Architectural Resilience In Coastal Communities: Biomimicry As A Design Tool

by

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Submitted in partial fulfilment of the requirements
for the degree of Master of Architecture

at

Dalhousie University
Halifax, Nova Scotia
March 2024

Dalhousie University is located in Mi’kmaq’i,
the ancestral and unceded territory of the Mi’kmaq.
We are all Treaty people.

Contents

Abstract

The coastline is a dynamic landscape feature that divides the land and sea, shaped by natural systems over billions of years. Critical climatic factors, including increased tidal action, coastal erosion, and inundation, are creating continuous change along the coast and implementing architectural challenges within existing coastal communities. This thesis proposes an architectural solution that implements resilient design in an existing coastal community—tailored to address critical climatic factors, enhancing community connectivity, and articulating the essence of biological structures, allowing residents of the coastal settlement to continue to thrive along the coast. Neil's Harbour, Nova Scotia, is explored as a case study on how to shift our perspective from traditional methods of settlement to living in harmony with dynamic landscapes, leveraging local land and programmatic relationships to repair existing climatic impact and create a layered approach to resilient design.

Acknowledgements

This thesis would not have been possible without the motivation and guidance from my thesis committee, Cristina Verissimo, Ismet Ugursal, and Chris Harvey-Clark.

Cristina, I appreciate your commitment to helping me connect the pieces of my interdisciplinary work. Your architectural guidance and efforts to help me effectively integrate my research into my design are truly appreciated.

Ismet, I would not have been able to navigate the intricacies of hydrodynamic flows without your assistance.

And Chris, I extend my gratitude for sharing valuable insight on the ecology of maritime marine life. Your profound knowledge on sharks has greatly enriched my understanding of the species and helped me to understand how to emulate natures solutions in architectural practice.

In addition I'd like to thank my professors from Dalhousie's Environmental Science and Sustainability Facilities, in particular Patricia Lane for supporting me through my Environmental Impact Certification and encouraging my interdisciplinary work. Thank you for truly inspiring me to consider the impact of architectural practice.

To Jennifer Strang for helping me navigate through GIS and learn to produce visualizations of data. I have learned so much about the province of Nova Scotia through this process.

To my parents, thank you for continuing to support me through my academic career. Your guidance has been critical in keeping me on track.

To my friends who have stood by me in this process and provided unconditional support.

And finally to the Studio 3 crew for being the best companions through BEDS and M.Arch. I would not be here today without you, thank you for your encouragement.

Chapter 1: Introduction

Globally, coastal communities are encountering unprecedented challenges due to the increasing threats of climate change. Over the past billion years, coastal landscapes have evolved under various hydrologic, ecological, and geological conditions, in combination with coastal processes and human and non-human habitation. Today, rising sea levels and coastal erosion are emerging as the most impactful climatic challenges and threats to coastal communities. These environmental issues pose immediate and long-term risks, affecting the resilience and sustainability of these coastal regions. The immediate risks of rising sea levels and coastal erosion include storm surges and increased flooding, which can result in sudden and severe damage to residential and commercial infrastructure and local ecosystems. On the other hand, the long-term risks involve the gradual and continuous loss of coastal land, ecosystems, and habitats.

As sea levels rise and erosion progresses, tidal action, weathering, and rate of sediment deposition are additionally changing, creating a cumulative impact over time. These impacts put coastal communities at a greater risk of loss of valuable land, displacement, economic loss and degradation of essential ecosystem services. Architecture plays a crucial role in creating community resilience by designing structures that can withstand and respond to environmental changes to protect the well-being of both human and marine ecosystems -as coastal communities present unique ecosystem services, economic contributions, cultural heritage, and recreational opportunities.

In this context, the concept of biomimicry emerges as a powerful design tool that draws inspiration from nature's organic solutions to create sustainable and resilient architectural solutions by emulating nature's patterns, strategies, and systems to solve human challenges. By studying the intricacy of natural mechanisms and resilient features found in coastal ecosystems, architects and designers can learn about existing innovative solutions and abstract those ideas to protect communities and enhance their ability to thrive in dynamic environments. Traditional architectural approaches often neglect to acknowledge the vulnerability of coastal landscapes to dynamic conditions leading to the degradation of coastal communities. However, by embracing biomimicry, architects can develop an inherent resilience of coastal ecosystems. In the same way, nature has evolved sophisticated adaptations to endure harsh coastal conditions over millions of years -offering architects a multi-faceted approach to architectural resilience in coastal communities.

This thesis explores the utilization of biomimicry in architecture to address increasing threats of climate change and pressing challenges faced by Nova Scotian coastal communities. The dynamic coastal systems of Neils Harbour, Nova Scotia, are explored as a case study to understand the unique dynamic systems of Nova Scotia's coastline that are changing rapidly, putting local infrastructure and local economies at risk. The region's coastal landscapes play a vital role in local economic activities and are intertwined with the cultural heritage of the coastal communities, reflecting historical practices and maritime traditions -emphasizing the urgent need to develop innovative solutions for architectural resilience. In this context, biomimicry draws inspiration from the local coastal ecosystem and emphasizes nature's adaptive strategies that have evolved in autochthonous species, such as the shark. The complex and evolutionary characteristics of the shark inspired the design of a structure that not only builds upon the use of a hard-engineering solution in coastal communities to withstand the impacts of climate change but also contributes to the long-term sustainability and well-being of the coastal community. Establishing a solution that presents architectural resilience in Neil's Harbour to ensure the preservation of the Harbour's health and functionality is crucial to sustaining the community's ecological, economic, and cultural vibrance.

Proposed is the envisioned inhabitable breakwater that draws inspiration from sharks' dynamic movements and morphological characteristics. Beyond serving as a resilient barrier, this transformative structure doubles as a dynamic functional space hosting outdoor recreation space, interior event space, a local café, public lecture halls and an expansive marine archive for community use. In addition to an extensive marine observatory, with an underwater viewing area that intertwines educational displays on maritime marine life. Additionally, hosting a private state-of-the-art marine research facility that houses various marine research labs, a marine autopsy lab, and a private land-based aquaculture lab, providing economic benefits to the Neil's Harbour community and symbolizing a commitment to living in harmony with coastal dynamics while facing coastal living challenges and fostering shared resilience between inhabited and uninhabited spaces.

Thesis Question

How can biomimicry as a design tool in architectural address climate change threats and challenges in coastal communities of Nova Scotia, enhancing community connectivity and promoting sustainable development?

Chapter 2: Biomimicry as a Design Tool

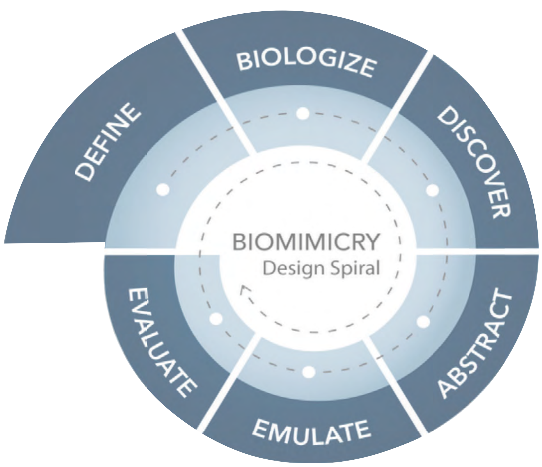
Field of Research

Throughout history, architects have looked at nature as inspiration for building forms and approaches, using nature as a source to base symbolic association and unconventional form for aesthetics. Biomimicry, however, takes this inspiration a step further by translating the biological adaptions of nature into functional architectural solutions (Pawlyn 2020, 2). Embracing human inhabitation as a piece of ecology within a greater network and resisting the temptation to return to conventional architectural approaches that neglect to adapt to changing environments. Arguing that nature provides us with more adaptive materials, systems, and structures then traditional architectural practices by shifting from linear to closed looped systems (Pawlyn 2020, 145). This shift in perspective encourages architects use the unique skills we have to look for opportunities to design for resilience and produce new resources, while widening systemic boundaries and empowering future generations.

Stages of the Design Spiral

The Biomimicry Design Spiral was developed by industrial designer Carl Hastrich in 2005 as a practical tool for designers to indirectly approach the translation from biology to design, viewing models of organisms as solutions to design problems (Alanbari, Alkindi, and Al_Ahbabi n.d., 2336). The spiral outlines a step-by-step process for turning nature's strategies into sustainable design solutions.

Encouraging designers to identify the functions that the design needs to perform and translate those functions into biological terms that can be explored. This exploration leads to the discovery of strategies that nature uses to accomplish these functions, acknowledging organisms morphology, physiology, behavior, and function within their ecosystem. Those functions are then abstracted back into technical terms, and emulated through design strategies. The designer then evaluates the emulated design solution against the original design brief, nature's patterns, and reflect on the ideas that emerged in the previous steps as they can be reapplied if the designer chooses to complete an additional lap around the spiral (Biomimicry Institute 2016). This thesis will explore the process of translating biological adaptions of nature into functional architectural solutions through implementing The Biomimicry Design Spiral as a practical design tool.



Define
- Identify functions that you want your design to perform
    - Mitigate tidal impact/control hydrodynamics
    - Reconnect coastal communities to the coastline

Biologize
- Translate those functions into biological terms
    - Tidal impact (natural process)
    - Ecology of the nearshore zone
    - Sharks & Hydrodynamics

Discover
- Discover strategies that nature uses to perform those functions
    - Sharks morphology, physiology & behaviour
    - Explore the function of shark denticles

Abstract
- Abstract those strategies back into technical terms
    - Efficiency of the shark skeleton (strong but light)
    - Sharks drag function used to cut wave energy

Emulate
- Emulate those strategies in your design solution
    - Structural efficiency (less dense materials)
    - Organic form (cuts wave action mitigating impact)
    - Inhabitable breakwaters enhances community connectivity
    - Observatory provides educational opportunity

Evaluate
- Evaluate your design against your design brief and Life's Principles, and then decide how you want to move forward
    - What was successful in the design?
    - What failed?
    - Where could the design be improved?

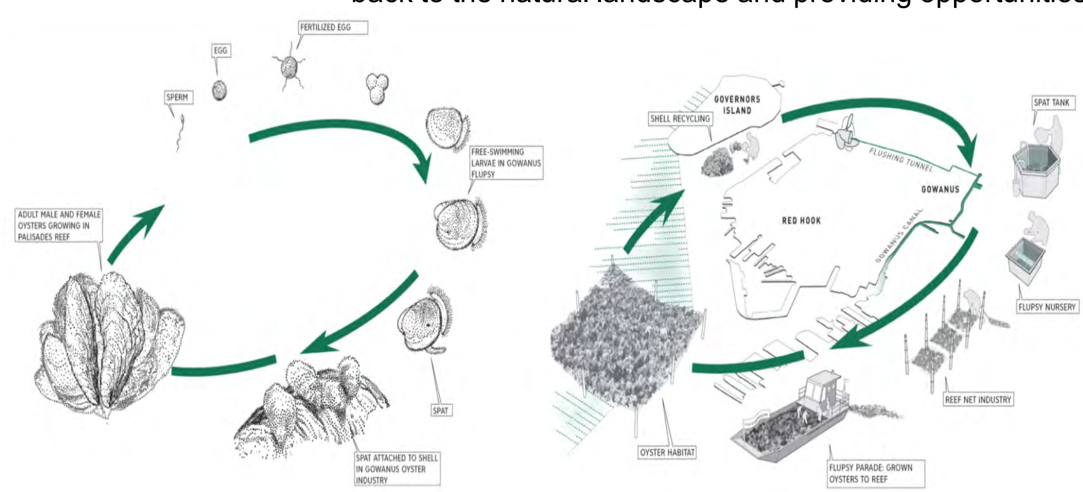
Preliminary application of Carl Hastrich's Biomimicry Design Spiral.

Case Studies

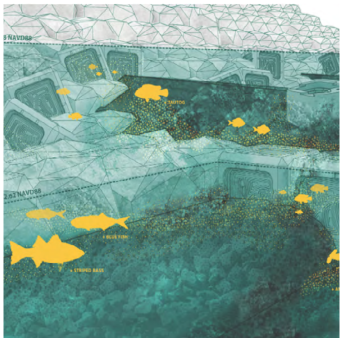
Oyster-tecture Project by SCAPE Studios (Marcus 2022)

Incorporating biomimicry as a design tool in architectural practice involves comprehending how to translate biological concepts and emulating biological ideas into architectural design attributes. The following case studies explore how biomimicry corresponds to building systems, climate-response functions, form, structure and building function.

SCAPE Studios Oyster-tecture Project, along the South Shore of Staten Island, New York, looks at using the life cycle of the oyster to constructing a living reef that supports marine growth, cleanses water and creates waterfront resiliency (SCAPE 2019). The living reef is composed of a woven web that generates a natural 3D landscape mitigating wave impact and cleaning millions of gallons of harbor water by mimicing the biotic filtration processes of oysters mussels, and eelgrass (SCAPE 2019). This project is unique as it uses the systematic approach of using life cycle as a strategy to foster local ecology to create natural structures of resilience. While reconnecting the community back to the natural landscape and providing opportunities of

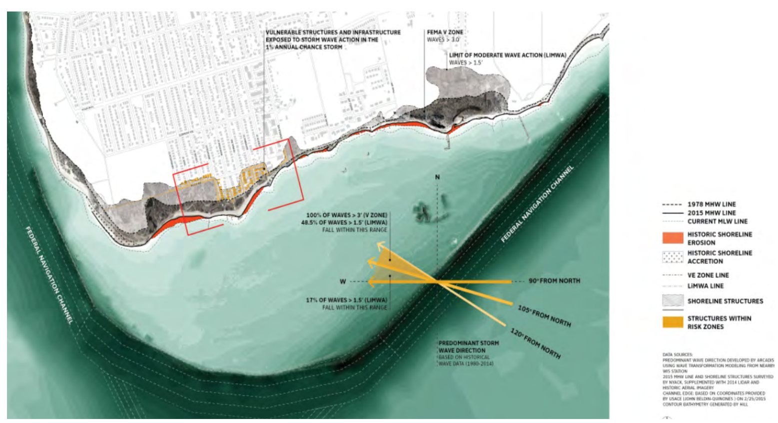


Approach to Oyster-tecture, SCAPE Architects (SCAPE 2022).



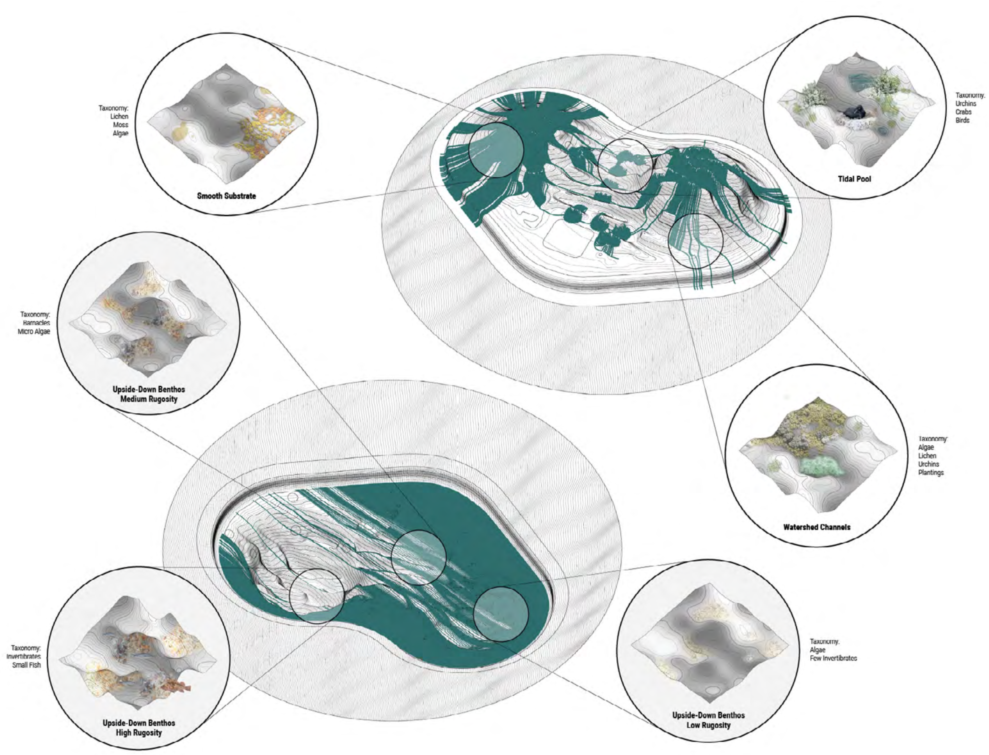
Complex reef ridges and streets in the Living Breakwater Project (SCAPE 2022)

The Living Breakwater Project, by SCAPE Studios is an extension of the Oyster-tecture project that explores physical, ecological, and social resilience. SCAPE studio looks at near-shore ecologically enhanced breakwater segments that intend to break wave action and reduce erosion at the Conference House Park beach while fostering ecology by providing a range of habitat spaces for oysters, fish and other marine species (SCAPE 2022). In hopes of eventually reversing the impacts of erosion, the studio designed “reef ridges”—rocky protrusions on the breakwaters that face the ocean—and “reef streets”—narrow spaces between the ridges, mimicking the formation of natural reefs which provide tidal resilience and habitat to marine species naturally (SCAPE 2022). These architectural systems provide an opportunity to enhance productivity in intertidal and shallow subtidal habitats while creating community resilience and protecting coastal infrastructure.

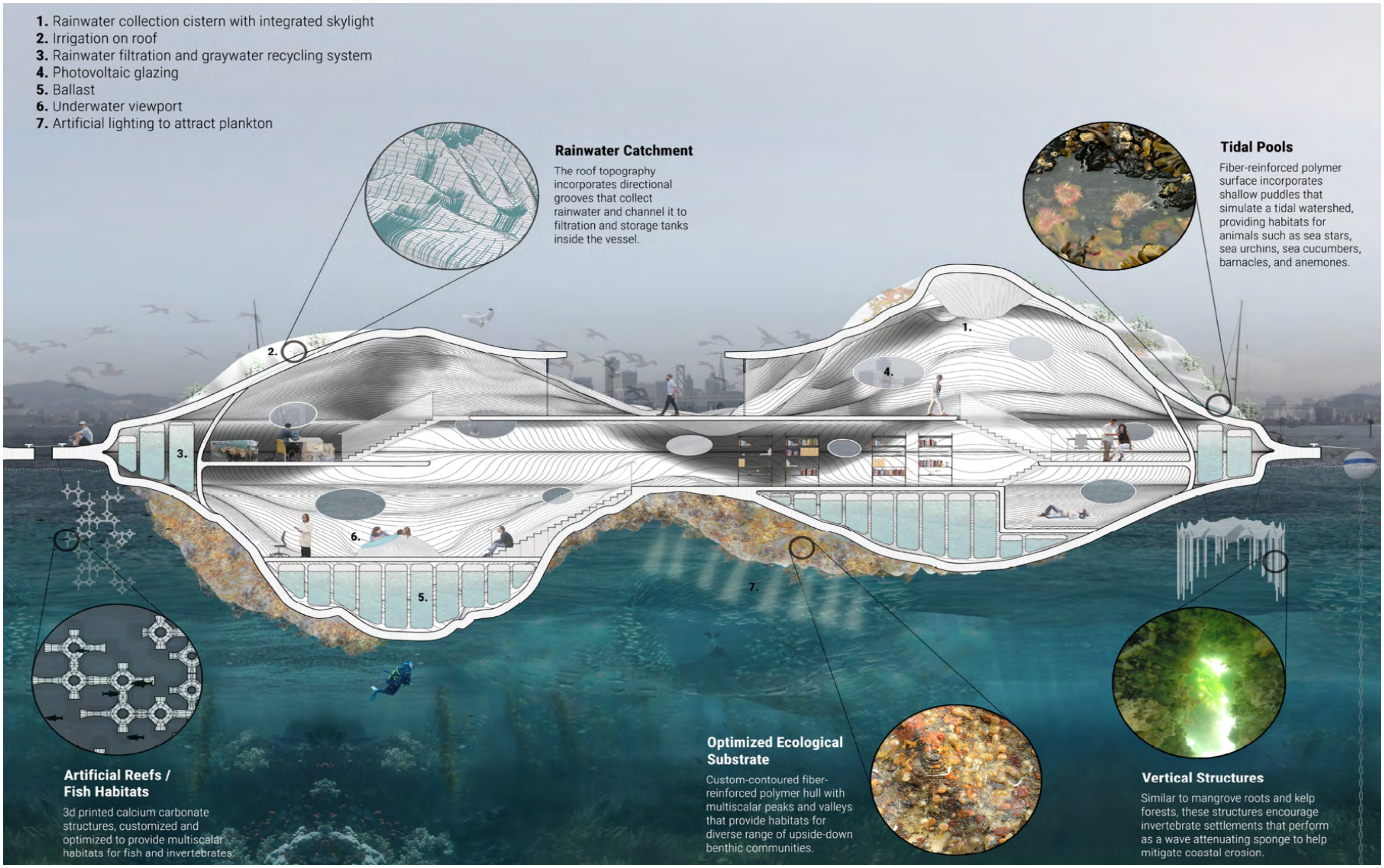


Approach to Living Breakwater Project, SCAPE Architects, 2014 (SCAPE 2022).

Buoyant Ecologies Float Lab, currently floating in San Francisco Bay, California, is a prototype for resilient coastal infrastructure. The design consists of a floating breakwater structure that mimics a shell formation with variable topographies that perform above and below the water (Marcus 2022). The surface topography is designed to channel rainwater, producing watershed pools for intertidal or terrestrial habitats. In contrast, the underwater topography consists of valleys and peaks that vary in size to provide habitats for different marine species like urchins, mussels, and crabs (Marcus 2022). Supporting the idea that in large masses biological growth can help to mitigate wave action and reduce tidal erosion -some of the primary imposed by climate change, creating a structure that enhances community resilience. In addition, the center will provide a research observatory implementing a program within the breakwater system and emphasizing the idea of encouraging ecological education.



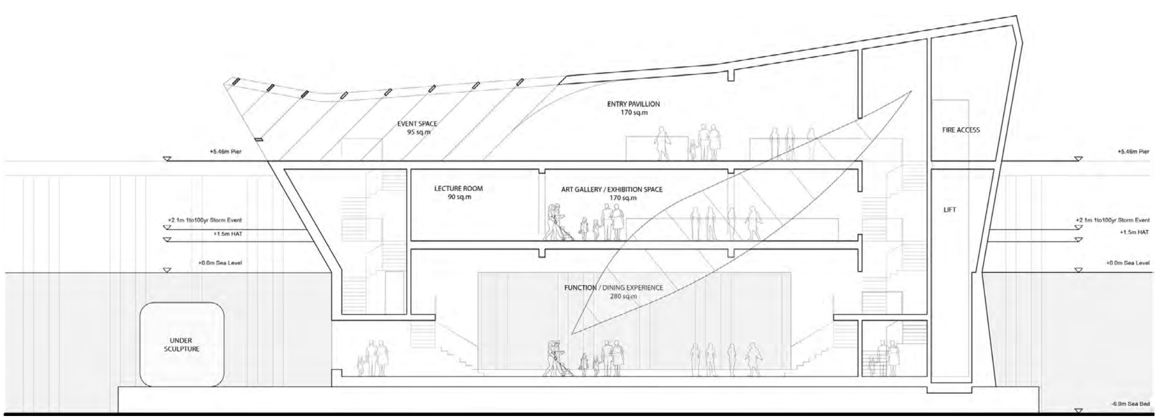
Variable typologies in the Buoyant Ecologies Float Lab Prototype (Marcus 2022)



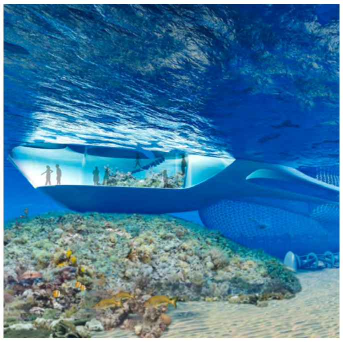
Section of the Buoyant Ecologies Float Lab Prototype, CCA Architecture, 2022 (Marcus 2022).

Baca Architects public observatory mimicking the form of a whale breaching (Crook 2021)

The Australian Underwater Discovery Centre (AUDC), designed by Baca Architects, is a public observatory, proposed to be positioned two kilometres at sea beside Busselton Jetty off the coast of Geographe Bay, Western Australia. The project explores the use of biomimicry in inspiring, functional building forms by mimicking an abstraction of a native whale surfacing in the bay (Crook 2021). The design draws from local marine inspiration and emulates the hydrodynamic efficiency inherent in the whale's movement, suggesting potential improvements in fluid dynamics for aquatic structures (Crook 2021). The design additionally seeks to replicate the structural resilience exhibited by whales in dynamic oceanic conditions, using the whale's broad form to ensure structural stability against tidal action (Crook 2021). Beyond functionality, the concept holds aesthetic value, intending to connect the structure to local marine life and provide educational awareness by creating a unique experience of viewing the ocean floor from an underwater perspective.

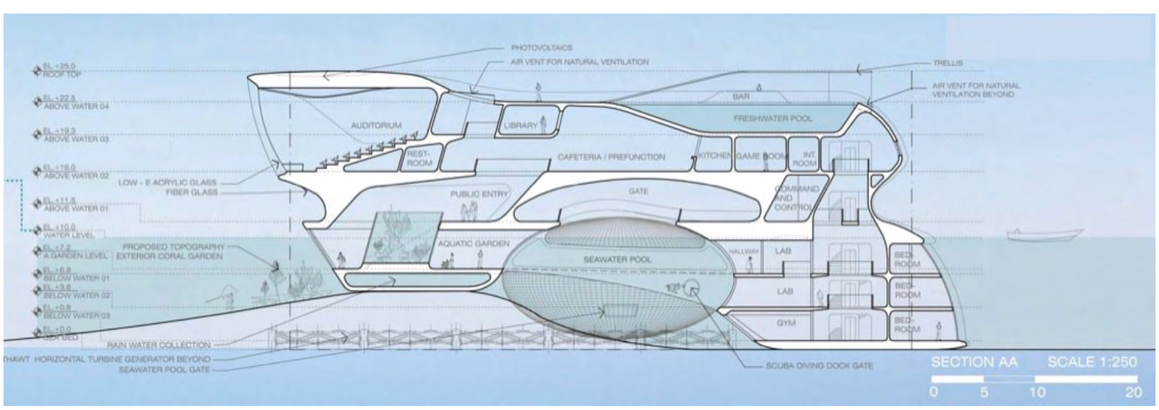


Section of the proposed AUDC, Baca Architecture, 2021 (Crook 2021).



Underwater view of Solus 4 Marine Research Centre, Bali (Crook 2021)

Solus 4 Architecture Studio presented a proposal for a Marine Research Center in Bali, Indonesia. The design proposal focused on using tsunami research to draw inspiration from wave dynamics and force patterns generated by tsunamis, translating them into integrated building forms (Jordana 2010). In 2004, the Indian Ocean earthquake and tsunami tremendously impacted the region of northern Sumatra, Indonesia, causing significant infrastructural loss and community displacement. The proposed 2500 square meter Marine Research Center to be situated 150 meters offshore from Kuta Beach is an effort to respond to climatic disasters and protect Kuta Beach (Jordana 2010). The research centre is intended to feature research labs, scientist accommodations, seawater pools, an aquatic garden library, and an auditorium designed to seamlessly blend with the natural aquatic environment, offering a direct visual connection to local marine life. The energy-efficient design incorporates transparent and opaque glass-based panels with embedded PV cells, tidal/current generators for power, rainwater collection, and seawater conversion systems for water supply (Jordana 2010). The design aims to make the unique shapes and programmatic elements of the Marine Research Center an iconic symbol for both scientific study and tourism in the region.



Section of the proposed Marine Research Center in Bali, Baca Architecture, 2021 (Jordana 2010).

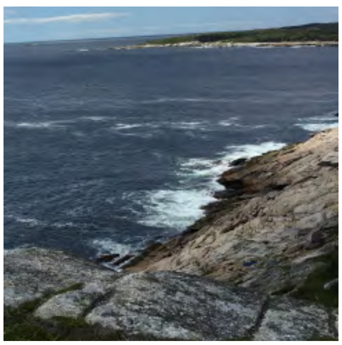
Chapter 3: Discovering Nature's Designs

Nova Scotia's Coasts

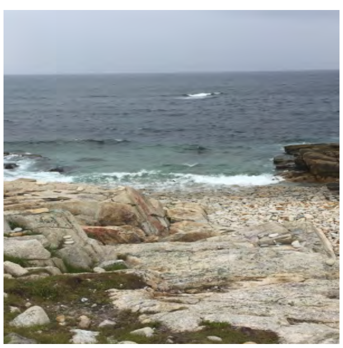
As biomimicry emulates the function of natural systems, it is essential to acknowledge the condition of the natural landscape and its predominant functions in Nova Scotia. Local coastal communities emerged from specific geographical, social, economic and cultural circumstances, including recreational and economic use of coastal lands (Cosgrove 1998, xi). Cultivation reshaped natural coastal landforms into settlements through human impact. Private ownership of coastal landscapes started as a means for a self-sufficient mode of production. However, it grew into a capitalist social division that impacted land relations and changed coastal properties into a means of economic value—increasing population density in coastal communities (Cosgrove 1998, 45).

Human impact from coastal communities has exerted additional pressures on coastal landscapes, including habitat destruction through urbanization and industrial development, pollution from runoff and waste disposal, and alteration of natural shoreline dynamics by disrupting sediment transport processes, leading to changes in beach erosion and accretion patterns, affecting coastal ecosystem as a whole. Climate change intensifies these pressures, leading to rising sea levels, increased storm intensity, and ocean acidification. Increasing populations have also led to overfishing, disrupting marine ecosystems and affecting the balance of coastal biodiversity. Collectively, these human-induced factors significantly impact the degradation of coastal environments, posing challenges for ecosystems, communities, and the overall resilience of coastal areas. In addition, though cultivation practices have evolved, coastal communities still neglect the ability to adapt to dynamic changes within their current environment.

Natural Landscape



The swash zone with higher topography.



The swash zone with lower topography.

Nova Scotia's unique hydrology, topography, and geology have collectively shaped coastal landscape features and formed the visible landscape over billions of years. Hydrology, the intricate study of water's journey through various phases in the atmosphere, across the land, and from the ocean to the atmosphere, serves as a conductor of this dynamic transformation (Brutsaert 2012, 2). Hydrology delineates the pathways through which terrestrial and marine forces have driven water to sculpt the intricate boundary between land and water. Nova Scotia's coastline is a unique landscape feature shaped by these forces to create a land-water boundary from the marine environment (Hughes and Baldock 2020). The landward boundary, known as the swash zone, is where surface and subsurface water meet in the nearshore zone, and wave energy dissipates as it meets the groundwater supply (Hughes and Baldock 2020). Initiating two primary water movements, the first is the landward-directed water flow called the swash, and the second is the backwash, which is the downslope movement of the water. These swash movements control sediment transport, which creates landscape features in intertidal zones (Hughes and Baldock 2020). Coastlines with higher swash experience more substantial tidal impact and higher sediment deposition rates, explaining the variance in Nova Scotia's topology and coastal slope.

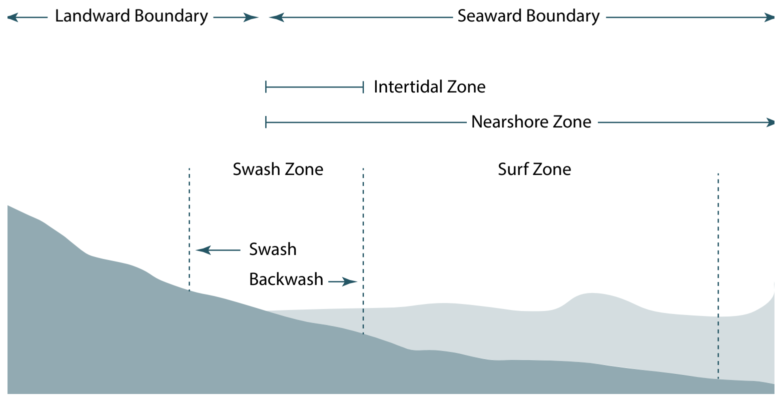


Diagram indicating the landward and seaward boundary of coastlines.

Inputs are areas where sediment is generated (cliffs where sediment can be eroded). As waves hit the cliffs, sediment is eroded and carried into tidal movements. Thus, input regions have more significant ranges in topology. In comparison, outputs are areas where deposition is dominant (rocky shores where sediment is deposited). Output regions have a less significant range in topology (Jackson and Short 2022, 158). In addition, regions with denser topology usually have greater tidal ranges, resulting from longer, less steep waves that dissipate the majority of their wave energy before reaching the coast, gradually shaping the coast over long periods of time. Regions with less dense typologies are often shaped quicker by stronger tidal action, where shorter but steeper waves dominate areas of low topology.

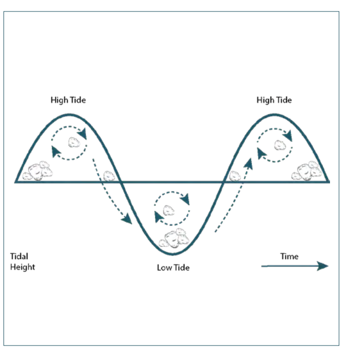


Diagram illustrating the movement of tidal flow from high to low tide and the influence of tidal action on sediment deposition.

This thesis will focus on understanding the interplay between Neil's Harbour sediment dynamics, topography, and tidal forces. These factors are crucial in comprehending coastal evolution and resilience to environmental factors in the region and help us as architects to assess the potential impact of coastal storms, storm surges, and extreme weather events that may impact proposed infrastructure.

Duncan's Cove, Nova Scotia, a region of low topology on Southeast shore showing surficial drumlins and flat to rolling coasts.

Cape Split, Nova Scotia, a steep landform on the Northwest shore carved by wave action and erosion, creating a split with cliffs, beaches, stacks, and skerries (Nova Scotia Parks).

Coastal landforms are geologic features that are shaped through by the simultaneous operation of sediment transportation, deposition processes and erosion over geologically short periods of time. Coastal landforms include the development of beaches, cliffs, and spits. Regional geology encompasses the broader geological characteristics of a larger area, considering factors like rock types, fault lines, and tectonic processes over billions of years. The geological difference between geological landforms and regional geology lies in the scale and focus, with coastal landforms concentrating on specific interactions at the shoreline, while regional geology examines the overall geological framework of a larger region. The makeup of geological landforms starts with the solid rock that lies beneath the soil and other surficial materials (Fensome and Williams 2022, 113). This rock is called bedrock -the foundation of surficial geology. Nova Scotia's coastal bedrock consists mainly of sedimentary and igneous rocks, with variations of sandy silt rocks (Fensome and Williams 2022, 113). The Goldenville Formation (predominating along the Eastern and South shores) comprises metasandstone-graywacky, wacky, and quartzite (all igneous and sedimentary rocks). These rocks tend to create a foundation for flat to rolling coastlines with surficial drumlins as their main coastal landscape feature (Nova Scotia Gov.).

In comparison to the North Mountain Formation (predominate along the Bay of Fundy) is comprised of basaltic sedimentary and volcanic units, which comprise stronger rolling ridges with exposed Bedrock is the solid rock formation that lies beneath surficial materials and supports the makeup of coastal landforms (Fensome and Williams 2022, 113). Sedimentary and Igneous rocks create a foundation of flat to rolling coastlines with surficial drumlins. Volcanic units comprise surficial rolling ridges with exposed rock, wave-cut terraces, and sea arches, stack and splits as surficial coastal landscape features (Nova Scotia Gov. 2019). These features contribute to the topography -shape, height, and depth of these regions.

