. Also, the sea level changes dramatically when high tide and low tide daily and seasonally switch. Another reason is that the design aims to create a place where human visitors can also get closer to water. A floating structure can make this happen. There are "buoys" (shown in blue dash lines) beneath the overwater structure and attached to the solid piles, to generate floatation. The buoyancy force depends on how much percent of the "buoys" are immersed in water. When the water level is in the middle, the buoyancy force approximately equals the gravity of the overwater portion of the structure. If the water level is high, the elastic force of the "buoys" can offset a larger buoyancy force. And when the water level goes down, the elastic force from the pilings compensates for the floatation loss. In contrast, the seagrass planting bed is always lower than the water level to keep the eelgrass meadow being covered by enough brackish water.

The reason why pilings extend their surface area is to enlarge potential vertical spaces for some marine animals such as blue

mussels and oysters to grow. On the surface of the pilings, the texture should be rough in order to make these animals easier to attach to. Another natural process enhanced by pilings is accelerating sediment accumulation at the bottom of the structure. The two-dimensional extension of the pilings captures sediment brought by wave action. Over time, the bed layer is expected to be a nutrient-rich habitat.

There are some other natural processes through a potentially satisfying implementation of this prototype. On the seagrass planting bed, a grid of substrate buffers could sustain the position of substrate patches so that the planting bed could tolerate some wave action. Moreover, the substrate layer contains scattered gravel and small size revetment stones. The gravel and revetment stones are anticipated to reduce subtidal wave energy on the surface of the seagrass planting bed and are likely to be a source of new sediment under the influence of water erosion. When the eelgrass meadow is mature, the meadow will eventually take the responsibility of erosion control because of an established root system. Natural processes will be working mutually to gradually develop the

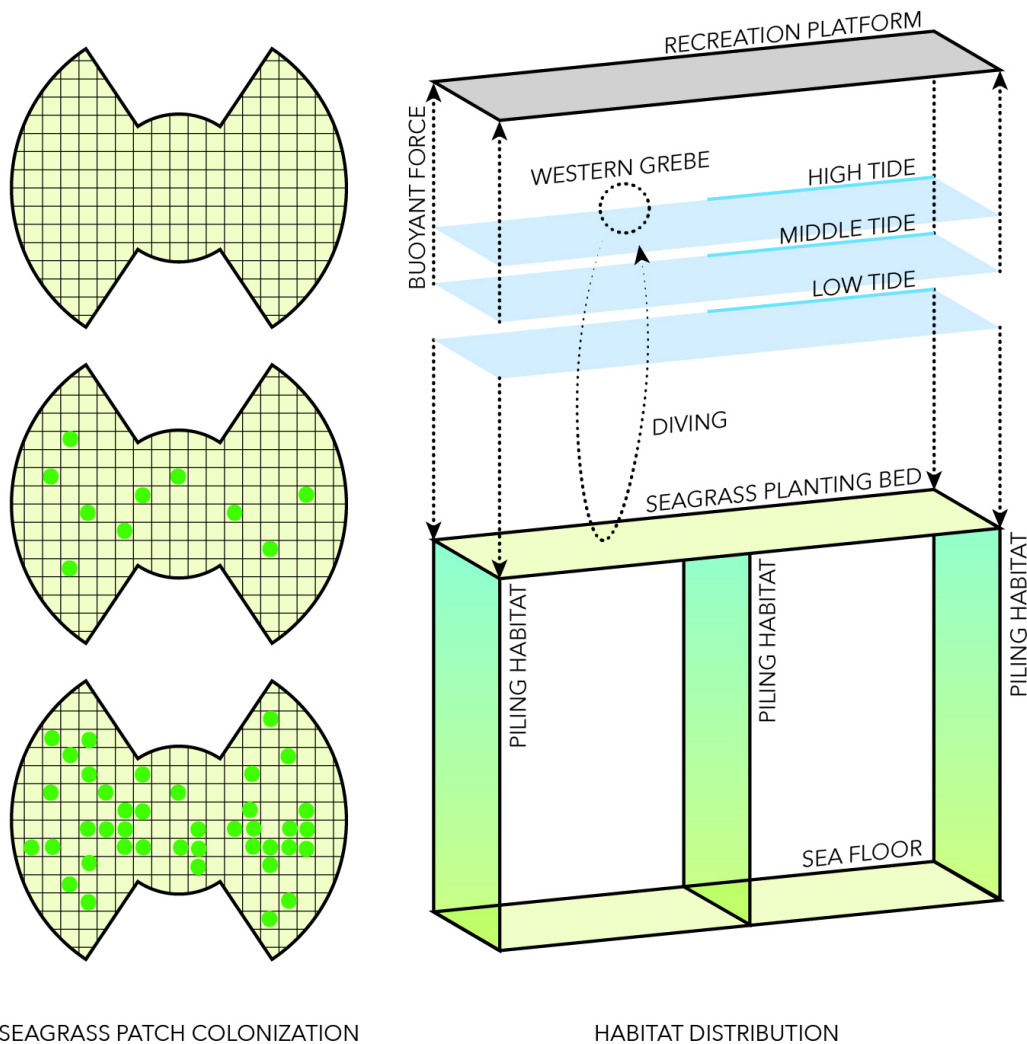


Figure 4.6 Seagrass meadow formation by natural processes, and vertical habitat zonation

ecosystem, continuously maintain the ecosystem function, and independently support long-term sustainability. Also, the mature eelgrass meadow mitigates wave action above the planting bed.

In terms of multifunctionality, and during global change, the focus on marine aquaculture is getting higher in many countries. This prototype can also be a proper location for growing seafood, especially the cultivation of shellfish for human society. The aquacultural facilities can be fixed on and around the structure.

With the evolution of design characteristics pushed by natural processes, a vertical zonation of animal communities may be observed (figure 4.6). The humans use the space overwater, Western grebes, and other birds forage on the water surface, shellfish species are using a broad range of the

vertical space. As an expected result, the vertical zonation enriches the marine food web.

Prototype T5-Sp2

Riverine zones for the green heron

Prototype T5-Sp2 is riverine open spaces for green herons during their breeding season, and this prototype concentrates on a site-scale intervention along urban rivers (figure 4.7). The spatial manifestation of this prototype can be regarded as a meandered stream with a series of constructed swamps in a backwater green space next to the mainstream of an urban river. For the hydrologic system, this prototype carries water from the river and slows down the speed of water flow by a meandering water channel. To control the water quality of the new ecosystem, phytoremediation partially cleans up water from the mainstream of the river. The appearance of phytoremediation for pollutant removal is less intrusive and more aesthetically pleasing in a natural landscape so that the design with phytoremediation can be completely merged into the natural atmosphere of this prototype. Also, phytoremediation plants can

create a very ecologically functional habitat for wildlife, which can be another benefit of this method. Additionally, sediment control is required in this prototype.

Since this prototype is about a comparatively terrestrial landscape, and because of green herons' preference when selecting a location for breeding and foraging, planting design concepts should provide a large number of native plant species grouping together at a site-scale to build a higher species richness. A community with higher species richness is more resilient to drift, invasive plant species through dispersal, and fluctuations including diseases and resource availability. The spatial pattern of this prototype is a meandering stream corridor that forms a large patch of wetland edge habitat. The anticipated process and change of this prototype are organic matter accumulating over time after landscape architectural treatments are done on-site. As a result, suitable sites for nesting and foraging would increase steadily.

