The Power of Sound: Tuning into the Rising Volume in the Gulf of Maine

by

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

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Abstract

Marine species that function acoustically rely on sounds contained by the dynamic composition and material properties of the ocean's reflective surface. Ocean soundscapes are being impacted by anthropogenic disturbances that penetrate the environment and disorient marine life. In Nova Scotia, local whale watching businesses depend on populations impacted by ship traffic in the Gulf of Maine. This thesis argues that conflict between the actors - ships, visitors, and whales - can be translated by using researchers to bridge understanding between the whale below and our perception above. The project proposes coupling a visitor center with an oceanic research center for seafloor materials, acoustics, and habitat off the province's northwestern coastline in the Bay of Fundy to the Gulf of Maine. Sites were chosen within the Bay, an acoustic volume, where unique energetic channels allow the passage of water, creating opportunities for connection between volumes and thresholds of flow and sounds.

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I want to thank David for advising me with your knowledge on the acoustics involved in this project. Your expertise on ocean acoustics and curiosity about its relationship to architecture was so helpful.

To my friends and family, thank you for being a constant support and confidant throughout all the work and late nights. Mom: you knew I had it in me to finish this project, even when I was discouraged, and you were always there, reminding me every step of the way. Grandma: you kept me company from afar and were always there to pick up the phone when I needed to talk something out. Throughout my thesis, and all of my life, it would be impossible to list all the times you both reminded me how capable I am.

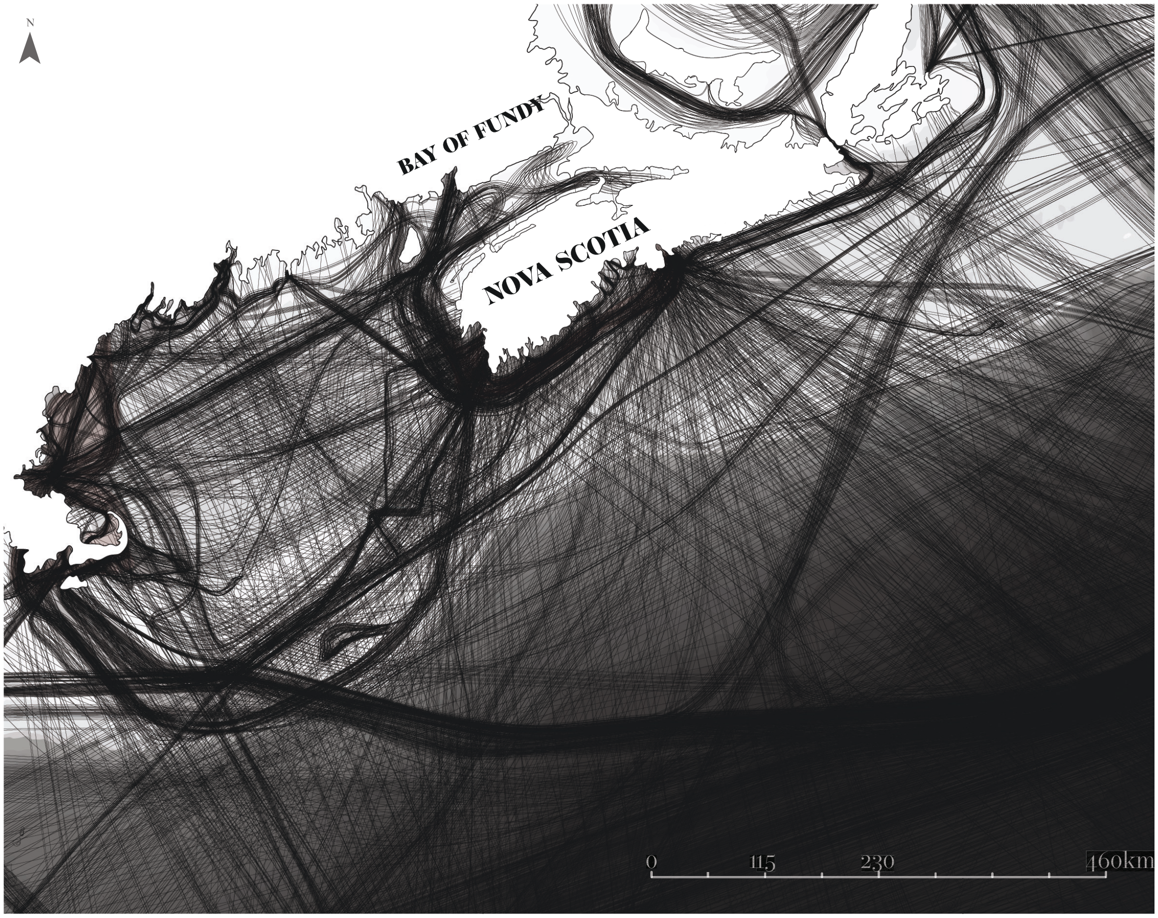
To the best friends I was lucky enough to make during my architectural education, I am so grateful to know you and can't wait to see the amazing things you accomplish.

Chapter 1: Introduction

Our experience of the ocean from land and on the surface. The vantage point is off the coast of Brier Island, Nova Scotia.

Who is Listening?

Our perception of the ocean is most often thought of as a void and a purely functional surface. This belief has long restricted what we comprehend to our experiences on the shore and above. This is because the sound particles move through vibration of water molecules, where sound produced above the surface is transferred through the vibration of air particles (Brekhovskikh and Lysano 2003, 183-226). This separation has fueled our imagination, which expanded during the 19th century when subsidized steam vessels replaced sail boats and ocean transportation became much more accessible (Mentz 2020, 80). It has been perceived, constructed, and managed under modernity (since the 1500's) as the least expensive means of transporting commodities from point of production to point of sale. As our transportation needs have increased over time, ships



Densities of ship traffic displayed in a map of the Gulf of Maine and ocean surrounding Nova Scotia. Image shows all ship traffic in 2020 with the most black areas documenting upwards of 330,000 vessels along that route (data from MarineTraffic 2020).

have become faster, larger, and extremely dense across the surface. This has created an ever growing stream of traffic that has increased the levels of acoustic disturbances to the marine environment below the surface.

The ocean is a space that has been used to generate profit through various actors: firstly, those shipping goods view the ocean as a mere surface to be crossed with little interest in exploring the depths. Secondly, the fisherman uses its resources to sustain their income and depends on the health of the ocean for their livelihood. And thirdly, the oceanographer analyzes the ocean through a set of discrete locations: routes of ocean currents, storm centers, coastlines, and islands. These moments, each relating to each other and with their own distinct nature, contribute to the ocean's grand physical system. Each actor views the ocean as an area of both predictability and unpredictability, and they have each developed a means (insurance) or technology for exploring or dealing with this unpredictability.

Photograph of Marie Tharp with some of her drawings of the Mid-Atlantic Ridge and ocean floor.

An expansive ocean ridge was inferred by Matthew Fontaine Maury in 1853, but what was later named the Mid-Atlantic Ridge was not confirmed using sonar until 1925 (Manz and Rössler 2008). In 1950, a team of Bruce Heezen, Maurice Ewing, and Marie Tharp mapped the underwater mountain range and found that it consisted of varied topography including hills and trenches (Ewing et al. 1953, 856-868). They also found that it was the longest geological feature on the planet, dividing the North American Plate and Eurasian Plates, and the South American Plate from the African Plate. At this time, sonar had begun to broaden ocean exploration by using sound propagation to transmit signals and navigate underwater. Today, we can see that the quality of acoustic feedback and reverberation of the sounds are impacted by reflectivity of the ocean surface and absorption or reverberation of the sea floor (Bolghasi et al. 2016, 280). The different experiences and limitations of the actors and their relationship to the ocean's surface can result in conflict due to not understanding the impact.

Below

The Whale

The breach is a necessary experience for the whale as they must surface to breathe in fresh air. The whale punctures the acoustical barrier of the surface and spends a moment above the confines of the water itself. This whale is one of many different species that are found off the coast of Nova Scotia including Finback whales, Minke whales, Blue whales, Humpback whales, and the endangered North Atlantic right whales. Other species have been less frequently spotted, including the Sei whale, Blue whale, Long-Finned Pilot whale, Sperm whale, Killer whale, Atlantic White-sided dolphin, Common dolphin, White-Beaked dolphin, Harbour porpoises, and Grey seals (Trowse et al. 2014, 8-13).