Neil's Harbour's diverse coastal consisting of a combination of cliffs and lower lying rocky shores.

Explaining that Nova Scotia's coastal landscape is a product of unique hydrologic, topographic, and geologic conditions working in tandem over billions of years. This history illuminates the complexities of dynamic processes, varied topologies, and the delicate balance between sedimentation and erosion, providing insights into the heightened vulnerability faced by coastal communities in Nova Scotia.

This thesis explores Neil's Harbour, Nova Scotia, a coastal region that is particularly susceptible to the detrimental effects of coastal erosion due to its geological composition. The region is characterized by a combination of hard sandstone and softer shale formations, contributing to its diverse topography (Nova Scotia Gov. 2019). While cliffs in the area are predominantly formed from sandstone the regions more resilient rock type, they are constantly subjected to the relentless forces of wave action and tidal influences, intensifying erosion processes (Nova Scotia Gov. 2019).

The powerful wave action from the Atlantic Ocean, coupled with tidal forces and weathering processes, contributes to the gradual erosion of the coastal cliffs, impacting local coastal infrastructure. At the same time, other areas with softer shale less dense in topography may be prone to accelerated

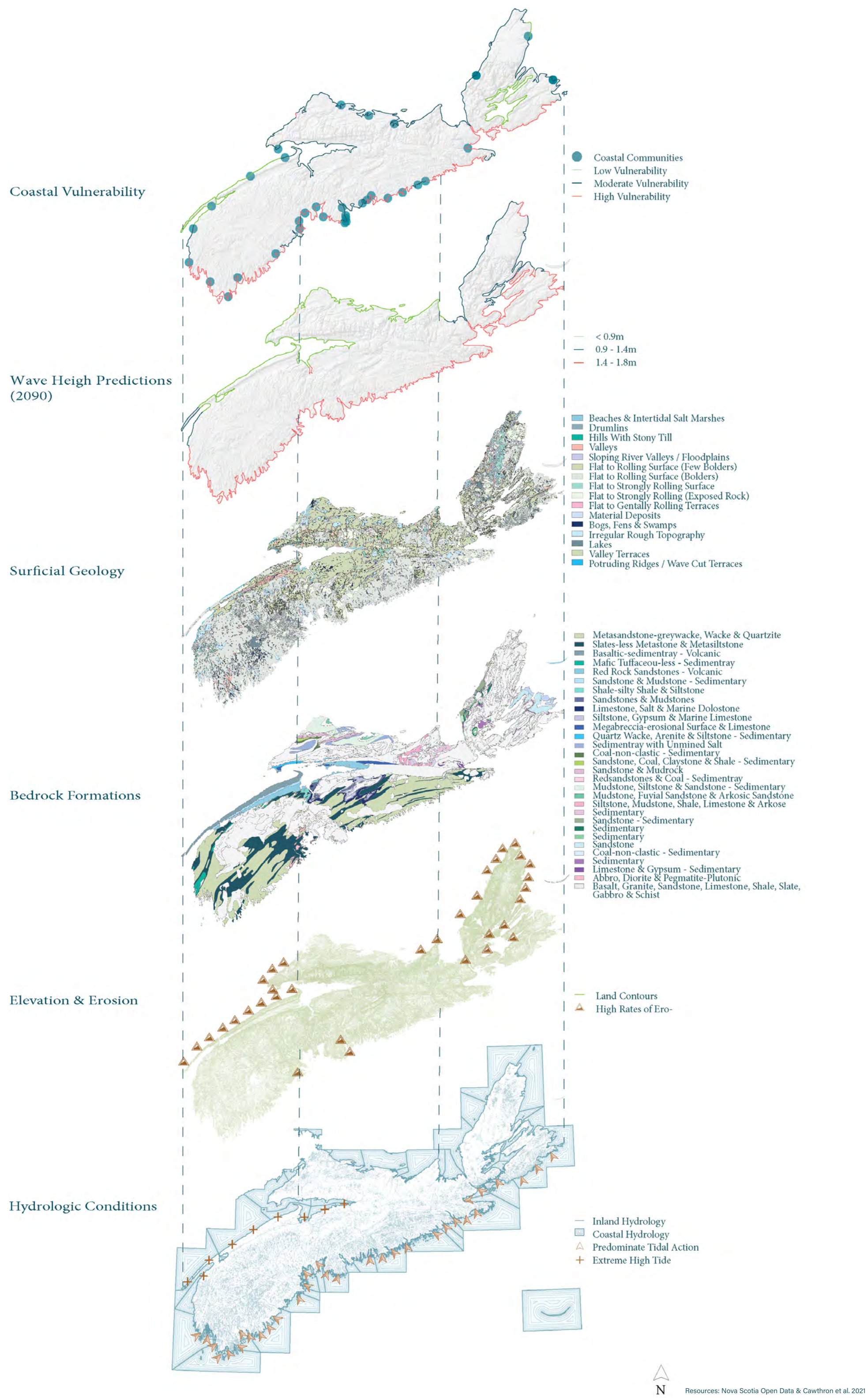


Illustration of Nova Scotia's natural landscape features (hydrology, topography, and geology), 2090 wave height predictions and their relation to coastal vulnerability in local coastal communities (Data from Nova Scotia Open Data).

erosion and sediment transport (Fensome and Williams 2022, 113). Understanding wave height predications and the hardness of the bedrock is crucial for assessing coastal resilience as it helps to provide a basis for strategies to mitigate erosion, stabilize cliffs, and protect infrastructure along the coastline. Thus, Neil's Harbour provides an ideal case study, highlighting the intricate interplay between geological composition and coastal erosion dynamics. Emphasizing the need for comprehensive mitigation strategies to protect coastal communities and ecosystems against the imminent threat of erosion.

Turtle Grove a traditional Mi'kmaq settlement along Nova Scotia's Eastern shore (CBC/Radio 2016).

Cultural Landscape

The province's cultural landscapes illustrates the evolution of human society and settlement over time. Cultivation of Nova Scotia's coastal landscapes began thousands of years ago with the Mi'kmaq people (Government of Nova Scotia 2022). The Mi'kmaq people dispersed traditional settlements strategically across the province based on resource availability for survival. Coastal landscapes provided the Mi'kmaq with food sources, access to water, and means of transportation for trade (Government of Nova Scotia 2022). Increased cultivation of coastal landscapes occurred over three hundred years from the 1600s to the 1900s as European colonization took place (MacLeod 1995, 1). Europeans were drawn to the province's coastal regions for their implicit resources, initiating the densification of small coastal settlements and evolving them into coastal communities and further implementing cultivation due to economic land relations, creating a capitalist social division, and reshaping coastal landscapes.

European Colonization along Nova Scotia's South Shore (Nova Scotia Archives 2022).

Industrialization began to occur with increased migration and industrial industries like shipbuilding and mining were introduced. The earliest record of industrial shipbuilding occurred in 1605 in Port Royal (Allaby 1973). Substantial population increases occurred in the late 1700's and early 1800's. Larger scale ship building became necessary to export plentiful timber resources and fish and fur trade excelled, further cultivating coastal landscapes as port communities were developed on the Province's South East and South West shores (Allaby 1973). In addition, the rapid development of coal mining began in the 1880's, as Canada's first steel plant was constructed in Sydney, NS, leading to a massive influx of immigration (MacLeod 1995, 147). Mining communities were developed on coastal lands near mining sites, and extreme land cultivation occurred, severely impacting the natural landscape and exploiting the

Irving Ship Building, Halifax's operational shipyard since 1889 (Irving Shipbuilding Inc.)

Aerial view capturing the urban landscape of Sydney, Nova Scotia, once recognized as Membertouk, a historical Mi'kmaq coastal settlement nestled along the eastern shores of Cape Breton Island, Nova Scotia (North Sydney 2019).

In contrast, nearing the end of the eighteenth century, the preference for a cultivated and human-dominated landscape was challenged (MacLeod 1995, 14). Thus, the idea of "rustic" living as a reaction against wars, economic depression, and urban society's stress came with anti-modernism sentiments arising in the 1920's (MacLeod 1995, 14). Nova Scotia's rugged coastlines became interesting landscapes not only for economic benefit but also for recreational use as they were aesthetic. Dispersing density of coastal communities across the province, leaving the three types of coastal landscapes seen in the province today; natural landscapes, working waterfronts and coastal settlements.

Hand netting a tradition commercial fishing method prior to the 1900s (Nova Scotia Archives 2020a).

Simultaneously, Nova Scotia's seafood industry has significantly contributed to the development of the province's cultural landscape. Dating back hundreds of years, the Mi'kmaq people acknowledged that the coastline provided an abundance of marine resources, initiating the development of strategic coastal settlements and the province's longstanding tradition of fishing and seafood harvesting (Pisces 2022, 1). During the early colonial period of the 1600-1800s, fishing became a vital economic activity for growing coastal settlements. Nova Scotia's coasts provided abundant populations of fish, particularly cod, creating a lucrative economy (MacLeod 1995, 10). Salted cod became a major export commodity, creating sustainable trade relationships with Europe and the Caribbean (MacLeod 1995, 176). Following the peak of colonization efforts, commercial aquaculture was introduced in the 1800s in American oyster farming, followed by a federal hatchery program to enhance wild salmon stocks (Kraly 2013).

Drying cod fish 1950 (Collier 1950).

Fishing wharf 1950 (Collier 1950).

By the 1900s, coastal settlements had transformed into more structured and interconnected communities shaped by economic, technological, social, and governmental factors (MacLeod 1995, 180). After significant changes in the cultural landscape, Nova Scotia's fishing industry expanded with technological innovations, economic shifts, and environmental considerations. Advances in fishing gear, such as trawl nets and longlines, coupled with the introduction of the railway and steamships during the Industrial Revolution, significantly increased the efficiency of harvesting operations and facilitated more efficient means of transportation for seafood to markets, continuing to boost the seafood industry's growth (MacLeod 1995, 23). Cold storage, refrigeration, canning, and freezing technologies also revolutionized seafood preservation and distribution. New technologies led to the establishment of land-based commercial fishing plants and commercial aquaculture facilities, expanding the industry's capacity to meet growing demand.

Hauling in fishing net 1951 (Collier 1950).

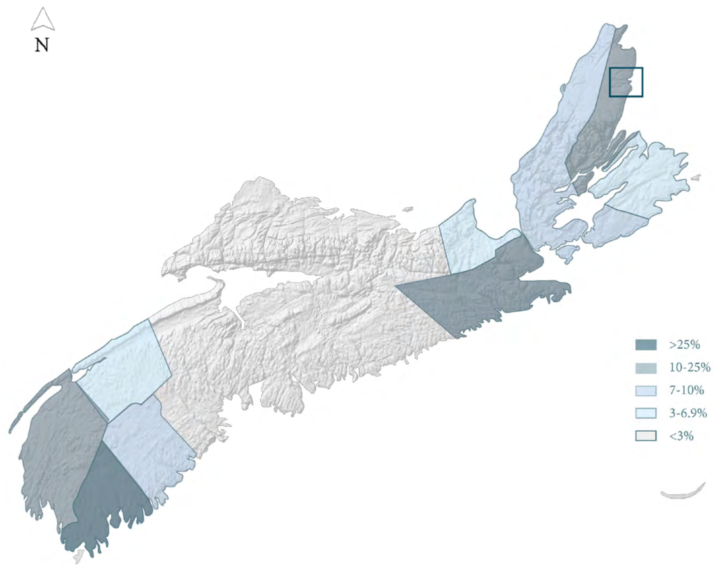
Vessels and wharves in Bridgewater, Nova Scotia, including the steamer that ran from Bridgewater to Halifax (Nova Scotia Archives 2020b)

Urban salmon aquaculture farm at Rattling Beach, Nova Scotia (Fishfarming Expert 2020).

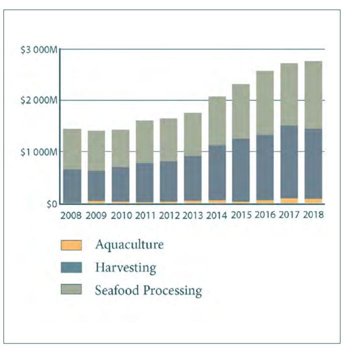
Improved transportation infrastructure and globalization facilitated the worldwide seafood trade (MacLeod 1995, 180). Initiating a substantial industry for lobster fishing in Nova Scotia during the 19th century marked a shift in the perception of lobster from a lower-class food to a sought-after commodity. Lobsters were originally abundant in the region and were not highly valued until increased trade introduced the shellfish species into a new global market, elevating its status and transforming lobster into a high-class delicacy (Pisces 2022, 69). In addition, the aquaculture industry witnessed notable strides, encompassing the establishment of salmon farming sites, the growth of American oyster farming, the initiation of the European oyster trade, the introduction of mussel farming, controlled fish egg hatching pioneered by the Department of Fisheries and Oceans, the establishment of the Aquaculture Act, the harvest of farmed salmon, the issuance of the first provincial lease, the introduction of the initial finfish specified lease, the first reported statistics on farmed scallops, and the introduction of the first recirculation hatchery (Kraly 2013).

The 20th century saw continued development, with the rise of modern fishing techniques and the establishment of fish processing plants along the coast. However, the industry faced challenges, including fluctuations in fish stocks, environmental concerns, and changes in international markets. In recent decades, there has been a more significant shift towards sustainability and responsible fishing practices (Pisces 2022, 37). Nova Scotia's seafood industry has diversified to include a variety of species beyond cod and lobster in the global market, and aquaculture has also gained importance and developed a platform for land-based farming, contributing to the province's reputation for high-quality seafood (Kraly 2013).

Today, it has been acknowledged that Nova Scotia's seafood industry is pivotal in shaping the social, cultural, and economic landscapes of Nova Scotia, as local commercial harvesting facilities and businesses serve as a fundamental foundation for the sustained success and prosperity of the province's rural coastal communities (Pisces 2022, 2). The fishing and aquaculture industries alone employed 18,973 people in Nova Scotia in 2019 and supported another 5,479 jobs in the seafood processing industry (Pisces 2022, 9). In addition, Nova Scotia has been Canada's seafood leader for years, with an annual value of $2.8 billion in 2018 -the largest by any metric in Canada (Pisces 2022, 4). In 2018, Nova Scotia's seafood industry contributed $1.6 billion to the provincial economy, including direct production and indirect impacts such as supply chain purchases and employees spending wages on other goods (Pisces 2022, 5).



Depiction of Nova Scotia’s seafood industry as a percent of total country employment, 2019 (Pisces 2022).



Nova Scotia seafood industry exports in millions, divided into the three integral sectors: aquaculture, harvesting, and seafood processing, 2018 (Pisces 2022, 4).

This modernized industry current comprises three integral sectors: aquaculture, harvesting, and seafood processing. The strategic division of sectors into aquaculture, harvesting, and seafood processing sectors offers advantages such as specialization, effective management, targeted regulation, improved economic analysis, improved supply chain coordination, opportunities for innovation, and enhanced community engagement (Pisces 2022, 4). In addition , the economic value provided by the seafood industry is primarily driven by exports, which have shown impressive growth over the past ten years. These exports have been increasing the value of the seafood industry over time and bringing prosperity to local businesses, employees, and communities (Pisces 2022, 12). Seafood exports are additionally divided into the sectors of shellfish, groundfish, pelagics, and marine plants due to their cultural significances tied to catch methods and regional traditions.

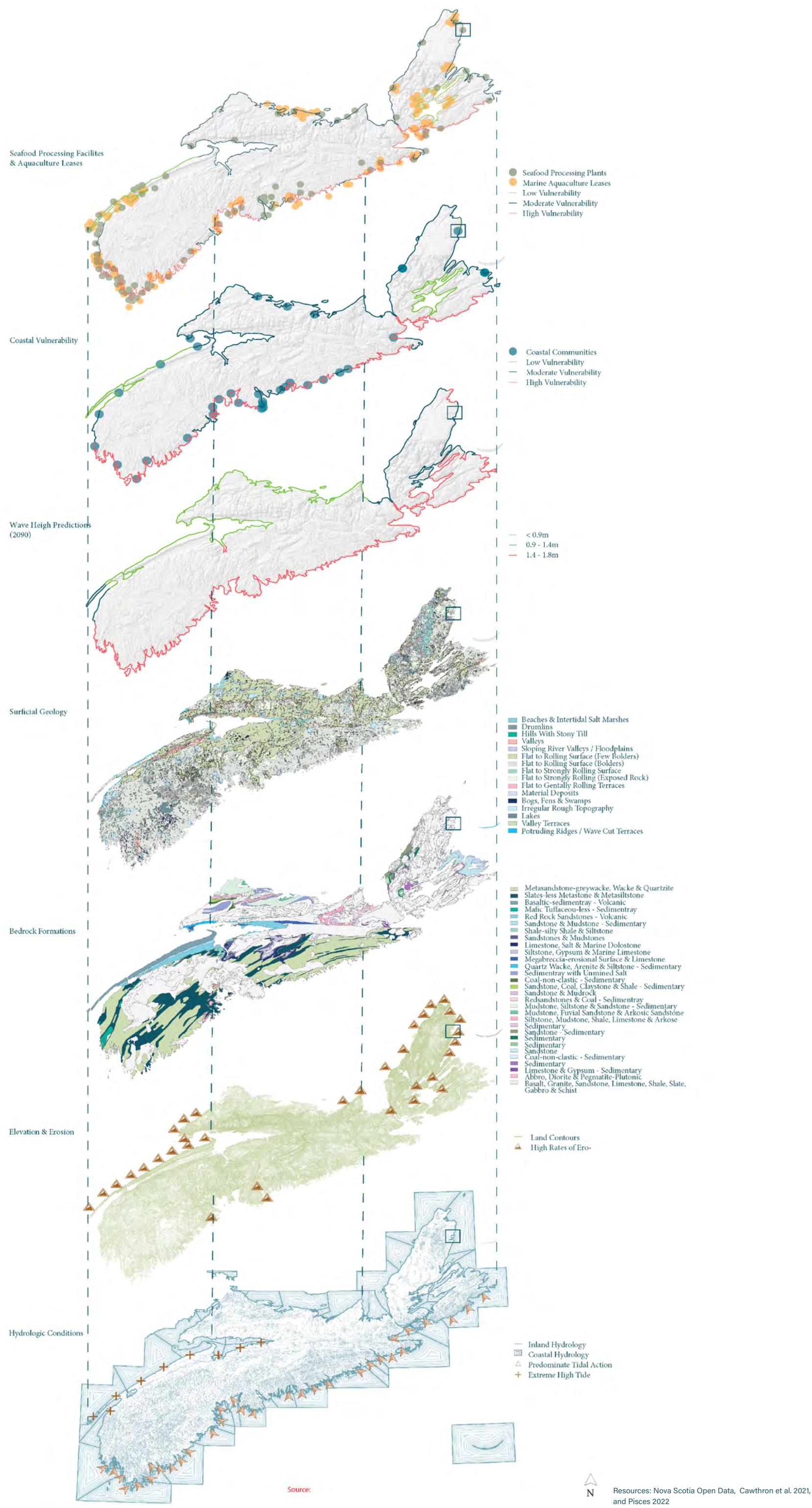
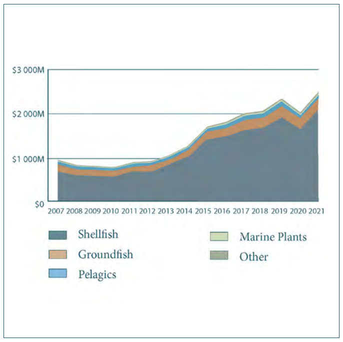


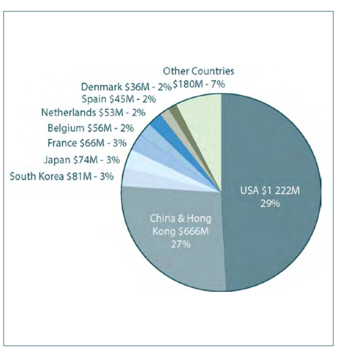
Illustration of Nova Scotia’s natural landscape features (hydrology, topography, and geology) alongside future projections for wave heights in 2090, aiming to establish a connection between these dynamic elements and their impact on coastal vulnerability and resilience of active seafood processing plants and aquaculture facilities situated in the region’s local coastal communities -highlighting Neil’s Harbour (Data from Nova Scotia Open Data).



Nova Scotia seafood industry exports in millions, indicating sectors of shellfish, groundfish, pelagics, and marine plants, 2021 (Pisces 2022, 4).

Each sector represents a distinct category of marine resources and fishing practices, reflecting the diversity of the province's coastal culture. Shellfish, including lobster and crab, often involves traditional trapping methods and is central to many coastal communities' identity and livelihoods. Groundfish, like cod and haddock, may involve more traditional fishing techniques and is historically significant in Nova Scotia's fishing heritage. Pelagic species, such as mackerel and herring, often involve different catch methods like netting and have their own cultural importance. Marine plants, including seaweed, may represent a connection to traditional uses in local cuisine or other cultural practices. By categorizing exports into these sectors, Nova Scotia acknowledges and preserves the rich cultural tapestry woven into its fishing traditions and methods.

Overall exports highlight international success and local innovation that has transformed the industry, providing new opportunities (especially for youth) to secure higher-paying jobs in the modernizing industry. In 2021, Shellfish (mainly lobster) dominated Nova Scotia's exports, representing 84% of total export value, helping to increase employment opportunities and revenue in local communities (Pisces 2022, 72). The seafood industry remains a vital component of the provincial economy, providing employment and contributing to the cultural identity of coastal communities and continues to evolve, adapting to changing environmental conditions, market demands, and conservation efforts to ensure the long-term viability of Nova Scotia's rich maritime heritage. Neil's Harbours local fish plants, commercial harvesting facilities and associated businesses make up over 25% of regional employment, serving as a fundamental foundation for the sustained success and prosperity of the community..



Nova Scotia seafood exports in millions, 2021 (Pisces 2022,13).

Ecology of the Nearshore Zone

The biological features of the marine environments surrounding coastal landscapes are particularly notable as they support an abundant variety of life. Ranging from the tiniest single-celled plankton to the largest animal on earth, the blue whale. Providing numerous examples of systematic approaches to dealing with hydrodynamics and allocating a basis to derive architectural solution from. The nearshore region exhibits the most tidal action and creates the landward boundary from the oceanic region. Organisms that inhabit the nearshore region are divided into three broad categories, plankton, nekton, and benthos species. Plankton are buoyant microscopic organisms that float nearthe oceans surface as they are unable to swim and require a sufficient amount of sunlight to photosynthesize (Tait and Dipper 1998, 23). Nekton are the more powerful swimming animals, vertebrates and cephalopods, that are capable of travelling from one place to another independent from the flow of the water (Tait and Dipper 1998, 23). Benthos species are animals, which live on or hover slightly above the sea floor.

Ecology of Nova Scotia's nearshore zone, Polly's Margaret's Bay, Nova Scotia, 2024.

The biological features of the marine environments surrounding coastal landscapes are particularly notable as they support an abundant variety of life. Ranging from the tiniest single-celled plankton to the largest animal on earth, the blue whale. These marine species provide numerous examples of systematic approaches to dealing with hydrodynamics and allocating a basis to derive architectural solutions. The nearshore region exhibits the most tidal action and creates the landward boundary from the oceanic region. Organisms within the nearshore region are divided into three broad categories: plankton, nekton, and benthos

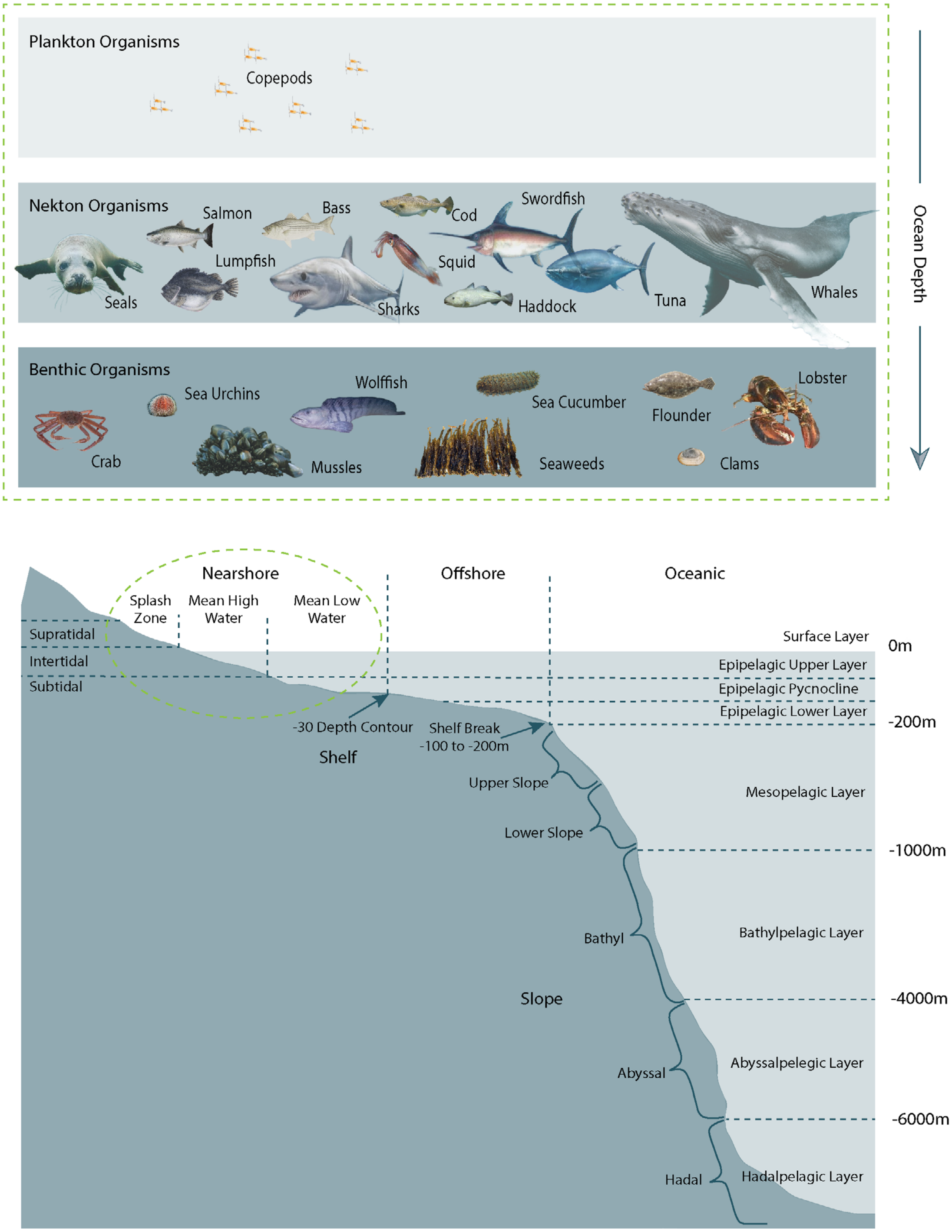


Illustration outlining examples of organisms found within the nearshore region are divided into three broad categories: plankton, nekton, and benthos species. Indicating a range of water depths where these species are found (Data from Harvey-Clark 2021).

species. Plankton are buoyant microscopic organisms that float near the ocean's surface as they cannot swim and require sufficient sunlight to photosynthesize (Tait and Dipper 1998, 23). Nekton are the more powerful swimming animals; vertebrates and cephalopods can travel from one place to another independent of the flow of the water (Tait and Dipper 1998, 23). Benthos species live on or hover slightly above the sea floor (Tait and Dipper 1998, 23).

Local marine mammal, whale (Whale Watching 2023).

Further categorization of species into marine mammals, cartilaginous fish, fish, cephalopods, invertebrates, seaweeds, and birds provides a thorough understanding of the diverse ecosystems within the marine environment. Each category represents a distinct group of organisms with unique ecological characteristics, roles, and behaviours. Marine mammals are warm-blooded vertebrates adapted for life in water that play a crucial role in marine food webs and contribute to the overall health of ocean ecosystems (Harvey-Clark 2021). Cartilaginous fish, defined by their unique skeletons made of cartilage, contribute to the balance of fish populations and often control ecosystem dynamics, additionally playing a crucial role in marine food webs and contributing to the overall health of ocean ecosystems (Harvey-Clark 2021). Fish exhibit scales and gills and play a significant role in marine ecosystems by contributing to biodiversity, nutrient cycling, economic livelihoods, and cultural traditions, serving as indicators of ecosystem health (Harvey-Clark 2021). Cephalopods, characterized by soft bodies and tentacles, provide an important food source for many marine species. Invertebrates lack a backbone and are vital for nutrient cycling and provide food for various predators (Harvey-Clark 2021). Seaweeds contribute to coastal ecosystem stability and provide habitats for

Local cartilaginous fish, great white shark (Harvey-Clark 2021).

Local fish, cod (Harvey-Clark 2021).

Local benthic fish, Atlantic Wolf Fish (Harvey-Clark 2021).

Local invertebrate, crab (Harvey-Clark 2021).

Local seaweed, kelp (Harvey-Clark 2021).

numerous marine organisms (Harvey-Clark 2021). Birds, both coastal and migratory, warm-blooded and feathered, are indicators of ecosystem health and contribute to nutrient cycling (Birds of Nova Scotia n.d). The categorization allows researchers, conservationists, and policymakers to target specific conservation efforts and management strategies tailored to the needs of each group, ensuring the overall health and sustainability of marine ecosystems.

Among the diverse marine mammals in Nova Scotia's nearshore zone are gray seals, harp seals, various whale species, the white-sided dolphin and the porpoise, all classified as nekton (Harvey-Clark 2021). Various cartilaginous fish, mainly sharks, including common migratory species like the Porbeagle, Manok and Great white, also fall into the nekton category (Harvey-Clark 2021). Local finfish, including Atlantic Mackerel, Pollock, American Eel, bass, tuna, haddock, and halibut, among other species, and cephalopods, including squid, are additionally classified as nekton (Harvey-Clark 2021). Other fish species, such as Atlantic cod, herring, and salmon, alongside invertebrates like lobster, oysters, muscles, crabs, and sea scallops, are classified as nekton and benthos species (Harvey-Clark 2021). In addition, various seaweeds like sugar kelp and dulse are part of the benthos category (Harvey-Clark 2021). Local bird species, including coastal ducks, puffins, herring gulls, and razorbills, are also considered nekton (Birds of Nova Scotia n.d). This diverse array of species across plankton, nekton, and benthos contributes to the vibrant and complex marine ecosystems shaping Nova Scotia's coastal natural landscapes.

However, the nearshore ecology plays a multifaceted and crucial role in sustaining coastal communities and contributing

Species of the Nearshore - Offshore Zones

Marine Mammals:
Gray Seal (Halichoerus grypus)
Harp Seal (Pagophilus groenlandicus)
Minke Whale (Balaenoptera acutorostrata)
Humpback Whale (Megaptera novaeangliae)
Sperm Whale (Physeter macrocephalus)
Northern Right Whale (Eubalaena glacialis)
Pilot Whale (Various species)
White-sided Dolphin (Lagenorhynchus acutus)
Porpoise (Phocoena Phocoena)

Cartilaginous Fish:
Great White Shark (Carcharodon carcharias)
Mako Shark (Isurus oxyrinchus)
Porbeagle Shark (Lamna nasus)
Blue Shark (Prionace glauca)
Thresher Shark (Alopias vulpinus)
Dogfish Shark (Various species)
Basking Shark (Cetorhinus maximus)
Greenland Shark (Somniosus microcephalus)

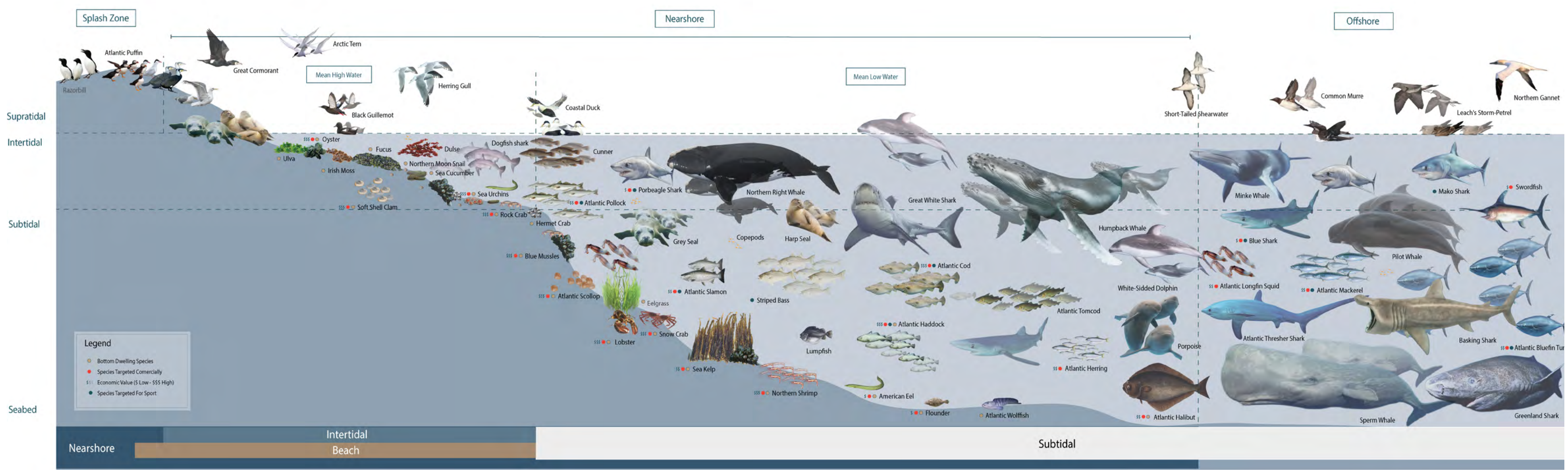
Fish:
Atlantic Cod (Gadus morhua)
Atlantic Herring (Clupea harengus)
Atlantic Mackerel (Scomber scombrus)
Pollock (Pollachius pollachius)
American Eel (Anguilla rostrata)
Atlantic Salmon (Salmo salar)
Flounder (Various species)
Striped Bass (Morone saxatilis)
Atlantic Wolffish (Anarhichas lupus)
Cunner (Tautogolabrus adspersus)
Atlantic Tomcod (Microgadus tomcod)
Lumpfish (Cyclopterus lumpus)
Atlantic Haddock (Melanogrammus aeglefinus)
Atlantic Bluefin Tuna (Thunnus thynnus)
Swordfish (Xiphias gladius)
Atlantic Halibut (Hippoglossus Hippoglossus)

Cephalopods:
Atlantic Longfin Squid (Doryteuthis pealeii)

Invertebrates:
Oyster (Crassostrea)
Blue Mussel (Mytilus edulis)
Soft-Shell Clam (Mya arenaria)
Snow Crab (Chionoecetes opilio)
Lobster (Homarus americanus)
Atlantic Sea Scallop (Placopecten magellanicus)
Northern Shrimp (Pandalus borealis)
Hermit Crab (Various species)
Rock Crab (Cancer irroratus)
Sea Urchin (Strongylocentrotus droebachiensis)
Northern Moon Snail (Euspira heros)
Sea Cucumber (Various species)
Copepods (Various species)

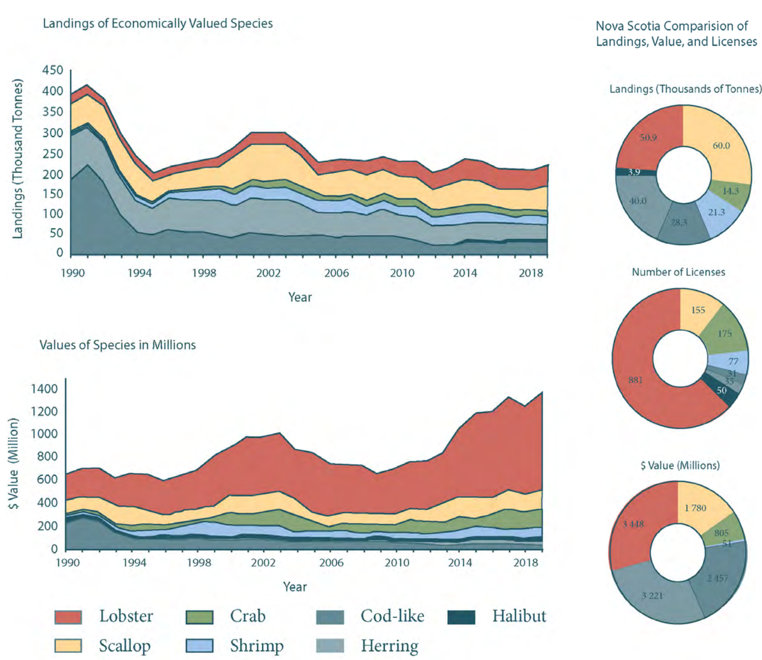
Seaweeds:
Sugar Kelp (Saccharina latissima)
Eelgrass (Zostera marina)
Dulse (Palmaria palmata)
Irish Moss (Chondrus crispus)
Alaria (Alaria esculenta)
Fucus (Various species)
Ulva (Various species)

Birds:
Coastal Duck (Somateria mollissima)
Black Guillemot (Cepphus grylle)
Atlantic Puffin (Fratercula arctica)
Great Cormorant (Phalacrocorax carbo)
Herring Gull (Larus argentatus)
Razorbill (Alca torda)
Leach's Storm-Petrel (Oceanodroma leucorhoa)
Arctic Tern (Sterna paradisaea)
Common Murre (Uria aalge)
Short-Tailed Shearwater (Ardenna tenuirostris)
Northern Gannet (Morus bassanus)



Exploring Nova Scotia's Nearshore Ecology: A vibrant illustration showcasing the diverse relationships among marine species. Highlighting the intricate relationships among marine species the illustration captures the essence of Nova Scotia's coastal ecosystem. Providing a guide to discover the dynamic interactions between species crucial for local fisheries and the delicate balance of the nearshore environment. The visual narrative emphasizes the range of habitats, from the benthic realm to the open water column, providing a comprehensive overview of the diverse marine life within the region (Data from Harvey-Clark 2021).

to their cultural landscape. Rich in fish and invertebrate species, these habitats are essential for local fisheries, supporting the foundation of local diets and contributing to food security and economic sustainability (Charles 2001). In addition, coastlines serve as nursery grounds for various marine species, which are crucial in sustaining healthy fish populations (Charles 2001). The economic importance of Nova Scotia's nearshore ecology to local communities is evident through data on landings, value, and licensing for key marine fisheries. The significant contributions of species like lobster, sea scallop, snow crab, and others underscore the economic impact of these fisheries (Cawthron et al. 2021, 16). Showcasing that the fishing industry is thriving while emphasizes the vital role that nearshore resources play in sustaining livelihoods, supporting local economies, and contributing to the economic resilience of Nova Scotia's coastal communities.