To implement this prototype, important design elements are a constructed stream, a water inlet, phytoremediation forebays, in-

Prototype T5-Sp2

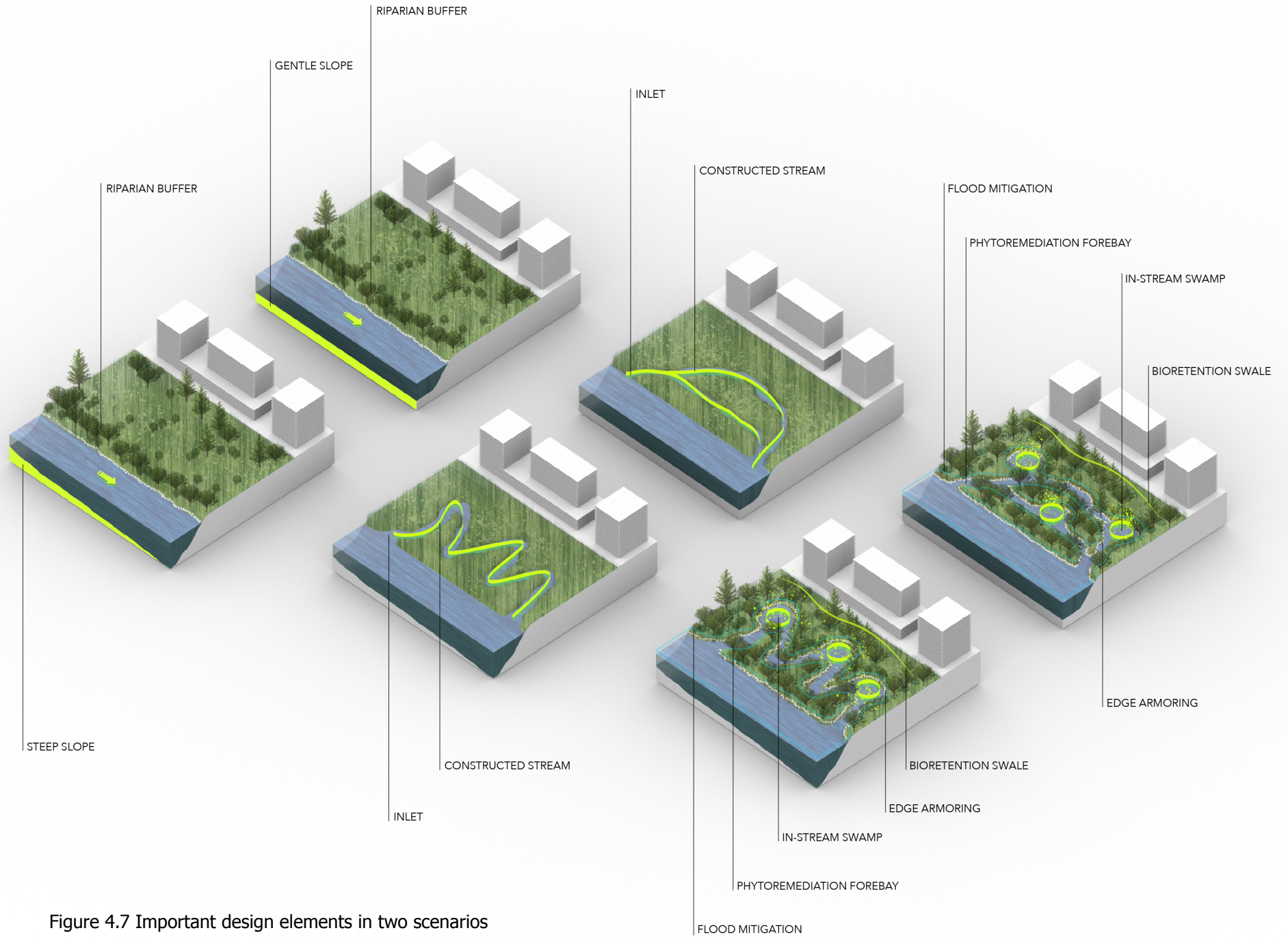


Figure 4.7 Important design elements in two scenarios

Prototype T5-Sp2

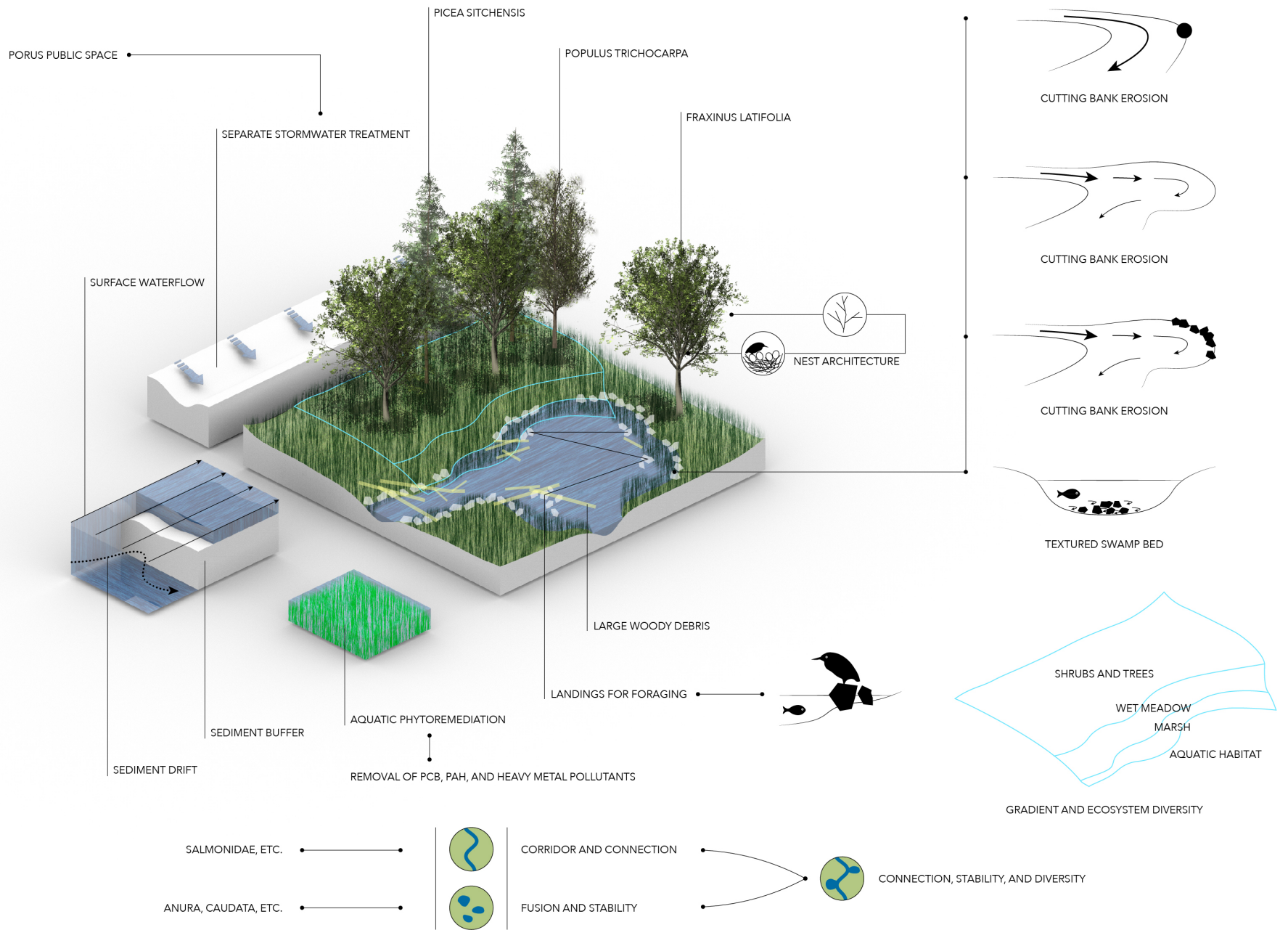


Figure 4.8 Zoomed in details and mechanism

stream swamps, edge armoring, and bioretention swales (figure 4.7). When implementing this prototype, topography and height difference are the foundation of a functional hydrologic system. The six axonometric diagrams (figure 4.7) are in two groups. The upper three out of the six are in scenarios where the speed of water flow in the mainstream is already low because of gentle slopes at the bottom of the river channel, while the lower three are in circumstances that the speed of water flow in the mainstream is high due to a steep slope. For the scenario with slowly moving water in the mainstream, the constructed stream corridors are more straight, because there is no significant height difference. There can be more than one channel of constructed streams in order to cover more areas of the open space. In this case, in-stream swamps can form parallel connections, or both parallel connections and series connections, which means that there may be one or more swamps in each channel. For the scenario with a higher speed of water flow in the mainstream, the constructed stream corridor should be more meandering to limit the angle of slope. In this scenario, one channel of the stream is sufficient to cover the whole site. Along the constructed stream channel, swamps are placed in series

connections. This prototype should have the capacity to retain and detain a large column of stormwater caused by flooding in winter.

Zooming into segments of the proposed landscape, there are more details and processes revealed (figure 4.8). The sediment buffer keeps sediment drift by only allowing surface water to flow into the new stream system so that water carrying much sediment near the bottom of the river channel does not get access to the inlet of the backwater stream because of saltation.

To involve phytoremediation in a connected hydrologic system to partly take up dissolved pollutants in water that will enter the critical habitat where the main portion of the backwater stream and swamps are located and distributed, aquatic phytoremediation plants can be placed at and around the inlet of the backwater ecosystem. Depending on regular site monitoring and the assessment of landscape performance in the future, managerial decisions may vary, and these decisions adjust the area of required aquatic phytoremediation.