The whale has limited eyesight, but its ears are highly developed to communicate and listen for necessary environmental feedback. Experiencing the depths of the ocean are familiar, the spaces punctuated by temperature and acoustic signals that send the whale spatial cues. Interactions with ships are increasingly frequent as traffic streams expand and densify the ocean's surface. There were always other species to coexist with, but these ships

Below: The whale has an acoustic relationship below the surface of the water that is impacted by intrusive sounds introduced by acoustic disturbances. Pictured is a whale experiencing noise produced by the cavitation of ship propellers.

are intruders that carve through the surface at inconceivable speeds and create noise that make navigation and foraging impossible at some points of proximity. The noise produced by ships makes finding food and other whales difficult because of the increased volume of the ambient ocean by these acoustic disturbances.

As more ships and lanes populate the open ocean, the chance for intersections between whales and ships arise. These intersections create not only collisions between ship noise and marine communication, but physical collisions that can result in death for the whales as they become acoustically disoriented (“The Threat from Vessel Strikes” n.d.).

On

The Ship

This ship is either a cargo vessel, tanker, fishing boat, or one of the many other types that occupy the open water every day (MarineTraffic 2020). The ship moves with the power of the propeller causing powerful surges of water as a wake in its path. The propeller cavitation is the low frequency sound created from the variation of water vapor cavities as water pressure moves across the propeller blade (Zhang et al. 2008, 64-71). The sound produces long wavelengths and can travel far in water before encountering suspended particles to scatter, absorb, or reflect it (Munk, Worcester and Wunsch 1995, 180-206). Since these signals are the farthest reaching and longest lasting type to send underwater, submarines also use this range to communicate underwater across far distances. Coincidentally, this is the range that many marine species use to communicate, a conflict between manufactured and natural sounds imperceptible to the ships.

The ship makes its way from port to port, a clear mission and without obstruction on the horizon. Each ship confidently travels a prescribed course while interrupting an acoustic landscape in its wake, disruptions to the underwater world concealed by the surface. As ships travel the globe they cross oceans, bays, and various national boundaries from origin to destination. This method of transportation across the ocean makes international borders and transnational regulations for open water difficult to monitor. The captain increases the speed as it reaches open water, the Vessel Speed Rules expire once they reach this threshold. At this point, ships resume full speed even over areas that are

On: The ship charts its course on the surface of the ocean without perceiving its impact below.

segments of important migratory pathways for whales. The whir of the engine increases past the 10-knot limit and the wake increases below the ship. Although the most effective way to reduce collisions is by keeping whales and ships apart, a 10 knot speed limit is the next line of defense ("The Threat from Vessel Strikes" n.d.). When the rules expire, protection for the whale is removed and both the chance for physical intersections and noise produced by the propeller of the accelerating ships is increased.

The Visitor

Visitors to Nova Scotia strengthen their relationship to the ocean through opportunities to interact with whale watching

On: The visitor is curious about the whale and the existence of life below the surface, but their perceptual capabilities and experience aboard the tour boat restrict perception to what they can see.

and ocean based industries. The visitor books a whale watching tour with one of the local businesses and set off with the hope of coming across seals, porpoises, or a Humpback whale if luck is in their favor. When the interaction does occur, it is a fleeting moment of awe as the whale surfaces before it joins the depths of the ocean once again. The experience feels immense and inspiring but fleeting at the same time. As the visitor scans the horizon to see the whale's reappearance, they are surprised by the density of massive supertankers they can see on the horizon, what feels like a short distance away from the whale's breach. The fragment of time the visitor sees the whale above the surface feels inconsequential as they realize their ignorance of what occurs during the rest of their 80–90 year lifespan underwater. The visitor leaves the province feeling both amazed by the whales and troubled by the unknown below.

The experience below the ocean's surface remains a mystery for the visitor to Nova Scotia. They want to understand the complexity of life under the water's surface and experience the habitat below them. We can visit the underwater environment by diving below the surface, but due to the perceptual capabilities of the human ear humans will never be able to communicate acoustically through water or experience the intensity of the ship's propeller overhead. This impacts our ability to comprehend how detrimental the global shipping network has become for marine species that function acoustically to survive, especially since humans remain a species reliant on sight above all other senses.

The Researcher

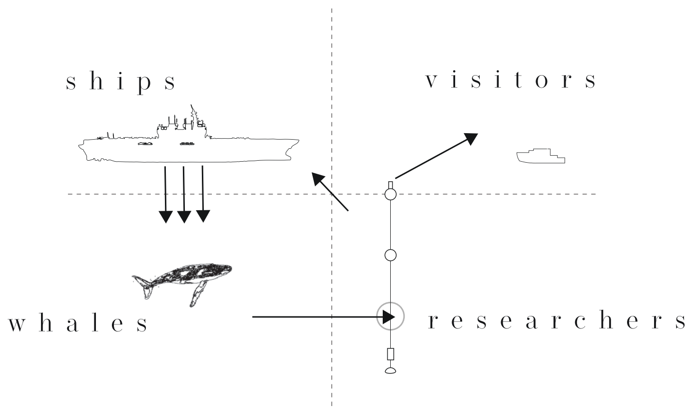
The researcher joins a team that is studying the Gulf of Maine's sea floor, noting complex forms and varying depths throughout. She has focused her studies on underwater acoustics for quite some time and understands that it requires a medium to travel as it cannot occur in a vacuum. This leads her to consider how different mediums can impact sound transmission and introduces the study of material characteristics and their acoustic properties (Schafer 1993, 37).

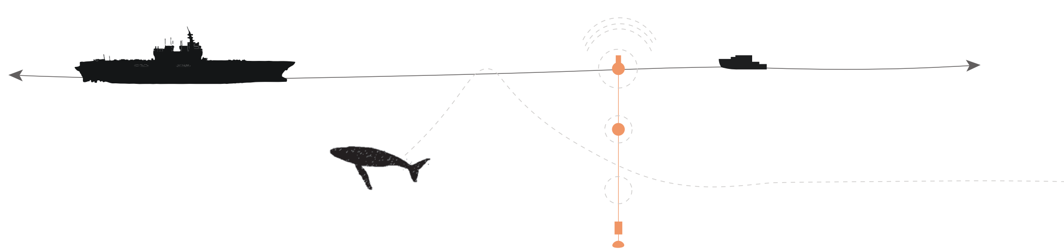
The team she joins studies the significance of sediment distribution, water compositional layers and their contribution to sound transmission speed and reflection off the ocean floor in the Bay of Fundy, a site close to her home in Nova Scotia. Sound is a transfer of energy that results

On and Below: The researcher uses recording devices like gliders and bottom mounted hydrophones to perceive below the surface, and translates these audio recordings for human perception. This demonstrates an invaluable ability to connect those above and below the surface through acoustic experiences.

in vibration of molecules as it travels through a medium - either solid, liquid, or gaseous (Eagan 1972, 105-112). She learns that salt water creates conditions that facilitate sound transmission much better than air does, in fact up to 5 times faster underwater. This researcher is familiar with how molecules move through air, as they alternate between contracting and expanding through a medium, referred to as compression and rarefaction, they create pressure differences that the human inner ear can perceive.

Her team monitors a cluster of hydrophones located off Brier Island's coast, a small island in Nova Scotia located at the entrance to the Bay of Fundy, and they are pleased with the density of information the monitor acoustically registers. There are significantly more whale calls recorded during the months of May to June which is a busy time for migration





The intersections between actors are dictated by their relationship to the surface, and their ability to perceive acoustic impact. For example, this diagram demonstrates the power of researchers to perceive above and below, and facilitate connections between the whales and the visitors. They also have the ability to inform shipping industries about negative impacts of noise on marine species.

into the Gulf of Maine. The amount of ambient noise the monitor receives is also worth noting, the levels of ambient sound have significantly increased since the team began in 2010. She wonders about the ramifications.

When the first recordings of whales underwater were broadcast to the public, people were amazed and began to relate the communication to a human way of expressing themselves. The researchers bridged a gap between our experience of the whale on the surface, and our understanding of their life below. For the context of this project, researchers will once again connect the visitor and the whale through auditory experiences.