Charts showing value of fish caught in Nova Scotia from 1990 to 2018, including popular species like lobster, scallop, crab, shrimp, herring, halibut, and others (Charles 2001).

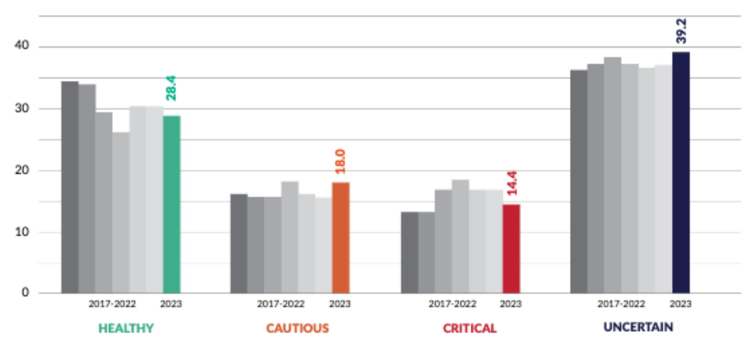
Furthermore, the high biodiversity in these ecosystems provides cultural and traditional significance, enriches the environment and connects communities to their heritage. Providing opportunities for research, education, and economic activities like aquaculture, offering additional sources of income (Charles 2001). The resilience of coastal communities to climate change is also enhanced when supported by healthy nearshore ecosystems, which act as natural defences against climate-related challenges. Thus, the significance of nearshore ecology extends far beyond its ecological role, shaping the diverse aspects of coastal community life.

Local marine fishers in Nova Scotia target a variety of finfish and shellfish species for various commercial and recreational purposes. Atlantic Cod holds historical significance among the finfish species and has been a crucial commercial fish, although populations have faced recent challenges (Pisces 2022). Haddock, another valuable whitefish, is often found alongside cod, while Pollock is targeted for both domestic consumption and export (Pisces 2022). Atlantic Salmon is caught for commercial and recreational purposes, and tuna species, including Bluefin, are popular targets for sport fishing offshore. Atlantic Herring serves as bait and is processed for various seafood products, and Mackerel is harvested for its meat. Swordfish, sharks (such as blue and porbeagle), and American eels are also caught for various purposes.

In the shellfish category, lobster stands out as one of the most valuable species targeted by Nova Scotia fishermen (Pisces 2022). Followed by snow crabs and other popular harvesting species, including clams, scallops and blue mussels cultivated in various areas. Nova Scotia is also known for its oyster production, with varieties of oysters gaining global recognition for their quality (Pisces 2022). In addition, sea urchins are harvested for their roe. The targeted species reflect the rich marine biodiversity of Nova Scotia and support both the economic activities and cultural practices of local communities.

Climatic Impact on Marine Ecology

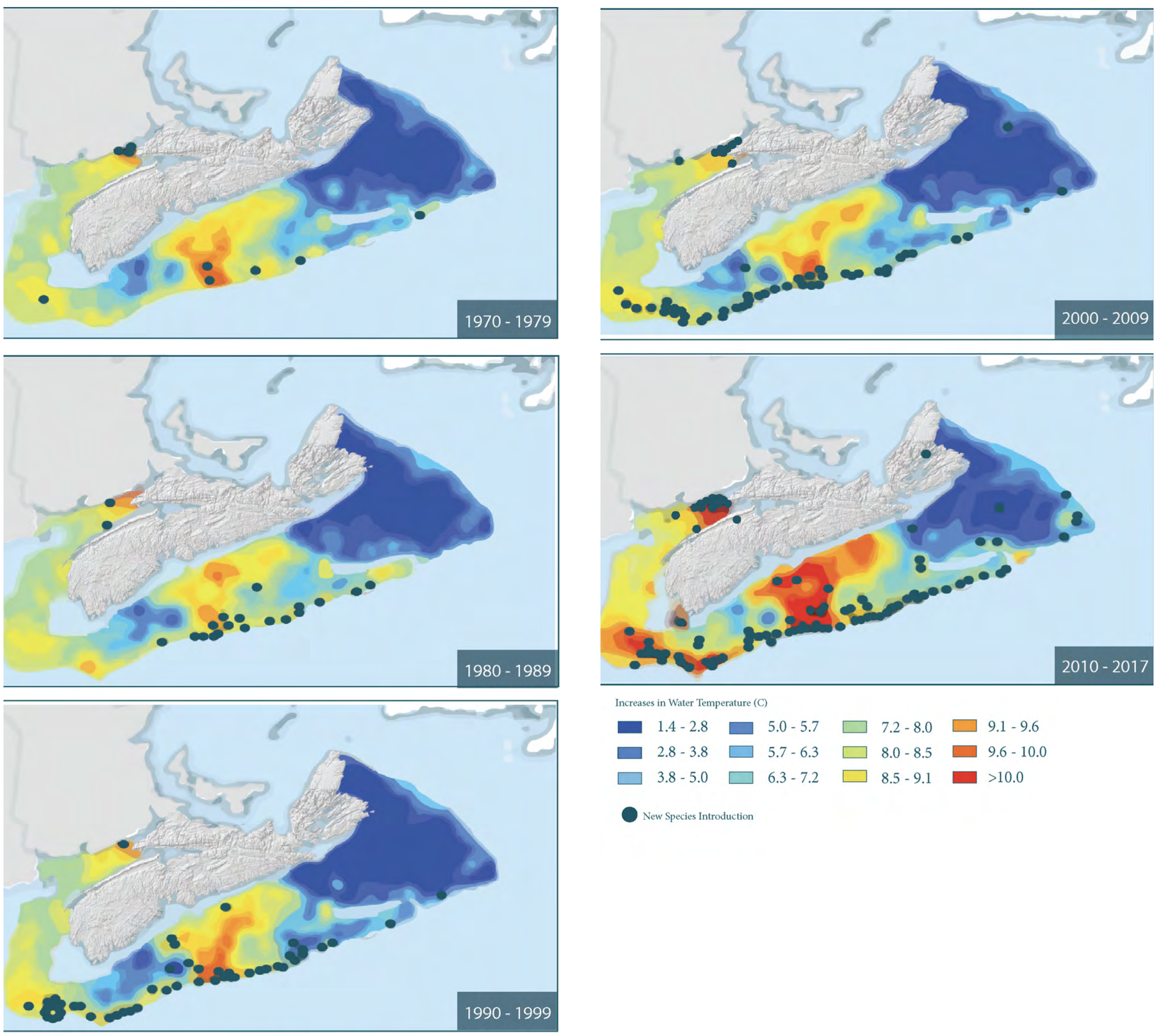
In the context of recent assessments of the Canadian fish stocks, minimal change has been observed in Canadian waters over the last several years, suggesting a relatively stable condition in the overall health and abundance of specific fish stocks (Oceana 2023, 5). However, the Northwest Atlantic is experiencing an increase in ocean temperatures, leading to more frequent and prolonged marine heatwaves-extreme prolonged oceanic water warming events (DFO 2018, 34). These warming trends pose challenges to the fishing industry, as marine organisms are typically adapted



Divisions of assessment for fish stock health. “Healthy” indicates stocks that are thriving and sustainably managed. “Cautious” suggests that the stocks are not in immediate danger but require careful monitoring and management. “Critical” signifies stocks that are at a concerning level, with urgent measures needed to prevent further decline. “Uncertain” category is used when there is insufficient data to confidently determine the status of the fish stocks. This assessment system aids the decision making process for fisheries management and conservation groups (Oceana 2022, 5).

to specific temperature ranges and environmental conditions. The notable rise in ocean temperatures can induce shifts in the geographical distribution of species.

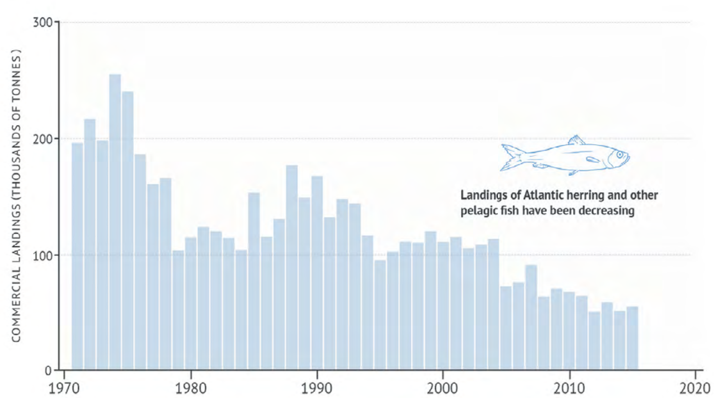
Species may migrate towards deeper or cooler waters to remain within their preferred temperature range, affecting migrational patterns, egg mortality, and broader ecological dynamics within food webs. Furthermore, ocean warming can potentially hinder the growth of certain shellfish species



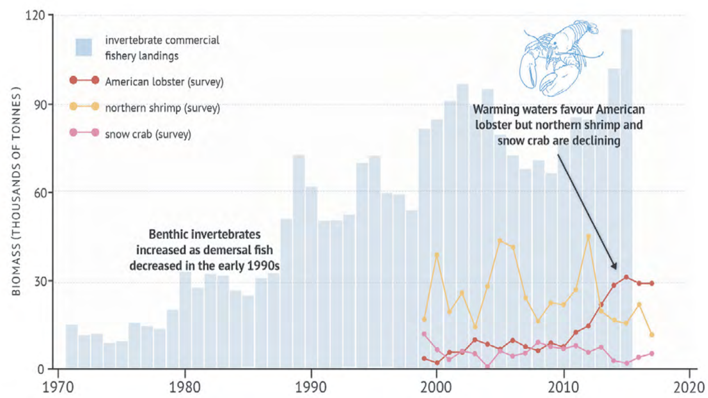
Changes in Nova Scotia’s water temperature over the past few decades are depicted alongside new sightings of warm-water species. Highlighting a recent rise in number and frequency. This environmental change can lead to alterations in biodiversity as different species adapt to new conditions, influencing the overall composition and dynamics of marine ecosystems (DFO 2018, 34).

and contribute to increased disease and parasite prevalence (Cawthron et al. 2021, 15). These changes may have repercussions for both local harvesting and the aquaculture industry. Presently, there has been a significant decline in pelagic fish observed over recent decades, attributed to these warming trends. As temperatures rise, it can alter the distribution and abundance of plankton, a crucial component of the pelagic food web. Changes in plankton populations can ripple through the ecosystem, affecting the entire pelagic community (DFO 2018, 33).

Furthermore, warmer waters may lead to shifts in the distribution patterns of fish species, influencing their migratory routes and availability in certain regions. Despite a substantial increase in the quantity and value of shellfish landings in Nova Scotia over the past three decades, with American Lobster landings reaching over 50,850 tonnes and generating over $880 million in value in 2019, studies highlight an optimal temperature range for lobster growth between 12 – 18 °C (DFO 2018, 33). If temperatures surpass this range, the risk of reduced habitat suitability and heightened disease prevalence threatens Nova Scotia’s fishing industry.



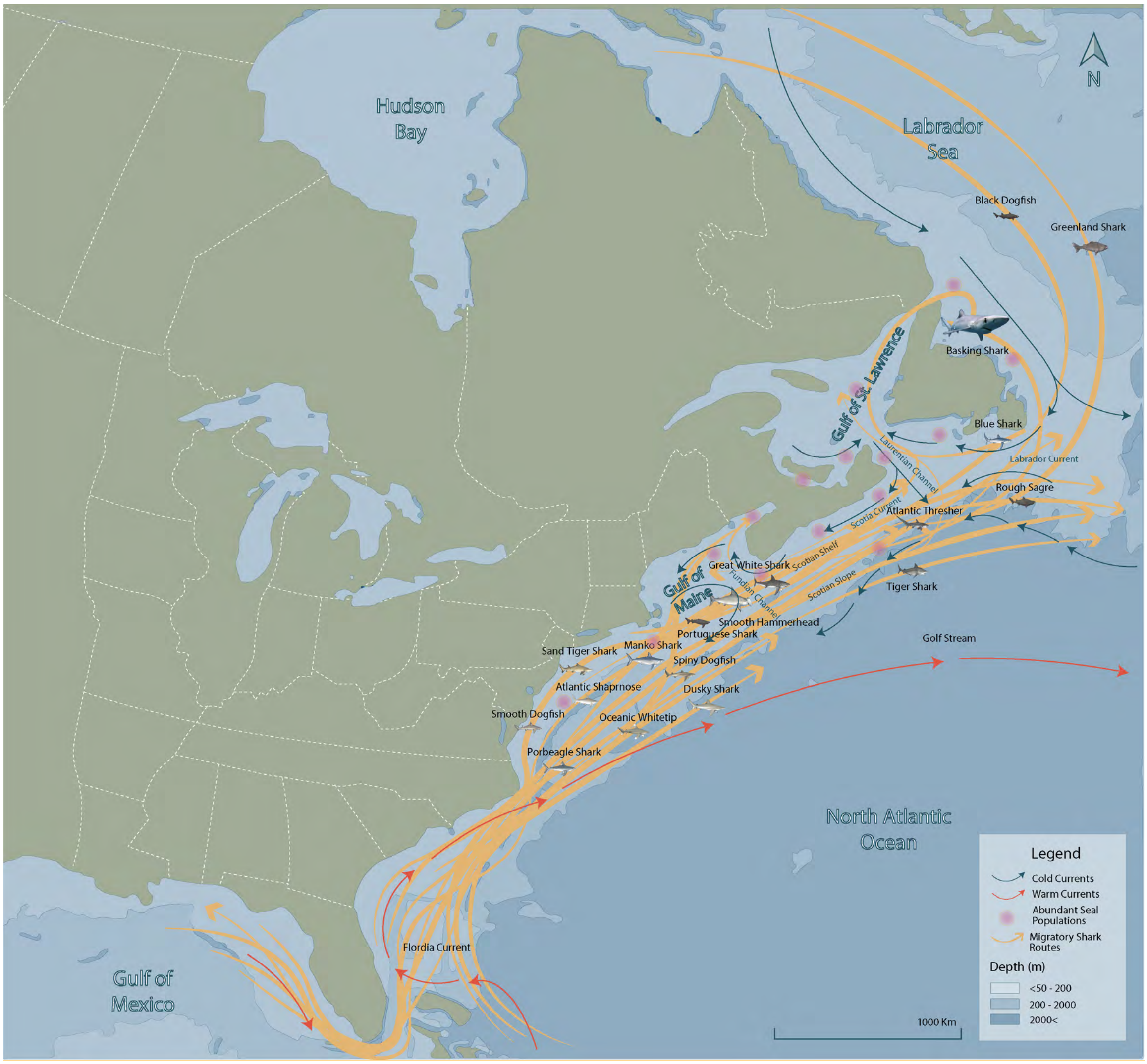
Commercial landings for pelagic fish on the Scotian Shelf illustrating a unsustainable decline in fish stock. (DFO 2018, 33).



Commercial landings for benthic invertebrate species on the Scotian Shelf exhibit a sustained upward trend. The data collection through research surveys commenced in 1999 (DFO 2018, 33).

Migratory Shark Species

These warming trends in the North Atlantic also influence the migratory patterns of various marine species. As ocean temperatures rise, migratory routes adapt, influencing a variety of species to follow the warm waters further North (Harvey-Clark 2021). This shift has influenced the integration of new species into the North Atlantic. Among these species new migratory shark species experiencing notable shifts in migration. Certain species are following the Gulf Stream from Southern States as far as Florida and North Carolina up to the Scotian Shelf as far as Newfoundland (Harvey-Clark 2021). Increasing the length of stopovers for various migratory shark species in the North Atlantic, including the Great White, Porbeagle, Blue and Spiny Dogfish. The abundant seal populations along the Scotian Shelf are additionally enticing migratory species to reside longer as they provide a sufficient food source for migratory sharks (DFO 2018, 28).



Migratory patterns of shark species including the Porbeagle, Smooth Dogfish, Oceanic White tip, Atlantic Sharpnose, Sand Tiger, Manko, Spiny Dogfish, Dusky, Portuguese, Smooth Hammer head, Great White, Tiger, Atlantic Thresher, Rough Sagre, Basking, Greenland, and the Black Dogfish through the Northwest Atlantic (Data from DFO 2021).

Although Nova Scotia has a wide range of native shark species, including the Blue Shark (Prionace glauca), Porbeagle Shark (Lamna nasus), and the Spiny Dogfish (Squalus acanthias), that are well-adapted to the cold waters of the Northwest Atlantic and have been migrating for years, new trends in ocean warming are contributing to the rich expansion of biodiversity within local shark species in marine ecosystems (DFO 2013). Rare sighting of species including that Black Dogfish, Portugese Shark, and Tiger shark have been recorded (DFO 2013). In addition to increased sightings of historically less abundant migratory populations, particularly the Great White (Bowlby and Gibson 2020). Although the magnitude of the recent population increase in species like the Great White for the Northwest Atlantic are currently uncertain, it is corroborated by various data collectors that the approximate population size has doubled from its minimum in the 1980's. Predicting a continued increase of various sharks in the Northwest Atlantic as temperatures rise (Bowlby and Gibson 2020).

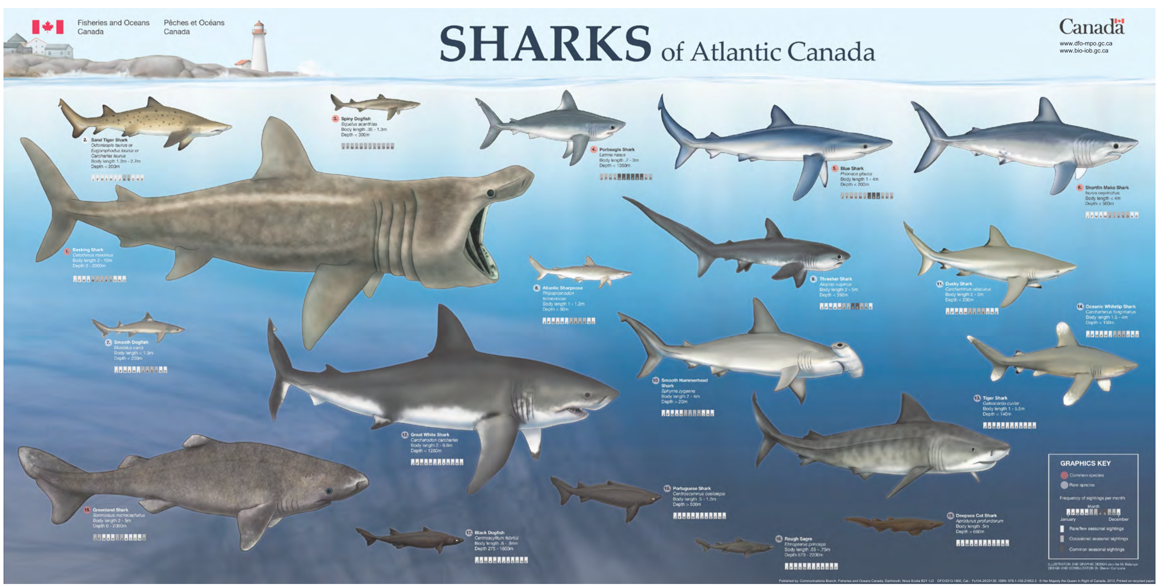


Illustration of migratory shark species to Atlantic Canada. Indicating common and rare speceis , while simultaneously noting frequency of sightings each month (DFO 2013). It can be noted that new migratory species like Great White Sharks are being seen more frequently in recent years.

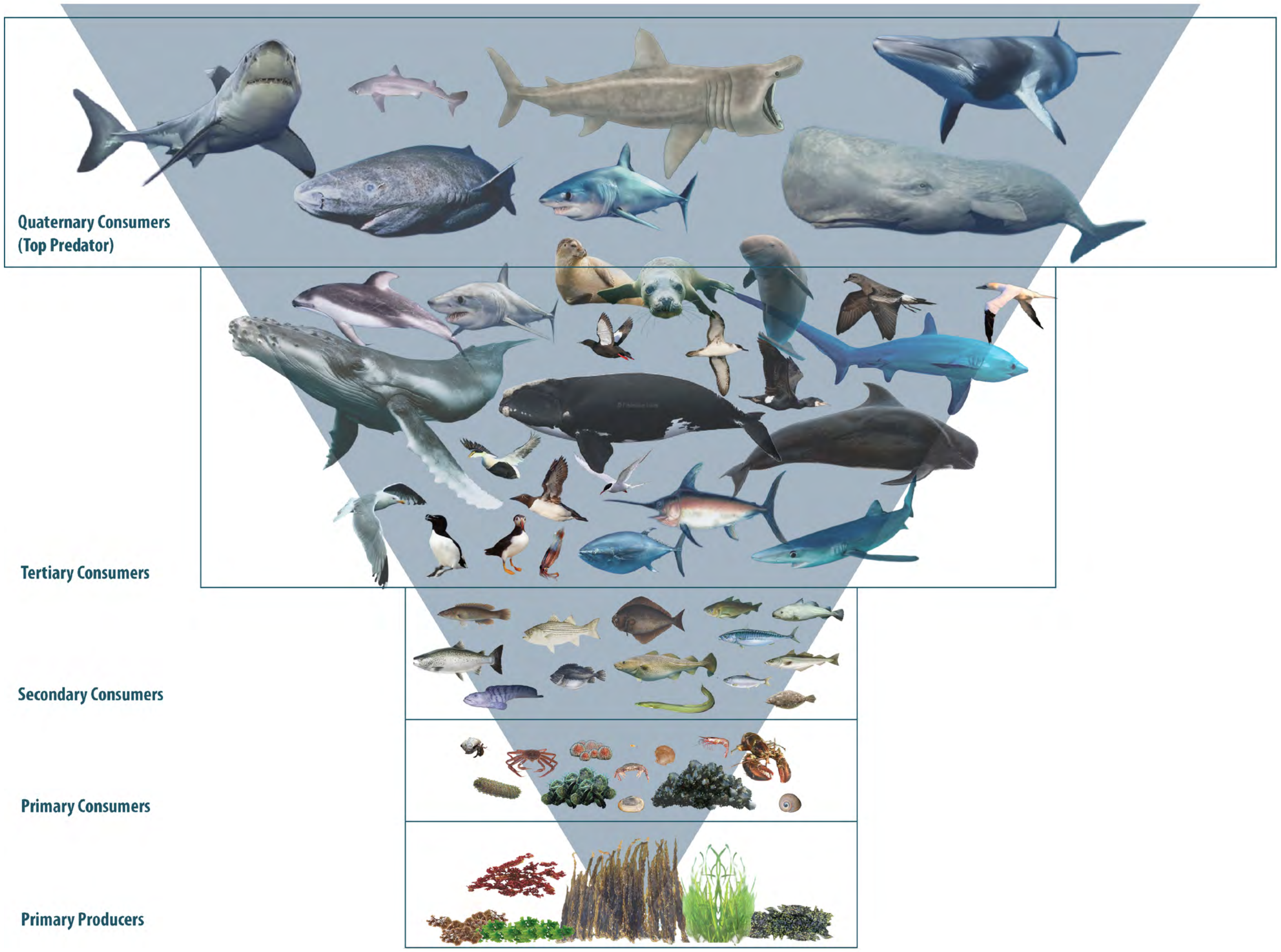
Sharks' Vital Role in the Marine Ecosystem

Sharks' are integral to marine ecosystems as they are apex predators that contribute to the ecosystem by regulating prey. Sharks' balance the local ecosystem by actively hunting larger prey species like seals and marine mammals

(Lucas and Natanson 2010). These prey patterns decrease predation pressure on smaller prey species like small fish and invertebrates, allowing them a greater chance for reproduction (Heupel et al. 2014, 293). In addition, various sharks' are categorized as scavengers and feed on dead or carrion (decaying flesh). Scavenging sharks' play a role in marine ecosystems by helping to clean up and recycle organic matter (Heupel et al. 2014, 293). Their predatory patterns are very complex compared to other large predators like whales, representing their resilience as a species.

The marine food web is a dynamic and intricate system characterized by various trophic levels. At its foundation are phytoplankton, microscopic organisms that harness sunlight to produce energy, serving as primary producers. Zooplankton and forage fish constitute the primary consumers, followed by small predatory fish and squid as secondary consumers. Tertiary consumers include large predatory fish, marine mammals, and apex predators like sharks. These organisms form a complex network of interactions, with decomposers, such as bacteria, playing a vital role in recycling nutrients. The balance and health of the marine ecosystem rely on the synergistic relationships among these diverse components, emphasizing the significance of conservation efforts to preserve this intricate web of life.

At the top of the trophic divisions, whales' and sharks' play distinct roles in the marine ecosystem, each with unique characteristics contributing to their resilience (Kiszka, Heithaus, and Wirsing 2015, 268). Whales' predominantly serve as filter feeders, using specialized structures to strain food particles from the surrounding water, meaning that they primarily consume small fish and other microscopic



Quaternary Consumers - Top Predators
Great White Shark (Carcharodon carcharias)
Mako Shark (Isurus oxyrinchus)
Dogfish Shark (Various species)
Basking Shark (Cetorhinus maximus)
Greenland Shark (Somniosus microcephalus)
Minke Whale (Balaenoptera acutorostrata)
Sperm Whale (Physeter macrocephalus)
Northern Right Whale (Eubalaena glacialis)

Tertiary Consumers
Porbeagle Shark (Lamna nasus)
Blue Shark (Prionace glauca)
Thresher Shark (Alopias vulpinus)
Gray Seal (Halichoerus grypus)
Harp Seal (Pagophilus groenlandicus)
White-sided Dolphin (Lagenorhynchus acutus)
Porpoise (Phocoena Phocoena)
Humpback Whale (Megaptera novaeangliae)
Pilot Whale (Various species)
Atlantic Bluefin Tuna (Thunnus thynnus)
Swordfish (Xiphias gladius)
Atlantic Longfin Squid (Doryteuthis pealeii)
Coastal Duck (Somateria mollissima)
Black Guillemot (Cepphus grylle)
Atlantic Puffin (Fratercula arctica)
Great Cormorant (Phalacrocorax carbo)
Herring Gull (Larus argentatus)
Razorbill (Alca torda)
Leach's Storm-Petrel (Oceanodroma leucorhoa)
Arctic Tern (Sterna paradisaea)
Common Murre (Uria aalge)
Short-Tailed Shearwater (Ardenna tenuirostris)
Northern Gannet (Morus bassanus)

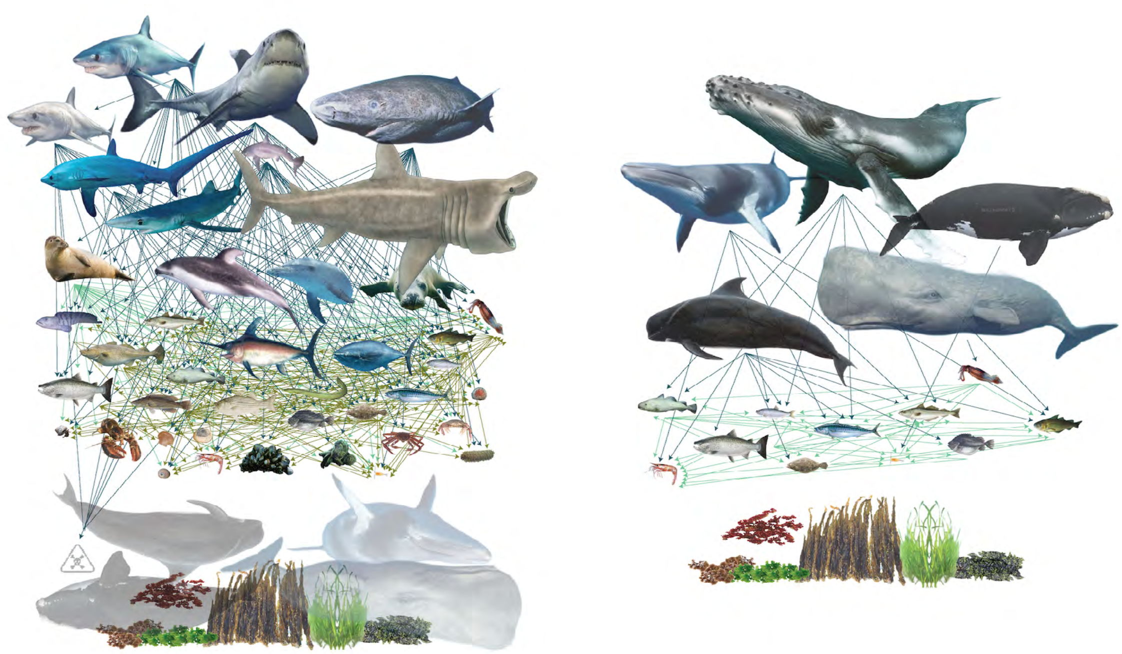
Secondary Consumers
Atlantic Cod (Gadus morhua)
Atlantic Herring (Clupea harengus)
Atlantic Mackerel (Scomber scombrus)
Pollock (Pollachius pollachius)
American Eel (Anguilla rostrata)
Atlantic Salmon (Salmo salar)
Flounder (Various species)
Striped Bass (Morone saxatilis)
Atlantic Wolffish (Anarhichas lupus)
Cunner (Tautogolabrus adspersus)
Atlantic Tomcod (Microgadus tomcod)
Lumpfish (Cyclopterus lumpus)
Atlantic Haddock (Melanogrammus aeglefinus)
Atlantic Halibut (Hippoglossus Hippoglossus)

Primary Consumers
Oyster (Crassostrea)
Blue Mussel (Mytilus edulis)
Soft-Shell Clam (Mya arenaria)
Snow Crab (Chionoecetes opilio)
Lobster (Homarus americanus)
Atlantic Sea Scallop (Placopecten magellanicus)
Northern Shrimp (Pandalus borealis)
Hermit Crab (Various species)
Rock Crab (Cancer irroratus)
Sea Urchin (Strongylocentrotus droebachiensis)
Northern Moon Snail (Euspira heros)
Sea Cucumber (Various species)
Copepods (Various species)

Primary Producers
Sugar Kelp (Saccharina latissima)
Eelgrass (Zostera marina)
Dulse (Palmaria palmata)
Irish Moss (Chondrus crispus)
Fucus (Various species)
Ulva (Various species)

Exploring the trophic divisions of Nova Scotia's Nearshore Ecology, separating primary producers, and primary, secondary, and tertiary consumers. Emphasizing sharks' as apex predators that regulate the marine ecosystem due to their resilient predatory patterns (Data from Harvey-Clark organisms as their primary food source. Their role in the marine environment is crucial for maintaining ecosystem equilibrium by moderating prey densities and dispersing nutrients via fecal plumes. In contrast, sharks' fulfill a more complex predatory role.

Sharks' serve as apex predators, exhibiting inherent resilience against other predatory species due to their adaptability and pivotal role in regulating lower trophic levels (Heupel et al. 2014, 294). They primarily consume a variety of marine organisms, ranging form larger fish line tuna to smaller fish like Atlantic herring, in addition to seals, squid, crustaceans, and other sharks. By controlling the population of larger prey species, sharks prevent overgrazing or smaller species in lower trophic divisions, maintaining ecosystem diversity and stability. In addition, some shark species are scavengers, meaning that they primarily feed on carrion or dead organisms, rather than actively hunting live prey.

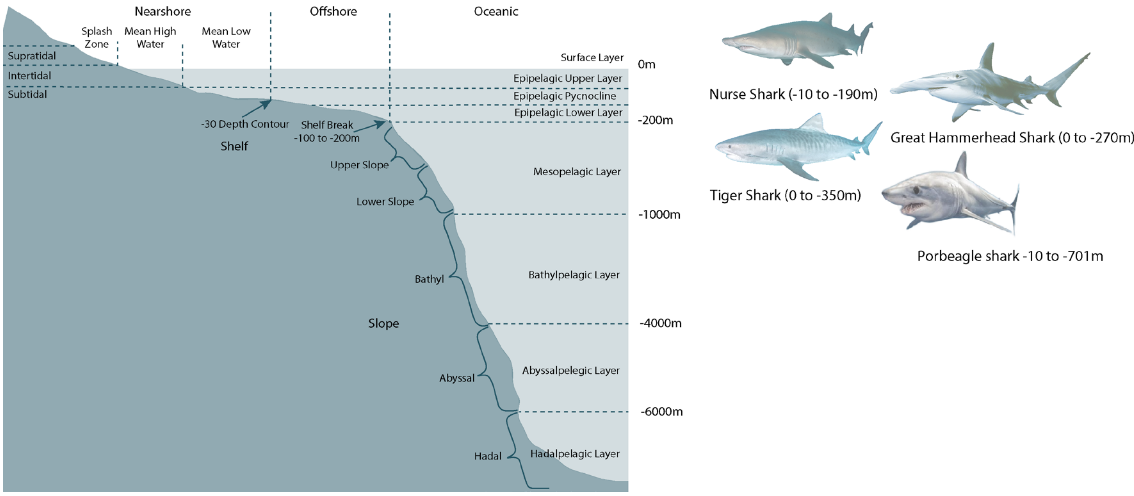


A comparison of food webs between various shark and whale species, emphasizing the complexity of the shark's food chain representing its adaptability and resilience as a species (Data from Harvey-Clark 2021).