Even though the speed of water flow is remarkably slowed down, there might be some circumstances that flooding would increase water volume and cause cutting bank erosion. To address this potential risk, the in-stream swamps can be placed around the cutting bank to allow more space for water flow to turn. Additionally, rocks can be placed along the stream bank where the substrate is loose. Rocks should also be embedded in the swamp bed in such a manner that the crevice among the rocks attracts fish to come and hide in a stony shelter.

The ecotone around the swamp, as it is shown in the diagram, includes aquatic habitat, marshes, wet meadows, and shrubs and trees. The tree species should incorporate native species of deciduous trees, e.g. *Fraxinus latifolia*, in order to establish an energetic nutrient cycling. Some trees should be planted close to the water body, in which way green herons can nest right above the water in these trees. Fallen branches of the trees will become the building material of green herons' nests.

The rocks along the edge of swamps also perform as landings

where green herons can stand and wait for their prey to come. Large woody debris is another element to further diversifying the ecosystem, and be a platform for green herons to use for foraging as well.

A natural stream or a creek always possesses a land mosaic pattern of the corridor, thus animal dispersal is more likely to happen due to connectivity. In contrast, a natural pond or a swamp is usually a stable aquatic environment. The integrated stream & swamp system can take advantage of both of them by having both connectivity and relatively calm water which green herons also desire. For example, fish get to swim to the backwater environment and find a secluded niche to reproduce. Therefore, connection, stability, and diversity can be achieved.

Prototype T4-Sp3

Overwater structure for the purple martin

This is the prototype for purple martins during their breeding season, and the corresponding urban waterfront typology is

Prototype T4-Sp3

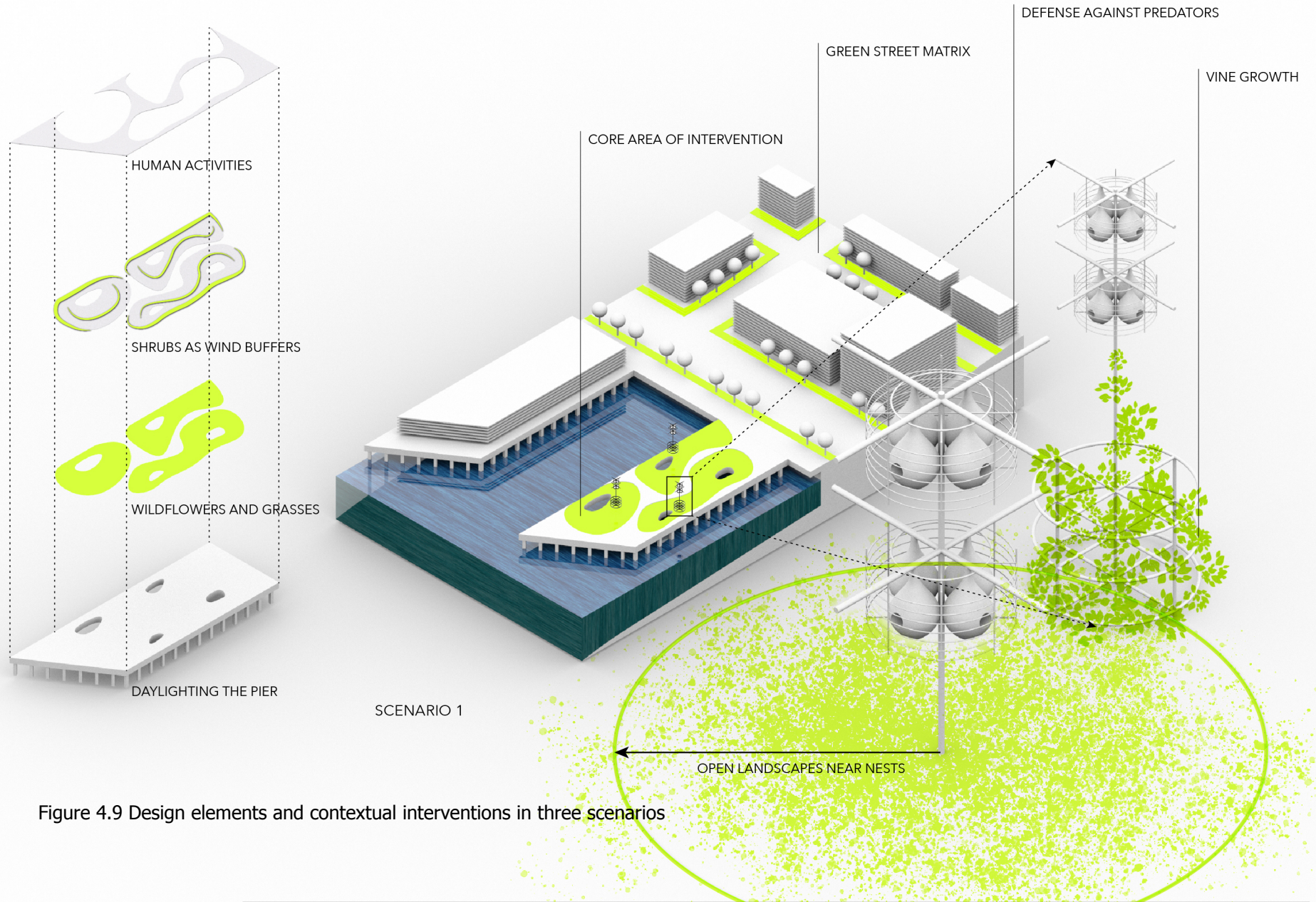
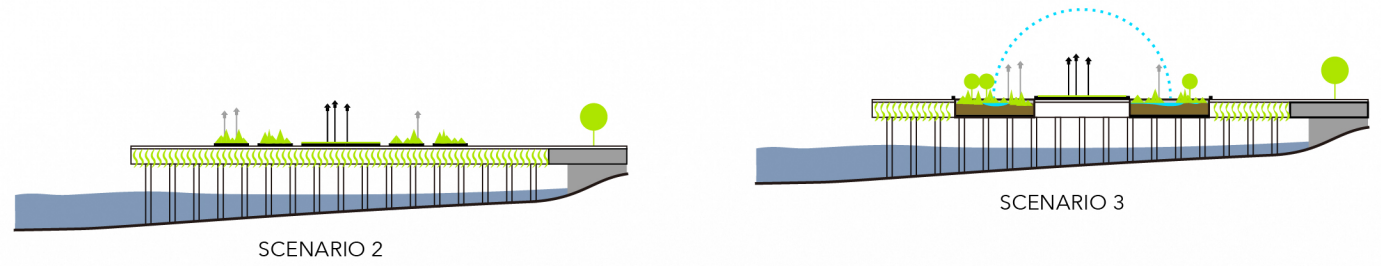


Figure 4.9 Design elements and contextual interventions in three scenarios

overwater structures. Instead of building new structures, this prototype aims for adding a green layer on the top of the existing overwater structure to replace the hardscape in the built environment. Because of the essence of impervious surface replacement, the focal typology can be extended to some other more territorial built environments including parking lots and green roofs that are near the urban waterfront. To ensure efficiency for nesting, this prototype utilizes birdhouses because purple martins are adaptive to human-made nests, and on the other hand, it is less possible to plant plenty of trees on the overwater structure and wait for the tree holes to appear naturally. Figure 4.9 shows three scenarios of planting design. All of the scenarios are reflecting purple martins' needs. In general, the concept of planting design should be to attract flying insects and bring about open landscapes near purple martins' nests. An essential design characteristic of all these different scenarios is abundant wildflowers (figure 4.10). Nectaries attract insect pollinators, and purple martins feed on an increasing number of flying insects.