Thesis Question

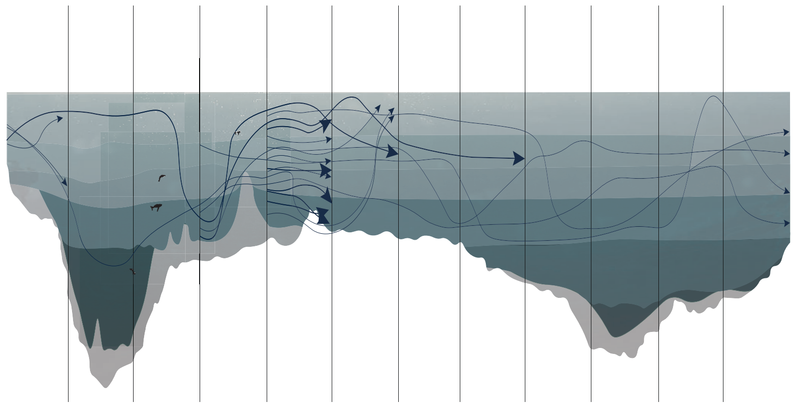
Informed by the experiences and limitations of these actors, my thesis question is: Can the project translate the underwater experience of the whale to humans using architecture (materials and form) as well as programming to position source sounds above and below in amplifying and dampening conditions? Can this experience construct auditory relationships between actor groups shaped by empathy of what lies below the ocean's surface, rather than a purely visual understanding?

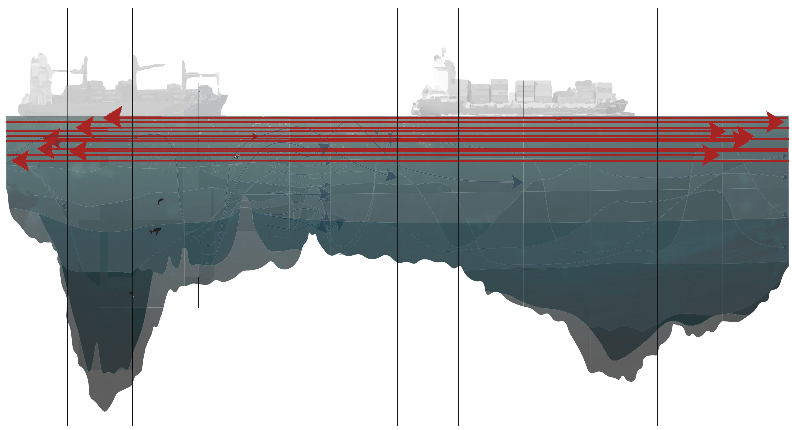
Chapter 2: The Ocean

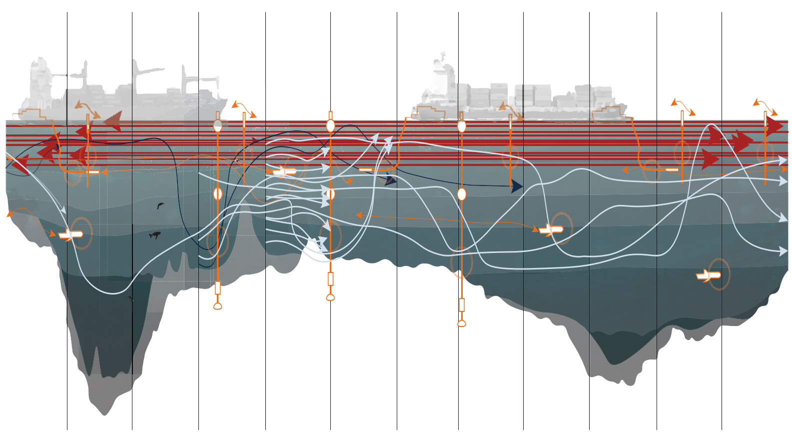
Our curiosity to understand the ocean leads us to pursue opportunities for interaction, while the bulk remains unreachable. Opportunities present in aquariums, visitor centers, diving, and boat tours to name a few, yet each provide interested visitors with a glimpse of ocean life. The ocean's surface will always restrict our perception of the environment below, however, much like we seek to understand microscopic particles and unfathomable galaxies, the quest for underwater interactions can provide important educational advantages that bring us closer to understanding what goes on below. This understanding can advance our compassion towards marine life and mobilize sustainability efforts inspired by our desire to be near the ocean and interact with large expanses of water. Research has long searched for answers as to why we feel calmed by large masses of water and experience therapeutic effects that lower our heart rate and blood pressure. We may be able to quantify the physiological effects, but historically humans have been inexplicably drawn to the ocean, while holding a sense of reverence for the immensity of the unknown that stretches horizontally and vertically (Mentz 2020, 81).

Perceiving Sound Underwater

Research looks for ways to understand the vast ocean environment and can now employ underwater recording devices to reveal marine communication similarly to how sonar is used to acoustically reveal the underwater topography. We use hydrophones to translate sound underwater by converting the vibration of water molecules to electrical voltage that can be recorded. Hydrophones







The actors have sectional relationships that are determined by the topography of the Gulf of Maine. The whales move between deep ocean depths and breaching the surface, using acoustic feedback from their environment to navigate through sea floor topography towards food sources and potential mates (top). The flow of the ships occupy the top of the water column, creating dangerous opportunities for physical intersections with whales (middle). To inspire our curiosity further, technology has now advanced to reveal audio and visual recordings of the ambient environment and organisms that use acoustics for life functions below. Research has a powerful ability to capture the whale calls and produce audible translations for humans on land (bottom).

read pressure changes in the surrounding water; this is homologous to the way we perceive sound through the vibration of air molecules around us (Jing et al. 2022). Since our ears were not developed to understand vibrations of water molecules in the same way as marine species, we employ technologies to translate for us.

When we listen to these recordings, we can interpret the sounds by amplifying them to a level of human perception. This is an attempt to recreate an underwater listening experience on land. These underwater audio recordings, even absent of visual information, have also shown therapeutic effects and in fact, whale call recordings are popular for people with trouble falling asleep due to their rhythmic nature and low pitch. Many people find they can match their breath to the repetitive tone of the calls, much like the repetition of the waves crashing on the shore - a familiar experience we find to be calming. The ocean sounds can also correspond to the experience of being in the womb where the fetus is enveloped in fluid up until the birth, an innate experience that is common to us all.

Sound

On land, Murray Schafer and his team investigated acoustics on land using compositional analysis through their lens as trained composers. Schafer was an ecologist and composer and was critical of sound pollution in Western cityscapes. He worried about the destruction of ‘soundmarks’ - or sounds we discern as unique features of an environment. In the context of this project, we will consider whale calls a soundmark of the underwater ocean environment.

He began supplementing his conventional music notation with introductions from the landscape, creating a new language incorporating natural acoustics into his compositions. This was a way for him to tune into the natural sounds that were occurring around him and integrate them into a new type of music, an alternative to solely manufactured sound. In his most famous publication, *The Soundscape: Our Sonic Environment and the Tuning of the World,* Schafer outlined visual notation for the soundscapes he observed (1977). This type of analysis began to breakdown the sounds in our environment that produced what Schafer called 'soundscapes' or the auditory landscape around us. He outlined principles for mindful acoustic design that included a respect for the ear and voice, and a knowledge of the rhythm and tempi of the natural soundscape. Schafer produced descriptions of acoustic environments with a process of characterizing soundscapes that followed a system:

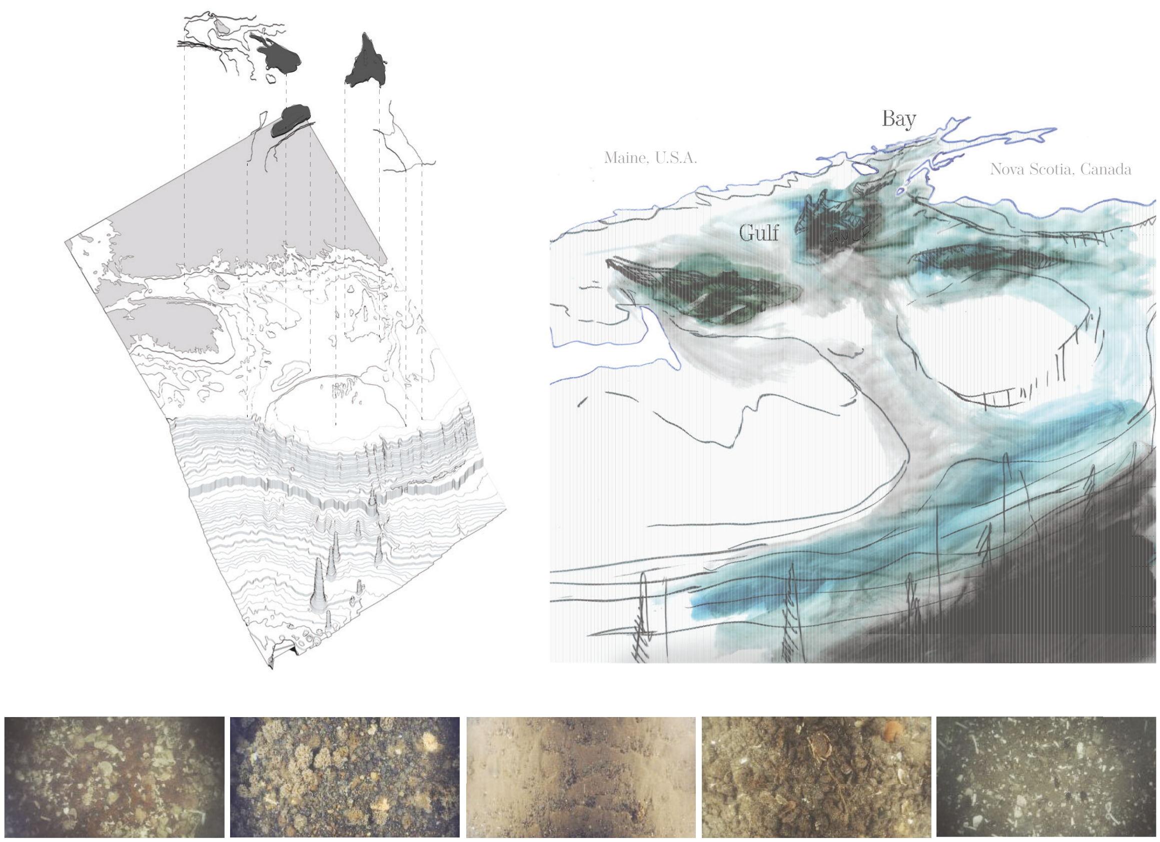
Exercise creating visual notation for an acoustic experience of waves crashing on the shoreline.