These sharks' play an important ecological role in marine ecosystems by helping to recycle nutrients and maintain the health of the ecosystem, while preventing the spread of disease from decaying species.

Sharks' complexity and resilience over other distinct marine species like whales are additionally highlighted through their reproductive abilities. Their reproductive characteristics include faster rates of reproduction with shorter gestation periods, resulting in increased numbers of offspring, which exemplify sharks' adaptability and resilience within marine ecosystems (Heupel et al. 2014, 294).

While sharks', whales', and other marine organisms face habitat loss, pollution, and climate-related challenges, sharks demonstrate remarkable resilience through their ability to adapt to dynamic environments. Diversity among the species highlights sharks capacity to inhabit various levels of the water column based on their unique morphological characteristics and influences migratory patterns. Some shark species are renowned for their extensive migrations, while others prefer more localized movements or remain sedentary within specific habitats. In addition, these migration patterns are influenced by feeding behaviour, reproductive cycles, and environmental conditions. Thus, this thesis will focus on showcasing the robust complexities of the shark that foster its resilience as a highly intelligent inhabitant of the nearshore zone.



Sharks' are nekton species that can reside in nearshore to oceanic waters depending on the tendencies of individual shark families. Nurse shark families reside closest to the coastline in waters ranging from -10m to -190m (Data from DFO 2021).

Exploring Sharks' Resilient Timescale

The hydrodynamic performance of shark skin has been perfected through adaption over the past 450 million years. Providing evidence that the shark species has undergone countless iterations of natural selection, refining their form, structure, and behaviour for optimal performance in their coastal habitats (Shadwick and Goldbogen 2012). The timescale of sharks adapting to coastal environments is relevant to architecture as it offers insights into the successful coastal strategies proven to be adapted over millions of years of evolution. Acknowledging the structural integrity of the sharks unique form and adaption of its hydrodynamic performance to thrive in dynamic coastal environments, translating resilient design to withstand the impacts of climatic hazards like storm surges, erosion, and sea-level rise (Shadwick and Goldbogen 2012). Adaptive and resilient design relates to timescale through the practice of biomimicry as the shark as a species has grown and regenerated iterations of its unique morphological characteristics throughout the lifetime of various species, adapting to their features to changing needs. Similarly, architects can embrace adaptive and resilient design principles that allow the building to respond to evolving requirements.

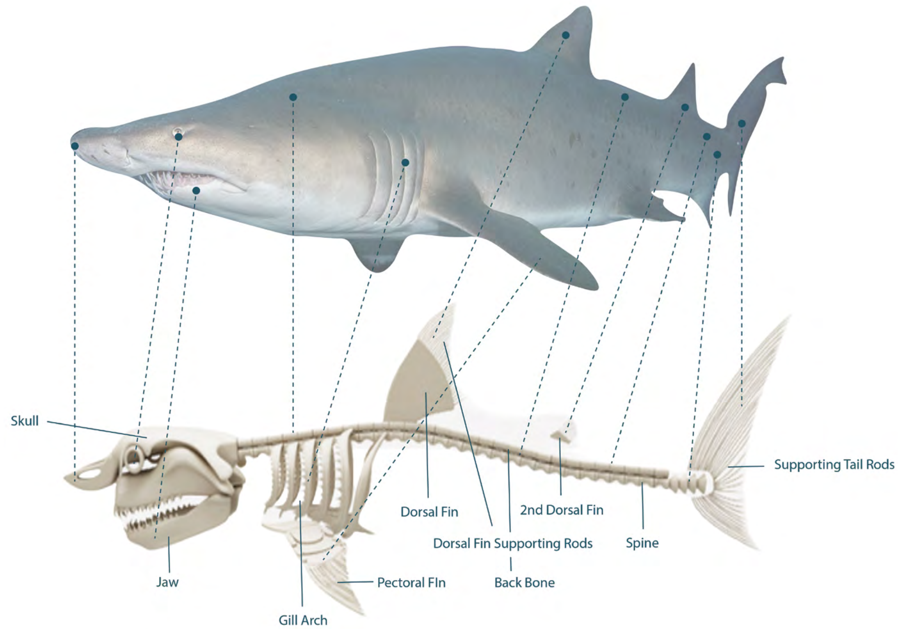
Over time biodiversity in urban coastal settlements has decreased due to the impact of implementing hard engineering solutions to protect the existing landscapes. Sharks, however, have adapted over time to coexist within coastal ecosystems. Demonstrating that architectural designs can be integrated to enhance fragile coastal environments and contributes to the ecological environment. Inspiring architects to create resilient designs that minimize ecological disruption, promote biodiversity and contribute to the overall health of coastal ecosystems. Furthermore, architects can learn from the efficiency and optimization of sharks' adaptations and create buildings that are energy-efficient, structurally robust, and environmentally responsive while aesthetically reflecting an elegant visual appeal, like that found in nature and establishing a sense of harmony with the coastal surroundings.

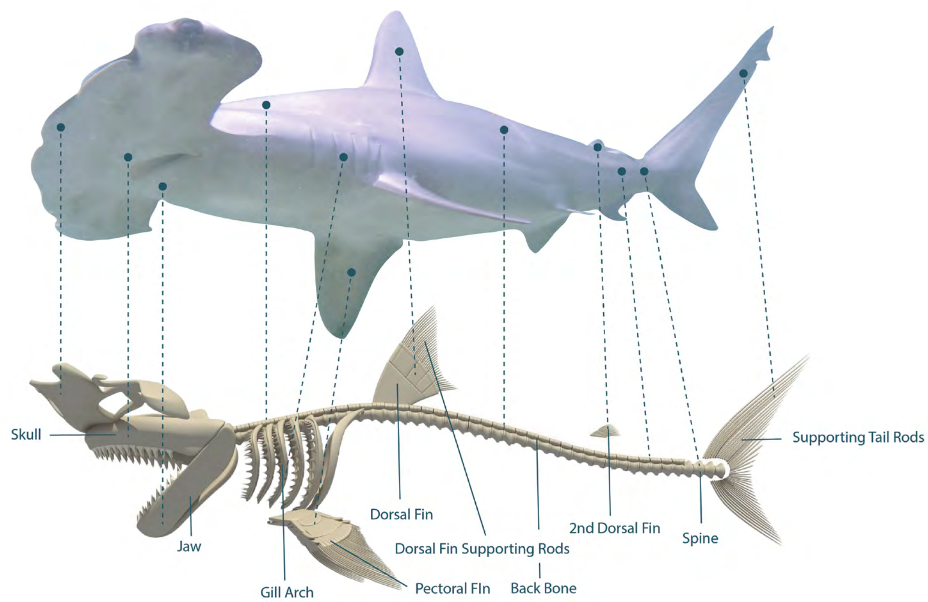
Sharks' Anatomy and Locomotion

Sharks' are among the oldest vertebrate lineages dating back 450 million years, in which their success is credited to their diversity in morphology and locomotor design (Shadwick and Goldbogen 2012). Their body forms range from flexible and slender to stiff-bodied, dependent on their behavioural patterns. Despite their diversity, sharks all have similar anatomy. Sharks' have an internal skeleton made of cartilage - strong and durable but also lightweight and flexible- which is lighter than bone and helps keep the shark buoyant while swimming as they do not have a swim bladder -buoyancy organ (F.O.C 2016).

The cartridge found in the shark's skull, jaw, and backbone is stronger than the cartridge found in the shark's gill arches, spine, pectoral fins, dorsal fins, pelvic and anal fins, caudal fin and supporting rods as it is calcified - creating a more durable structure to the anatomy of the shark's skull, jaw, and backbone (F.O.C 2016). The pectoral fins (side fins) are the fins that provide lift -balance, and steering. Water passes beneath these fins the same way air would flow under a plane's wings, applying a lift function that helps the shark to float. The dorsal fin (top fin) keeps the shark upright and allows them to swim straight. The pelvic fins (bottom fins) are stabilizers, and the caudal fin (tail) acts as a propeller (Government of Canada (F.O.C), 2016). This anatomy is designed to provide the shark with strong locomotion skills, allowing them to swiftly navigate through oscillation periods, waves, and ocean turbulence.

In terms of locomotion, sharks are grouped by shallow-bodied (anguilliform) and deep-bodied (carangiform/thunniform) forms. Shallow-bodied forms are characterized by their long, slender, and flexible morphologies. Predominantly representing slow benthic swimmers that use their entire bodies (head to tail) to move left to right in a series of sinuous waves -anguilliform swimmers. These sharks are generally found in shallow coastal waters or along the continental and insular shelves and respond to more active tidal conditions (Sternes and Shimada 2020).





A comparison of the morphological makeup/anatomy of native migratory shark species, the porbeagle and newer migratory species, the hammerhead shark (Data from DFO 2021).

Deep-bodied forms are characterized by their large pectoral fins, sternward dorsal fins, and strong caudal fins (tail) and are further subdivided into two subgroups; carangiform and thunniform swimmers. Carangiform swimmers are predominantly strong, fast, pelagic swimmers with large, powerful crescent-shaped caudal fins. These sharks' use the back half of their bodies to create a series of sinuous waves allowing them to accelerate quickly with strong force (Sternes and Shimada 2020). Thunniform swimmers, like carangiform swimmers, are predominantly strong, fast pelagic swimmers with large, powerful caudal fins. However, their lateral movement is limited to the caudal region of the body. Morphologically these sharks' are generally very stiff and use their caudal regions to push large amounts of water, creating a thrust force that allows them to also accelerate quickly (Sternes and Shimada 2020). In addition, both carangiform and thunniform swimmers use their dorsal and ventral fins to help cancel out side-to-side motion induced by the tail motion. Allowing deep-bodied sharks to alter the

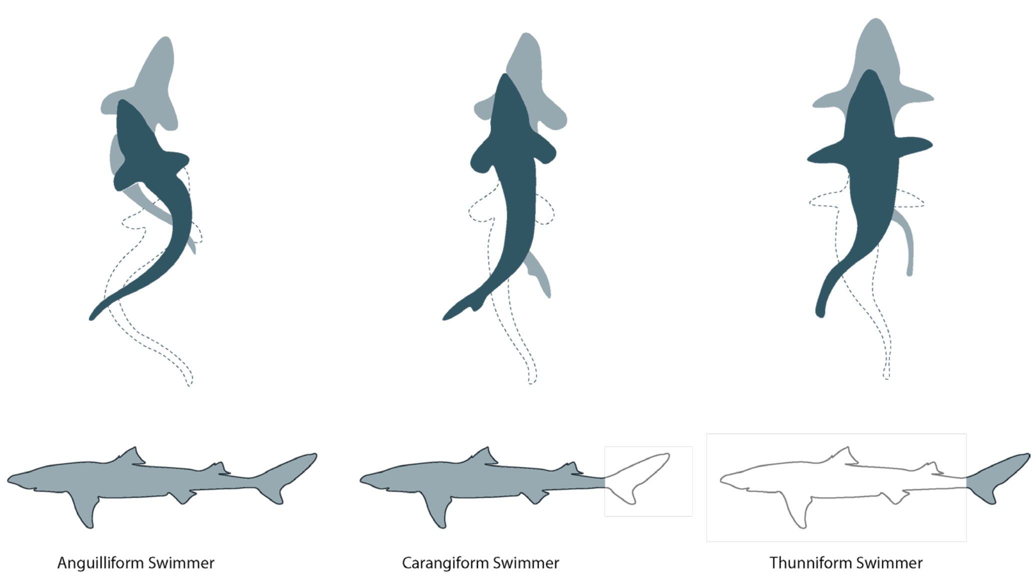


Diagram explaining the movement of shallow versus deep bodied swimmer (Sternes and Shimada 2020) oncoming flow so that it interacts with the tail, enhancing thrust and efficiency (Sternes and Shimada 2020). These sharks' generally live in pelagic regions and interact with less dominant tidal action.

Sharks' Mechanical Behavioural Patterns

Shark morphology additionally impacts the function of their biological systems mechanically. Their bodies are controlled by hydrostatic pressure -the pressure exerted by a fluid at equilibrium due to the force of gravity- shortening and lengthening their skin as they bend (Wainwright, Vosburgh, and Hebrank 1978, 747). As their muscles are securely attached to both their skin and backbone, the skin acts as an external tendon, transmitting muscular force to the tail activating lateral movement in the caudal region creating a thrust force and pushing the shark forward (Wainwright, Vosburgh, and Hebrank 1978, 747). Sharks' internal pressure increases from slow to fast swimming, activating stronger force in the caudal region allowing sharks to swim at an accelerated pace. In addition, the thrust force must match the drag force applied from their pectoral and dorsal fins, increasing the power needed to swim non-linearly with velocity.

This force-velocity relationship is closely tied to the movement of muscles in sharks. The sharks' mussels possess both red and white muscle fibers, each serving specific purposes in locomotion (Wainwright, Vosburgh, and Hebrank 1978, 748). Red muscles are aerobic and optimized for continuous, slow swimming, facilitating efficient oxygen consumption. While, white muscles are generally anaerobic and designed for brief bursts of speed or rapid acceleration. This dual muscle system allows sharks to adapt their swimming behavior to varying conditions, conserving energy during steady swimming and exerting bursts of speed when needed (Wainwright, Vosburgh, and Hebrank 1978, 748).

In terms of respiratory functions, these muscles additionally control the sharks gills that serve as crucial anatomical features for sharks to breath. The shark's gills are specialized organs positioned on the sides of a shark's head to facilitate the shark's ability to breathe underwater. The gills comprise delicate filaments rich in blood vessels that enable the shark to extract oxygen from water and expel carbon dioxide, vital for respiration and metabolic processes during swimming (F.O.C 2016). As the shark swims, it opens its mouth to allow water to flow over the gills. Through diffusion, oxygen from the water enters the shark's bloodstream while carbon dioxide exits into the surrounding water. This exchange sustains the shark's oxygen supply and removes metabolic waste, ensuring continuous respiration. Blood rich in oxygen is then carried away from the gills by the dorsal aorta to nourish the shark's body tissues, while deoxygenated blood returns to the gills via the ventral aorta for reoxygenation (F.O.C 2016).

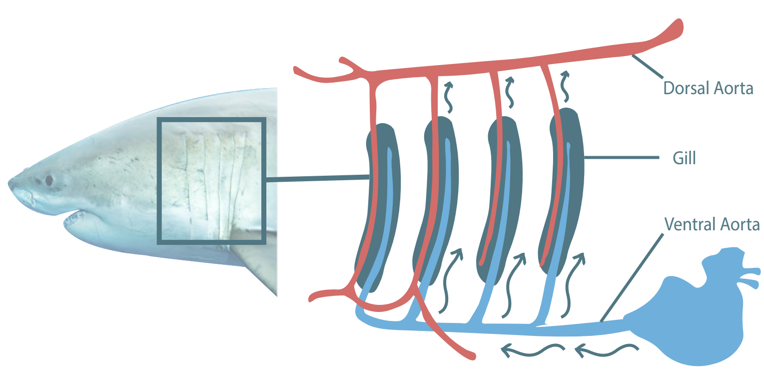
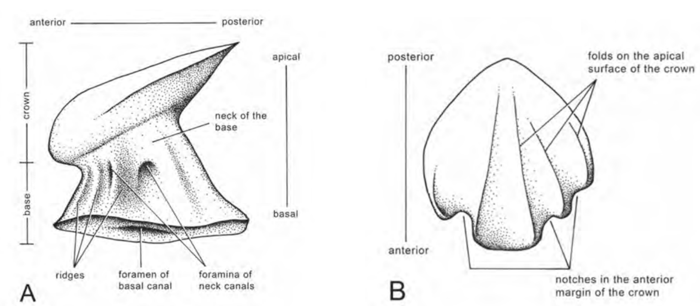


Diagram outlining the position of the sharks gills and their respiratory function (Data from DFO 2021).

Sharkskin and Denticles

One of the sharks' most remarkable morphological features is their unique skin structure, due to its resilient and robust composition. The exterior layer of the sharks skin is characterized by microscopic tooth-like structures that are embedded into their skin to improve the sharks swimming performance by enhancing thrust and decreasing hydrodynamic drag force (Wainwright, Vosburgh, and Hebrank 1978, 748). The profile of these denticle's vary between different shark species from anterior to posterior depending on the sharks morphological build, predatory patterns, and marine habitat. However, each denticle is embedded into the shark's skin by a canal, that firmly anchors the denticle in place, providing stability and structural integrity to the shark's skin (Wainwright, Vosburgh, and Hebrank 1978, 748). Allowing the denticle to become an integral part of the shark's outer layer, while being controlled by movement of hydrostatic pressure through the sharks body.



Morphological build of a shark denticle showing the canal (Thies and Leidner 2011, 73).

Each individual denticle has a layered composition of pulp, dentine, and enamel (Wainwright, Vosburgh, and Hebrank 1978, 748). The canal is made up of dentine and hosts the pulp cavity that is attached to the sharks central nervous system. Hosting the nerves and blood supply that keep the denticle's alive and active. The dentine is the calcified tissue of the body that creates the structure of the denticle and protects the pulp cavity and the enamel is the exterior protective coating developed to protect the denticle from damage. This structure is uniquely embedded into the thin outer boundary layer of sharks skin, composed of a flexible collagen fibers substrate. This substrate is used to passively control the orientation of denticle's and change the characteristics of the water flow boundary around the sharks body (Wainwright, Vosburgh, and Hebrank 1978, 748). As the boundary layer is bent denticle's are passively bristled, increasing the applied drag force and allowing the shark to slow down as they approach their prey or rest. Denticle's are additionally oriented in a particular way to provide optimal performance, the anterior faces the sharks head and the prosterior faces the sharks tail for hydrodynamic efficiency.

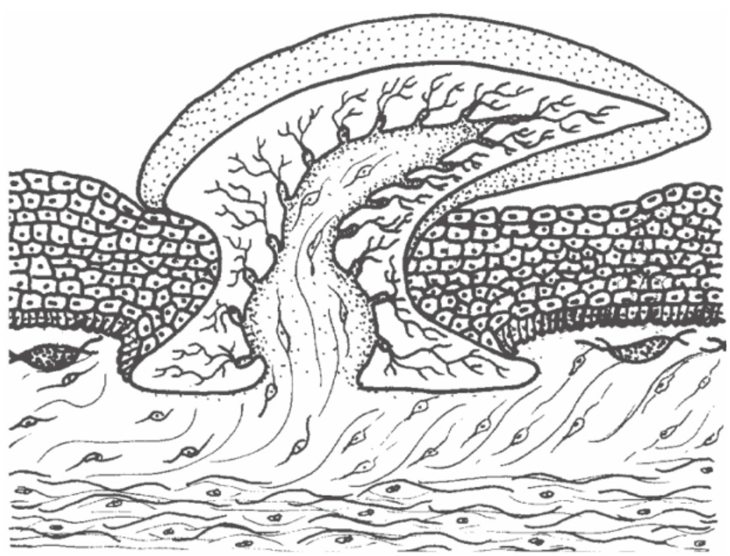
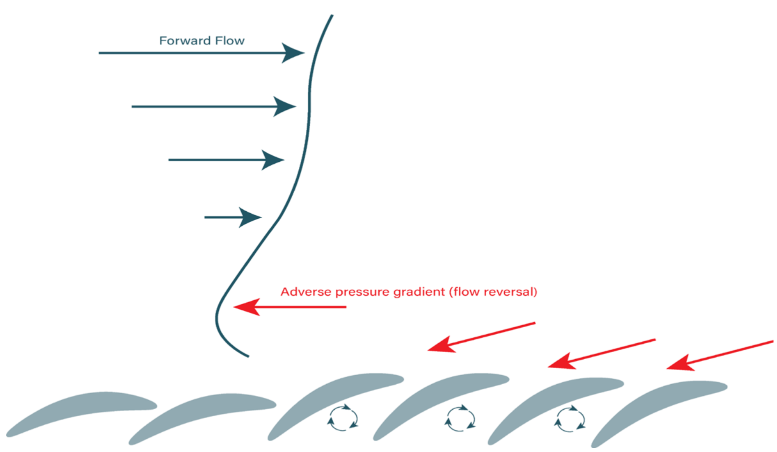


Diagram showing a cross-section through a single denticle.
(Thies and Leidner 2011, 73).

At rest, when the shark's internal pressure is low and the muscles on both sides are at the same length the red muscles are activated. This activation causes the fibres in the skin to bristle at an angle, effectively separating hydrodynamic flow and passively increasing drag pressure, which helps dissipate wave energy (Wainwright, Vosburgh, and Hebrank 1978, 748). In contrast, when the shark swims bending the fibres within the body the white muscles are activated as the shark swims and the muscles on one side shorten while increasing in the cross-sectional region, causing the skin to tighten and decreasing the denticle angle. This adjustment provides passive flow control by delaying flow separation and reducing drag pressure, ultimately enhancing the shark's swimming efficiency (Wainwright, Vosburgh, and Hebrank 1978, 748). Therefore, the interaction between the sharks' unique skin structure and their muscular movements illustrates how their morphology optimizes hydrodynamic performance in the marine environment.



Schematic drawing showing activation of fibers that bristle the sharks denticles interrupting the forward flow in the oceanic boundary layer (blue) and subjecting it to an adverse pressure gradient (red) by forming cavity vortices (blue arrow circles) - where wave energy is dissipated. This function would act slow a sharks swimming speed or allow them to rest (Data from Thies and Leidner 2011, 73).

Identifying Species

This thesis explores the diversity of the Ground Shark (Carcharhiniformes) order—the largest order of sharks, with over 270 species, ranging from 0.15 m to 7.4 m in length (Shark Research Institute). These sharks have the ability to inhabit various regions of the water column depending on morphological build and are characterized by their five gill openings, two spineless dorsal fins, large caudal fins (with greater upper lobes), and prominent anal fins (Dillion, O'Dea, and Norris 2017). A further division of the ground shark order subdivides species into families of the Nurse Shark (Ginglymostomatidae), Hammerhead Shark (Sphynidae), Requiem Shark (Carcharhinidaen) and Tiger Shark (Carcharhinidae) (Dillion, O'Dea, and Norris 2017). The most common species from these families sighted in the Nova Scotia region are various Nurse Shark's (Ginglymostomatidae Family), Dusky Shark's (Carcharhinidaen Family), the Atlantic Thresher (Carcharhinidae Family), Tiger Shark's (Galeocerdo Family), and the Spiny Dogfish (Galeocerdo Family).

Nurse sharks are bottom-dwellers that typically inhabit shallow waters. These sharks use their oral muscles to actively suck water into the mouth—buccal pumping— supplying oxygen to the gills without swimming. Thus, they are able to rest on the ocean floor and can be found anywhere in the intertidal zone to the depths of the epipelagic zone (up to 165 ft) on rock and coral reefs (Shark Research Institute n.d.). Nurse Sharks denticle's are typically thick crowned with V-shaped peaks and function to create abrasion strength.

Hammerhead sharks are coastal-pelagic and semi-oceanic dwellers, generally found near the sea floor or close to the ocean bed. They are capable of swimming at various depths in the water column. However they often dwell near the surface of the water from depths of 3 ft to more than 262 ft, over the continental shelves (Shark Research Institute n.d.). Hammerhead sharks denticle's generally have a thick crowned V-shaped peak with ridges on either side and function to increase drag reduction and abrasion strength.

Requiem and Tiger shark families are a mix of coastal-pelagic oceanic dwellers. The are usually seen in solitude, at the surface with the tips of their dorsal and tail fins out of the water. However, they have been photographed at depths of up to 1,007 ft. The species typically dwell inshore at night to feed and retreat to the offshore region by day, making them active swimmers (Shark Research Institute

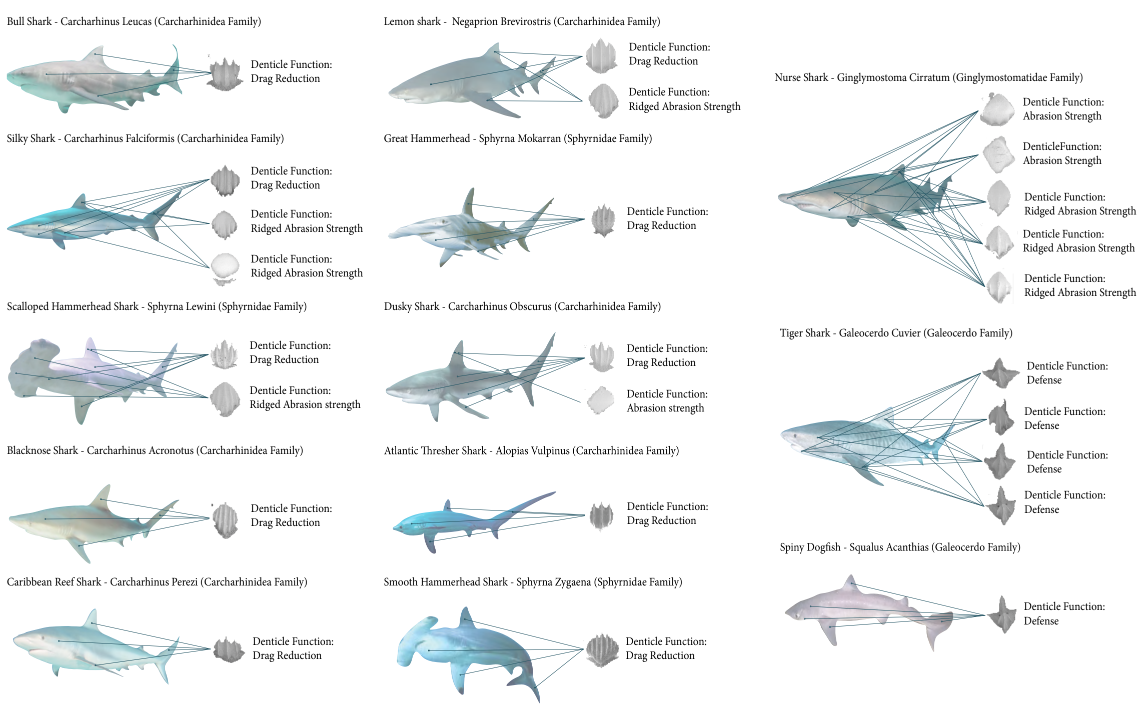


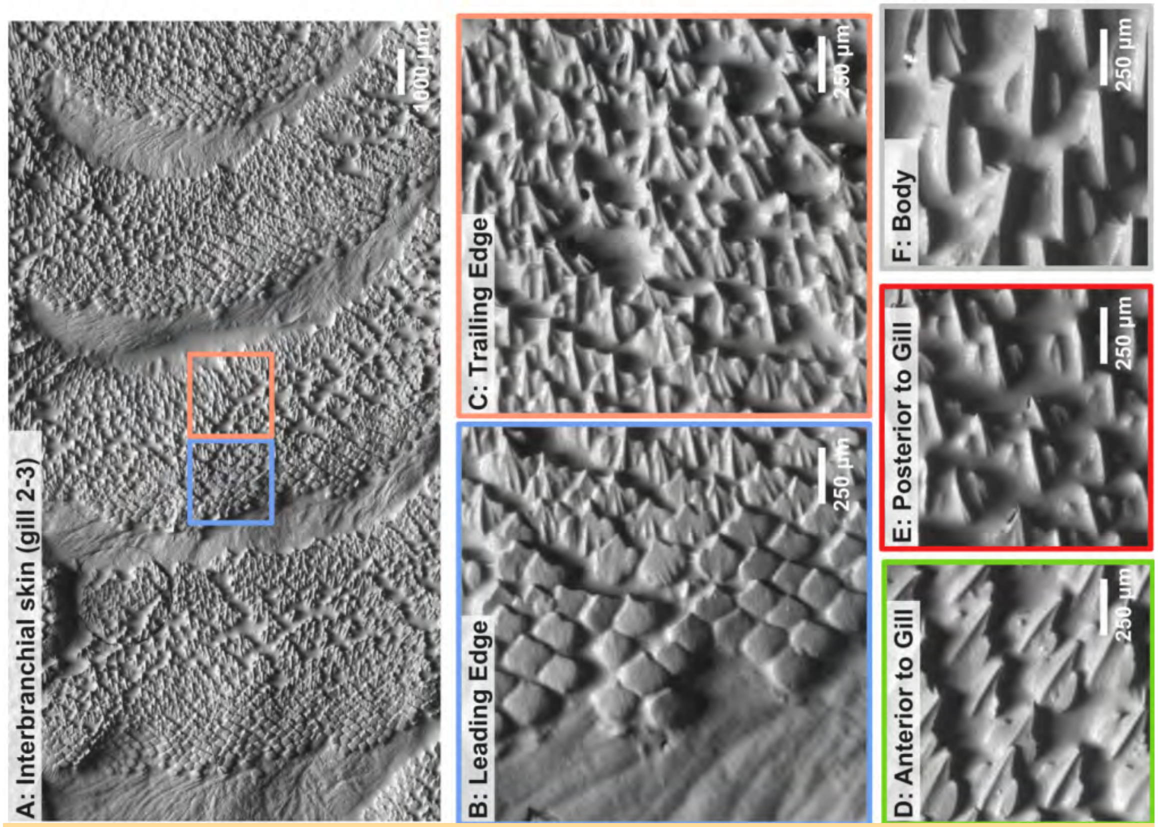
Illustration of sharkskin denticles on a variety of nearshore to oceanic shark species, indicating denticle placement and function (Data from Wainwright, Vosburgh, and Hebrank 1978, 748).

n.d.). Their v-shaped pointed denticles typically have one predominate crown and function to increase their defence abilities against other species.

Variation in Pattern

Shark denticle patterns are complex due to the multitude of factors they need to address in the shark's environment and physiology. These factors include hydrodynamics, protection against abrasion, drag reduction, and defence mechanisms. In addition, denticle morphologies differ not only across species but additionally from the leading to trailing edges of the shark's head to the posterior to gill (Gabler-Smith et. al. 2021). This thesis explored four functional groups of denticle's, including denticle's for; drag reduction (1), abrasion strength (2), ridged abrasion strength (3), and defence (4).

Studies show that fast, pelagic sharks are covered by highly ridged, thin denticles intended to increase drag reduction and defence functions, while bottom-dwellers and coastal sharks are covered in thick, unrigged denticles with a single peak for abrasion strength that protects the shark from the changes in substrate-ocean water while also increasing drag function (Dillion, O'Dea, and Norris 2017, 118). Though the denticle's shape, size, length, height, orientation, spacing and surface topography change from species to species, it is proven that these ridges decrease hydrodynamic efficiency when bristled by disrupting the boundary layer between the skin and water across all shark species increasing friction in the water and dissipating its energy. Allowing them to control the water flow while reducing turbulence as water flows around the shark's body (Dillion, O'Dea, and Norris 2017, 125).



Images of shark denticle surface profilometry from five regionsof the sharks body illustrating the difference in denticles between the leading and trailing edge (Gabler-Smith 2021, 7)

Hydrodynamic Performance

In terms of hydrodynamic performance, when a shark swims, water flows over its body, creating a thin layer of slower-moving water called the boundary layer along its skin. This boundary layer creates resistance, or drag, that opposes the shark's movement through the water. The shark's denticle's interact with this boundary layer in both a bristled and unbristled state (Gabler-Smith et. al. 2021, 3). A shark angles or bristles its denticle's by controlling the movement of hydrostatic pressure through its body. The bristled denticle's disrupt the boundary layer of water by altering its flow patterns. This disruption helps to delay the separation of the flow from the shark's skin, which in turn reduces pressure drag—a significant component of overall drag. By delaying flow separation, the denticle's allow the water to flow more smoothly over the shark's body, reducing the force of drag acting against it (Gabler-Smith et. al. 2021, 3).

In addition, the ridges and grooves on the surface of bristled denticle's further manipulate the water flow by creating turbulence and generating micro vortices—small whirlpools or eddies—in the boundary layer. These micro vortices help to mix the surrounding water, improving fluid dynamics and reducing resistance to the shark's movement (Gabler-Smith et. al. 2021, 3).Overall, the combined effects of disrupting the boundary layer and creating micro vortices contribute to the efficient hydrodynamic performance of sharks.

Alternatively, non-bristled denticle's increase the thrust performance of the shark, optimizing fluid flow and enhancing the efficiency of a shark as it swims through water. Due to the shape and texture of the denticle's the shark is still able to control the water flow while reducing turbulence around its body, but drag reduction is now minimized. Non-bristled denticle's additionally help to ensure a smoother flow of water over the shark's skin, increasing they're hydrodynamic performance and allowing them to accelerate with significant speed through the water boundary (Gabler-Smith et al. 2021, 3). In this sense, the v-shaped crown, or ridges of the denticle, cut through the water, dissipating a reduced amount of wave energy in comparison to bristled denticle's.

Chapter 4: Defining Function of Design

Intended Design Function

Design function in biomimicry is shaped by a deep dive into the intricacies of biological systems, processes, and strategies found in nature. Then applying that knowledge to inform architectural design solutions. This thesis reviewed the vast ecology of the nearshore zone to highlight the regional reliance on coastal resources. In addition, to highlighting the complexities of coastal dynamics that marine organisms deal with regularly. Inspiring architectural solutions tailored to mitigate the impact of coastal challenges based on the unique adaptions of marine organisms. In this context, the shark species emerges as a symbolic figure, as the shark embodies a remarkable resilience finely attuned to the nuances of these dynamic coastal environments.

The intended design function of this project is to combat climate-related challenges, including increased rates of tidal action, coastal erosion, and inundation, by mitigating the impact of coastal dynamics and implementing architectural solutions within coastal communities. An inhabitable breakwater is proposed to be implemented within the Neil's Harbour, Nova Scotia community to absorb wave energy, act as a barrier against erosive forces, and intercept storm surges, protecting the coastal community from impending climate-related challenges while maintaining a healthy marine ecosystem. Through this intervention, architecture becomes a crucial tool to protect the coastal landscape, infrastructure, and local ecosystem against the detrimental effects of climate change, ultimately enhancing resilience and sustainability in coastal regions. In addition, the breakwater will slow sediment transportation and deposition rates that currently threaten coastal landscapes and infrastructure stability. Overall, the project aims to address these coastal challenges comprehensively, while harmoniously protecting Neil's Harbour's coastal landscapes, infrastructure, and ecosystem for the future.

Mitigate Tidal Action

Increased tidal action is a critical climatic factor that threatens coastal communities particularly in low-lying coastal regions. Tidal action represents a distribution of energy passed through the ocean in a circular motion to create waves. The ocean's surface water is disrupted in the offshore to oceanic regions by wind or the sun and moon's gravitational pull, initiating friction that causes the water's surface to move up and down creating waves (Jackson and Short 2022, 40). Changes in wave shape and behaviour are seen as waves dissipate into water of decreasing depth. The waveform approximates a curve in deep water, but no water movement occurs below the wave base, leaving the wave behaviour unaffected in deep water (Jackson and Short 2022, 65). However, as the waves progress into shallower water, the waveform changes, creating a wave crest (the highest part of the wave) and widening the troughs (the lowest part of the wave) increasing wave energy and tidal impact (Jackson and Short 2022, 65). Therefore, coastlines are the most vulnerable to tidal impact as shallow waters experience more extreme tidal action due to wave impact.