Scenario 1 is a multilayered prairie and public space. Firstly, the

overwater structure should be drilled so as to allow daylight to penetrate the hard surface. Secondly, Above the existing structure, the next layer is a prairie of wildflowers produced by ground covers, and continuous natural greenery from grasses. Thirdly, there can be some small shrubs forming strips in the prairie to widen the scope of plant species richness. Fourthly, the elevated public space is the top layer. The design form of the public space can be quite flexible. In this diagram, the public space layer is only corridor pathways reaching scenic viewpoints, but it can also be adjusted to accommodate specific functions or social events. Within each patch of prairie, a group of birdhouses is placed above ground on the top part of a pole, and the defense against predators is mandatory around birdhouses. At the lower portion of the bird tower, some vines grow on the skeleton. The vegetation around each bird tower is always short enough to maintain an open landscape that purple martins favor. There might be some criticism of the birdhouse towers protruding from a flat vegetation base and reshaping the skyline of the sea. However, I believe that these extremely noticeable structures are, on the other hand, cultural symbols delivering a message of human-bird coexistence, and stimulating

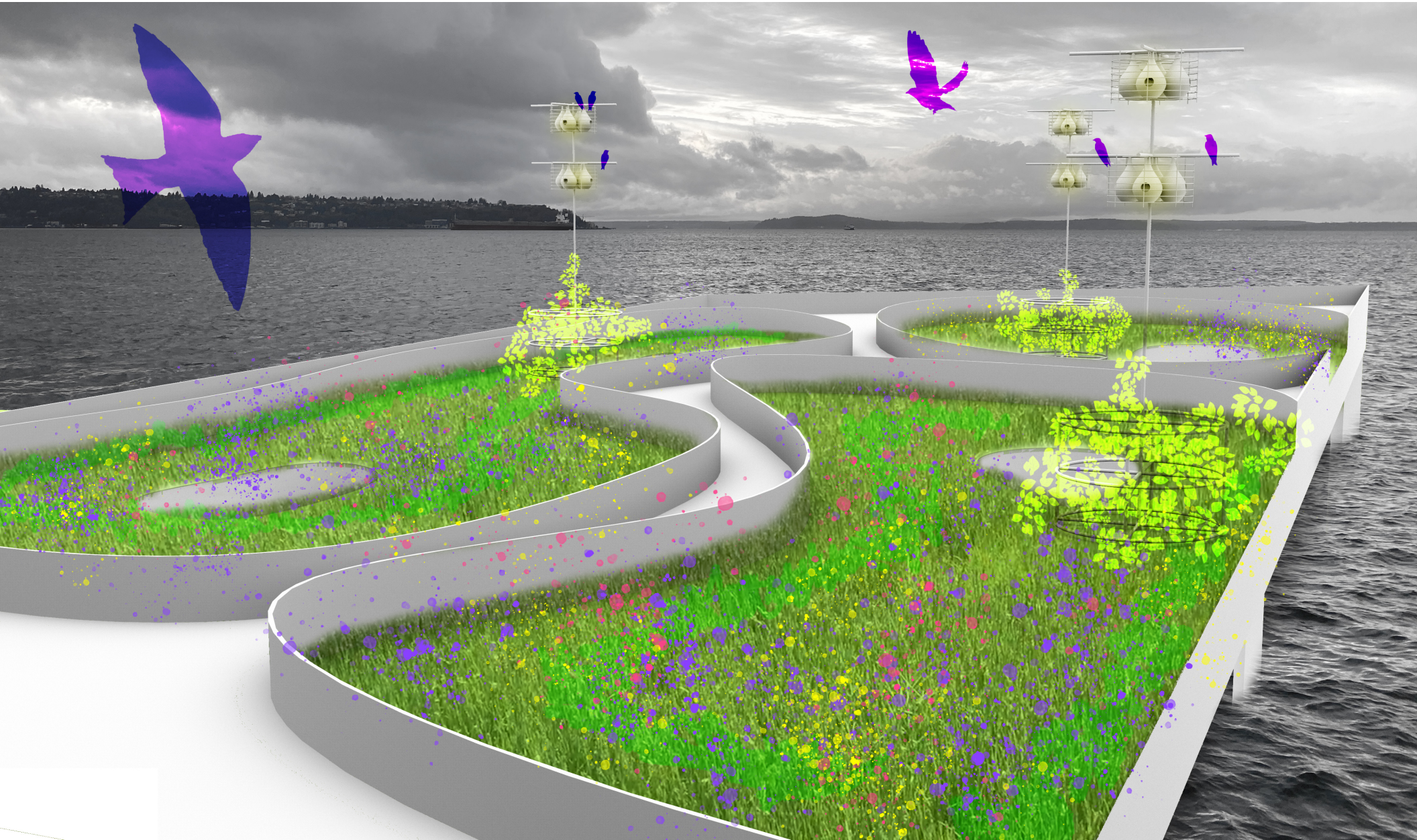


Figure 4.10 A pier with abundant wildflowers

the imagination of how the urban environment could be in future cities (figure 4.10).

Scenario 2 and scenario 3 are two other examples of design interventions. The diagrammatic sections of these two scenarios consider both purple martins and their competitors. In these two scenarios, birdhouse poles in black in open landscapes are for purple martins, while the birdhouse poles in grey in shrubberies are for their competitors. In scenario 2, instead of having a vegetative layer at a lower elevation compared to the layer of public spaces, the planting design here is based on a series of planters. In these planters, similarly, there can be ground covers producing showy flowers, and grasses, and small shrubs. The planters can be organized by adapting to the layout of public space design and be a component of a public space design project. Scenario 3 presents some opportunities for embedding plant communities in the overwater structure below the ground level. This strategy enables a thick substrate layer to be placed in these overwater structures. In this situation, some small trees may adapt to the condition in this waterfront typology. Rainwater gathers in the

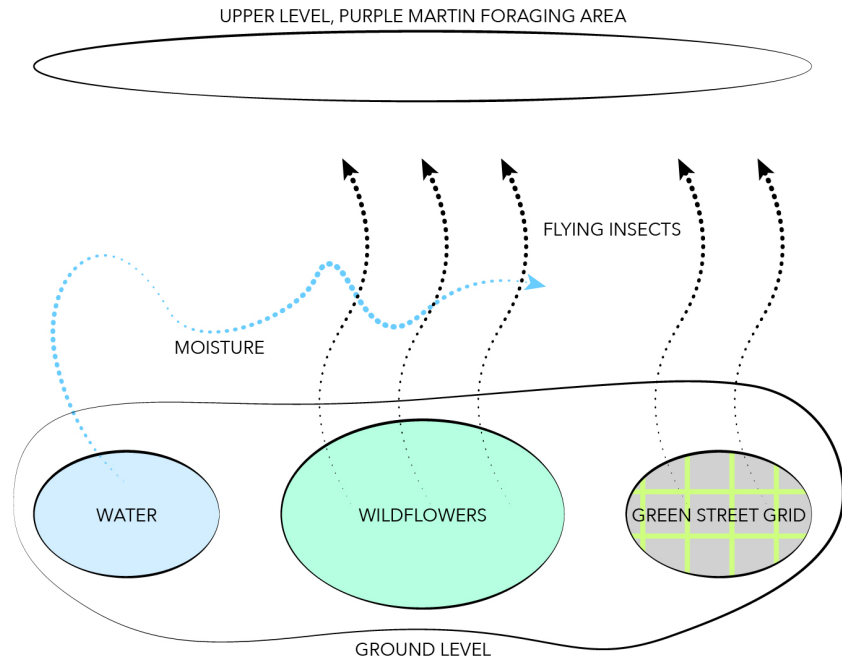


Figure 4.11 Three ground level factors contributing to food abundance

topographical depression where plants are settled. A concentration of moisture and plants constitute a preferable atmosphere for insects.

The proposal posted by this prototype does not stop at the site

boundary. A larger-scale green network would enhance insect abundance. Surrounding the focal site, a green street grid would supply additional wildflowers, and concurrently envision biophilic urbanism in a whole district. The moisture from the sea, the intense wildflower area, and the street grid together add to food abundance at a higher level where the purple martin forages (figure 4.11).

Another extension of this prototype lies in typological flexibility. The reason why this prototype is primarily focused on overwater structures is that the site limitations are noticeable. It does not indicate that this prototype only works well on overwater structures. For some materially and geographically identical built environments, such as parking lot redevelopment, and rooftop spaces of future buildings, design decisions can also adopt this prototype in preparation for replacing impervious paving and build a strong human-bird relation.

Prototype Mix T1-Sp1, Sp2, and Sp3

Open landscapes along freshwater lake shorelines for the Western grebe, the green heron, and the purple martin

This section is an exploration of a mix of multiple prototypes. In some scenarios and particular sites, it is possible to consider the conservation of all of these three species in one site, but different temporal scales depending on the lifecycle of bird species, and the seasonality of the ecosystem.

Prototype Mix T1-Sp1, Sp2, and Sp3 is taking T1, open spaces along freshwater lake shorelines, as a typological example to harness parts of the overlapping design characteristics from Prototype T1-Sp1-1, T1-Sp1-2, T1-Sp2-1, T1-Sp2-2, and AHP. Prototype T1-Sp1-1 is open spaces along freshwater lake shorelines for Western grebes during their wintering season (cut); Prototype T1-Sp1-2 is open spaces along freshwater lake shorelines for Western grebes during their wintering season (fill); Prototype T1-Sp2-1 is open spaces along freshwater lake shorelines for green herons during their breeding season (cut); Prototype T1-Sp2-2 is open spaces along freshwater lake shorelines for green herons during their breeding season (fill); Prototype AHP is accessory habitat provision for purple martins during their breeding season.