1. Experience the environment and document unique sounds. Note continuous vs. intermittent sounds.

2. Classify sounds based on prominence, regularity, and amplitude: Identify the background, foreground, and feature sounds.

3. Notate sounds to document the experience, either for translation or to incorporate into conventional compositions.

These principles can be carried forward when analyzing the underwater acoustic environment, taking special consideration for the introduction of anthropogenic noise. Several factors affect underwater sound propagation, reverberation, and attenuation of these sounds, including surface roughness, sea floor composition, and topography (Bolghasi et al. 2016, 275-287). The topography is dictated



Topographic features in the Gulf of Maine and sediment supply to the Bay of Fundy, between Nova Scotia and New Brunswick (data from NSCC AORG 2017-2019).

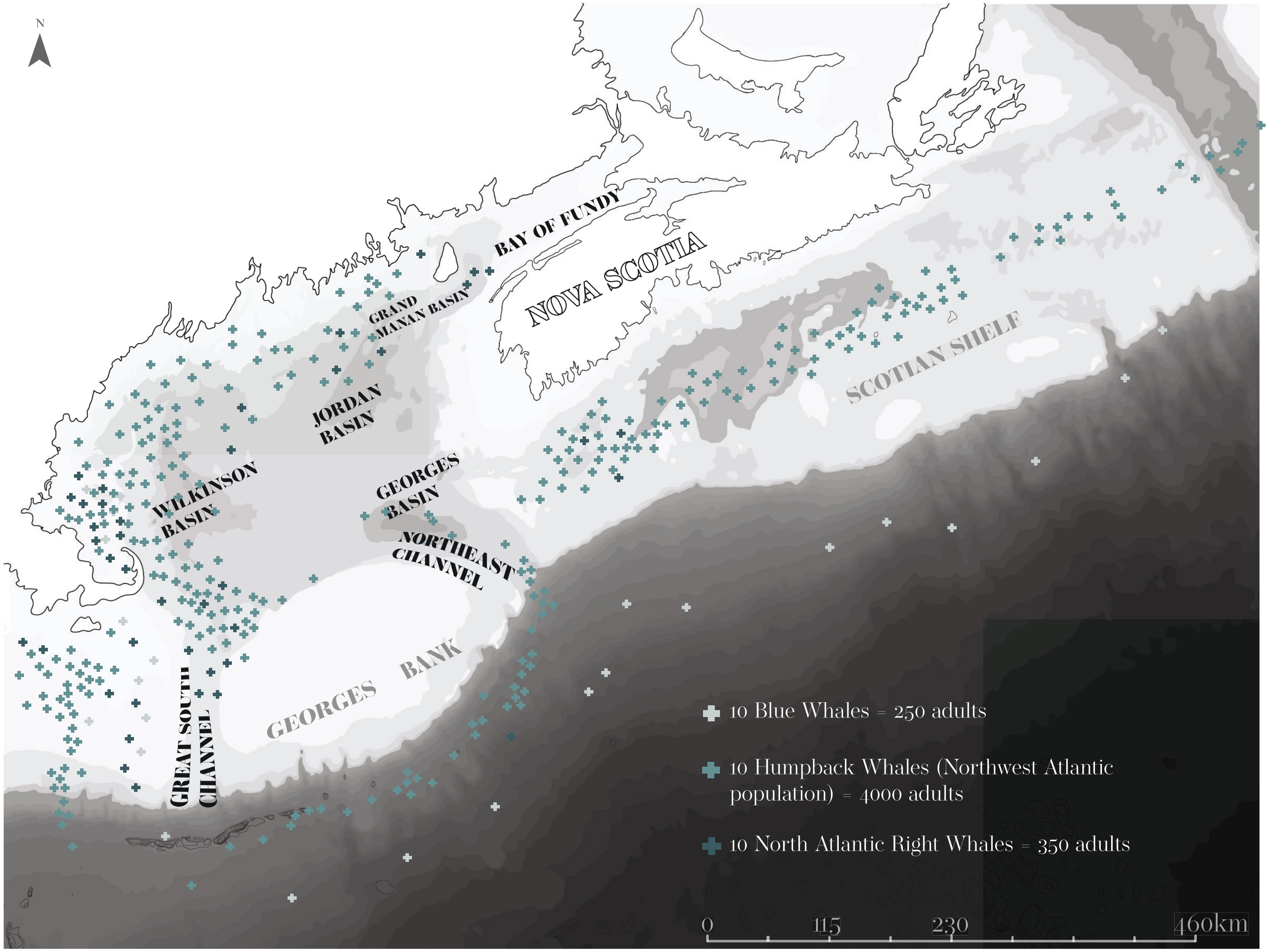
by materials that impact sound transmission by creating dampening or amplifying effects, for example hard surfaces reflect sound while porous materials increase sound absorption.

The Bay of Fundy

Acoustically, the Bay of Fundy, situated between Nova Scotia and New Brunswick, has complex forms and varying depths that were the result of a continental ice sheet that retreated about 14,000 years ago (Sonnichsen 2010). There are collections of sand particles, up to 20 m high, that fluctuate each time the tide cycles through. The distribution of sand, a very porous material, is important when considering the depth of cover that is available to dampen the reflectivity of the bedrock underneath.

Sound Transmission in Water

The water itself is a medium that impacts sound transmission as well. As sound particles move through a medium, they vibrate, which leads to interactions with other particles suspended in the medium. The lower the frequency, the longer the wavelength, and these sounds travel the farthest in water before being scattered, absorbed, or reflected by other particles (Munk, Worcester and Wunsch 1995). The currents of the ocean also impact sound transmission as temperature and water pressure work at different depths. In deep water, pressure indicates sound transmission strength, while shallow water is more impacted by temperature gradients. Temperature decreases with depth of water and creates a thermocline, which also demonstrates the decreasing speed of sound with depth. At a depth of 750 meters, the temperature changes become so minimal that it can be considered uniform (isothermal) and this is where



Ship traffic entering the gulf has the potential to impact whales along migration pathways. Colored dots indicate whales recorded by passive acoustic monitors placed by researchers from various institutions bordering the Gulf of Maine in Canada and the USA (data from NOAA 2019-2021).