The wave impact is determined by four priority characteristics: periods, wavelengths, direction and phases. Wave periods

-time of oscillation/movement- are defined by the transfer of waves from an offshore point to nearshore coastal zones (Jackson and Short 2022, 40). The distance between wave crests determines wavelengths, wave direction is accounted for as the relative coordinate of movement based on wind force, and wave phases are defined as the exact time that the wave crest surfaces (Jackson and Short 2022, 62). A wave breaks when it becomes too steep to be stabilized or when its energy is transferred to another wave or current (Jackson and Short 2022, 139). Surface currents are generated when a change in wind direction occurs, and forces from the Earth's rotation are applied, or landforms (bathymetry and coastal landforms) interact with incoming waves. In addition, differences in salinity and temperature between water masses can lead to currents as a result of contrasting densities. (Jackson and Short 2022, 142). In contrast, tides represent the regular rise and fall of the ocean's waters controlled by the moon's gravitational pull.

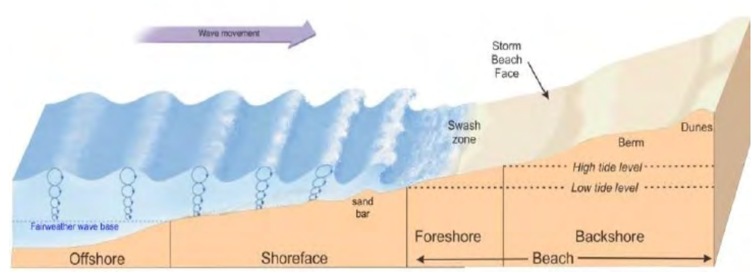


Illustration of ocean regions where tidal action takes place showing differences in wave flow from deep to shallow waters (Jackson and Short 2022, 65).

Tidal action plays a huge role in controlling coastal dynamics. As waves travel from offshore to shallower waters, their impact intensifies, especially in areas with varying tidal patterns. The continuous impact of tides and waves can lead to increased coastal erosion, affecting infrastructure stability. Thus, in designing for resilience, we must consider varying patterns of tidal action and work to protect existing coastal communities from the impending tidal impact that is causing land deterioration over time. The inhabitable breakwater project is intended to serve a dual purpose: absorbing a portion of impending wave energy in the nearshore zone to protect the coastline of Neil's Harbour while additionally facilitating a controlled natural flow around the breakwater to ensure a continued healthy circulation of nutrients, marine organisms, and sediments along the coastline to help sustain the marine ecosystem.

Slow Rates of Erosion

Coastal erosion is another critical climatic factor that additionally threatens coastal communities, particularly in elevated coastal regions. The process of coastal erosion is driven by sediment transportation and deposition and influenced by coastal landforms and tidal action in the nearshore to offshore zones in combination with the hydraulic and geologic conditions of the regions (Jackson and Short 2022, 188). Sea-derived sediment transport is activated by a combination of hydrodynamic mechanisms, including wave flow, tides and wind, which control deposition rates. The fluid motion from tidal action initiates a drag force that lifts individual grains from the seabed and moves them with the oscillation period (Jackson and Short 2022, 188). Sediments are left to settle when the wave energy is released in the nearshore zone. The geological conditions of the region influence the grain size, weight and shape of local sediments. Variability in wave heights will lead to variability in wave energy, which will determine the size of sediment that the wave can transport (Jackson and Short 2022, 117).

Sediment loss along the coastline typically occurs during the process of undercutting, where wave impact mobilizes force that is counteracted by the gravitational force on the grain of bedrock or surficial materials (Jackson and Short 2022, 190). Breaking sediment loose from coastal landforms and carrying them seaward during oscillation, as low tide occurs.

Land-derived sediment deposition occurs from mass movements (i.e, landslides, rockfalls, and debris flows), over a range of time. These movements are more dominate in regions where cliffs are composed of porous material susceptible to active undercutting (U.S. Department of the Interior n.d.). Local hydrology additionally influences the seaward movement of sediments, as fluvial force from rivers push sediments into estuary regions where freshwater rivers meet the ocean and sediments are transported into the oscillation cycle (Jackson and Short 2022, 205). Likewise the process of weathering can dissolve rock through chemical change breaking sediment and sending it seaward in oscillation (National Geographic Society n.d.). Coastal

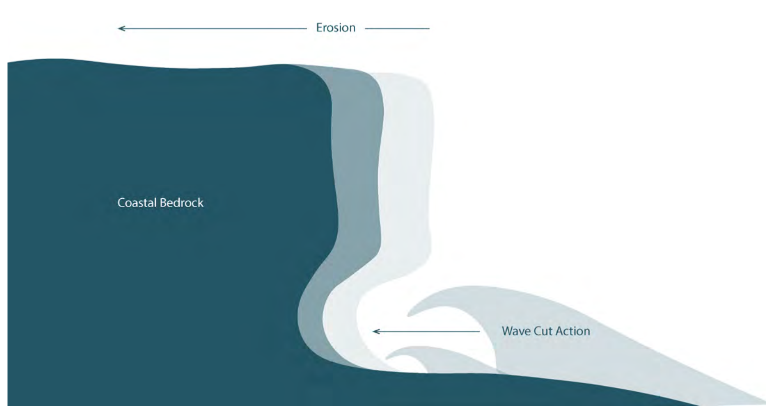


Illustration of the impact of the undercutting process on geological features at a headland.

and tidal action. However, extreme weather events and changes in force implemented upon local hydrology and geology break the bind of plant roots and release sediment into the oscillation cycle.

Increased rates of coastal erosion pose a significant threat to coastal communities and ecosystems, leading to a net loss of sediment and altering the configuration of coastal landforms. Neil’s Harbour is especially vulnerable to these erosive influences due to its exposure to the open ocean, facing direct impacts from waves, tides, and wind. These forces contribute to the gradual degradation and undercutting of coastal landscapes, resulting in land loss over time. The existing coastal landscape holds value for the region, as it supports local residences and critical marine infrastructure essential to the economy. Furthermore, these landscapes are vital for local marine life, providing diverse habitats, crucial nursery grounds, abundant food sources, and essential migration routes. As coastal landscapes change, the community may encounter challenges related to land use, potential displacement, and the degradation of ecosystem services. Thus, preserving these areas is crucial for sustaining local biodiversity and coastal communities’ economic and cultural well-being. The proposed inhabitable breakwater emerges as a strategic intervention to address erosion-related challenges. Its optimal angle is designed to protect coastal dynamics, acting as a barrier against the erosive forces of waves and tides, contributing to the preservation of the valuable coastal landscapes and the overall well-being of Neil’s Harbour.

Prevent Inundation

Risk of inundation in coastal communities is increasing as tidally influenced flooding, coastal storms, and surge related flood events are occurring more frequently. Localized flooding occurs when there are changes in local weather like enhanced wind speeds that increase wave heights and send more wave energy landward. Significantly impacting wave run-up - the maximum vertical extent of the wave extended landward from the nearshore zone (NOAA n.d.). In addition, overtopping can occur due to increased tidal action, sending wave crests over the top of coastal structures, potentially damaging coastal infrastructure that boarder these coastal protection structures in urban coastal communities (NOAA n.d.). Tidal action can also be influenced by wind speed, wave height, oscillation periods, nearshore bathymetry, and land cover near the shoreline. High-tide flooding occurs more commonly in low-lying coastal regions when changes in oscillation occurs like extreme high tides (NOAA n.d.). These tides occur when the sun, moon, and earth align a few times a year, increasing wave run-up and creating potential flooding conditions.

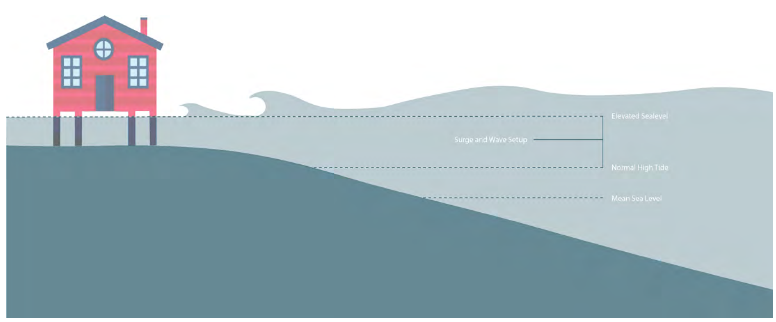


Illustration of the coastal inundation process indicating mean sea level, high tide, and elevated sea level. When elevated sea level occurs coastal landscapes often flood (Al and Westerhof 2019,12).

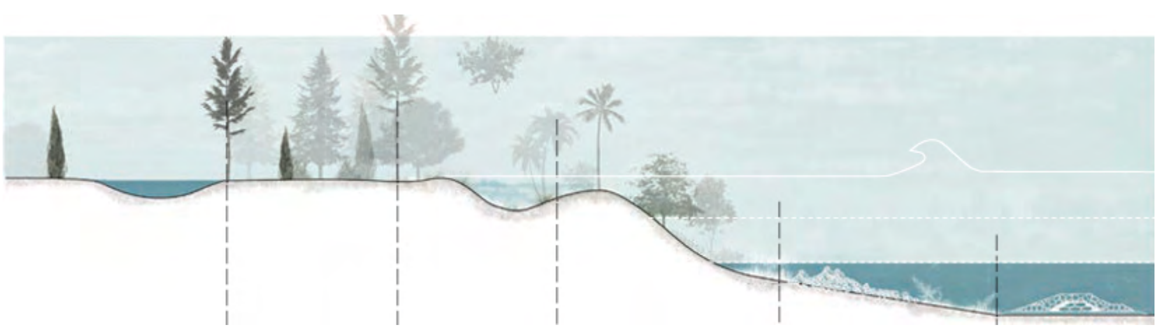
Severe storms like hurricanes and nor-easters send strong winds that drive increased wave energy landward, creating storm surge - an abnormal seawater rise above predicted sea level during a storm (NOAA n.d.). An abnormal rise in sea level quickly changes the habitability of coastlines, putting coastal infrastructure at risk of flooding, especially in low-lying regions. Flooding can damage both the natural and built coastal environments, wiping out habitats and coastal infrastructure. Thus, in designing for resilience, we must consider the impact of coastal storms and surge-related events. The proposed inhabitable breakwater intends to serve as a resilient barrier to storm surges by intercepting and absorbing a significant portion of the incoming wave energy generated by severe storms like hurricanes and nor'easters, preventing flooding and damage to Neil's Harbour's natural and built environments.

Evaluation of Existing Coastal Solutions

Resilience signifies the capacity to adapt to changing conditions and endure disruption. Current methods to protect coastal communities from dynamic changes include utilizing both soft and hard engineering solutions to mitigate the impacts of climatic factors. Soft engineering involves the implementation of nature-based solutions, such as beach nourishment and restoration efforts that aim to foster ecosystem resilience and mitigate the impacts of climate change. In contrast, hard engineering involves the construction of rigid structures like seawalls and levees to confront natural forces directly and mitigate their impact. However, both of these defence strategies lack acknowledgment of their adjacent impacts and consideration of the public realm -addressing the need for a new, more adaptive coastal defence strategy that embraces human inhabitation as a piece of ecology while working to mitigate the impact of coastal processes and climatic pressures.

Soft Engineering Solutions

Soft solutions utilize the natural environment and its ecology to reduce erosion, stabilize coasts, and provide natural flood protection (Al and Westerhof 2019,13). Examples of soft solutions include managed retreats, beach nourishment of natural stabilizers like dunes and vegetation, implementing living coastlines, and ecological regeneration, which protect the inland area while maintaining views and protecting access to the coast. These defences are better adapted to coastal dynamics than hard solutions as they allow natural sediment deposition and require less maintenance, eliminating economic stress on coastal communities (Al and Westerhof 2019,13). However, these defences often neglect to absorb enough wave action to fully protect the coast from inundation, especially in storm events, discouraging coastal development (Al and Westerhof 2019,13). Limitations to soft solutions additionally include restricted structural strength, time-intensive results, and dependency on natural processes. Soft solutions are not permanent solutions, as mitigated wave action still poses a risk of future erosion and

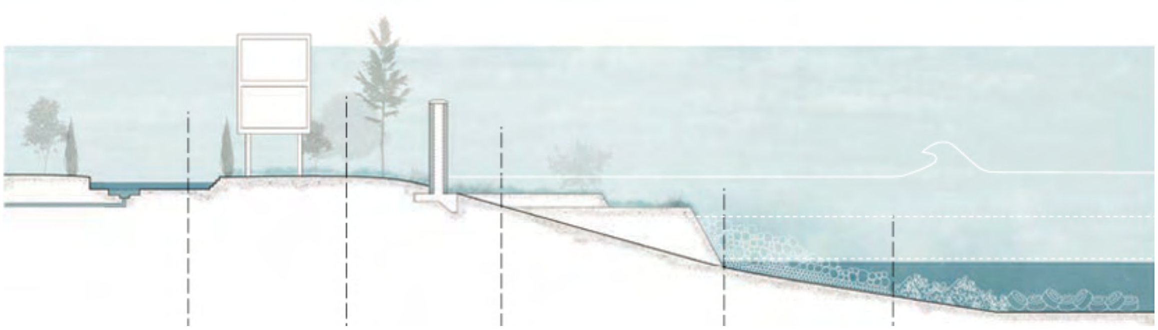


Soft solution focused on utilizing the natural environment to stabilize the shoreline providing natural protection of the built environment. Retreat would allow natural protection of the built environment (Al and Westerhof 2019,13).

flooding -addressing the need for a solution that permanently protects coastal infrastructure without disrupting the natural landscape and coastal ecology.

Hard Engineering Solutions

Hard solutions are permanent structures that aim to dissipate wave energy and mitigate sea level in attempt to control flooding (Al and Westerhof 2019,12). Examples of hard solutions include seawalls, floodwalls, revetments, groynes, gabions, and breakwaters designed to block tidal action in specific areas to protect the built environment. Though these solutions successfully absorb incoming wave force, reducing the intensity of wave action and mitigating the impact of coastal erosion, they interfere with sediment deposition and coastal ecology (Al and Westerhof 2019,12). When blocking tidal action in a specific region, the wave force is redirected, transporting sediments to an adjacent region through longshore drift (Mossop 2019, 180). In addition, hard solutions can cause increased erosion rates in adjacent regions and reshape adjacent landscapes through sediment deposition. These processes impact



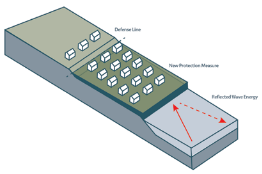
Hard solutions focus mitigating sea level rise and flood control to protect the built environment. A seawall would protect coastal infrastructure by mitigating wave impact and implementing development on higher grounds would prevent further damage to property (Al and Westerhof 2019,12).

coastal ecology, particularly in the intertidal zone, as habitats are modified, altering the ecosystem and causing certain species to relocate. Engineered surfaces also often retain contaminants and facilitate new habitats for invasive species, causing further degradation of local ecology (Waltham and Daffornab 2018, 554). However, hard solutions can be difficult to maintain - addressing the need to evolve existing hard engineering solutions to prioritize long-term sustainability and enhance both community and ecosystem resilience.

Comparing Hard Solutions

This thesis will explore the dominance of hard engineering solutions over soft engineering alternatives in coastal communities, examining why hard solutions maintain a stronger precedent for resiliency. One of the main challenges with soft defences is the potential for rapid deterioration or failure due to immediate or intense climatic threats (Al and Westerhof 2019,14). Soft defences like dunes or vegetative can take time to establish and mature. Thus, their effectiveness is often compromised during extreme weather events like storms causing sudden erosion. However, hard defences like seawalls, revetments, and breakwaters provide immediate and durable protection, withstanding strong forces and offering a more reliable barrier against sudden environmental challenges (Al and Westerhof 2019,14).

A study of various hard engineering solutions was completed to mitigate the impacts of rising sea levels, storm surges, and erosion while strengthening resilience in coastal communities. Several strategies were considered in this study. Each strategy presents a distinct set of advantages and challenges. The strategies examined were protect and

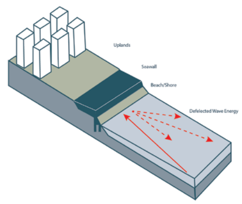


Protect + Reclaim

A strategy of buidling that capitalizes on the value of a new protection measures to rising sealevel, such as a dike to implement the reclaimation of property infront of an existing defense line.

Pros
- Oppertunity for new waterfront views.
- Oppertunity to capitalize on value of infastructure.
- Value created from new development offset infastructure costs.

Cons
- Expensive to build infastructure and elevate land.
- Potential environmental cost of of reclaimation like distruction of local habitats.
- Wave overtopping cause cause failure of defense and lead to flooding.
- If development density is increased failure of new protection measure could occur.
- If nessecary residents may push back on relocation during devleopment.

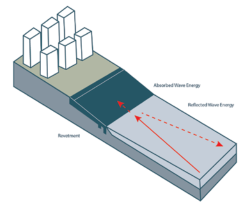


Seawall

A strategy that implements a vertical barrier to protect upland areas from the impact of waves, tidal action, storm surges, and coastal erosion.

Pros
- Deflects and dissipates wave energy.
- Provides a physical barrier.
- Long term solution for rise in sealevel.
- Effectively minimizes property damage.
- Can be designed to include public space.

Cons
- Expensive to build infastructure.
- Can increase beach erosion leading to beach vanishing.
- Can interrupt natural coastal processes, altering sediment transportation processes, causing longshore drift, and erosion in unprotected areas creating changes in the local ecosystem.
- Habitat disruption or loss can occur.

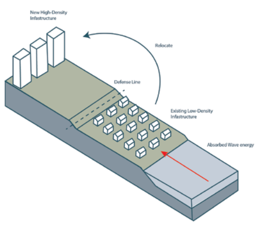


Revetment

A strategy that implements a structural barreir on a sloped surface to absorb wave energy and prevent erosion.

Pros
- Absorbs, refelcts & dissipates wave energy.
- Helps to reduce coastal erosion.
- Minimal maitenance required.
- Structure can be extended/modified and has a long life span.

Cons
- Expensive to build infastructure
- Has a major impact on the landscape and can cause loss of habitat and disruption to the local ecosystem.
- Takes up a significat amount of space.
- Site acess can complicate construction.
- Could cause downstream erosion.

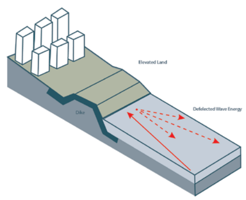


Retreat & Reoccupy

A strategy of buidling that accepts rise in sealevel and implements a retreat by building new infastructure behind an existing defense line and relocating exisiting lower-density developments.

Pros
- Long term solution for rise in sealevel.
- Oppertunity to capitalize on value of infastructure.
- Value and tax revenue created from new development offset infastructure costs.

Cons
- Expensive to rebuild infastructure.
- Large operation and maintenance costs.
- Environmental costs to new construction like distruction of local habitats.
- Residents may push back on relocation.

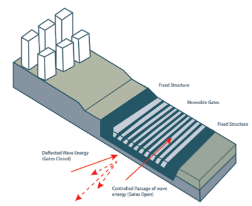


Dike

A strategy that implements a structural barreir to control or redirect the flow of water and provide flood protection in low-lying areas.

Pros
- Deflects and dissipates wave energy.
- Provides a physical barrier to prevent the overflow of water and protect low-lying areas from flooding.
- Provide resistance to erosion.
- Can be designed to enhance beach nourishment (retain sand and sediments).
- Height allows waterfront views.

Cons
- Potential environmental cost of like distruction of local habitats.
- Wave overtopping cause cause failure of defense and lead to flooding.
- Can alter sediment transportation processes, causing longshore drift, and erosion in unprotected areas creating changes in the local ecosystem.

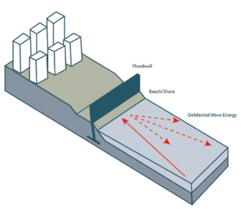


Surge Barrier

A strategy that implements a fixed damn structure with movaeable gates to prevent innudation.

Pros
- Absorb and refelect wave energy.
- Provides a physical barrier to prevent innudation.
- Can intigrate inhabitable space.

Cons
- High installation, opperations, and maintenance costs.
- Can redirect flow of tidal action with enough force.
- Protect best when coupled with another protection measure.
- Human error poses a risk in manual opperations.
- Potential to disrupt local ecosystem.

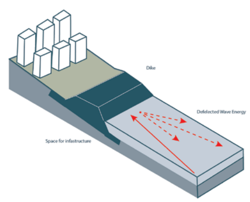


Floodwall

A strategy that implements a vertical artifical barrier to withstand wave impact and protect against issues like risisng sealevel and flooding.

Pros
- Deflects wave energy.
- Provides a physical barrier to prevent the overflow of water and protect low-lying areas from flooding.
- Minimum space requiremnet, ideal for densly populated areas.
- Protects against flooding (high wall prevents over-topping)
- Wall can be designed with glass to avoid disruption of viewpoints

Cons
- Alters sediment transportation processes, causing longshore drift, and erosion in unprotected areas.
- Habitat disruption or loss can occur.
- Creates oppertunity for downstream flooding.

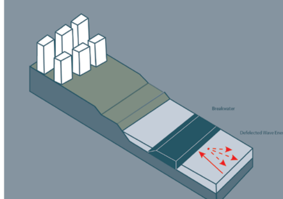


Multipurpose Dike

A strategy that implements a flood protection barrier that serves multiple functions beyond simply preventing flooding. Designed to provide space for additional infastructure that benefits the community, like roadways, commercial or residential space.

Pros
- Deflects and dissipates wave energy.
- Provides oppertunity for integration into urban fabric.
- Provides oppertunity for integration of broader strategies for sustainable development and natural resource management.
- Provides higher-lying lands less suseptible to flooding.

Cons
- Expensive to build infastructure and elevate land.
- Potential environmental cost of like distruction of local habitats.
- Wave overtopping cause cause failure of defense and lead to flooding.
- If development density is increased failure of new protection measure could occur.



Breakwater

A strategy that implements a structural barreir (either on or offshore) to protect the shoreline from tidal impact and dissipate and reflect wave energy to prevent innudation.

Pros
- Dissipates & reflects wave energy.
- Reduces sediment transportation, helping to improved water quality.
- Reduces the impact of coastal erosion.
- Can intigrate inhabitable space.
- Creates an opertunity for new habitats that offer shelter and protection for juvenile and adult fish.
- Promotes the growth of algae and other marine organisms creating a food source for larger predatory fish.

Cons
- Wave overtopping cause cause failure of defense and lead to flooding.
- Often require suplimentray barriers to protect properlly against innudation.
- Can impact sediment transportion depending on the design, orientation, and placement of the breakwater.

Diagram illustrating impending wave energy and the impact that individual hard engineering solutions have on the intricate dynamics of wave behaviour, including wave energy dissipation and reflection (outlined in red arrows). In addition, the diagram explains the importance of each solution with its pros and cons (Data from Al and Westerhof 2019,14).

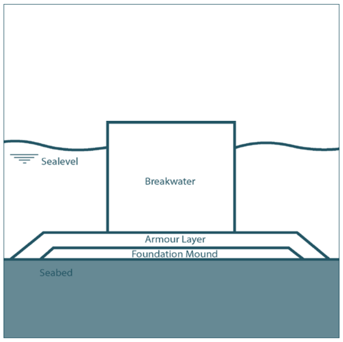
reclaim, retreat and reoccupy, and implementing floodwalls, seawalls, dikes, multipurpose dikes, revetments, surge barriers, and breakwaters. Each approach offers unique features, combining wave deflection, sediment control, and habitat preservation. After a thorough exploration, the Breakwater system emerged as the chosen solution, providing a holistic approach to coastal protection and community development.

The Breakwater system stands out as the optimal hard engineering solution for coastal communities, offering a comprehensive and practical approach to addressing the challenges of rising sea levels, storm surges, and erosion. Unlike other strategies such as Protect + Reclaim, Retreat & Reoccupy, and individual implementations like Floodwalls, Seawalls, Dikes, Multipurpose Dikes, Revetments, and Surge Barriers, Breakwaters uniquely combine the benefits of wave energy dissipation, sediment control, and habitat preservation (Al and Westerhof 2019,67). This holistic solution strengthens coastal resilience and integrates seamlessly with community development, providing a sustainable and adaptable defence against dynamic coastal forces.

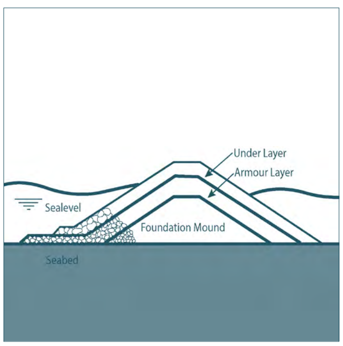
Examining Breakwaters

Breakwaters are vital components of coastal engineering and play a crucial role in protecting coastal landscapes against the forces of waves, storm surges, and erosion. A variety of breakwaters cater to specific coastal protection requirements. The Vertical Breakwater employs vertical walls to effectively counter waves and storm surges, providing robust protection against severe weather conditions. However, its impact may alter the coastal landscape, leading to beach erosion due to wave reflection in other areas (Takahashi 2002, 4). The Mound or Rubble Mound Breakwater utilizes large rocks or concrete units to absorb and dissipate wave energy, offering natural aesthetics and effective wave reduction. However, it can alter sediment transport, affecting nearby ecosystems (Takahashi 2002, 4). Tetrapod Breakwaters consist of concrete tetrapods on the seabed for wave reduction, ensuring stability, but they may occupy a significant area and disrupt underwater habitats (Gürer et al. 2005, 464). Caisson Breakwaters, large concrete or steel structures, form a solid barrier, offering reliable protection. However, their environmental impact may include disruption to marine ecosystems and sediment dynamics (Takahashi 2002, 5).

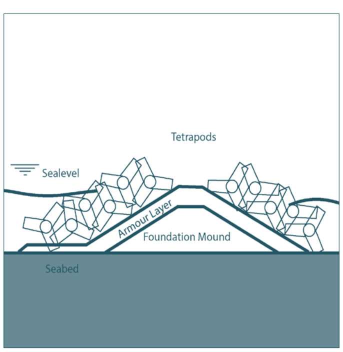
Emerged breakwaters operate partially below the water surface, combining visual minimalism with effective wave reduction, striking a balance between functionality and aesthetics. However, they may have limitations in extreme weather events, and sediment buildup could impact their efficiency (Saengsupavanich et al. 2022). Submerged breakwaters operate underwater to minimize visual impact, providing discreet protection, but they may face challenges in maintenance and pose navigation risks (Saengsupavanich et al. 2022). Composite Breakwaters blend different materials for tailored solutions, offering versatility but requiring careful design and maintenance (Takahashi 2002, 5). Floating Breakwaters adapt to changing conditions, providing flexibility, but need regular adjustment, and their efficacy in extreme weather conditions could be limited (FOC 1981). Permeable breakwaters allow water passage while reducing wave energy and promoting ecological benefits. However, they may have limited effectiveness in extreme



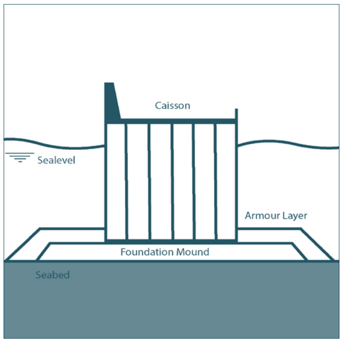
Vertical breakwater.



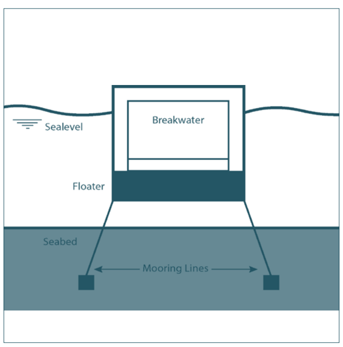
Rubble mound breakwater.



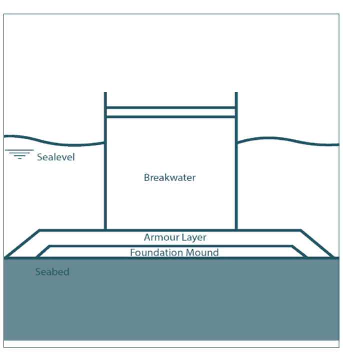
Tetrapod breakwater.



Vertical breakwater.



Floating breakwater.



Inhabitable breakwater.

conditions (Izzat Na'im, Shahrizal, and Safari, 2018, 3). Habitat Breakwaters support marine biodiversity, creating ecosystems, but require careful monitoring to prevent ecological imbalance and may face challenges in urban environments (Al and Westerhof 2019,68). Programming Breakwaters integrates recreational or civic elements for community benefits and enhances public spaces but may require ongoing maintenance for sustainable use (Al and Westerhof 2019,68). Each type of breakwater offers distinct advantages suited to diverse coastal environments, but considerations for both benefits and limitations are crucial in selecting the appropriate solution.

The thesis project aims to amalgamate the advantages of various breakwater types to create a multifaceted coastal protection solution. Drawing inspiration from Caisson Breakwaters, the design incorporates a large concrete structure embedded into the seabed to form a solid barrier against the forces of waves and storm surges. The anchoring helps to ensure the stability and effectiveness of the breakwater in providing coastal protection and prevents the breakwater from being displaced or moved by the wave action. Simultaneously, incorporating elements from both the Emerged and Programed Breakwaters. The design of an emerged breakwater offers distinct benefits for programming by providing accessible platforms above the water's surface. This elevated space allows for the integration of functional inhabitable elements, enhancing the breakwater's usability by fostering public spaces for community engagement, creating a harmonious balance between coastal resilience and community amenities and blending functionality with aesthetic appeal. In addition, incorporating features from Composite Breakwaters adds a layer of versatility that enhances its overall effectiveness. By implementing the use of different materials in the breakwater’s construction, a strategic combination of strength, durability, and environmental compatibility is created. Enabling the structure to withstand the forces of waves and storm surges while minimizing adverse impacts on the surrounding ecosystems.

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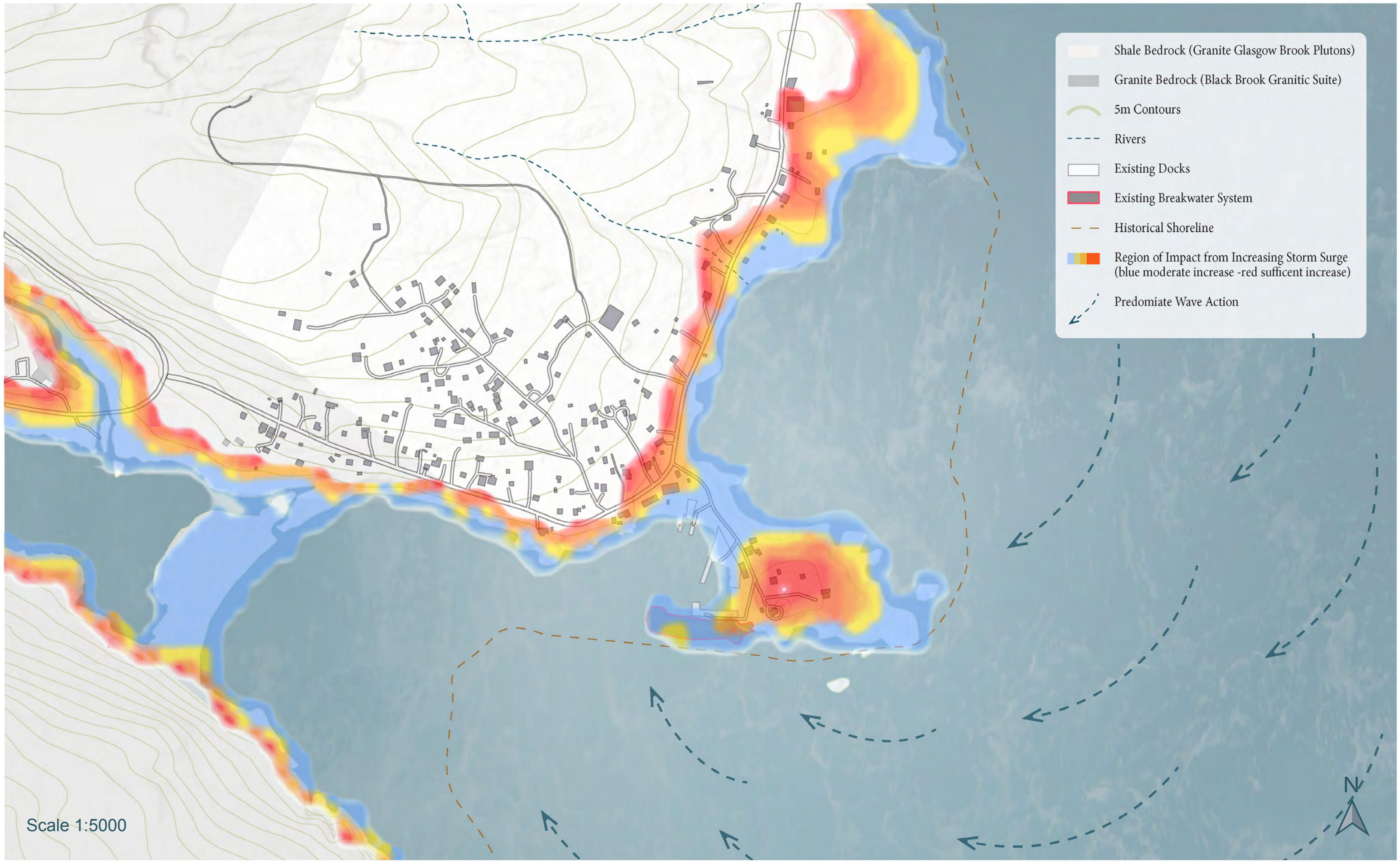
Chapter 5: Emulating Biologically Inspired Resilience in Design

Neil's Harbour As A Case Study

Neil's Harbour, Nova Scotia, is explored as a case study on how to shift our perspective from traditional methods of settlement to living in harmony with dynamic landscapes. Utilizing local land and programmatic relations to repair existing climatic impact and create a layered approach to resilient design. Geographically, Neil's Harbour is situated along the northern coastline of Cape Breton Island, facing the Atlantic Ocean. The region is directly exposed to the full force of the Atlantic Ocean, and its coastal position makes it susceptible to extreme weather events, including powerful storms, high winds, increased storm surges and heavy rainfall, which can amplify the local impacts of erosion and coastal flooding.

The coastline of Neil's Harbour is characterized by soft sedimentary rock formations, which are more susceptible to erosion than harder rock types. These formations offer little resistance to the relentless pounding of waves, leading to accelerated erosion rates and the gradual loss of land over time. The combination of strong wave action and soft rock formations contributes to significant coastal erosion along the shores of Neil's Harbour. Over time, the relentless pounding of waves wears away at the coastline, undermining the stability of coastal bluffs, cliffs, and shoreline infrastructure. This erosion threatens the integrity of coastal properties and infrastructure, compromising the natural ecosystems and coastal resources that depend on a stable coastline.



Neil's Harbour regional context map indicating sedimentary rock formations, the historic shoreline, predominant wave action, and regions of impact from extreme weather events (Data from Nova Scotia Open Data).