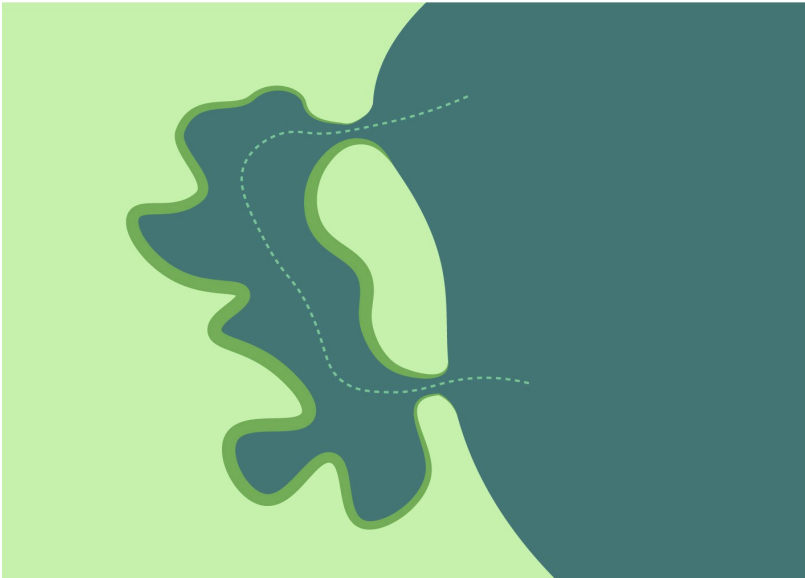


Figure 4.12 Prototype T1-Sp1-1

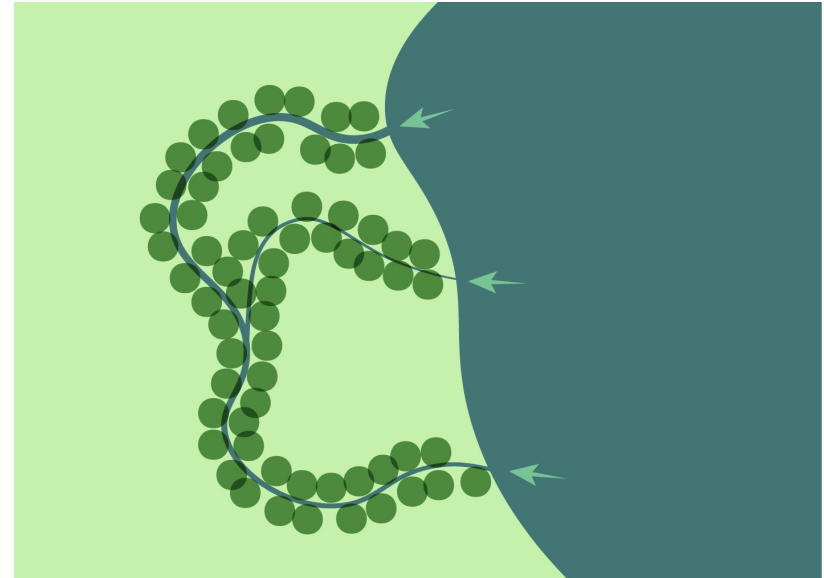


Figure 4.13 Prototype T1-Sp2-1

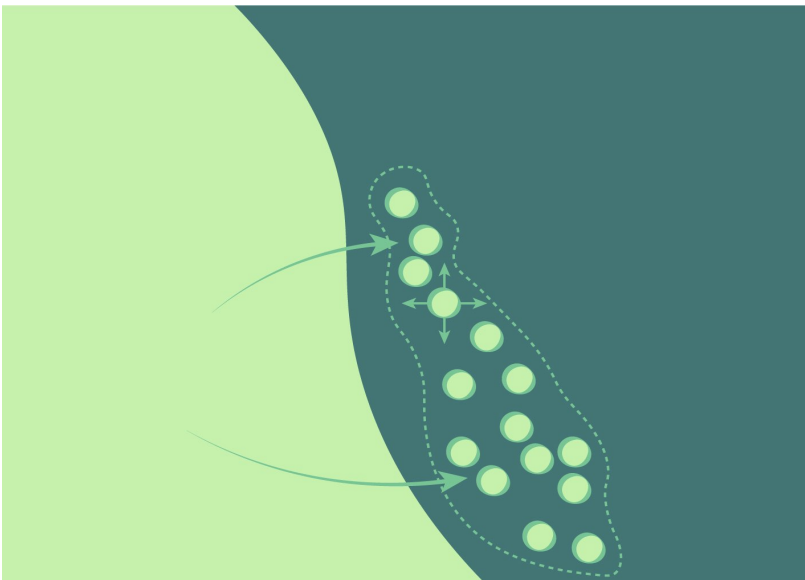


Figure 4.14 Prototype T1-Sp1-2

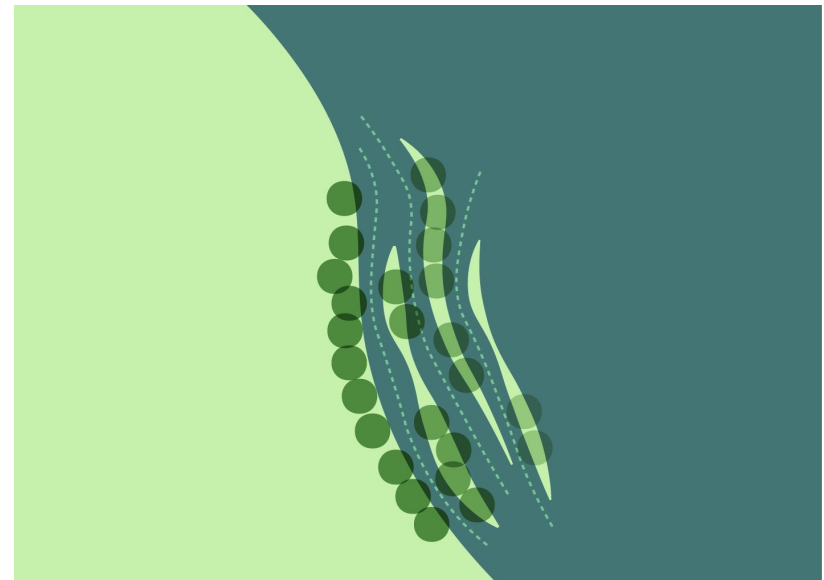


Figure 4.15 Prototype T1-Sp2-2

Prototype T1-Sp1-1 and Prototype T1-Sp2-1 aim to build freshwater ecosystems embedded in existing open landscapes along freshwater lake shorelines by cut. These proposed freshwater ecosystems are connected to the existing lake so that water flows in the constructed ecosystem from the freshwater lake to form an area with calm water and an additional patch of littoral habitat. Similar to another prototype discussed above, aquatic phytoremediation and stormwater buffers are also useful in these two prototypes. The differences between Prototype T1-Sp1-1 and Prototype T1-Sp2-1 are obvious:

Prototype T1-Sp1-1 (figure 4.12) is a series of deeper ponds. Freshwater flows from the lake to the constructed pond system. Around the constructed ponds, a natural ecotone is covered by plants in medium density. The spatial pattern of Prototype T1-Sp1-1 is eventually a patch of wetland habitat that forms a winding boundary between the existing freshwater lake and the terrestrial landscapes. The ecotones extend to the patch of aquatic habitat to diversify food chains and facilitate wintering fish, and thereby entice

Western grebes to forage in a prey-rich area.

However, Prototype T1-Sp2-1 (figure 4.13) pictures creating watercourses, rather than ponds, in existing open landscapes in the backwater area. The ecological design goal for Prototype T1-Sp2-1 is to promote extra areas of wooded riparian corridors, edge habitats, and shallow water. Because of the moderate intensity of construction, Prototype T1-Sp2-1 may be more flexible in a smaller space than Prototype T1-Sp1-1 which requires a relatively spacious site.