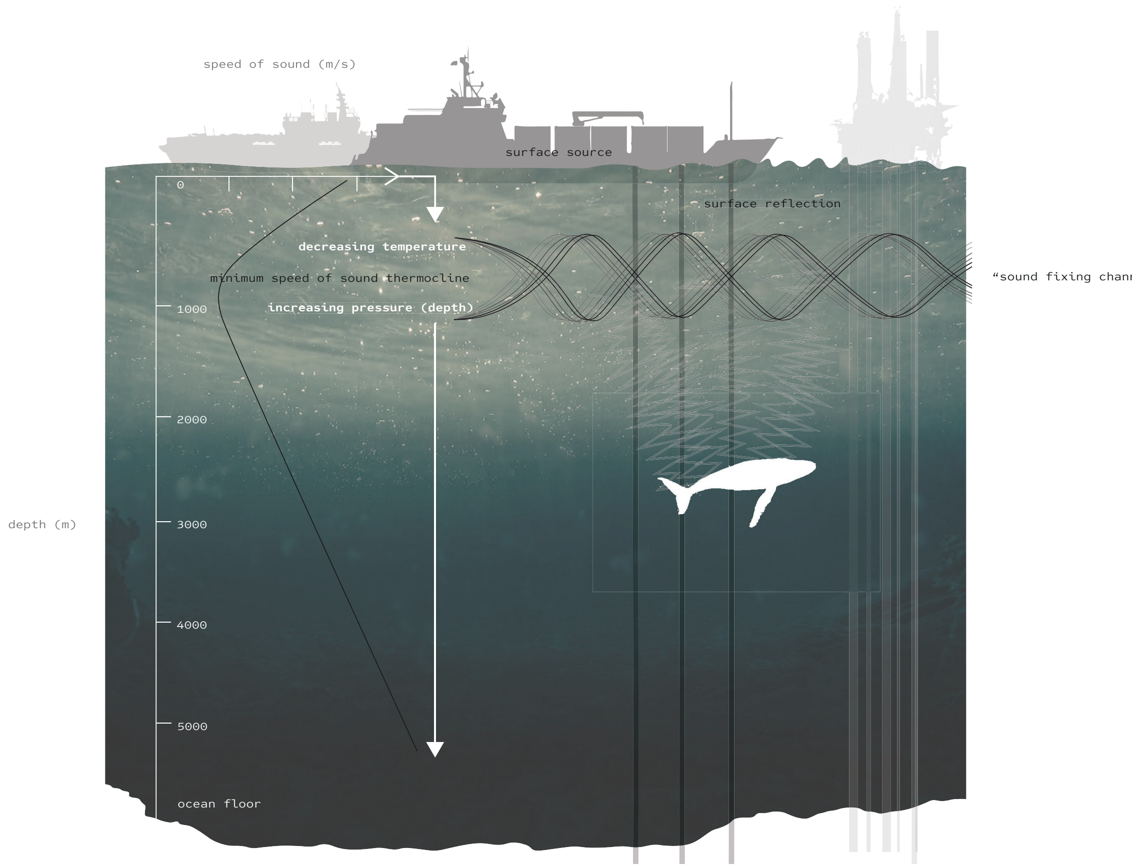
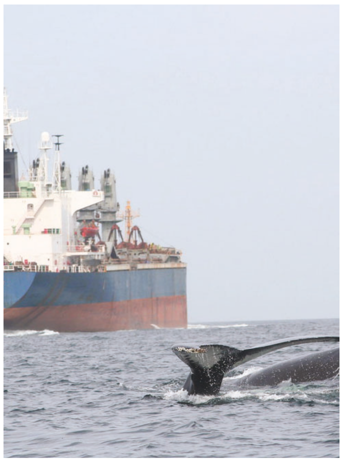


Diagram showing the ‘sound fixing channel’ for low frequency sounds operating between different densities of water.

the “deep sound channel” was found in 1943 by Maurice Ewing and J.L. Worzel (Trowse et al. 2014). This sound fixing and ranging channel allows low frequency sounds to travel exceptionally long distances because of the refraction that occurs between water of different densities, so sound waves travelling up to the ocean’s surface are reflected down and sound waves travelling deeper to denser waters are reflected up.

These are important considerations for researchers studying changes to the marine environment and global network of oceans as climate change continues to increase the temperature of the water itself (Staudinger et al. 2019, 532-566). Not only does warming ocean water affect the ability of marine species to survive by altering their supply of food and creating an inhabitable environment, it can also have consequences for sound transmission underwater.

Issue: Noise

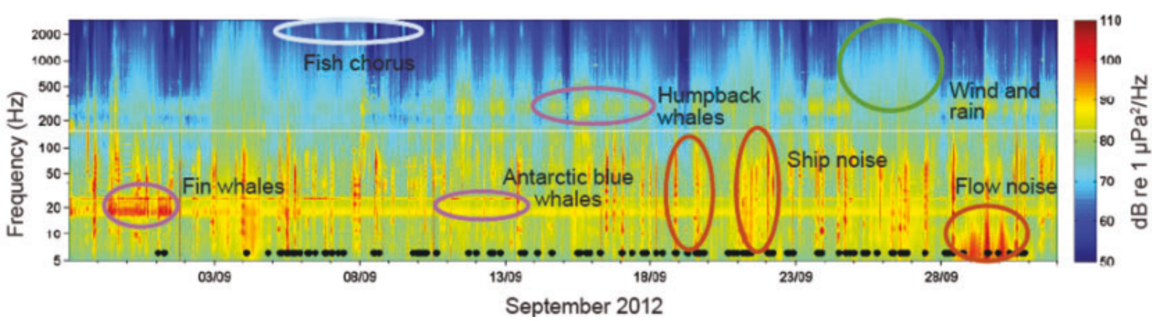


Whales co-exist with many sources of noise introduced to their environment (WCNE 2006).

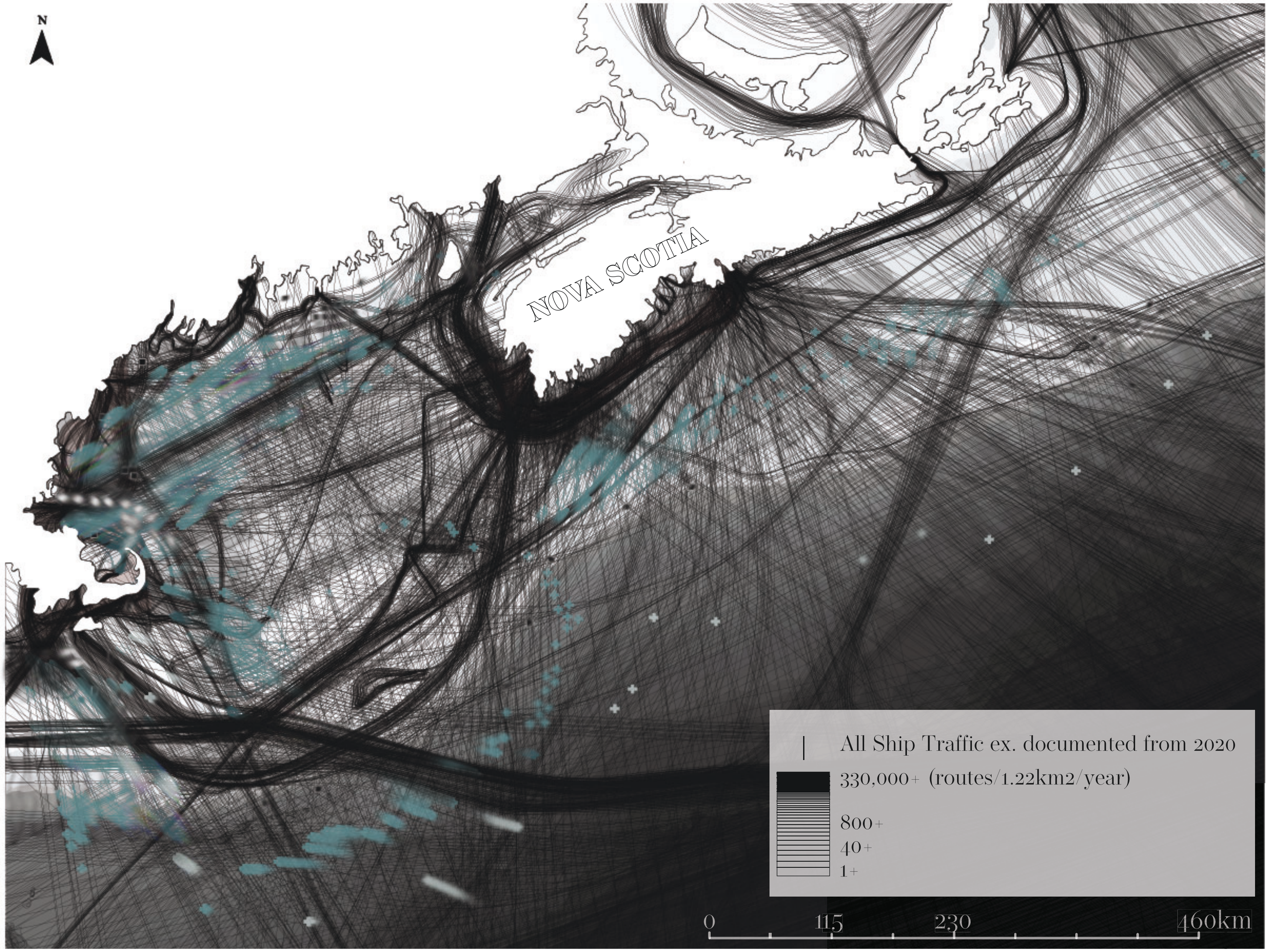
Manufactured sounds become acoustic disturbances in the environment when they have amplitudes that are higher than those found in the natural landscape. This prominent sound is registered as noise over the ambient soundscape and disrupts the focus of the listening experience. Human activity introduces these anthropogenic impositions to the marine environment through drilling, sonar exploration, ship strikes, and other sources of manufactured sound. In the frequency range of 20-500 Hz underwater, ambient sound is primarily due to noise generated by distant shipping. Even after removing any noise generated by ships close to the receiver, distant ships can still be detected - this is also the frequency that most marine communication occurs (Godin, Zabotin and Goncharov 2010).