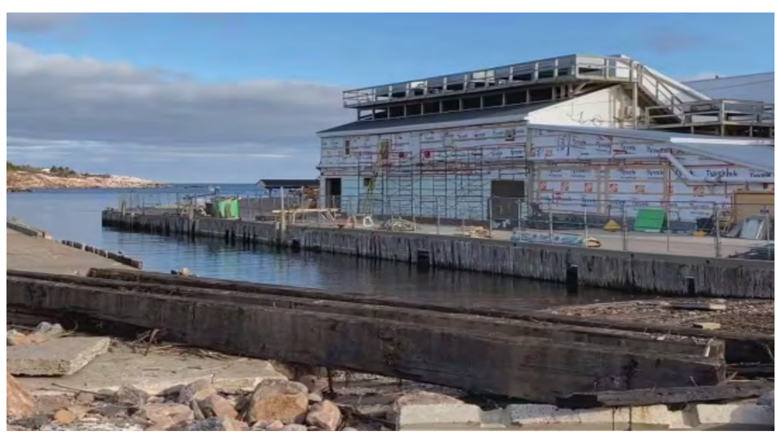
The vulnerability of Neil’s Harbour to coastal climate-related impacts significantly impacts the social and economic implications of the community. The loss of coastal lands and damage to infrastructure disrupt local livelihoods, including the fishing and tourism industries, which are relied upon for economic prosperity. Implementing both immediate and long -term consequences on local residents and businesses due to their reliance on coastal resources, affecting their well-being and economic sustainability.

In September of 2022, Neil’s Harbour encountered substantial harm to the community during a storm event where the impact of high tide in combination with the storm surge from Hurricane Fiona created six-to-eight-metre waves that toppled over the existing breakwater (Ayers 2022). Despite being designed as a protective structure, Neil’s Harbours existing breakwater could not withstand the significant storm surge resulting in substantial harm to the local roads, homes, and fish plant facilities (Ayers 2022).

Neil’s Harbours local fish plants, commercial harvesting facilities and associated businesses make up over 25% of regional employment, serving as a fundamental foundation for the sustained success and prosperity of the community. Thus, the loss of infrastructure, including the fish plant, during the storm event, had severe consequences, impacting both the immediate and long-term well-being of the community as the plant facilities employed a significant portion of the local population. This event highlighted the urgent need for enhanced resilience measures and updated infrastructure to protect the community against future climate-related challenges.

The coastline of Neil's Harbour, Nova Scotia after extreme storm surges from Hurricane Fiona, 2022 (Ayers 2022).

Destruction to New Heaven Road, Neil's Harbour, after extreme storm surges from Hurricane Fiona, 2022 (Ayers 2022).



Destruction to Neil's Harbour local fish plant facility, after extreme storm surges from Hurricane Fiona, 2022 (Ayers 2022).

Design Intent

Thus, a new innovative breakwater system is proposed to replace Neil's Harbour's existing failed breakwater. Intended to be implement as an architectural prototype to protect the local coastal community from impending climatic impacts, while fostering ecological growth and enhancing community engagement. The Neil's Harbour Observatory and Research Centre sets a precedent for innovative architecture that encourages living in harmony with dynamic landscapes. Intending to act as a resilient barrier against tidal action, sediment transport, deposition, erosion, and the escalating challenges posed by climate change, including rising sea levels while fostering space for community research and engagement and drawing inspiration from nature's resilience.

The proposed system will replace Neil's Harbour's existing failed breakwater system with the intent to explore the utilization of biomimicry in architecture to address the increasing threats of climate change and pressing challenges faced by Nova Scotian coastal communities. Directly addressing coastal dynamics by using abstractions of nature's adaptive strategies to inform form and structure while highlighting the intelligence of local marine species and their ability to coexist harmoniously in dynamic coastal environments. Signifying a community commitment to living in harmony with coastal dynamics and addressing the shortcomings of existing coastal solutions.

The breakwater will take on a new orientation, as the region experiences significant prevailing winds from the southwest and is exposed to the open ocean making it particularly vulnerable to both nor'easters and southwesterly storms.

Neil's Harbour regional context map indicating the proposed inhabitable breakwater system, prevailing winds and predominate wave action. (Data from Nova Scotia Open Data).

Thus, the structure will be strategically angled perpendicular to the incoming wave direction and against the prevailing wave path, to take on forces from Nor'easters. The powerful coastal storms that typically move up the East Coast of North America, bringing strong winds, heavy precipitation, and sometimes snow that commonly hit during the fall and winter months. In addition, to southwesterly storms that originate from the southwest and impact the region with strong winds and precipitation more commonly in spring or summer. Allowing the structure to intercept and break both daily tidal action and sufficient storm surges efficiently, reducing their energy before reaching the protected area of the harbour. Providing a protective barrier to local infrastructure and fostering a stable environment for marine species.

Abstraction and Emulation of Biological Terms

This thesis acknowledges that sharks stand out as a remarkable native species, that frequently migrate through the North Atlantic off Nova Scotia's coast. Showcasing their unparalleled hydrodynamic performances and the ability to adapt to changing coastal environments. Their evolutionary journey spanning over 450 million years has sculpted them into apex predators with streamlined bodies, efficient locomotion, and specialized sensory capabilities. The hydrodynamic efficiency of sharks is evident in their streamlined bodies and unique skin structures, which allow them to navigate coastal waters with exceptional agility. In addition, their adaptability is demonstrated through diverse anatomical features and behaviours, highlighting their resilience as a species to dynamic coastal landscapes. The spices additionally showcase their importance to the marine ecosystems, as they play crucial roles in regulating prey populations, fostering ecological balance, contributing to the overall health of coastal environments, and providing economic benefits to local seafood industries.

The importance of the sharks evolution lies not only in their survival but in the valuable insights it provides for designing resilient structures and strategies that harmonize with coastal dynamics and contribute to the sustainable coexistence of human communities with the ever-changing coastal environment. In abstracting form related to morphology and locomotion and applying principles of structural resilient based off sharks unique denticle features the architectural intent is to provide a resilience coastal structure that not only protects the existing coastal community but gives back by providing space for community engagement and economic opportunity.

Form Follows Function

The design of the inhabitable breakwater system will implement an arrangement of curved panels, drawing inspiration from the locomotion patterns of sharks, particularly focusing on the anguilliform swimming style exhibited by shallow-bodied shark species. Shallowed-bodied swimmers generate a sinuous wave movement as they navigate coastal conditions, providing a more streamlined interaction with the waves, minimizing resistance, turbulence, and dissipating portions of wave energy (Sternes and Shimada 2020). These locomotion patterns inspired the design of a long slender arrangement of streamlined curves intended to optimize the performance of the inhabitable breakwater. The design of these sinuous curves to constitute the foundational structural elements of the breakwater allows for more efficient wave energy dissipation compared to linear arrangements (Hussein and Ibrahim 2022). The curved form helps to reduce hydrodynamic drag and turbulence, enabling the structure to intercept and break waves efficiently by scattering the reflected energy rather than directly reflecting it (Hussein and Ibrahim 2022). This approach not only serves a functional purpose but additionally enhances the aesthetic appeal of the breakwater.

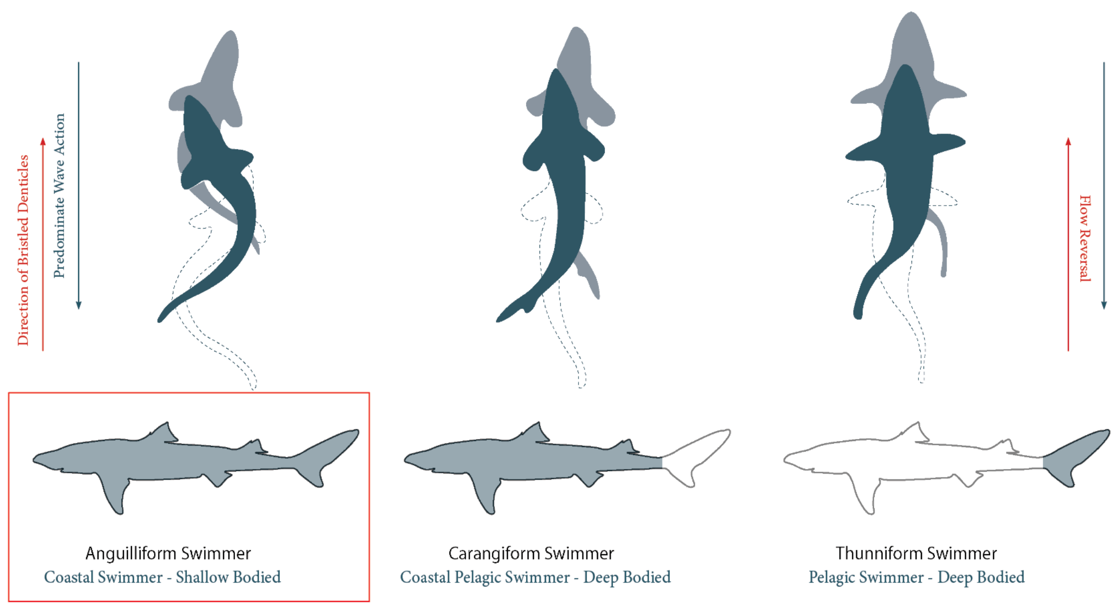
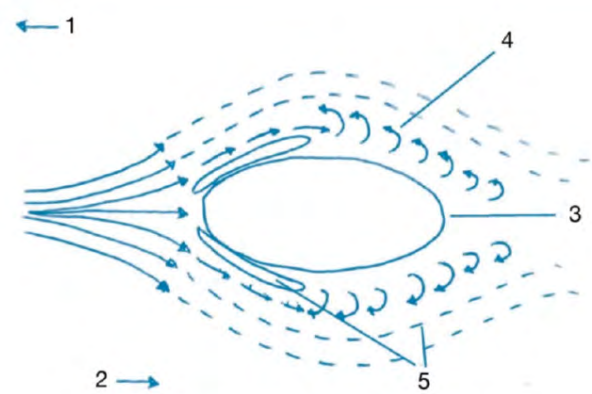


Diagram indicating the locomotion pattern abstracted for the inhabitable breakwater design (Sternes and Shimada 2020).

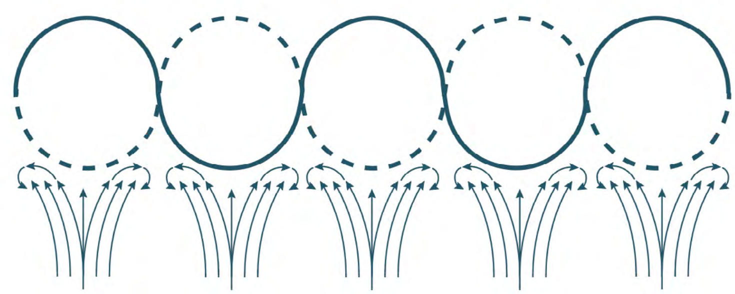
The interaction between tidal action and the shark is remarkable due to the shark's specialized streamlined curvature, which facilitates the smooth redirection of water flow. As tidal forces propel water toward the shark, its hydrodynamic shape efficiently guides the flow around its body, deflecting the water away and dispersing wave energy in the process. As water flows over the shark's body, it adheres to the surface due to the friction between the water molecules and the shark's skin. This creates a thin layer of water, known as the boundary layer, directly interacting with the shark's skin. This boundary layer can become turbulent in terms of fluid dynamics, creating drag that slows the shark's movement. This unique adaptation allows the shark to navigate through turbulent waters while controlling its resistance to turbulent flow. By efficiently managing the water flow around its streamlined body, the shark can minimize or maintain smooth movement through the water or maximize it to disrupt the flow and dissipate wave energy, stabilizing itself in turbulent waters. Contributing to wave energy dispersion and further highlighting the remarkable synergy between the shark's anatomy and the marine environment.



1: direction of acceleration, 2: flow direction; 3: shark body; 4: turbulent boundary layer; 5: laminar flow layers

Diagram indicating water flow around the sharks streamlined curvature (Data from Sternes and Shimada 2020).

Drawing inspiration from the sinuous movements of shallow-bodied swimmers, the design features a streamlined curvature that abstracts these natural motions into a series of fluid curves and contours. These elements mimic the undulating patterns created by the shark's interaction with its environment, emphasizing sharks' resilient adaptations evolved to live in harmony with dynamic conditions. The design captures the aesthetic beauty of fluid dynamics while additionally reflecting the functional efficiency of the shark's locomotion patterns.



Preliminary form diagram indicating refraction of dissipated wave energy off the exterior edges of the streamlined curvature.

Drawing inspiration from the robust design of Caisson Breakwaters and the adaptive strategies of the shark, the proposed inhabitable breakwater design emulates this streamlined curvature in a semi-submerged concrete structure. By replicating the sleek contours of a shark's body, the breakwater aims to optimize its performance in deflecting and dissipating wave energy. Prefabrication of individual concrete panels off-site offers several benefits, including enhanced quality control, reduced construction time, and minimized environmental impact during assembly. This array of streamlined curvature not only enhances the structural integrity of the breakwater but also improves its efficiency compared to traditional linear systems. The dynamic shape of the breakwater allows for more effective dispersion of wave energy and minimizes resistance to turbulent flow, ultimately contributing to the resilience of coastal communities against the relentless forces of the marine environment.

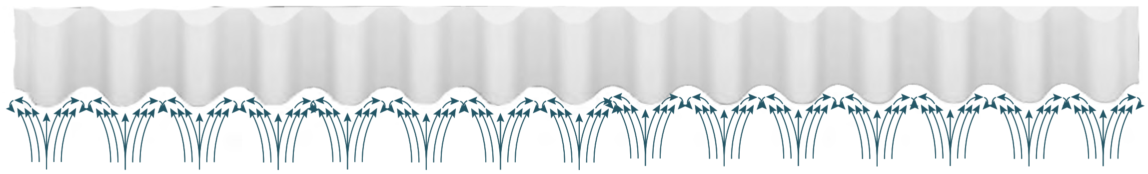
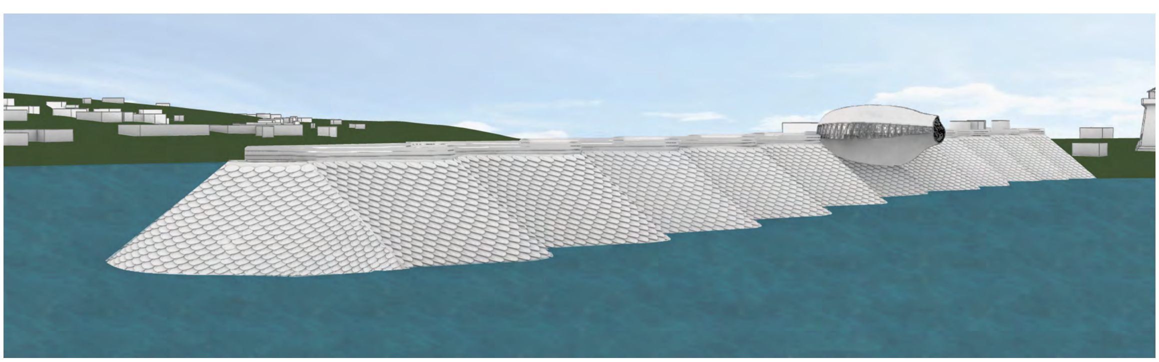


Diagram indicating the refraction of dissipated wave energy off the exterior edges of the assembled curvature of the inhabitable breakwaters.

Once the prefabricated panels are assembled they will cumulatively form a watertight structure embedded 3.5 meters into the seabed. Spanning 10.5 meters in height above the seabed, and emerging 7 meters above sea level, the breakwater will create a multi-dimensional space. Establishing an inhabitable platform above sea level for recreational activities and interior spaces catering to both public and private use, while creating new habitats for local marine species below sea level. The structure stands to represent a formidable barrier to protect Neil's Harbour against the relentless forces of tidal action and approaching storm surges, while creating an abundance of space to foster community engagement. Evoking the strength and resilience of both the shark and the caisson-style breakwaters while implying functionality of space to the coastal defense system.



Preliminary perspective depicting the emulated streamlined curvature of the breakwater, alongside the approach from the ocean, within the context of the surrounding community.

The implementation of the breakwater in Neil's Harbour is intended to foster community engagement by creating a vibrant hub with multifunctional spaces that encourage social interaction, recreational activities, and cultural events. The breakwater is intended to serve as a vital asset, offering protection and prosperity to the local community. Integrating marine biology labs and aquaculture spaces would facilitate research and education initiatives, fostering a deeper understanding of the marine environment and promoting sustainable practices. Beyond its primary function of protecting the community against coastal hazards like tidal action and storm surges, the exterior inhabitable platform above sea level provides a space for residents and visitors to gather for various activities, such as walking or enjoying scenic views. At the same time, the interior provides spaces that may host community events, festivals, or educational programs, bringing people together and strengthening social bonds. By serving as a focal point for community life, the breakwater creates opportunities for residents to connect with one another, share experiences, and build a sense of belonging. Furthermore, community members will have opportunities for active participation and collaboration in the ongoing development of the breakwater, fostering a sense of ownership and pride in their coastal environment.

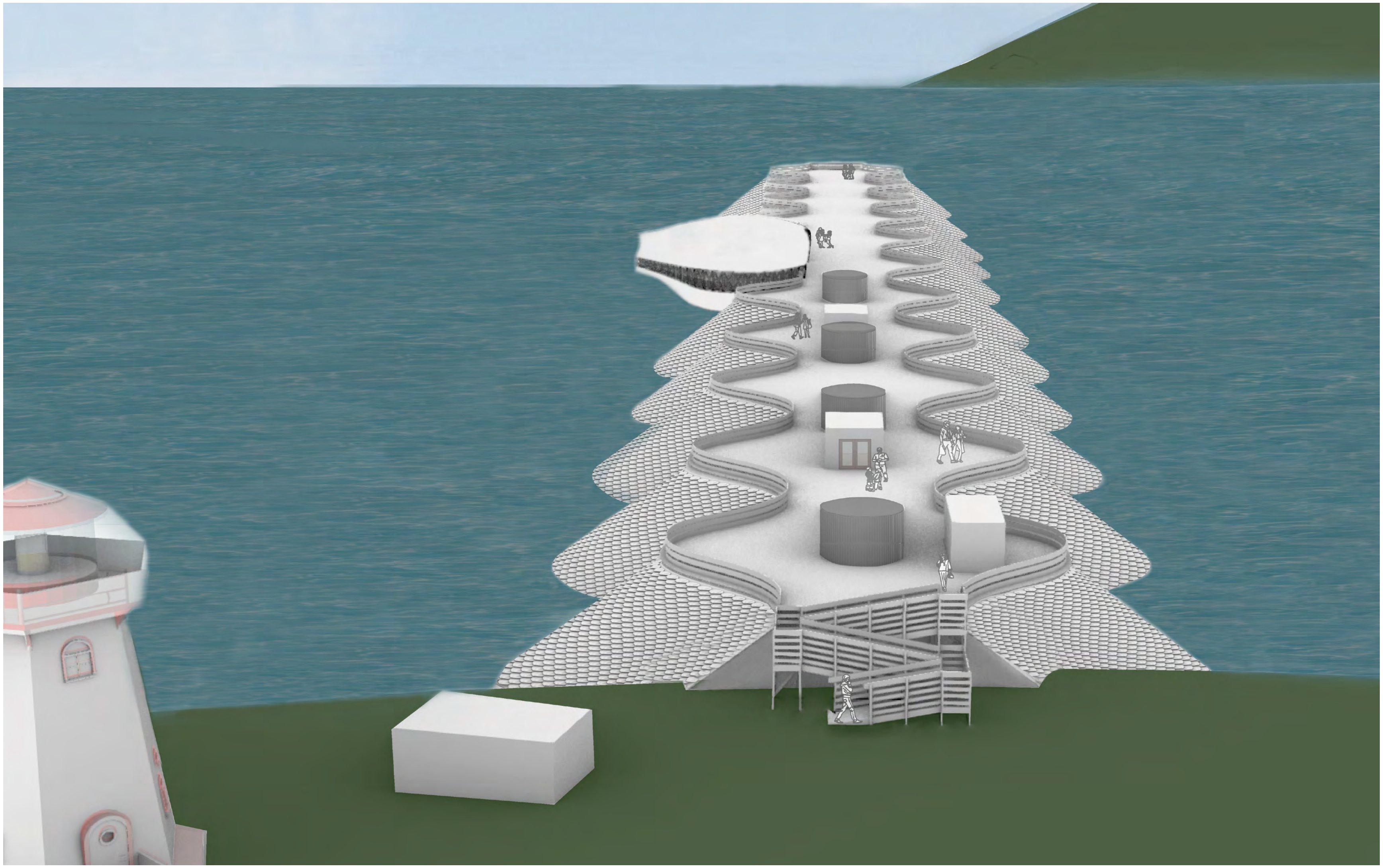
In addition, incorporating curvature in architectural design can positively impact the arrangement of space and enhance the user experience. The curved spaces promote a more fluid and natural flow within the habitable space of the structure. Unlike rigid, linear designs, the curves harmoniously guide occupants smoothly from one area to another, creating a sense of continuity and connectivity. This optimization is particularly beneficial in larger multifunctional spaces where efficient circulation space is essential, like observatories and galleries. Additionally, optimizing spatial efficiency while providing focal points and adding visual interest while incorporating a dynamic feel to the architecture, helping to make the environment feel more inviting and comfortable for occupants.

As residents and visitors approach the breakwater from the community of Neil's Harbour, they are greeted by a sense of anticipation and excitement. The road leading to the breakwater meanders through picturesque coastal landscapes, offering views of the protected harbour and surrounding ocean. The rhythmic sound of waves crashing against the concrete structure grows louder, heightening the sense of anticipation for inhabitants as they draw closer to the breakwater. The ramp will take inhabitants from ground level to the exterior inhabitable platform above sea level that serving a dual role in facilitating pedestrian access and serving as a pathway for transporting supplies and equipment to the breakwaters cargo elevator. The cargo elevator itself is essential for this design to ensure efficient logistical management, facilitating the transport of heavy equipment and supplies required for conducting research and experiments in marine biology labs and marine autopsy labs, as well as for stocking cafes and aquaculture spaces. Seamlessly integrating functionality with accessibility, ensuring efficient operations of the breakwater while enhancing the overall user experience. Finally, as inhbaitants step onto the breakwater's exterior platform, inhabitants will be captivated by the surrounding coastal views. Thus, whether embarking on a leisurely stroll, engaging in recreational activities, or attending community events, the approach to the breakwater sets the stage for memorable experiences and that connect users to the surrounding environment.

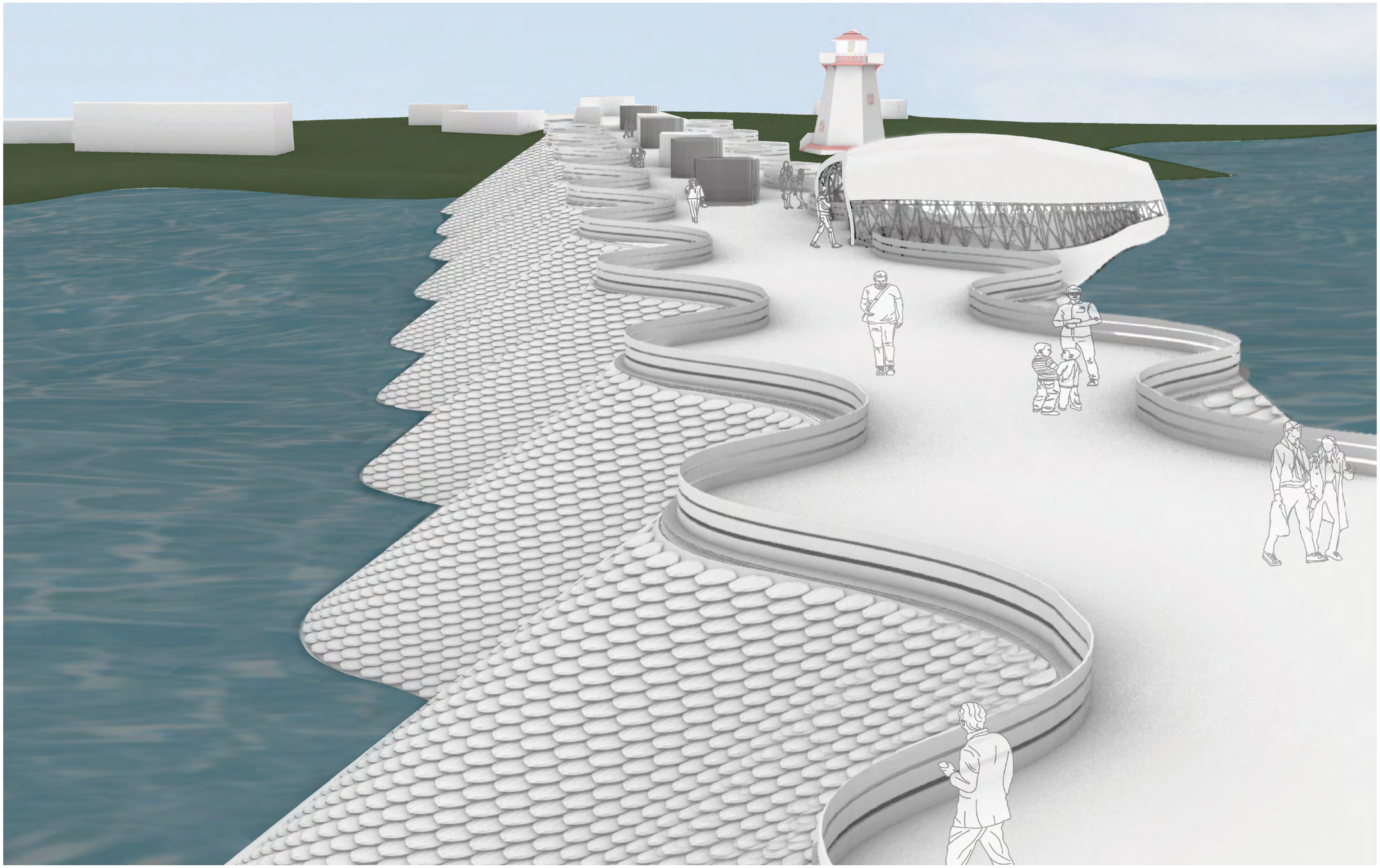
In contrast, when inhabitants look back from the breakwater towards the community, a profound sense of place is fostered by providing a unique perspective on familiar surroundings. From the breakwater, residents and visitors can witness the interplay between the breakwater and the coastal landscape, observing how the structure integrates harmoniously with its natural surroundings. This vantage point offers a chance to appreciate the community's resilience and connection to the sea and its cultural and historical significance. The sight of familiar landmarks, such as homes and buildings, reinforces a sense of belonging and identity, grounding individuals in their community's rich heritage and providing the opportunity to observe daily life unfolding in the community from afar and highlighting the interconnectedness of the communities residents and the coast. Serving as a powerful reminder of the community's past, present, and future, instilling a deep appreciation for its unique character and sense of place.

The curvature also provides acoustic benefits to diffuse sound as the curves limit echoes in large open spaces, contributing to better acoustics in public spaces. By mirroring the shark's sinuous swimming pattern, the breakwater aligns with the adaptive strategies seen in nature, contributing to its structural resilience against dynamic coastal forces. Incorporating this biomimetic design element enhances the breakwater's effectiveness in protecting the coastline and offers a visually striking representation of nature-inspired architectural resilience. This design application demonstrates that form following function is an applicable architectural principle learned from the anatomy and locomotion of the shark.

Aerial perspective of the proposed inhabitable breakwater in relation to the Neil’s Harbour community, providing context to community relations.



Aerial perspective showing community approach to the breakwaters and its connection to the headland.

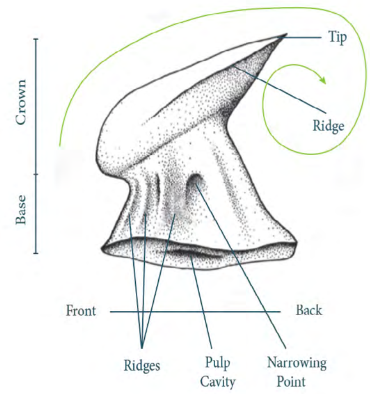


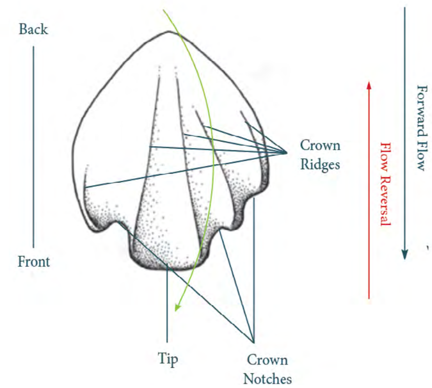
Perspective view showing inhabitation of the breakwater and views of the community.

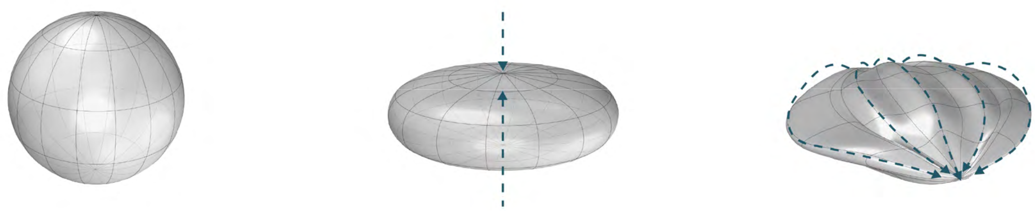
Insights on Structural Resilience

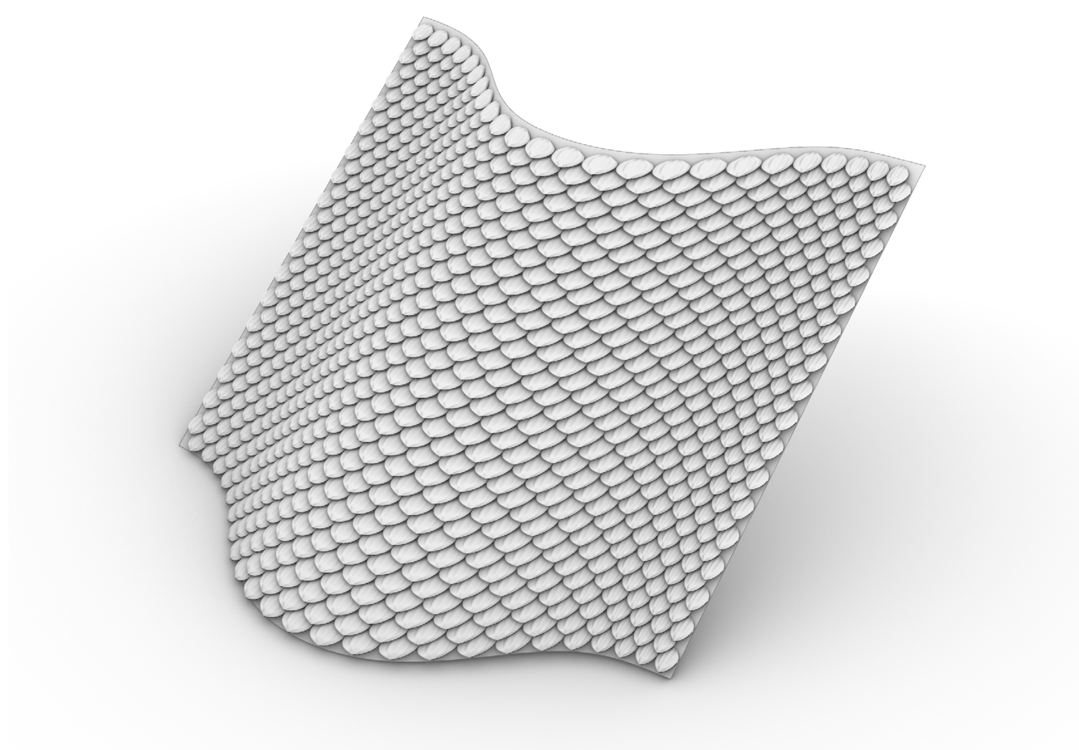
The structural resiliency of the shark's morphological features and adaptations is evident in various aspects of its anatomy, including its specialized microscopic tooth-like structures found embedded into the exterior layer of the shark's skin. These structures are intricately designed to withstand significant forces and stresses encountered in marine environments, providing hydrodynamic advantages and protection against abrasive forces -contributing to reducing drag, enhancing maneuverability, and offering a defence mechanism. In terms of biomimicry, the study of the shark denticle's portrayed in this thesis shows a comprehensive analysis of the denticle's unique characteristics, including shape, arrangement, surface texture, and functional adaptations. Emphasizing the success of its structural design.

The exterior precast concrete panels will feature functional arrays of upscaled denticles, mirroring an abstraction of those observed on the Atlantic Thresher shark. These enlarged denticle formations are strategically positioned to optimise drag reduction and hydrodynamic efficiency, much like their biological counterparts. By emulating the arrangement and spacing of shark denticles, the panels are engineered to influence both forward and reverse flow patterns around the breakwater structure. During forward flow, such as incoming waves, the denticle arrays disrupt and streamline the flow, reducing drag and minimizing resistance. In the case of reverse flow, like the receding water after a wave, the denticle formations help to dissipate energy by creating turbulence and breaking up wave action, thereby enhancing the breakwater's ability to withstand coastal forces and protect the shoreline. Through biomimicry-inspired design,









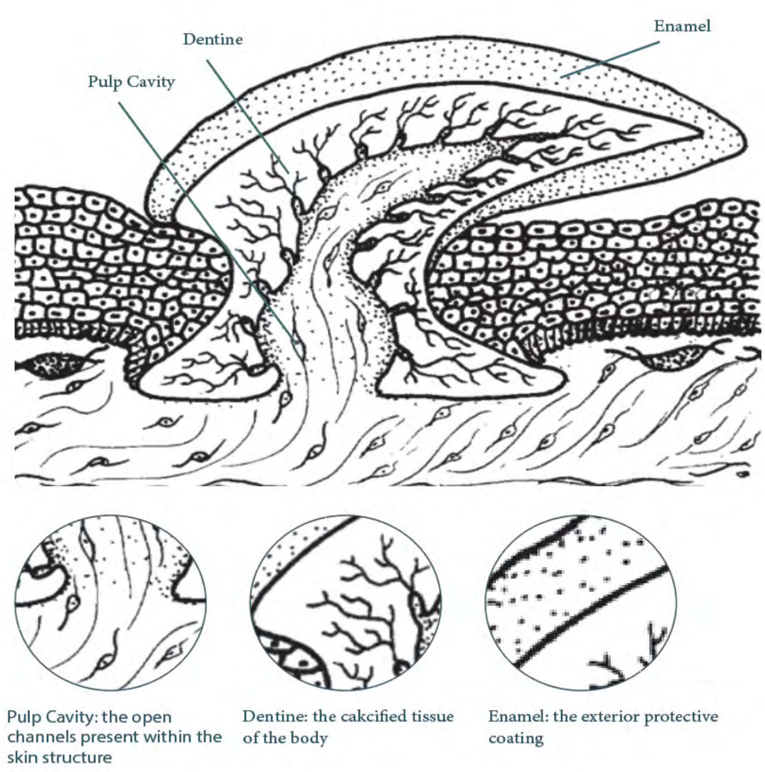
Emulation of the enlarged precast concrete denticles on the breakwater panel.

the integration of denticle arrays on the concrete panels aims to optimize the breakwater's performance in managing wave energy and enhancing its overall resilience in marine environments.

In addition the structure if the denticle is unique as it is embedded into the thin outer boundary layer of sharks skin, composed of a flexible collagen fibers substrate. By mimicking this layered structure from interior to exterior the opportunity for improved resistance against harsh coastal conditions, including strong winds, saltwater exposure, and impacts from debris is increased. Inspiring a fluid free-form structure the combines glass fiber reinforced concrete with a freeform, multijointed interlocking system, cladded with glass fiber reinforced concrete and triple pained windows. This approach allows for the optimization of performance, resilience, sustainability, and aesthetics, while drawing inspiration from nature's efficient and adaptive solutions.