Prototype T1-Sp1-2 and Prototype T1-Sp2-2 fix attention on some offshore ecological designs for Western grebes and green herons, respectively. These prototypes are used when the land area is not sufficient to hold extra ecological functions. A limited volume of landfills is the solution for space availability. In these two prototypes, artificial islands fulfill anticipated outcomes. Apparently, the spatial form of these two prototypes is distinct. Prototype T1-Sp1-2 benefits Western grebes in winter by raising fish abundance, while the design features of Prototype T1-Sp2-2 are driven by

Prototype Mix T1-Sp1, Sp2, and Sp3

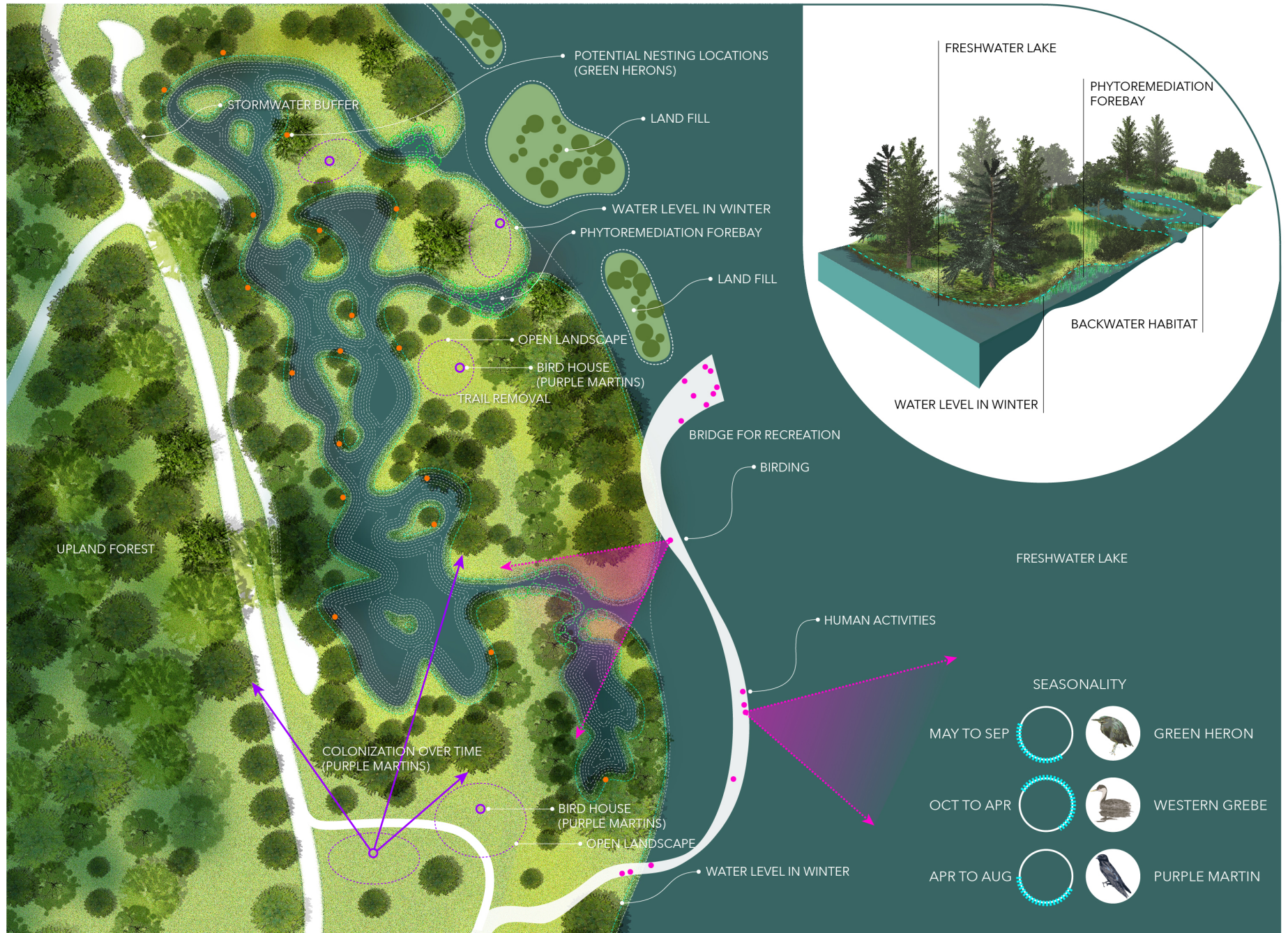


Figure 4.16 Plan view and ecosystem composition

green herons' foraging behavior and nesting preferences. These two derivations of ecological design concepts generate distinct structures of habitat.

Prototype T1-Sp1-2 (figure 4.14) unveils a group of micro artificial islands in an area that is not far from land. Insects and plants from land may keep colonizing these micro islands to furnish the food supply for fish through aquatic dispersal from the habitat edge. Adding to the number of micro-habitat islands multiplies food supply in the meta-habitat. To achieve this goal, the hydrologic system for Prototype T1-Sp1-2 is highlighting littoral zones on the edge of each micro island, thus food dispersal, including drifting insects and worms, becomes more efficient. A fish fueling station plus potentially obtainable amphibians eventually bring in Western grebes. Plants for the marsh are along the edge of each micro island, and ground covers and shrubs are planted around the high point in the center of each micro island.

Another prototype, Prototype T1-Sp2-2 (figure 4.15), offers a possibility for arranging some larger artificial islands that form a

stripe pattern near the land area on the plan view. The hydrologic system of Prototype T1-Sp2-2 represents an image of slow-moving water between the shoreline and the closest artificial island, and between every two artificial islands. In this prototype, dense trees, shrubs, and ground covers are expected to be growing on available islands. The spatial pattern of Prototype T1-Sp2-2 will be consequently picturing alternating terrestrial vegetation strips and shallow water corridors. Green herons would be able to maximize the advantage of the edge habitat in stretched green and blue patches that shape a group of foraging-nesting corridors. This prototype takes more time to fully erect its vegetation after succession and multi-stage cultivation of the plant communities is required.

Prototype AHP is an accessory bird conservation intervention that attaches to other prototypes to amplify species interactions and ecosystem services. In this thesis, the bird species playing this role is the purple martin, because purple martin's nesting structure is usually light and flexible. The food source of purple martins is often sufficient when there are wetlands around. With the prototypes



Figure 4.17 A shady and stagnant water body

developed for Western grebes and green herons as a foundation, additional nesting habitats for purple martins get marginal benefit because of an exemption of extra design and construction efforts for providing purple martins with food sources.

Prototype Mix T1-Sp1, Sp2, and Sp3 (figure 4.16) is one example when the site along the freshwater lake is spacious enough to achieve more goals. The structure of this prototype mix involves

both cut and fill mentioned in Prototype T1-Sp1-1, Prototype T1-Sp1-2, Prototype T1-Sp2-1, and Prototype T1-Sp2-2. The backwater portion represents connected ponds with trees directly planted along the bank, and there are both deep water and shallow water ponds so that these features benefit both Western grebes and green herons in different ways. A visualized example of this prototype mix shows that the lower portion of backwater ponds is deeper than its counterparts in the upper portion in the plan diagram (figure 4.16). Also, in this diagram, some trees are planted right on the edge of the ponds, aiming to provide green herons with nesting locations above water. There are three entrances to the backwater ecosystem. Phytoremediation forebays filter some pollutants in water that get into the backwater ecosystem. In order to accommodate the multifunctionality of bird conservation, this prototype mix requires a reasonably large area than the individual prototypes, and the aquatic habitat is a large patch of relatively stagnant water body partially shaded by trees for green heron nesting. There is a problem. A shady and stagnant water body (figure 4.17) always generates some unpleasant insect species. To address this problem, bringing in purple martins becomes a

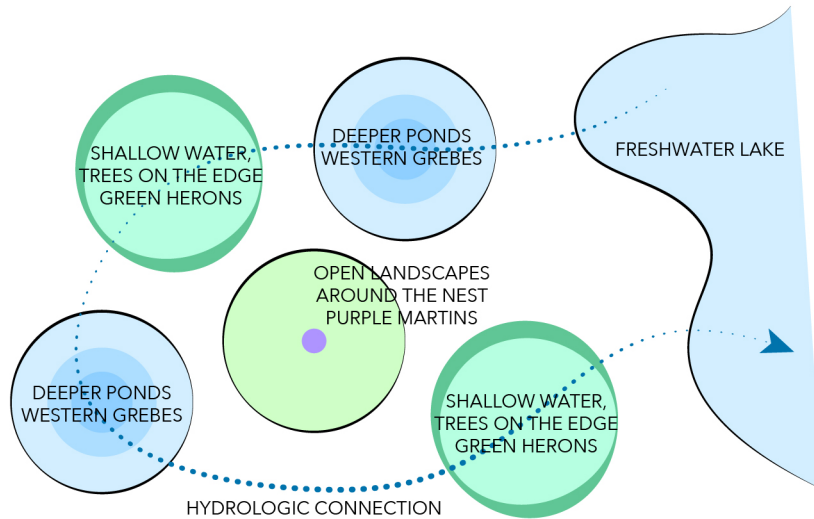


Figure 4.18 A combination of ecosystem functioning modules

potential tool to balance the shortcomings. To fulfill the desire of having purple martins on-site for mosquito control, some patches of original grasslands are preserved to be open landscapes. In these open landscapes, birdhouses are installed. Along with the process of ecosystem evolution, some natural cavities like tree holes emerge. On a long temporal scale, purple martins are expected to occupy these natural spaces for nesting.