Impacts on the Whale

Due to limited light penetration in the underwater environment, marine species have highly developed hearing that allows them to find prey, navigate and communicate with one another. This process is impacted by ship traffic when introduced anthropogenic sound creates noise with



A spectrogram of the dynamics between whale communication and other introduced sound off the coast of Australia. (Erbe et al. 2015)



Zones of conflict identified between whales migrating into the Gulf of Maine and ship traffic. The most dense zones (black) are documented as having upwards of 300,000 routes/1.22km²/year (data from MarineTraffic 2020).

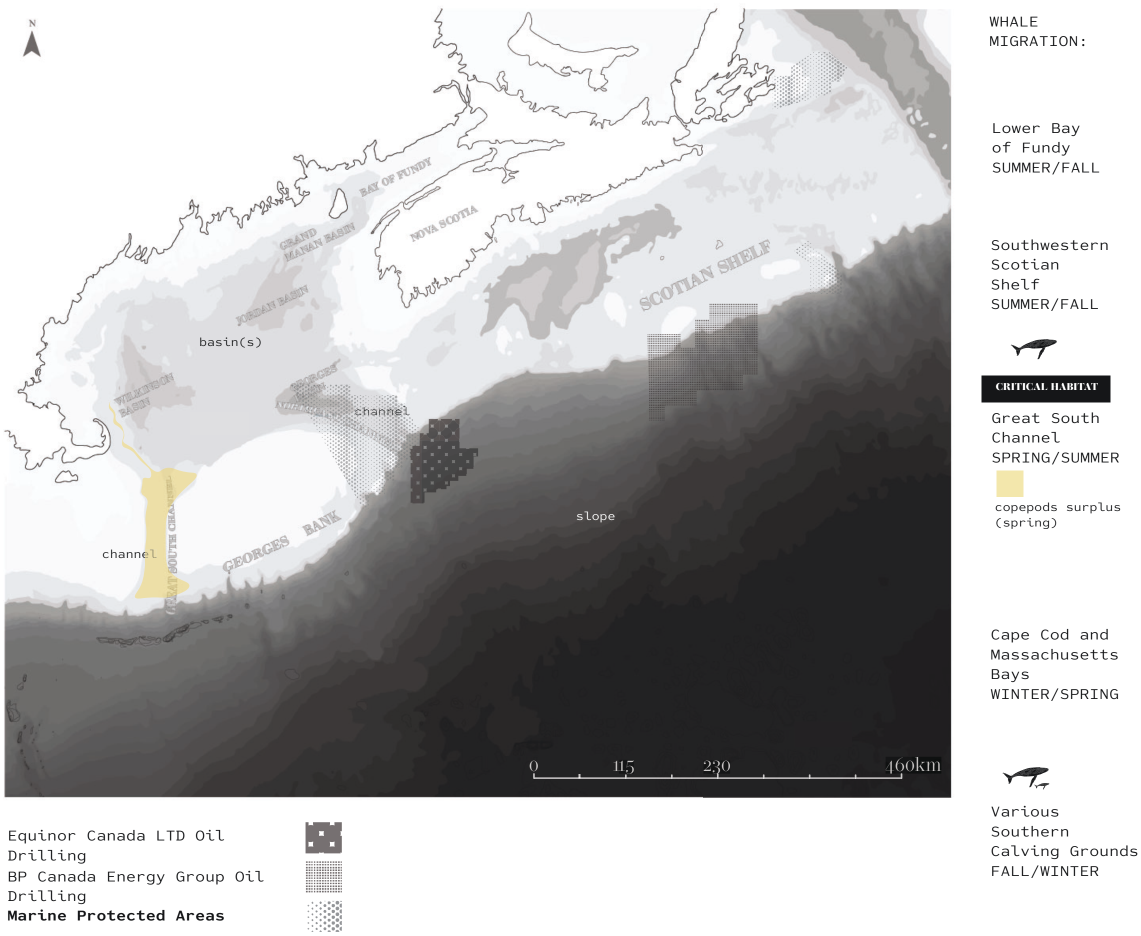
low frequency sounds in the same range as underwater communication (Parsons et al. 2009, 643-651). There are sources of acute and chronic noise. Military sonar surveys are an example of acute noise that are short in duration and used to create an understanding of the sea floor topography (Masud et al. 2020). As another example, offshore oil deposits are located through air blasts that occur every ten seconds, 24 hours a day for weeks into the seabed and create acoustic disturbances that can be measured up to 1200 kilometres away.

The impacts of shipping noise underwater have evaded our perception as disruptive sound is contained by the surface of the ocean. Since we cannot directly perceive sound through water molecules, and cannot experience the effects on the whales, we must consciously seek to understand the significance of these impositions to the marine environment. Although research findings have advanced through passive acoustic monitoring data, public awareness of the acoustic impacts on different marine species is just beginning to circulate. Noise can disrupt the natural methods of acoustic navigation for marine species, affecting their ability to hear incoming ships and being killed by collisions (Hill et al. 2017, 558-573). Restrictions for ship traffic speed and noise are difficult to establish because there are still legislative gaps in the shipping industry and the monitoring of ship speeds is hard to manage across such large bodies of water. In addition, manufactured noise can have lasting impacts on species evolution – their communication changes and simplifies as human noise creates competing sounds for them to navigate.

Chapter 3: Form, Pathways, and Materials

Actors

The North American right whale, Humpback whale and Blue whale all have well known migration routes that can take them thousands of miles between their winter calving grounds and summer feeding spots. These paths of circulation are important for migrating whales as they navigate from warm southern waters in the winter, to cooler, more productive water in the Gulf of Maine for the spring/summer months. In the warmer months, the whales become

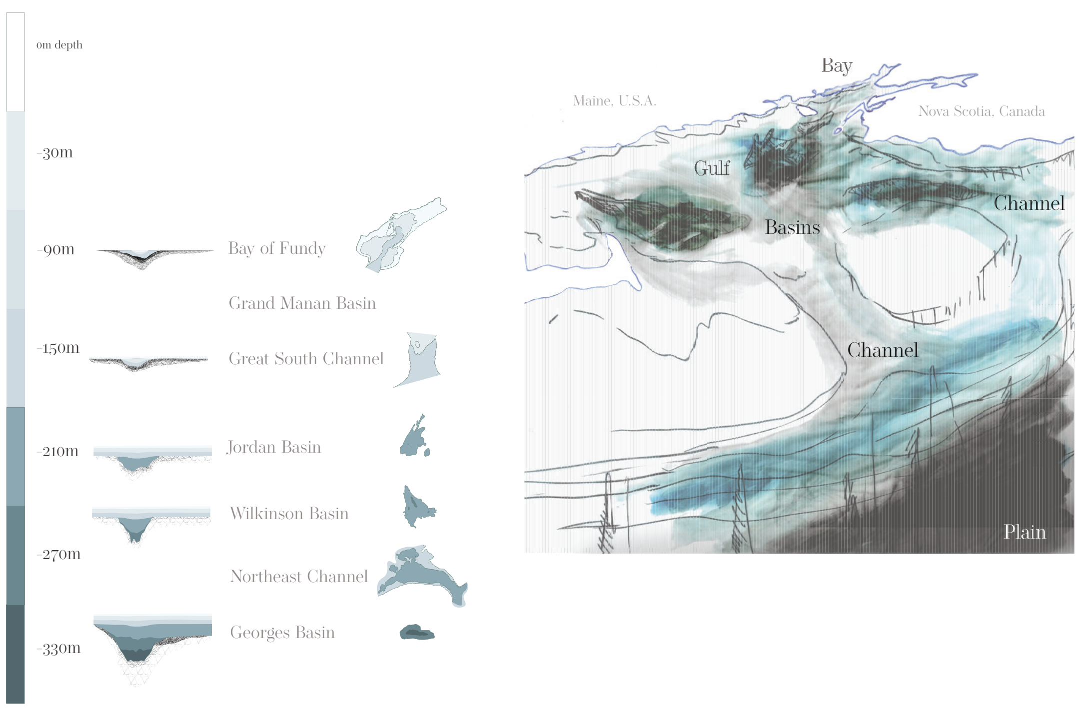


This project focuses on the migration paths of 3 different whale species into the Gulf. Blue Whales, Humpback Whales, and North Atlantic Right Whales all follow a similar trajectory up from southern calving grounds (data from NOAA 2020).