Serving as a testament to the innovative use of biomimicry in architecture, highlighting the potential for nature-inspired design solutions to address real-world challenges and adding a layer of visual interest and complexity and inviting visitors to marvel at the intricacies of natural forms translated into built environments. This creates a visually captivating architectural element and fosters a deeper appreciation for the beauty and functionality of biological structures. In addition, positioning the upper observatory as a focal entry point into the breakwater building enhances its prominence and significance within the overall design, drawing visitors' attention and inviting exploration. Overall, the combination of structural resilience, aesthetic appeal, and thematic significance makes the upper observatory a compelling architectural moment that enriches the user experience and contributes to the overall narrative of the breakwater design.

The layered and robust composition of shark denticles, which includes the pulp cavity, dentine, and enamel, offers a compelling inspiration for architectural innovation. Comparable to the internal organization of a building, the pulp cavity in shark skin represents a network of interconnected channels or pores/spaces that support fluid and gas exchange while fulfilling sensory functions. This concept stimulates inventive spatial arrangements aimed at enhancing the flow of circulation and interaction within interior spaces. In the breakwater design this provides an opportunity to implement dynamic spatial configurations between inhabitable areas. Facilitating movement and



The layered composition of the shark denticle indicating the pulp cavity, dentine, and enamel (Thies and Leidner 2011, 73).

circulation, fostering adaptable layouts and strategic openings to optimize efficiency and comfort for occupants within the upper observatory and breakwater.

The dentine, the calcified tissue that forms the structure of shark denticles, provides valuable insights for architectural design, particularly in structural components. Renowned for its strength and durability, dentine serves as a natural model for creating robust structural elements crucial for stability and longevity. In the breakwater design, dentine’s strength inspires the incorporation of load-bearing walls capable of supporting expansive interior spaces and the distinctive freeform structure. Additionally, the dentine’s mineralized composition, characterized by high compressive strength and hardness, informs the selection of breakwaters materials. Precast concrete is chosen to provide the necessary strength and load-bearing capacity, ensuring structural integrity and fostering dynamic spatial arrangements.

Furthermore, the insight additionally informs the selection of the embedded Freeform’s materials. A steel beam and bearing joint freeform structure draw inspiration from dentine’s qualities of strength, durability, and flexibility. Like dentine supports and protects the pulp cavity within a shark’s tooth, the steel beam and bearing joint system offer structural integrity and resilience to the upper observatory of the breakwater. Just as dentine withstands external pressures and impacts, the steel beams and joints provide strength to support the observatory’s weight and resist environmental forces. Additionally, dentine’s flexibility allows it to adapt to various forces during a shark’s movement; similarly, the freeform structure’s flexibility allows for dynamic spatial arrangements and architectural expressions, ensuring adaptability over time. Thus, the steel beam and bearing

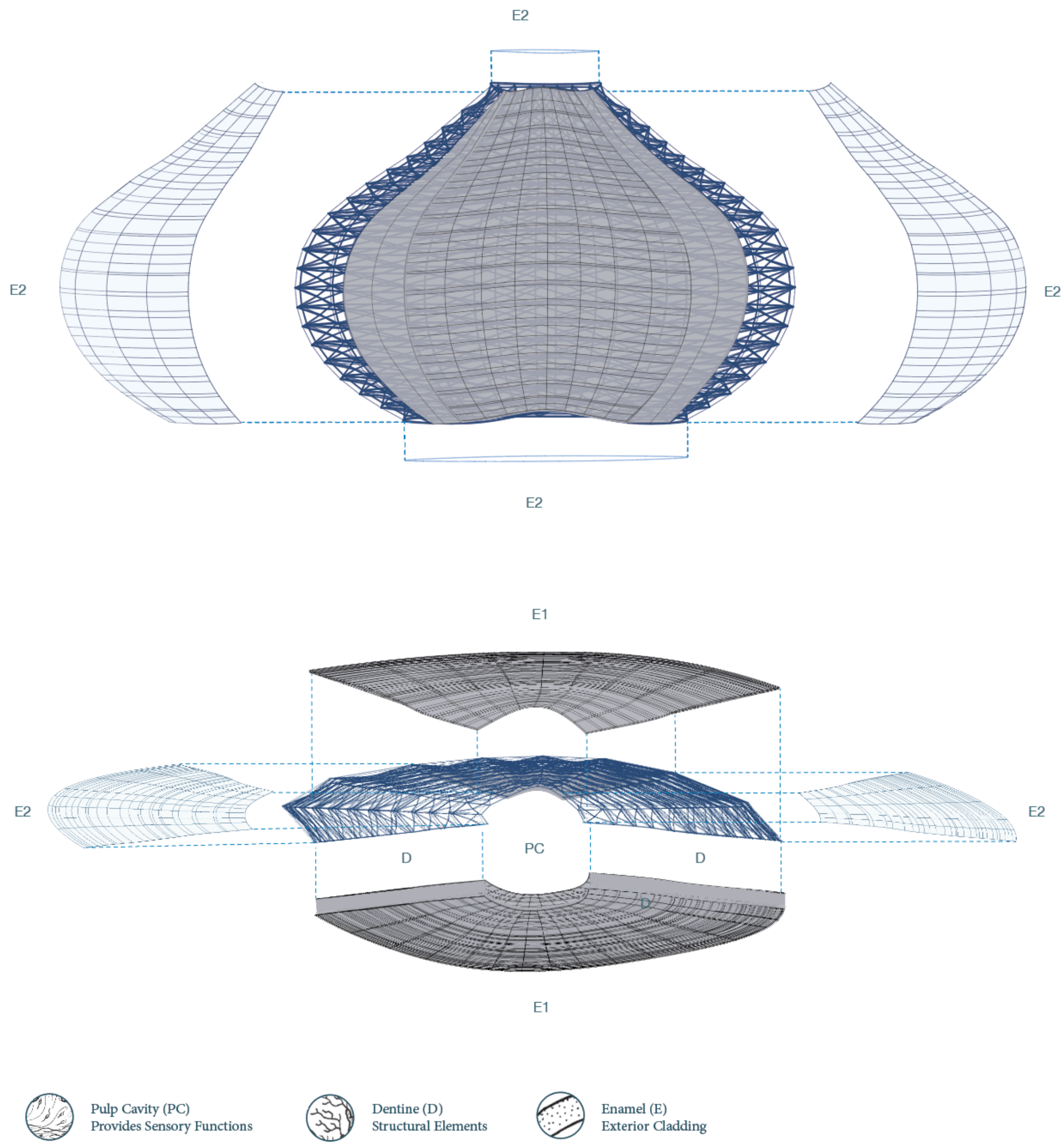
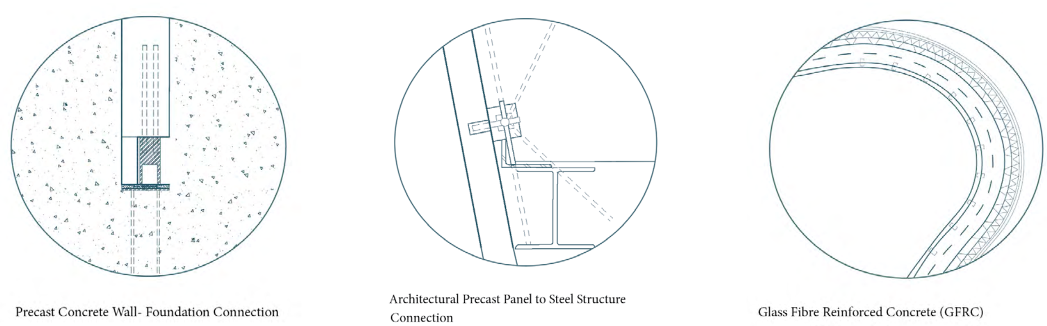


Diagram explaining biomimicry and the structure of the freeform embedded observatory.



Structural details showing freeform connections.

joint freeform structure embody the principles of strength, durability, and flexibility observed in dentine, contributing to the resilience and functionality of the breakwater's architectural design.

The enamel, acting as the exterior protective coating in shark denticles, serves to safeguard underlying tissues from external forces and environmental conditions. In the context of the breakwater design, this concept is integrated into the exterior cladding systems, which shield the building's interior spaces from weather elements, moisture, UV radiation, and potential damage. This inspires the use of durable materials, complemented by high-performance coatings like metal panels or glass-fiber reinforced composites, to establish a robust and resilient exterior envelope. Moreover, the water-repellent properties exhibited by enamel inspire the implementation of streamlined self-cleaning surface treatments for building materials, such as triple-pane glass and reinforced concrete in the upper observatory. These adaptations contribute to the maintenance of the building envelope's integrity, prolong its longevity, and minimize maintenance requirements.

Programing for Human Use

The inhabitable breakwater system will serve to enhance community connectivity by supporting the local heritage and showcasing a prototype for architectural resilience in coastal communities that promotes sustainable development and environmental stewardship. The integrated research center and public research observatory also intends providing an educational platform on coastal resilience and tidal dynamics while fostering a space for community engagement. As the shark works holds a complex relationship as a community facilitator the breakwater is designed intends to facilitate a complex program combining recreational, educational, and economic opportunities. The design divides the breakwater into three floors representing a division of public and private function.

Within the interior watertight space formed by the streamlined curved prefabricated concrete panels, the breakwater delineates a clear division between public and private areas, catering to various needs and functions. The public realm encompasses an expansive exterior platform offering breathtaking coastal views, complemented by interior amenities such as a cafe, event space, art gallery, and marine archive. This open and inviting space serves as a communal hub, fostering social interaction, cultural exchange, and appreciation of the marine environment. In contrast, the private domain hosts specialized facilities, including marine biology labs, a marine autopsy lab, and an experimental aquaculture facility. These spaces facilitate scientific research, educational endeavours, and innovation in marine-related fields, providing a controlled environment for experimentation and discovery. By hosting a combination of public and private spaces, the breakwater enhances community engagement and cultural enrichment while advancing scientific knowledge and sustainability practices, positioning itself as a versatile and invaluable asset to Neil's Harbour and its inhabitants.

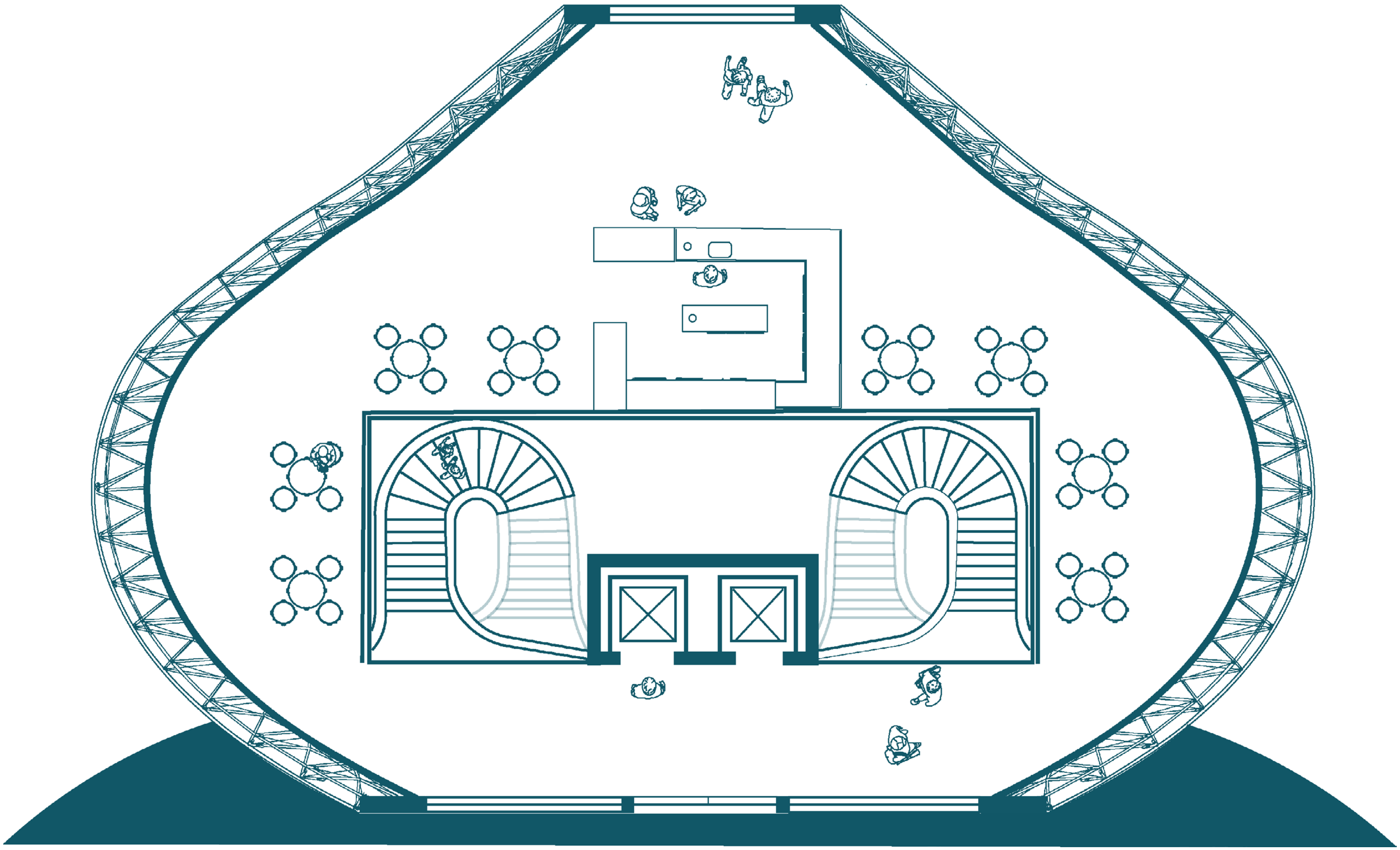
The approach to utilizing only a portion of the inhabitable breakwater's space for current programming while reserving the remainder for future development reflects a strategic and forward-thinking mindset. By intentionally leaving some space unallocated, the design allows for flexibility and adaptability to accommodate future needs, opportunities, and advancements in technology or community priorities. This approach ensures that the breakwater remains dynamic and responsive to evolving demands, maximizing its long-term utility and relevance. Furthermore, it enables phased development, where initial programming can be implemented efficiently and cost-effectively, with subsequent phases tailored to emerging requirements or changing circumstances. Overall, this approach emphasizes sustainability, resilience, and the ability to evolve over time, ensuring that the breakwater remains a valuable asset to the community for generations to come.

Preliminary longitudinal section indicating the utilization of space and approach to dividing public (green) versus private (blue) program within the inhabitable breakwater.

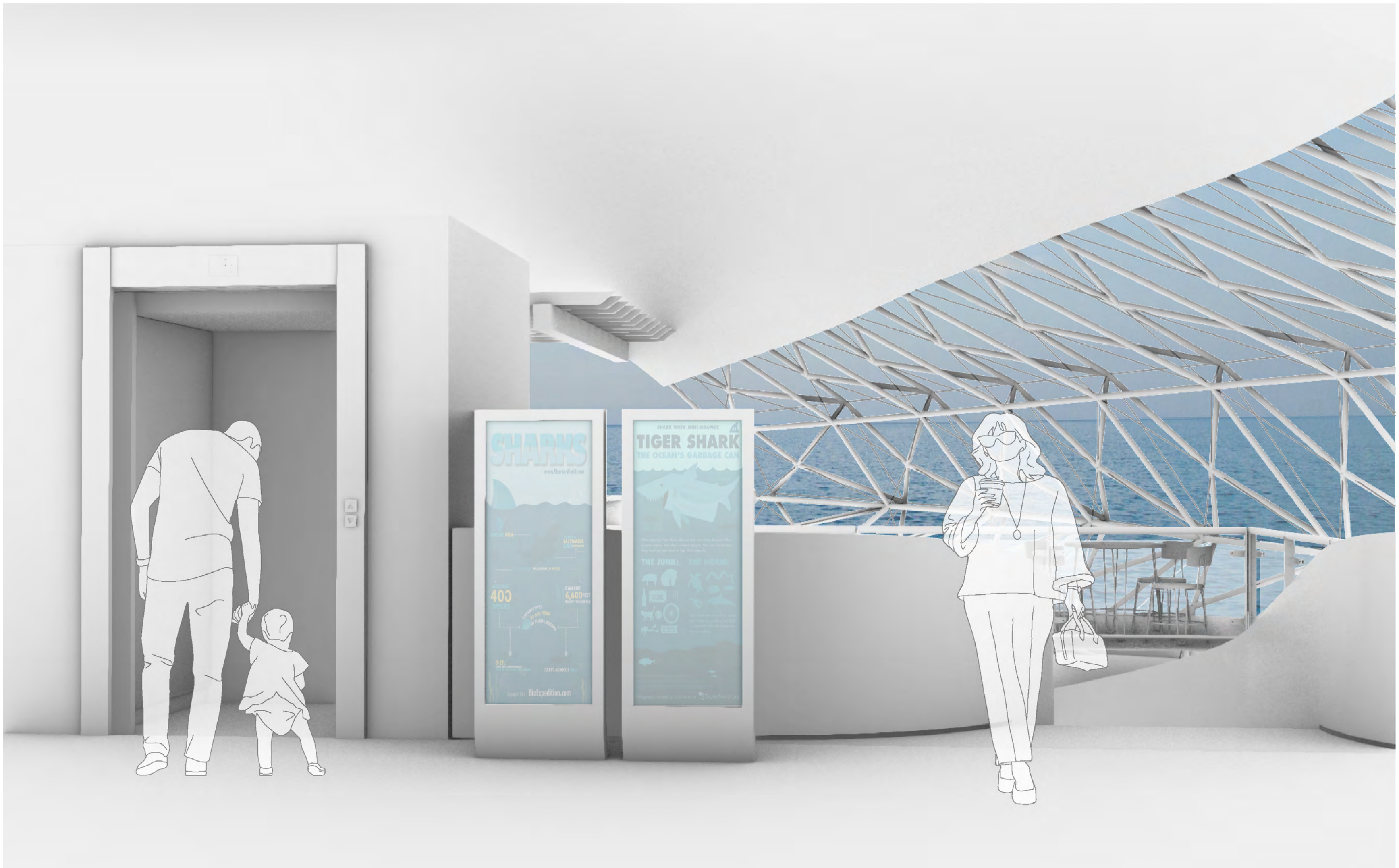
The design of the shark denticles, embeds their structure into the sharks skin providing strength, durability, and flexibility, influencing the architectural approach to the upper observatory and cafe within the breakwater. Inspired by the denticles seamless integration this innovative freeform design not only ensures structural integrity but also fosters a deep connection between users and the surrounding marine environment. By mimicking the adaptability of shark denticles, the upper observatory and cafe offer visitors a unique experience, allowing them to immerse themselves in the dynamic coastal landscape while enjoying panoramic views of the ocean. Serving as a focal point within the breakwater, this space symbolizes the harmony between human architecture and the natural world, inviting users to appreciate and engage with the marine environment in a meaningful way.

The freeform upper observatory serves as the focal entry point into the breakwater, offering visitors a unique and immersive experience as visitors embark on their journey into the structure. Its innovative design and striking architectural features capture attention, drawing people in and setting the tone for their exploration of the breakwater. This distinctive entryway not only provides access to the interior spaces but also serves as a symbolic gateway, symbolizing the connection between land and sea, and inviting individuals to engage with the marine environment. However, in addition to this focal entry point, other points of entry will be strategically implemented throughout the breakwater for safety and accessibility purposes. These secondary entry points, while less focused on narrative, will ensure that visitors can enter and exit the structure safely and efficiently, enhancing overall usability and convenience.

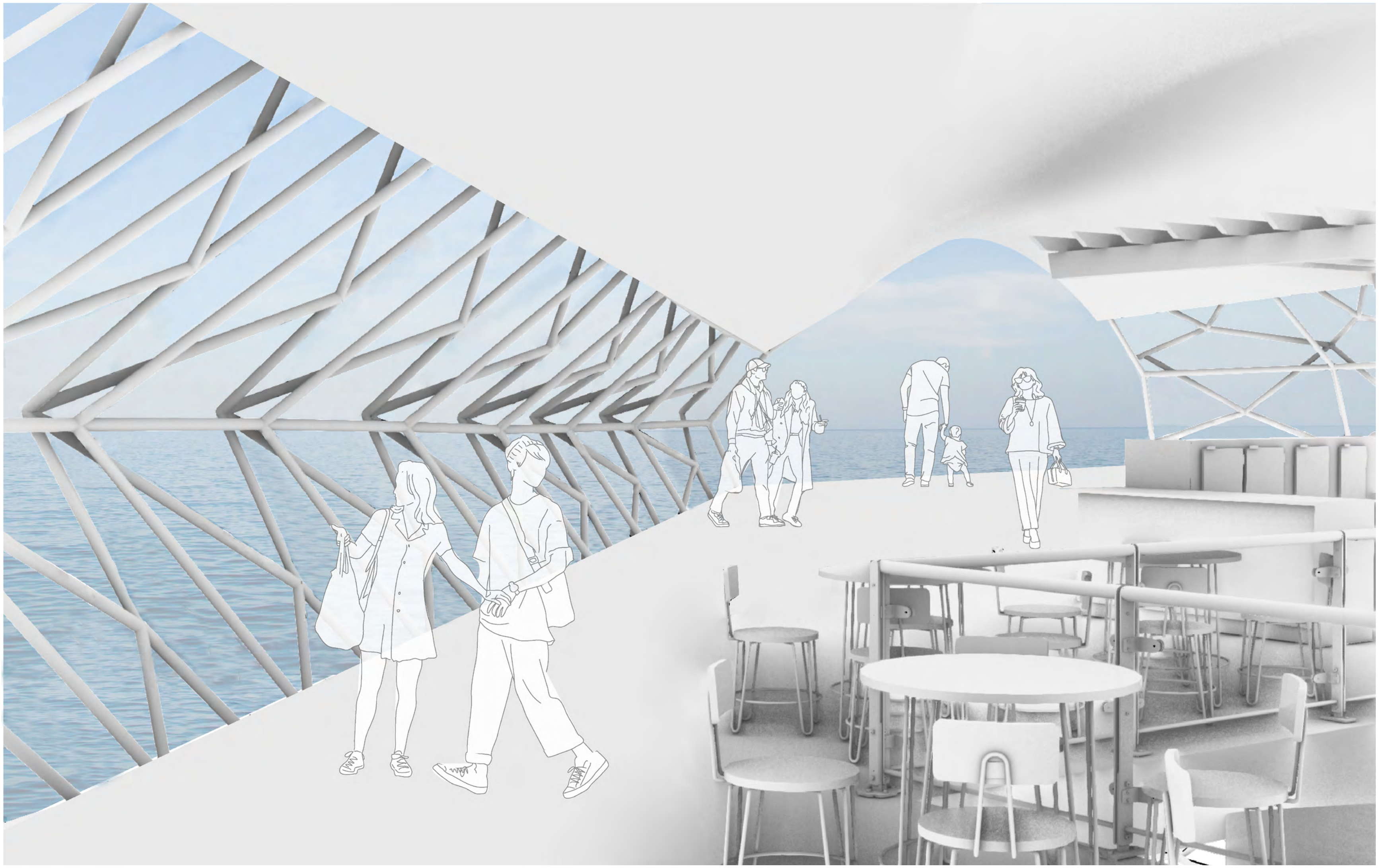
Users would inhabit the freeform upper observatory and cafe space by immersing themselves in a multifaceted experience that blends breathtaking views of the open ocean with interactive educational displays, social interactions, and the enjoyment of coffee. As visitors enter the upper observatory, they are greeted by panoramic vistas of the surrounding marine environment, creating a sense of awe and connection to the coastal landscape. Within the open observatory space there will be a cafe space, intended for users to engage in social interactions, fostering a sense of community.



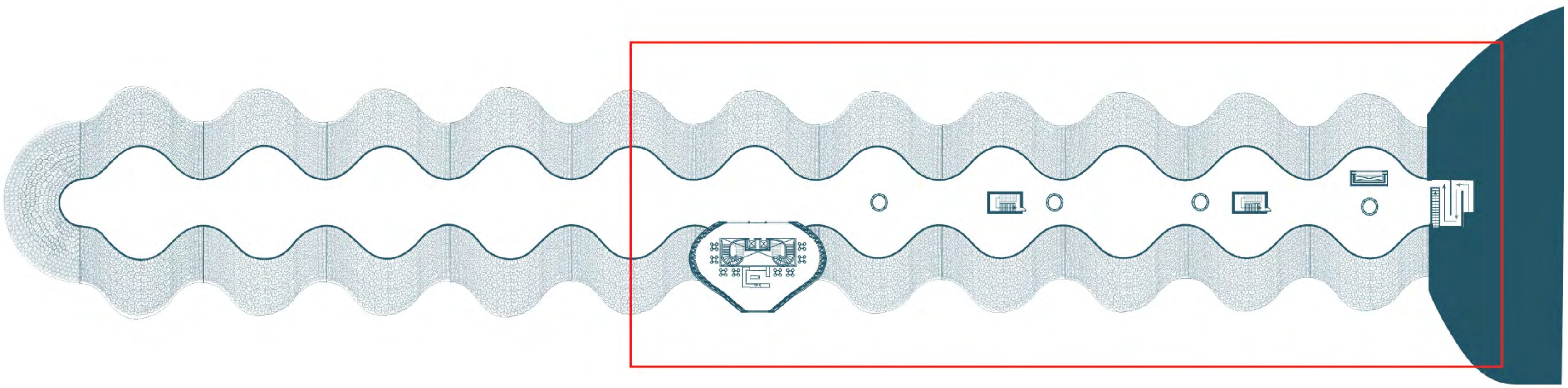
Floorplan of the upper observatory/cafe at +7 meters above sealevel.



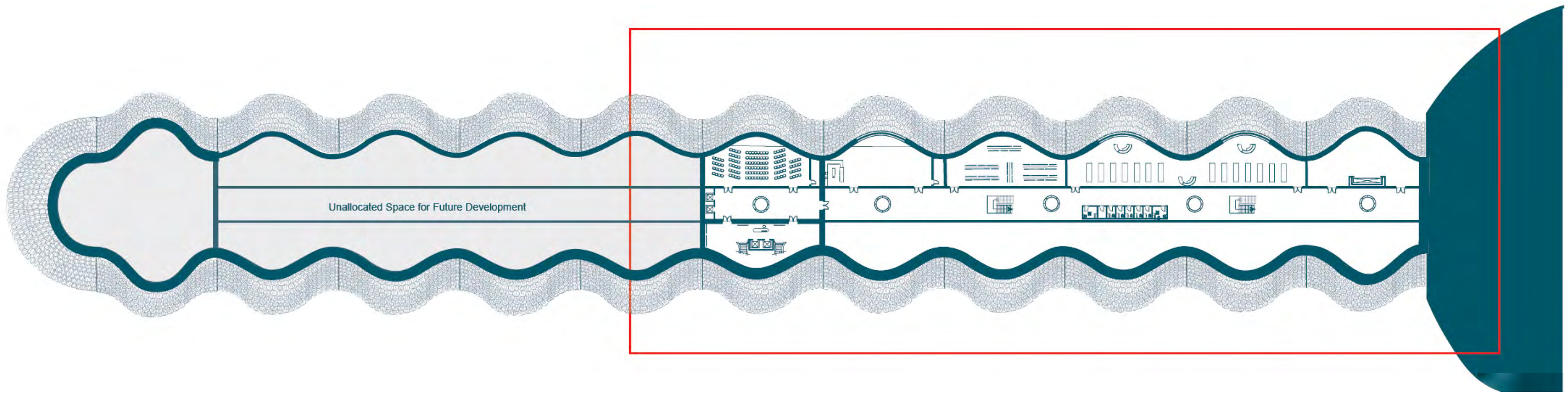
Inhabited perspective of entry into the freeform structure with circulation paths leading into the breakwater below.



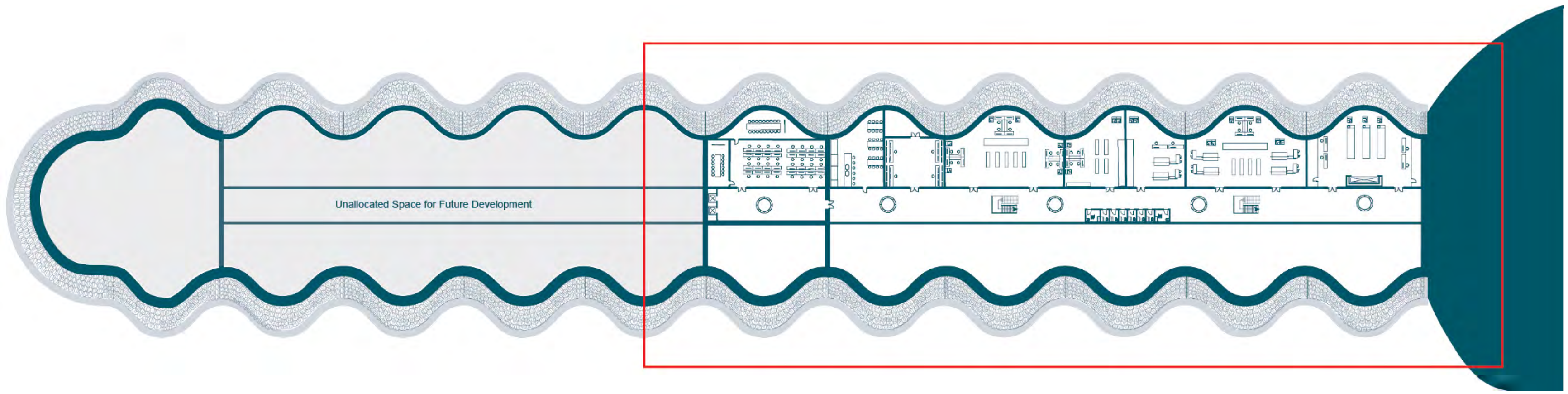
Inhabited perspective the upper observatory/cafe showing panoramic views of the surrounding open ocean.



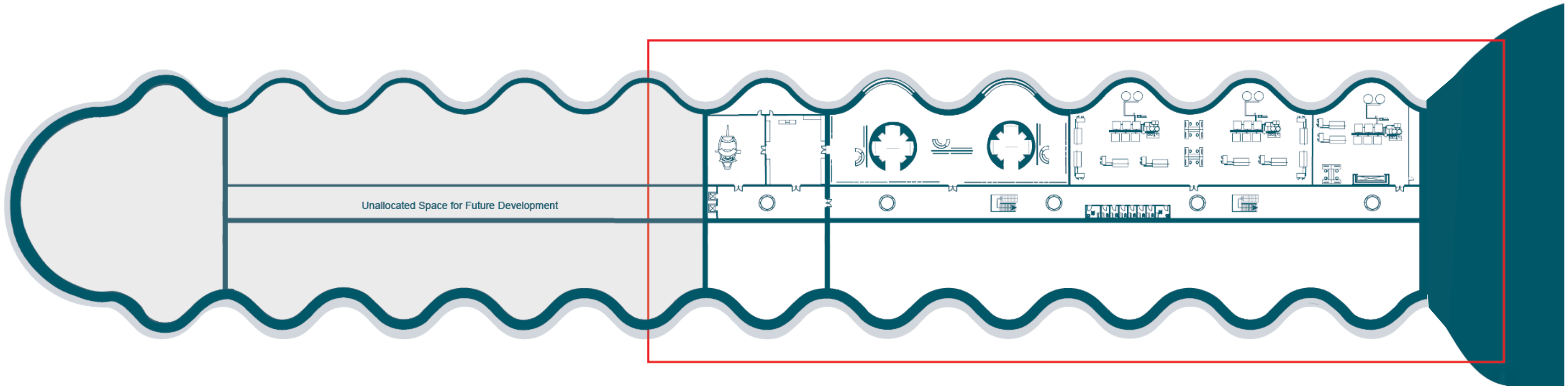
+7M Above Sealevel



+3.5M Above Sealevel

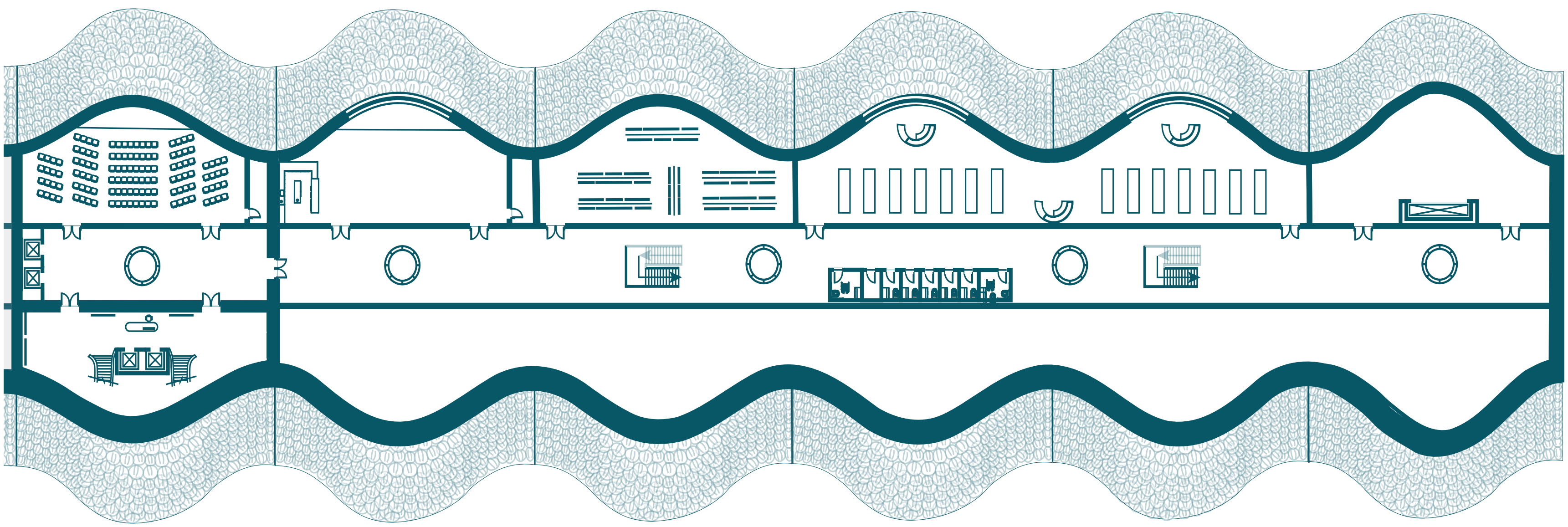


Sealevel

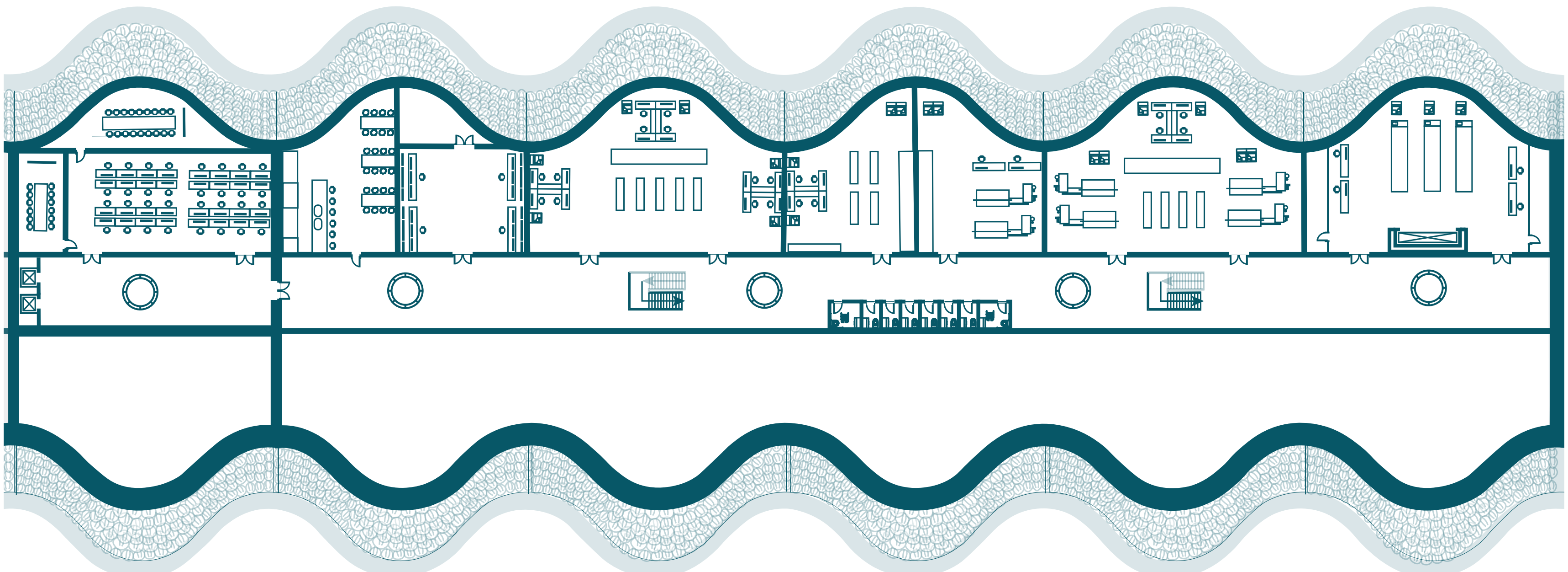


-3.5M Below Sealevel

Floor plans indicating unallocated space for future development and programed space highlighted for current development.