Species lifecycle and seasonality are considered in this example of prototype mix. The advantage of blending multiple prototypes is

overspreading all seasons in each year. Western grebes spend time in the Salish Sea area from October to April, green herons stay in the Salish Sea area from May to September, and purple martins breed in the Salish Sea area from April to August (BirdWeb, n.d.-c). This mixture of several prototypes is continuously functional across seasons.

To sum up, this prototype mix can be perceived as a combination of multiple ecosystem functioning modules (figure 4.18).

Prototype T2-Sp1, and Prototype T2→T3/T4

Feeder bluffs/sediment-rich coastlines for the Western grebe, and for the typologies of coastal open landscapes, and overwater structures

The uniqueness of these two prototypes is further improving the existing highly functional habitat and pushing the advantages forward to assist Western grebes and the development of other waterfront typologies and ecological design prototypes.

Because of the global seagrass loss, suitable habitat for saltwater fish consequently decreases. Waterbirds feeding on these fish near the marine shoreline may face food deficiency as well. These two prototypes focus on coastlines with a feeder bluff effect and other sediment-rich coastlines. The mechanism is taking the longshore drift as a source of power (figure 4.19). The longshore drift driven by the prevailing wind carries sediment from the sea to the shoreline, or the feeder bluffs generate sediment through erosion and the sediment accumulates on the beach. As shown in stage 1, this prototype proposes a subtidal rocky breakwater system to help to collect some sediment carried by longshore drift flowing back to the offshore area. The subtidal breakwater is in a dashed form, rather than a continuous line, to keep the intervention gentle. At stage 2, sediment has already been piled up around the subtidal breakwater. Because of the piled sediment being formed, it is more likely for seagrasses to colonize, and the shallow water area with more nutrients is growing and expanding. At stage 3, a terrace structure may appear and the substrate is expected to be stabilized by augmented seagrass

Prototype T2-Sp1
 Prototype T2 → T3/T4

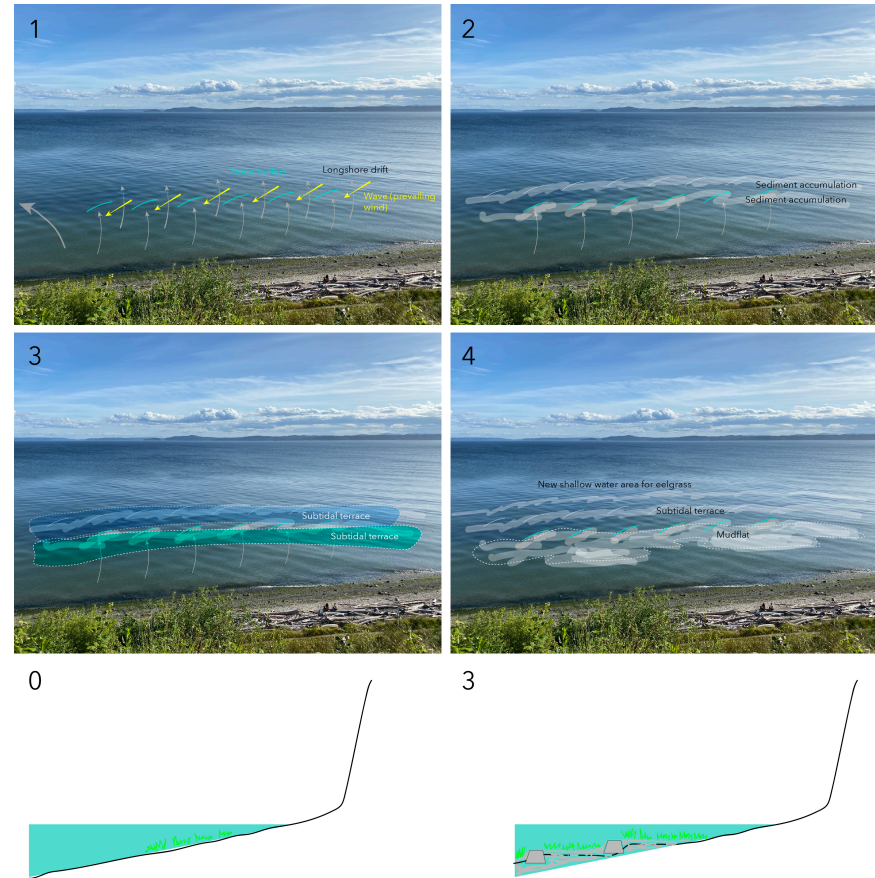


Figure 4.19 A process of new ecosystem formation

meadows. At stage 4, after a long time, some areas may arise from the subtidal space to becoming a tidal flat as a bonus of this prototype for more species than Western grebes. This growing process is particularly tolerable against potential sea-level rise.

Prototype T2→T3/T4 designates an area of the emerged lush eelgrass meadows and allows transplantation to the Typology 3 related prototype and the Typology 4 related prototype for Western grebes in other locations of the city. To ensure the survival rate after transplantation, this prototype suggests the use of containers for relocating a unit of the seagrass individual and the substrate associated with it.

Chapter 5

Reflection

Summary and takeaways

This section is a structural summary of the methods, the order, and the research-design framework I used (figure 5.1) in Chapter 2, Chapter 3, and Chapter 4. Also, this chapter discusses envisioned impacts of the city-scale interventions and the regional-scale interventions on bird conservation at the hemispheric scale. I would like to highlight that not only can the design prototypes discussed in Chapter 3 be generalized and used in different locations, but so does the framework. When someone is dealing with different ecoregions and different bird species and looking for opportunities to take “meta-” ecological design beyond the traditional site limit, the skeleton and process of the target species-typologies-prototypes model (figure 5.1) may also work by filling in different criteria and contents.

The first section is using a filter to identify target species. I propose

seven steps to determine the Western grebe, the green heron, and the purple martin being the group of target species. The first step is to understand all bird species of concern in a rough focal geographical region. In this case, I used the list of species of concern in the Salish Sea area (Zier, and Gaydos, 2016) that combined the lists of species of conservation concern from both British Columbia and from Washington. The second step is to identify migratory species. In this thesis, because I specifically look into the Salish Sea area and the Puget Lowlands, I excluded species; the great blue heron and the peregrine falcon are two examples that are migrating species in other regions outside the focal regions but are resident species in the Salish Sea area (BirdWeb, n.d.-d; BirdWeb, n.d.-e). The third step is to select bird species that are adapted to urban environments with frequent and intense human disturbance. Many threatened or endangered species do not tolerate highly urban environments, such as sandhill cranes and tufted puffins who are sensitive to human disturbance (BirdWeb, n.d.-f; BirdWeb, n.d.-g). The fourth step is to understand the resource consumption and exclude species that the city typically does not have the capacity to serve, or that may limit the