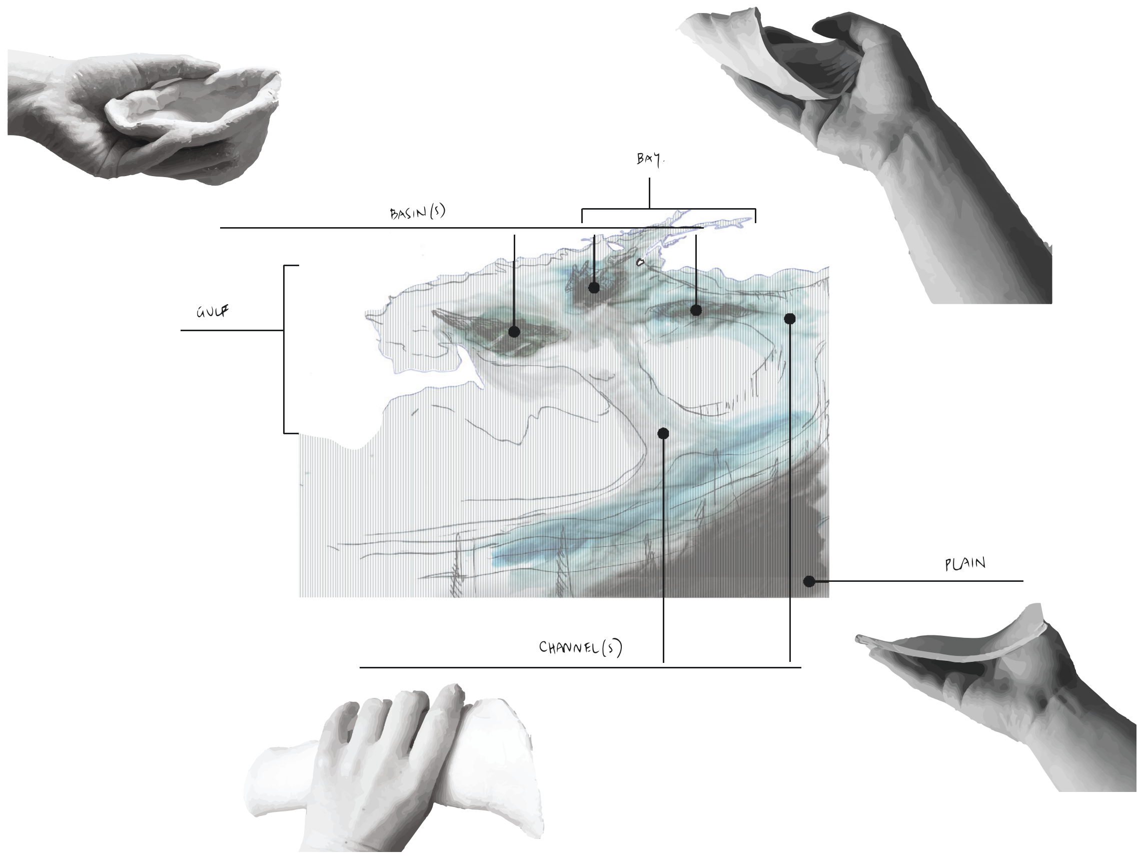
subjects of a whale watching industry populating the Gulf of Maine's coastline. The gulf is a semi-enclosed sea that is bordered by Massachusetts, New Hampshire, Maine, New Brunswick, and Nova Scotia, where ship traffic is also very dense due to the proximity of various ports along 12,000 km of jagged shoreline. For the context of this project we will be focusing on interactions for tourists interested in whale watching off the coast of Brier Island, Nova Scotia.

Vessel Pathways

The Gulf of Maine's sea floor has topographic features that organize space including deep basins, channels into the gulf, and the Bay of Fundy. These forms modulate sound transmission underwater as they have varying depths which impact their material composition and acoustic feedback. The term vessel describes containment of material within



Vessels shaped by sea floor topography in the Gulf of Maine have varying depths and material properties that inform the major points of conflict between cetaceans and ships.



Identifying forms through model making that are analogies for the sound transmission through these vessels underwater.

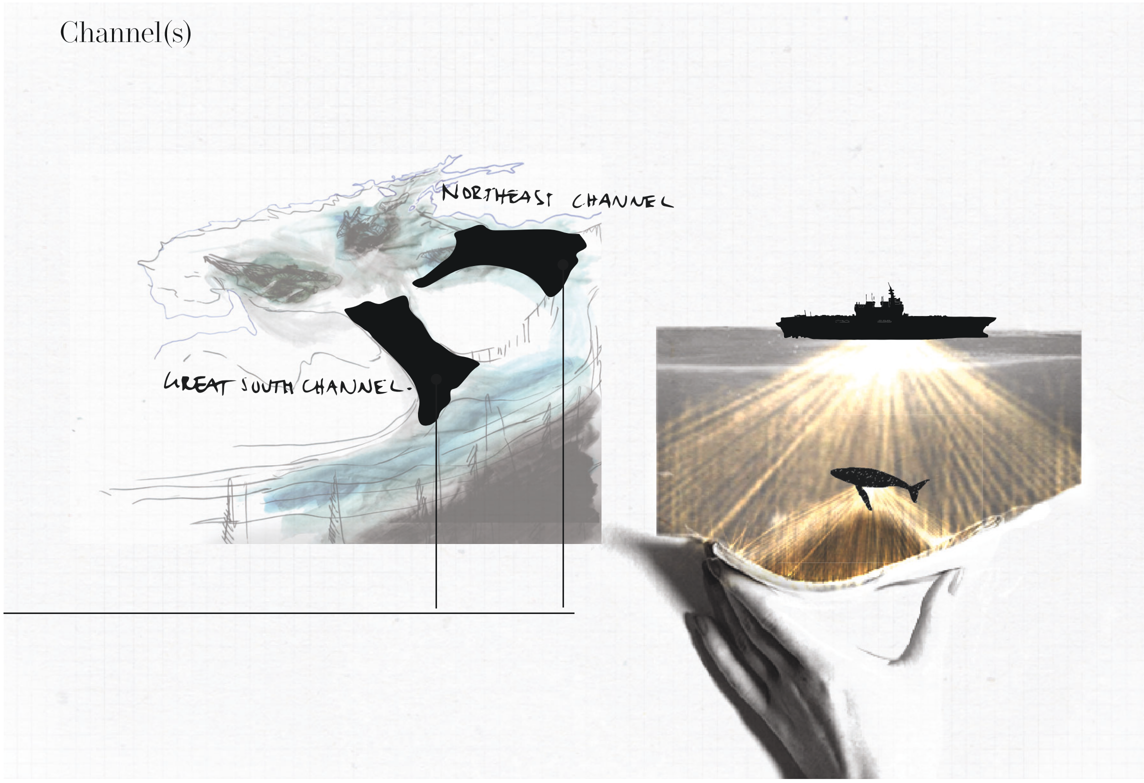
form, operating at various scales with the same objective (*Merriam-Webster* 2022). The vessels shaped by sea floor topography inform the major points of conflict between cetaceans and ships.

These pathways interact with the vessels to produce different acoustic experiences that can be translated:

The Channel(s)

Vessel Form

The plain extends out to the open ocean and holds deep water containing vast trenches and high ridges. The topography provides acoustic feedback that is important for the whale as they navigate towards the Gulf of Maine. An



Modelling a reflective form to experience the Northeast and Great South channel(s).

upward slope guides both the whale and its food sources up towards the channels into the gulf. These are shallow areas of nutrient dense grazing that are crucial for the whale and calf as they ascend along their migratory journey. These forms are important for shaping the journey of the whale and contribute to the survival of their species, however, they also become points of conflict as ship traffic flows across similar areas.