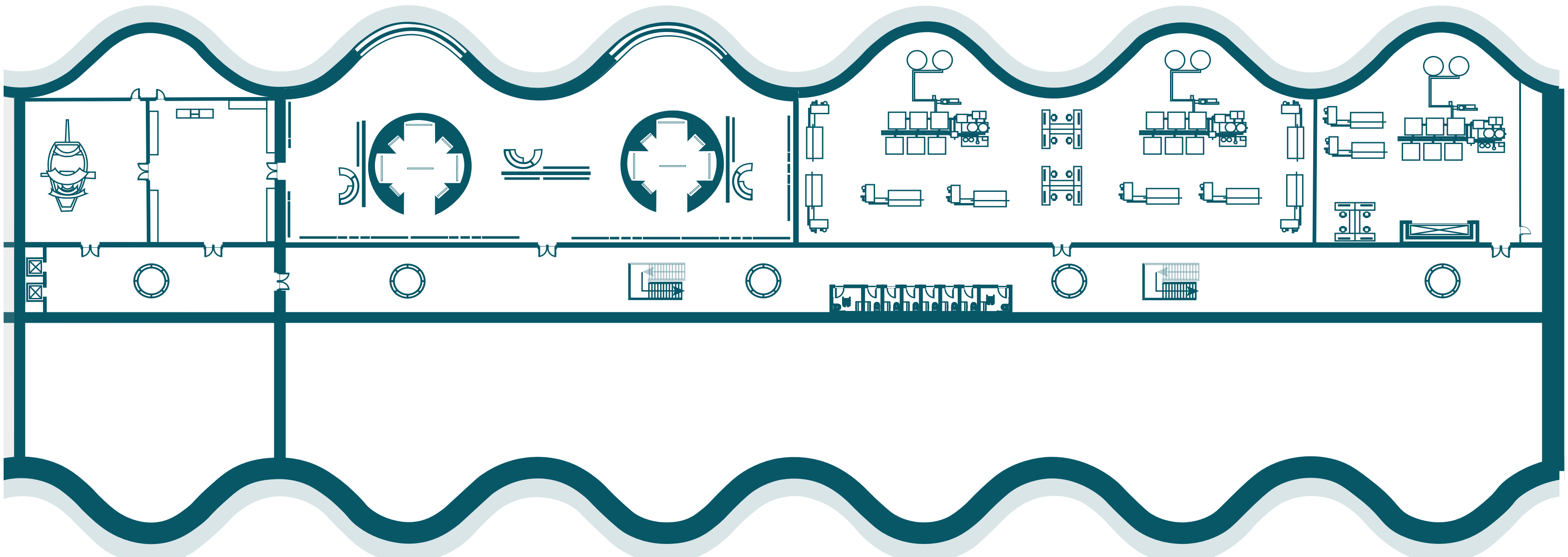


Floorplan at +3.5 meters above sea level indicating public program featuring an information centre, auditorium, event space, art gallery, and marine archive.

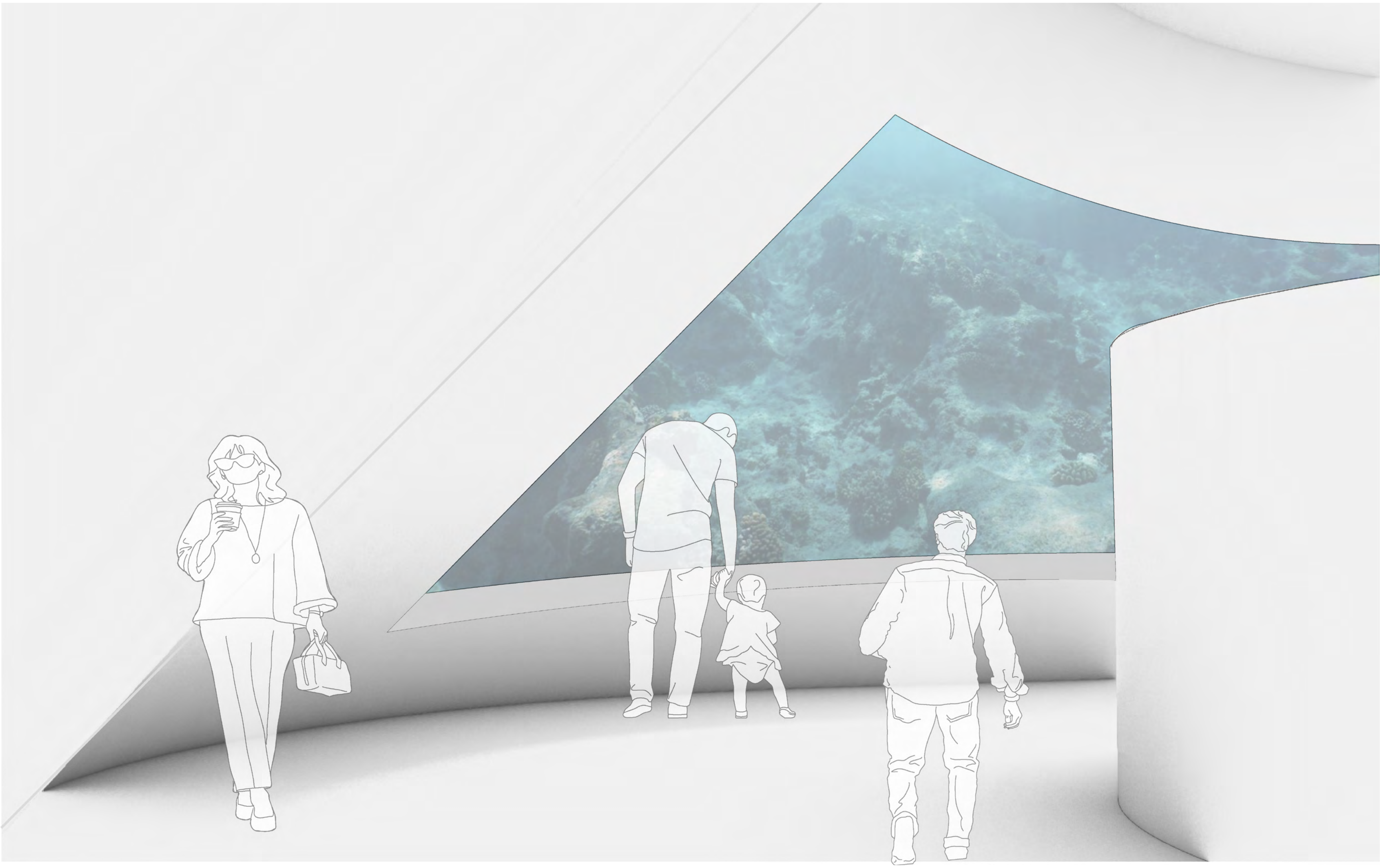


Floorplan at sea level indicating private program featuring office spaces, a remotely operated marine vehicle (ROV) control room, as well as both large and small wet and dry marine biology labs and a marine autopsy lab.

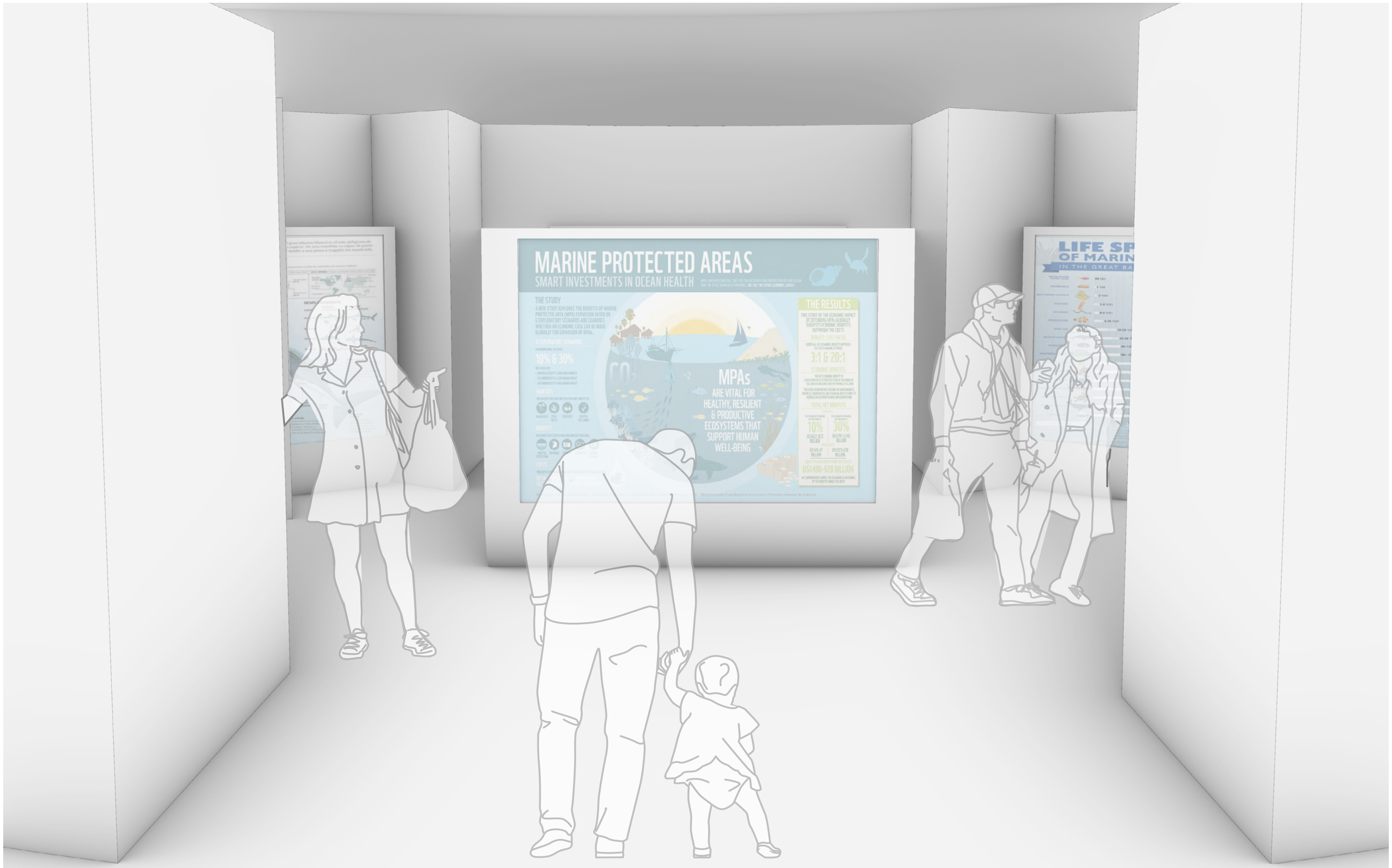
Inhabitation of the control room, showcasing exploration of the local marine environment.



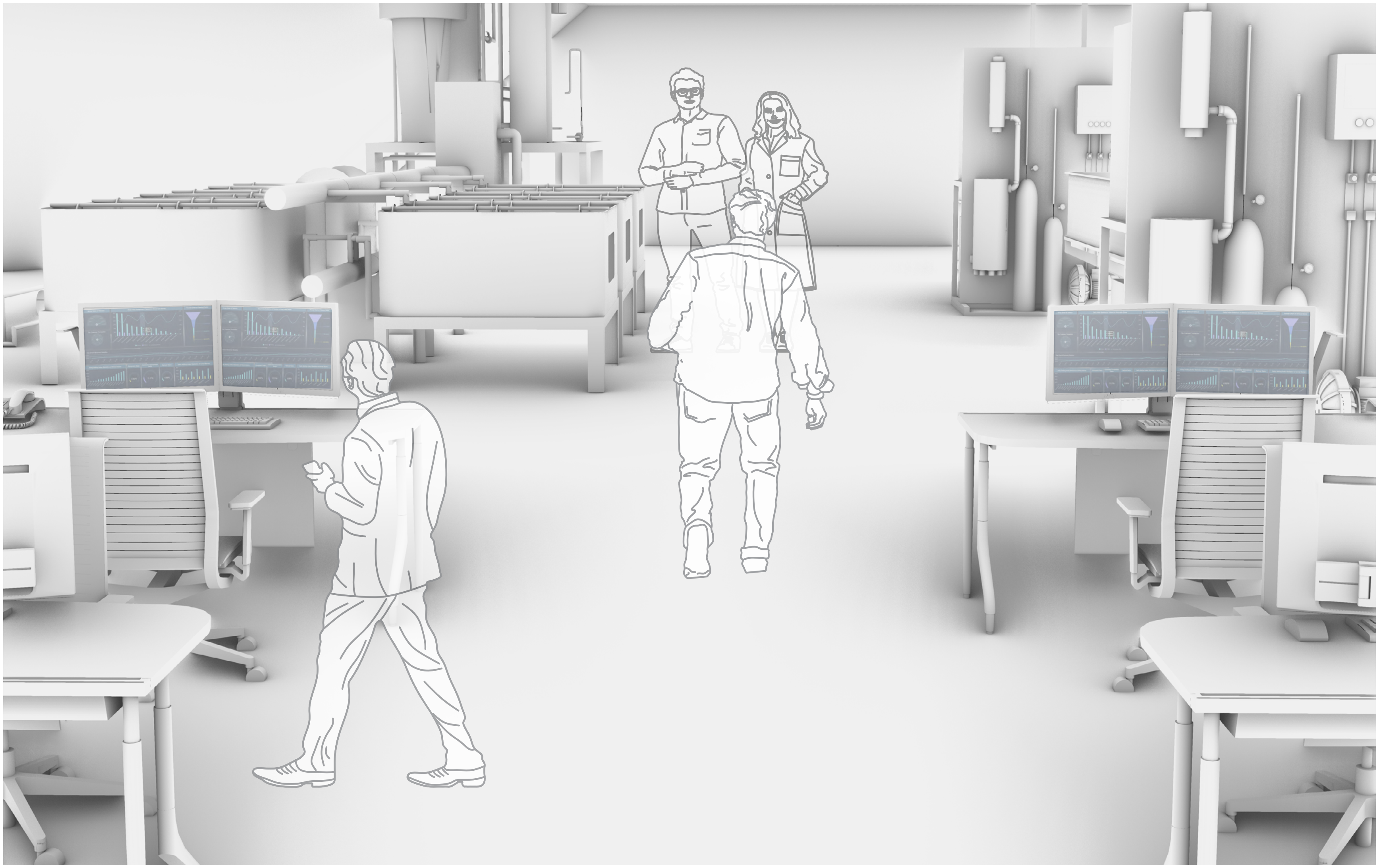
Floorplan on the seabed at -3.5 meters below sea level indicating a mix of public and private program featuring a kids zone, retail space, and underwater observatory for public use. In addition, to an experimental aquaculture lab for private use.



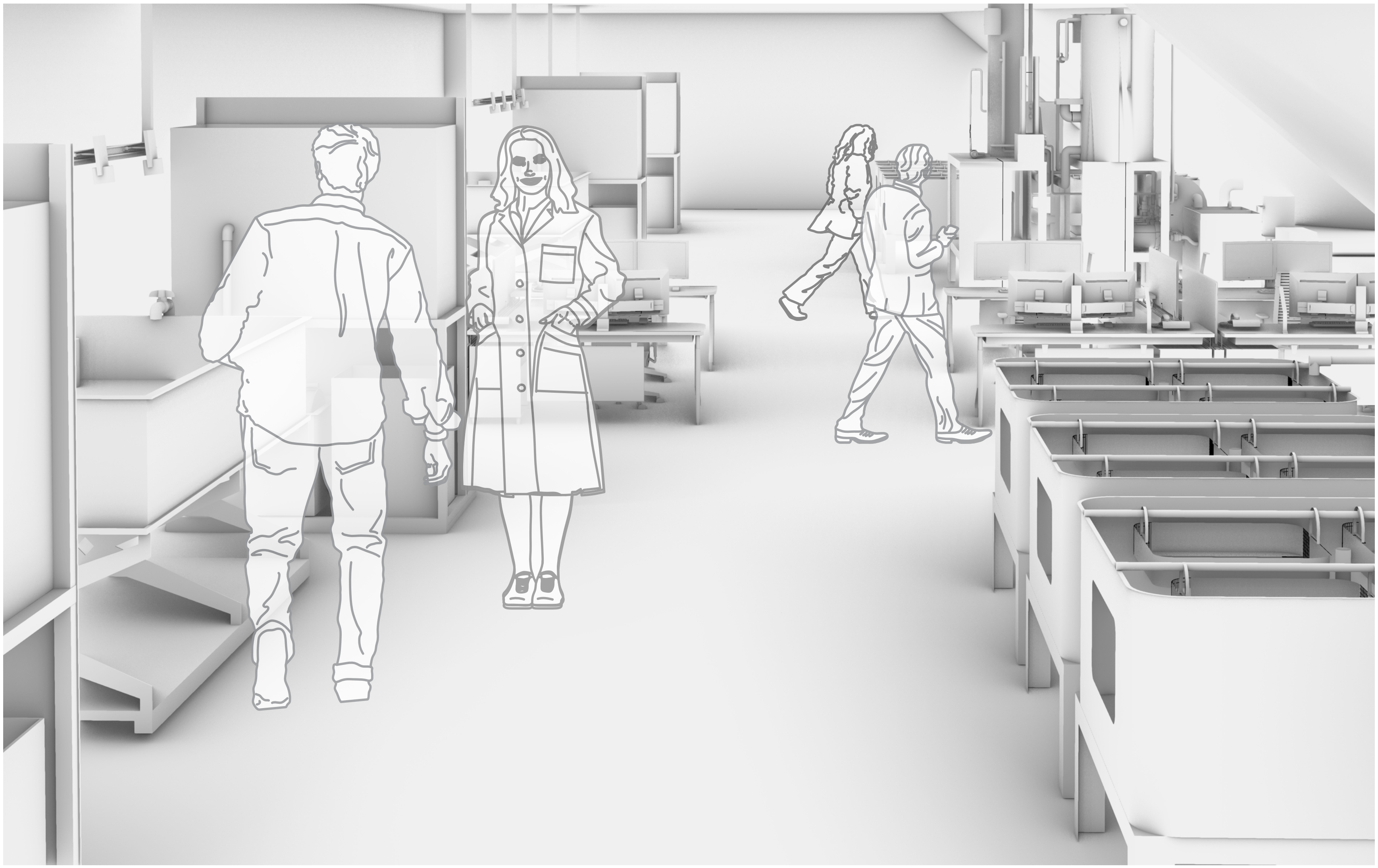
Inhabitation of the underwater marine observatory, displaying local marine life.



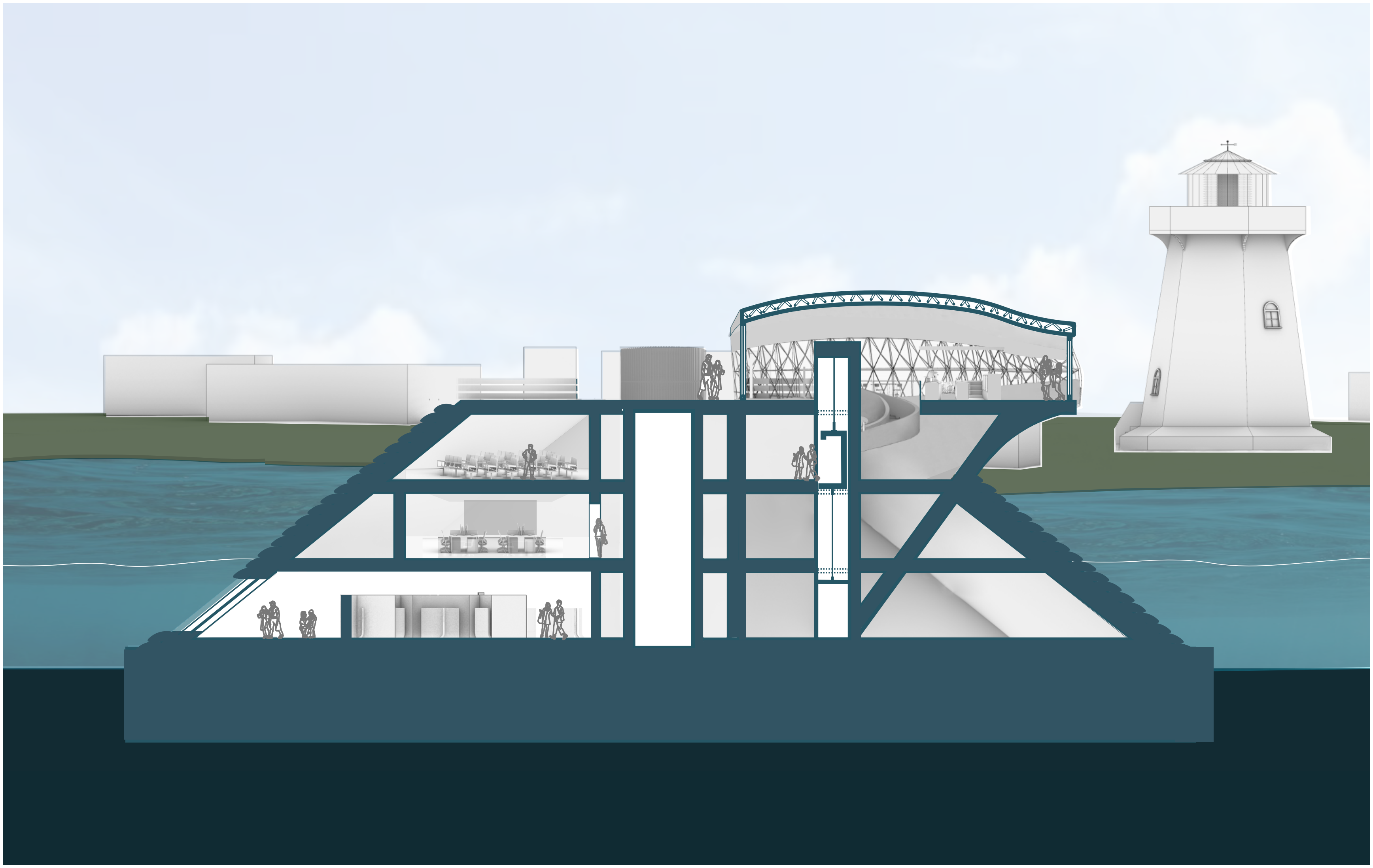
Inhabitation of the interactive displays in the underwater marine observatory, showcasing educational opportunities.



Inhabitation of the experimental aquaculture lab, showcasing work stations and the complex aquaculture infrastructure.



Inhabitation of the experimental aquaculture lab, showcasing aquaculture tanks.

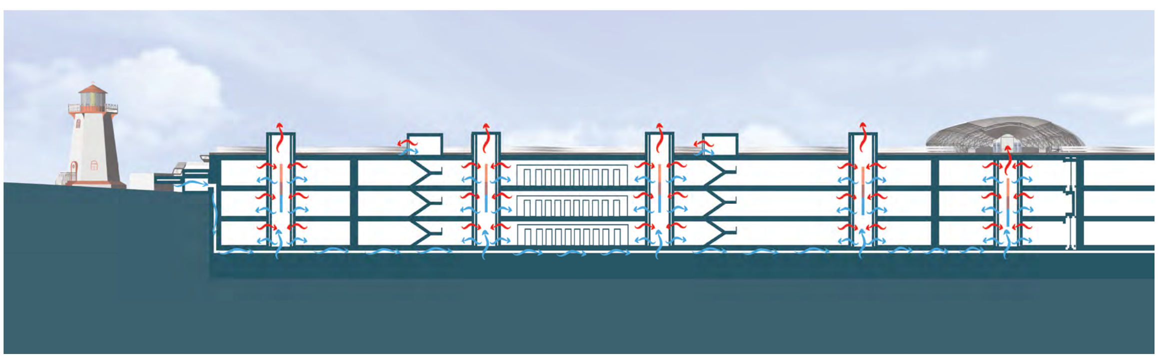


Bent cross section through the upper observatory/cafe, auditorium, office spaces, and underwater observatory.

The proposed program for the inhabitable breakwater will be an observatory and marine research centre. Going beyond its primary function as a resilient barrier, the transformative breakwater structure serves as a multifunctional space. The top level at 7 meters above sealevel will offering outdoor recreation areas and entry into the breakwater through the freeform structure or alternative entries. The second level at 3.5 meters above sealevel will host interior event spaces, public lecture halls, and an expansive marine archive for community engagement. The third level at sealevel will host private offices, marine biology labs and the marine autopsy lab, while the fourth floor embedded into the seabed at -3.5 meters below sealevel will incorporate a kids zone, retail space, and extensive marine observatory with an underwater viewing area, intertwining educational displays on maritime marine life and a land-based aquaculture lab. This comprehensive approach not only contributes to the economic prosperity of the Neil's Harbour community but also signifies a dedication to coexisting harmoniously with coastal dynamics. The project addresses the challenges of coastal living while promoting shared resilience between inhabited and uninhabited spaces. In conclusion the proposed public research observatory integrated into the inhabitable breakwater system, inspired by biomimicry addresses the need for coastal protection, community connectivity, and education on local marine life and tidal action. Demonstrating architectural potential for resilient and sustainable structures in coastal communities.

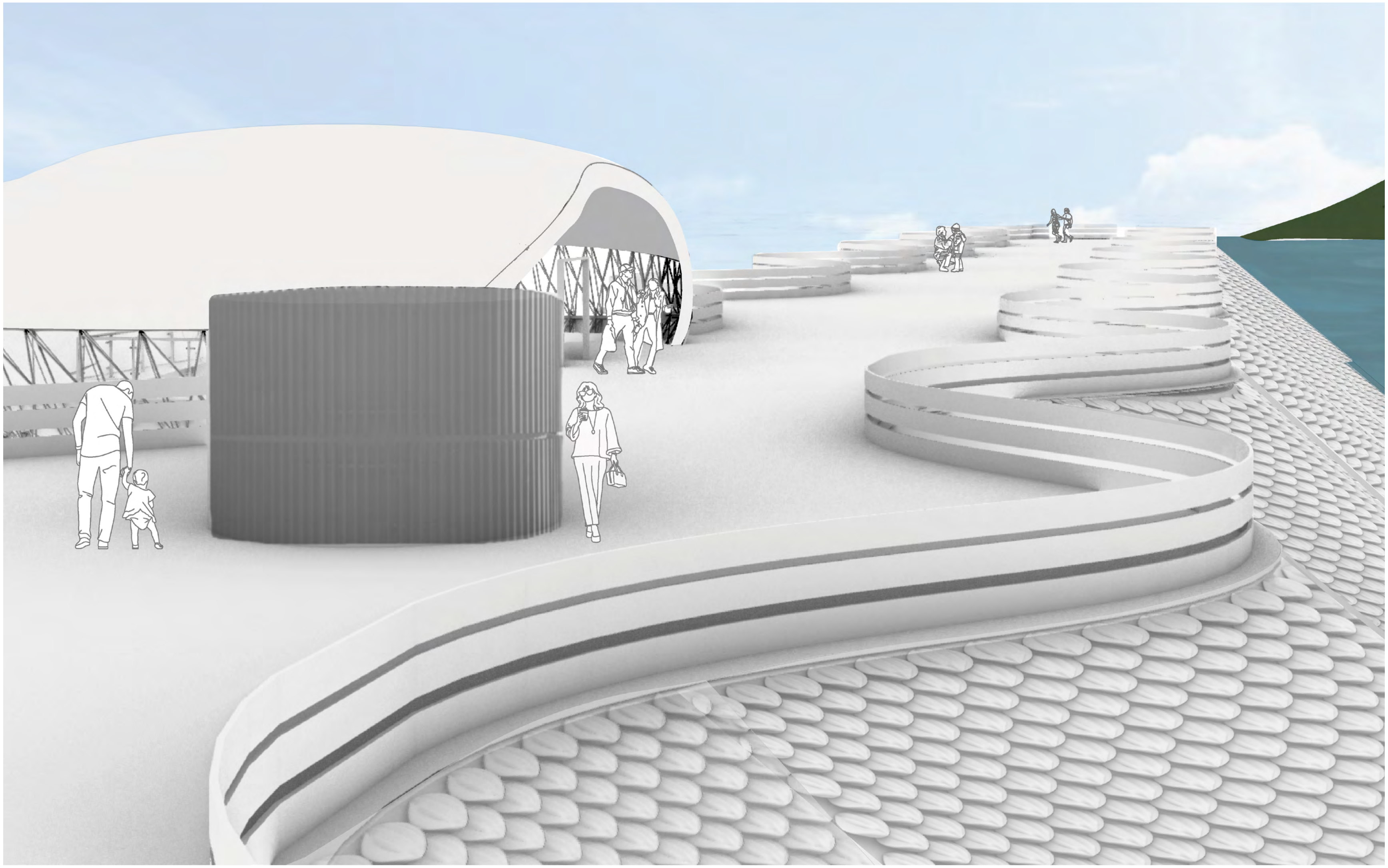
Ventilation

Applying biomimicry principles extends to developing innovative louvres for ventilation systems. The flexible fibre substrate in the denticle also allows for passive control of denticle orientation. In the context of the ventilation, the flexibility observed in shark denticles inspires a similar passive control approach. By implementing and arranging vertical ventilation shafts, the intent is to facilitate air exchange between the submerged structure and the external environment, ensuring a continuous supply of fresh air and removing potentially stale or humid air. This circulation is essential for maintaining the habitable space within the breakwater. In addition, louvres serve as a flexible ventilation application by offering a responsive system that adjusts its orientation or opening size based on environmental factors such as temperature, humidity, or air quality.



Longitudinal section showing air circulation in the vertical ventilation shafts, inspired by the shark's gills and their respiratory function.

This adaptability mirrors the passive control mechanism observed in shark denticles, showcasing a design approach that seeks efficient and adaptive airflow management. The ability to manipulate the louvres allows the ventilation system to regulate the amount of air intake or exhaust, providing versatile control over ventilation in marine structures.



Inhabited perspective of inhabitation of the exterior platform 7 meter above sealevel, indicating circulation around vertical ventilation shafts.

This flexible system draws inspiration from the resilience observed in shark biology, presenting a harmonious and adaptive solution for optimizing airflow conditions. The central corridor that hosts the shafts additionally serves as a metaphorical backbone, replicating the strength observed in a shark's spine. Similar to how a shark's cartilaginous backbone provides both support and flexibility to the structure of its body, the central hall anchors and supports the overall architectural design—acting as a unifying element, connecting different parts of the breakwater and providing stability.

The layered and robust composition of the shark denticles comprises the pulp cavity, dentine, and enamel, serving as a fascinating model for architectural innovation. The interior of the upper observatory and the breakwater building is similar to the pulp cavity within the denticle. Representing a network of open channels or spaces that facilitate fluid and gas exchange while providing sensory functions. This concept inspires inventive ventilation strategies to promote natural airflow, air quality, and thermal comfort within interior spaces. In the breakwater design, a freeform component extending from the primary structure mimics the pulp cavity, providing natural ventilation between inhabitable spaces. These structures function as ventilation chimneys, allowing air to rise and escape from lower levels. Furthermore, like the circulation space within the pulp cavity, open and fluid interior spaces optimize movement and circulation of occupants within the upper observatory and breakwater. This approach facilitates dynamic circulation patterns, strategically placed openings, and adaptable layouts to enhance efficiency and comfort for occupants.

Chapter 8: Conclusion

In conclusion, this thesis has delved into the potential of biomimicry as a design tool in architectural practice to confront the escalating threats of climate change in coastal communities like Neil's Harbour, Nova Scotia. Through a meticulous examination of the region's vulnerabilities and the intricate dynamics of its coastal environment, this study has proposed an innovative breakwater system that not only serves as a protective barrier against tidal action and storm surges but also fosters ecological growth and community engagement. Drawing inspiration from nature's resilience and the adaptive strategies of local marine species, particularly sharks, the proposed breakwater design embodies a commitment to living in harmony with coastal dynamics. By abstracting and emulating biological principles, such as the streamlined efficiency of sharks and their unique denticle features, architects can envision resilient structures that not only protect coastal communities but also contribute to their social, economic, and environmental well-being. This thesis underscores the importance of learning from nature's evolutionary journey and integrating these lessons into architectural practice to create a more sustainable and resilient future for coastal communities worldwide.

Through the principle of "form follows function," architects can design structures that seamlessly integrate with the natural environment, fostering a sense of harmony and connectivity between human communities and the surrounding ecosystems. By prioritizing structural resilience, architects can create buildings and infrastructure that withstand the increasing frequency and intensity of extreme weather events, providing stable habitats for marine life and ensuring the long-term sustainability of coastal ecosystems and furthermore, by fostering community engagement and providing spaces for interaction and education, biomimetic designs can empower local residents to become stewards of their environment, contributing to the collective efforts to adapt to and mitigate the impacts of climate change. In essence, biomimicry offers a holistic approach to architectural design that not only addresses immediate climate change challenges but also promotes resilience, connectivity, and sustainability in coastal communities for generations to come.

The inhabitable breakwater design, inspired by biomimicry and tailored to address the specific challenges faced by the coastal community of Neil’s Harbour, can serve as a blueprint for implementation of inhabitable breakwaters other regions that face similar climatic impacts. Offering a holistic approach to coastal resilience, community engagement, and sustainable development. By adapting and implementing this design in other coastal regions facing climatic impact, communities can enhance their resilience, protect valuable coastal assets, and foster a harmonious relationship between human societies and the natural environment.

In addition, offshore breakwaters that use the same streamlined curvature could be strategically placed to bolster coastal resilience and mitigate the impact of climate change on vulnerable coastal communities. By dissipating wave energy before hitting the main breakwater addition breakwaters will help to further stabilize the shoreline, by providing essential protection against erosion, coastal flooding, and storm surges. Additional offshore breakwaters would also create sheltered areas that support the growth of marine habitats, enhancing biodiversity and ecosystem health. Integrated into comprehensive coastal management strategies, offshore breakwaters contribute to sustainable development by promoting safe maritime activities, preserving coastal ecosystems, and safeguarding coastal infrastructure. Their adaptive design and flexible construction techniques ensure resilience in the face of evolving environmental conditions, making them valuable components of climate adaptation efforts worldwide.

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