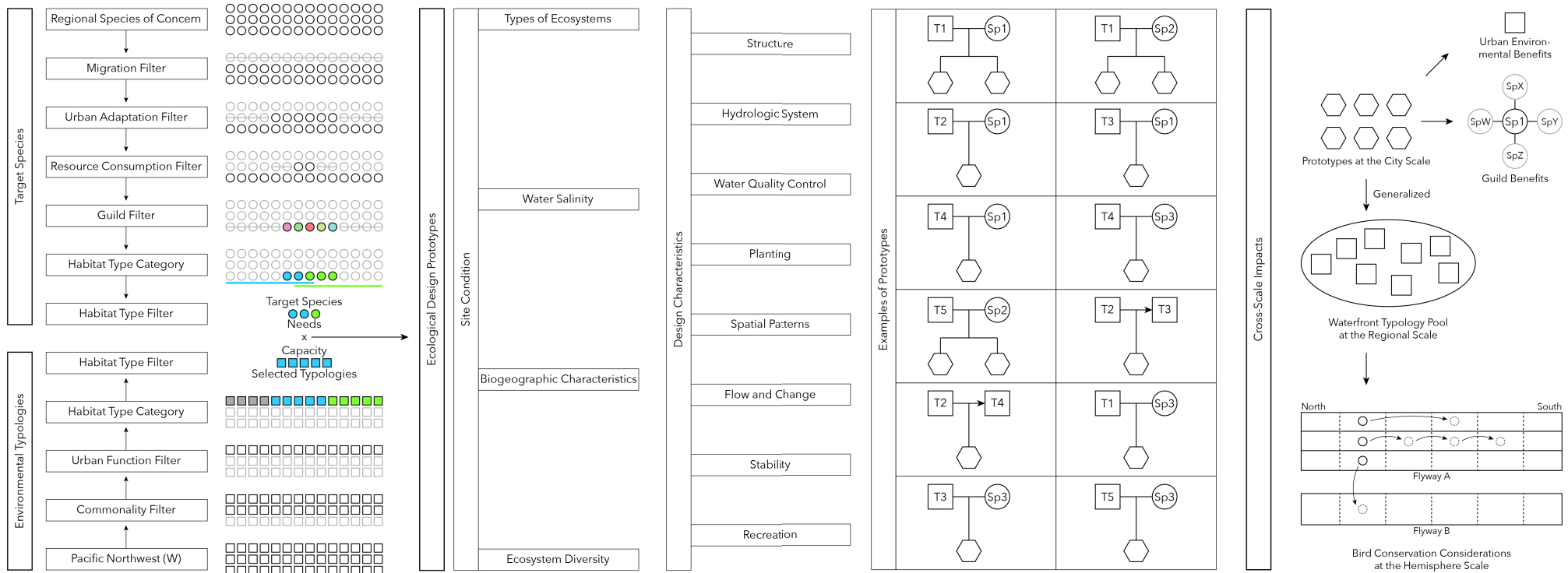


Figure 5.1 The whole structure of the research and design

abundance of other sensitive species in the predation relationship, or that is controversial to conserve because of a large quantity of food is required. Marbled murrelets (even though this species has been excluded in step 2 in this case) are a threatened species in Washington (Zier, and Gaydos, 2016), but they require a large-scale forest, and this would be very challenging to create additional

habitat for them in the city. Owls and hawks are closer to the top of a food chain, so this thesis does not include these species as the primary concern. Moreover, species that are controversial and sometimes are believed or misperceived to consume too many food resources from the environment are excluded as well. With these four steps, the majority of the species had been filtered out from

the pool. The fifth step is to use the bird guild to refine the target species. If the expected number of target species is three, then we always hope that these three target species cover different aspects of concern either starting from the species needs or from the environment. The bird guild can identify similar species whose habitat, behavior, and food sources are almost the same. In this thesis, I only chose Western grebes, rather than both Western grebes and Clark's grebes, in order to avoid too many overlaps on the species level. By finishing this step, each species in the pool should be relatively unique to each other. The sixth step is to categorize the species left into either more terrestrial habitat, or more aquatic habitat, or somewhere in between. In this thesis, I finally chose one species, the Western grebe, who primarily lives in the water in the focal region, one species that forage in wetlands but nest on the edge, the green heron, and one species that nest on land next to water, the purple martin.

From the bottom, the filtering process for environmental typologies is similar to the target species counterpart. First, there is intuitively a large number of urban environmental typologies in the west

portion in the Pacific Northwest (west to the Cascade Range) from Western Oregon to Southwestern British Columbia. There are multiple types of locations of the cities. Plenty of cities in western Oregon are in riverine areas, cities in the Salish Sea region are along the meandered coastline, and some cities facing the Pacific Ocean are located in estuarine areas. To environ a larger possibility of urban migratory bird conservation regionally, the next step focuses on the commonality of these environmental typologies. Therefore, the Puget Lowlands became a central area of concern because of the higher density of cities. These cities can be roughly categorized into coastal cities and riverine cities. The third step is to make sure the existing function in potential urban environments is not completely distinct from a sense of natural habitat. Apparently, the urban environmental typologies have to avoid airports, narrow streets, and neighborhoods with a large number of glass windows. The fourth step of narrowing down the environmental typologies is the same as the sixth step in choosing target bird species. So the categories of habitat types are water-related habitat and completely inland habitat. In order to conform to the choice I made in filtering target species, here I chose water-related habitat as well. As a

result, focal urban environmental typologies were narrowed down to five urban waterfront typologies.

These two sections and processes for selecting the target species and the environmental typologies took several iterations to be determined because sometimes there were some particularly important aspects that can be easily overlooked. These aspects are of either the attribute of one bird species or features of a certain environmental typology.

The next section is ecological design prototypes. There is a typological characteristics and design criteria framework. Because this is not design for particular sites, the typological characteristics and design criteria framework only discussed an ideal and general picture of each waterfront typology and each design prototype. For specific site design, the four aspects of existing site condition ((E1) types of ecosystems, (E2) water salinity, (E3) biogeographic characteristics, and (E4)) should be the central concern of site analysis, admitting that some details and wording should be changed when dealing with different circumstances. When it comes

to specific site design, the eight aspects are a guidance of creating a sustainable ecosystem for urban birds. These eight aspects involve both construction suggestions and anticipated natural processes, and both ecosystem functions for birds and ecosystem services for human society as an outdoor recreation space.

The fourth section is the cross-scale impacts. At the city scale, urban environmental benefits for humans are as valuable as conservation interests. For target bird species, the top to bottom relationship from the bird guild to one single species is reversed in that a suitable habitat for a single species will also benefit similar species. In this case, at least three groups of bird species can get benefits from the prototypes in cities. At the regional scale, many real-world sites in adjacent cities belong to the five categories of waterfront typology. Therefore, there are a lot of opportunities beyond the Seattle metropolitan area. A regional network of urban migratory bird conservation can be established over time ecologically and organizationally. Because of the nature of migration, the hemispheric scale is inherently connected by migratory birds. At the hemispheric scale, there are some

expectances as well. Even though this thesis does not talk too much about stopovers, a large number of migratory species indeed use stopover sites for refueling and resting, so these stepping stones are suitable locations to build high-quality habitats for birds in migration. These stepping stones can be located in urban environments to render greeneries and energetic spirits of cities. Some bird species migrate across two flyways. For these species, the ecological design and planning efforts should pay attention to cities located along more than one flyway. This framework with the hemispheric scale advocates for ecological design and planning explorations for bird conservation-oriented urban landscape architecture in different ecoregions along Pacific Flyway.

This work is a product of bridging migratory birds and landscape architectural solutions from a planning perspective aiming to light up an urban habitat network to serve resilient meta-populations of the three target species.

Limitations

Finally, I acknowledge that there are some factors that may cause some shortcomings of this research.

- 1) This research is not site-specific. Because the focus of this thesis is primarily on the exploration of the research-design framework, rather than the design addressing problems in an identified geolocation, the design characteristics are generalized. As a consequence, when there is a need to deal with site design for the target species, additional research for design is quite important. This includes the cultural setting of the site, the urban function in surrounding neighborhoods, resource availability, and potential disturbances that may weaken the proposed ecosystem functions.
- 2) Visualization of twelve ecological design prototypes is not evenly presented. Because of the number of prototypes mentioned in this thesis, it is less likely to standardize the drawing for each design prototype, e.g. having a formatted plan view, a section, a perspective vignette, and an analytical diagram of an equal size for every one of the prototypes. To solve this dilemma, the prototype section has to use the most helpful visual language to

articulate design thinking related to each prototype (table 5.1).

- 3) The extent to which anticipated outcomes can occur is not quantitatively analyzed or simulated. Since this thesis is structured to be a reflection of exploration processes developed from methods used in landscape architecture studios, future frameworks and methods of modeling and simulation are required to compensate for the lack of quantitative analysis. This can also be an opportunity for me to delve deeper into modeling and simulation of anticipated landscape performance in my future research.

Prototype	Drawing 1	Drawing 2	Drawing 3
T3-Sp1	Axonometric diagrams	Perspective vignette	Diagram of habitat distribution
T4-Sp1	Aggregated perspective	Section	Diagram of phasing and habitat zonation
T4-Sp3	Aggregated perspective	Rendered perspective	Diagram of resource flow
T5-Sp2	Axonometric diagrams	Axonometric analysis	
T2→T3/T4	Perspective vignettes	Sections	

Table 5.1 Prototype visualization

Prototype	Drawing 1	Drawing 2	Drawing 3
T1-Sp1-1	Plan diagram	Rendered plan in a mix	Diagram of ecosystem functioning modules in a mix
T1-Sp1-2	Plan diagram		
T1-Sp2-1	Plan diagram		
T1-Sp2-2	Plan diagram		
AHP			
T2-Sp1	Perspective vignettes	Sections	

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