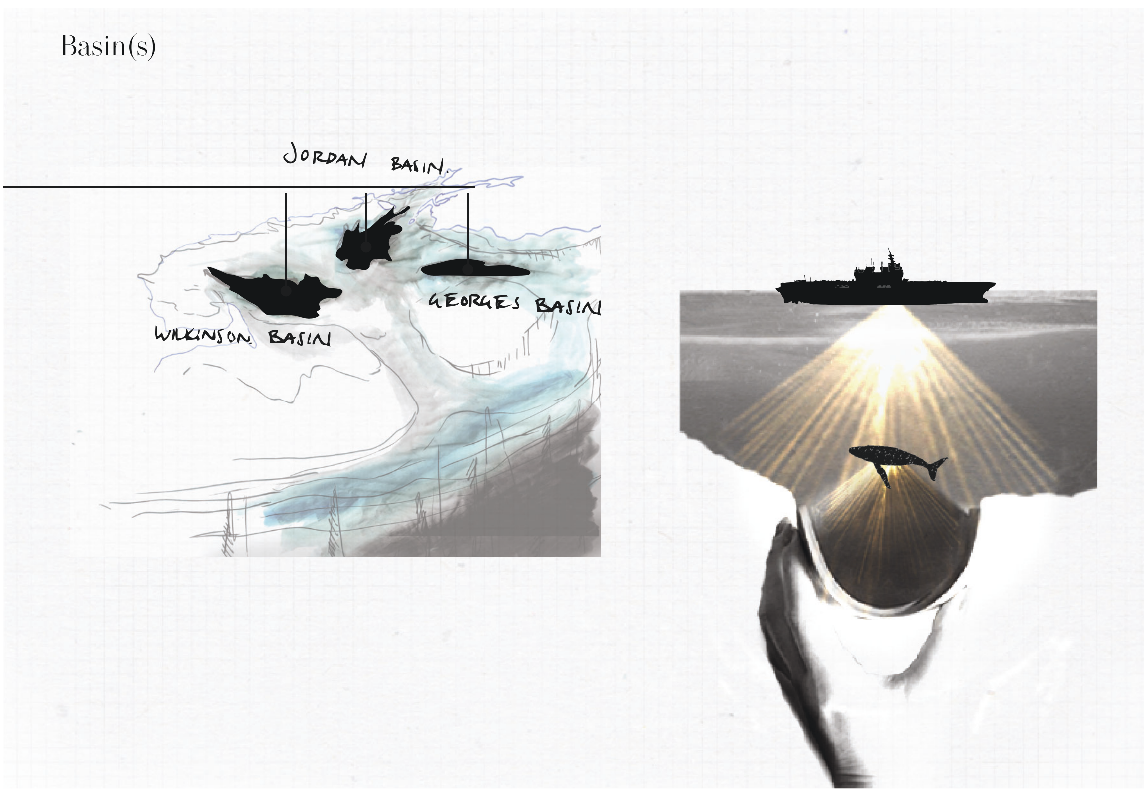
Pathways

The gulf is an important zone for many species of whales because of the influx of nutrients and food pushed up from the deep, cold ocean over Georges Bank. The banks forms two channels - the Great South Channel and the Northeast Channel – into the gulf. Incoming water enters along the Scotian Shelf and the Northeast Channel from the Labrador current, which is cold, rich in nutrients, and creates a counterclockwise flow in the Gulf. Outflow happens through the Great South Channel once the water has circulated throughout. The Great South Channel is a popular zone for whales along their migration because it has historically been a rich zone for copepods to collect, which are one of many important food sources found in this area (Dybas 2018, 6-11).

The Gulf and Basin(s)

Vessel Form

The Gulf of Maine is a semi-enclosed sea about 150-210 meters deep (excluding major basin depths), which is much shallower than the sea below which sinks to around 4800 meters at the base of the shelf. Powerful currents shift the distribution of sediment in the gulf, while the basins maintain



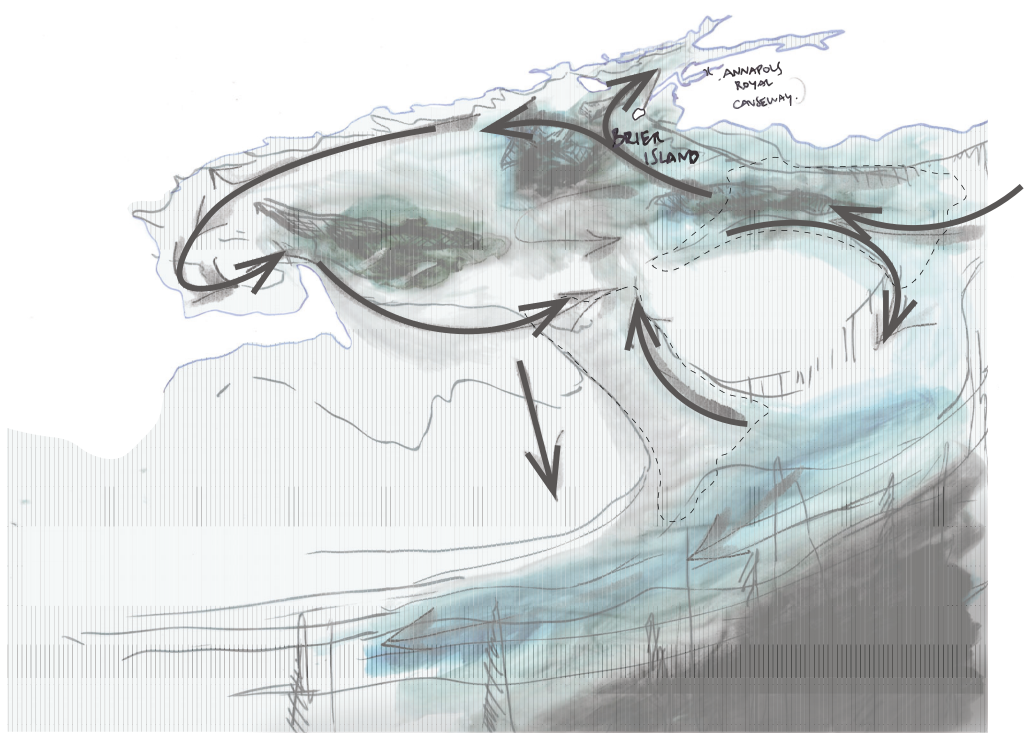
Modelling a deep and dampening space that punctuates the Gulf of Maine: the basin(s).

a composition dominated by more porous and dampening materials.

There are three main Basins that exist within the Gulf of Maine, from the greatest depth is Georges Basin at around 330 meters deep, Wilkinson Basin at 270 meters, and Jordan Basin at 210 meters. Additionally, there is the Grand Manan Basin 90 meters deep which is located beside Grand Manan Island at the entrance into the Bay of Fundy.

Pathways

The Gulf of Maine is shaped by a shelf of shallow water that brings the whales into closer proximity with ships overhead, while the Basins each provide varying depths of refuge. Whales enter the gulf through the channels and then continue off the western coastline. They interact with the perimeter of the Gulf while feeding in Cape Cod Bay and



Ocean Currents Circulating the Gulf

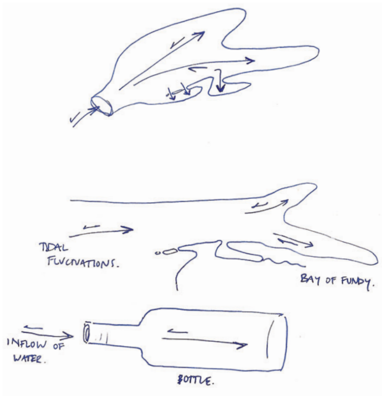
Powerful currents circulate water in and out of the gulf through the two channels. Zoomed in section on page 30.

surrounding areas, travelling north towards the entrance to the Bay of Fundy where they travel over the Wilkinson and Jordan basins. Another path exists for whales who bypass the Great South Channel and enter the Northeast Channel by travelling along Browns Bank towards the Scotian Shelf, another popular feeding zone. Along this pathway, Georges Basin is connected to the Northeast Channel and provides a much deeper area for whales to evade close boat interactions, as well as containing dampening materials like mud, sand, and clay, to dampen some of the traffic noise (Nyborg and Rudnick 1948).

The Bay

Vessel Form

At the northeast edge of the gulf, the Bay of Fundy has tides that are measured as the most powerful in the world with a tidal range of about 16 meters (FORCE n.d.). The sedimentation of the sea floor appears much more aggregated at the entrance to the Bay, mostly consisting of mixed gravel and bedrock. Sediment particles are pushed Northeast and back with the tides, so the interior Bay of Fundy region is constantly experiencing fluctuations in the distribution of sediment. Bedrock in the Bay is exposed by this process and creates a more reverberant space when compared to the general landscape of the gulf where mud, sand, and clay are distributed more densely and collected in the basins. Bedrock is a solid surface that is highly reflective and not porous. In comparison, sand and mud are much more absorptive and dampen sound transmission in the underwater environment (Nyborg and Rudnick 1948). During times of influx, the topography becomes softened by

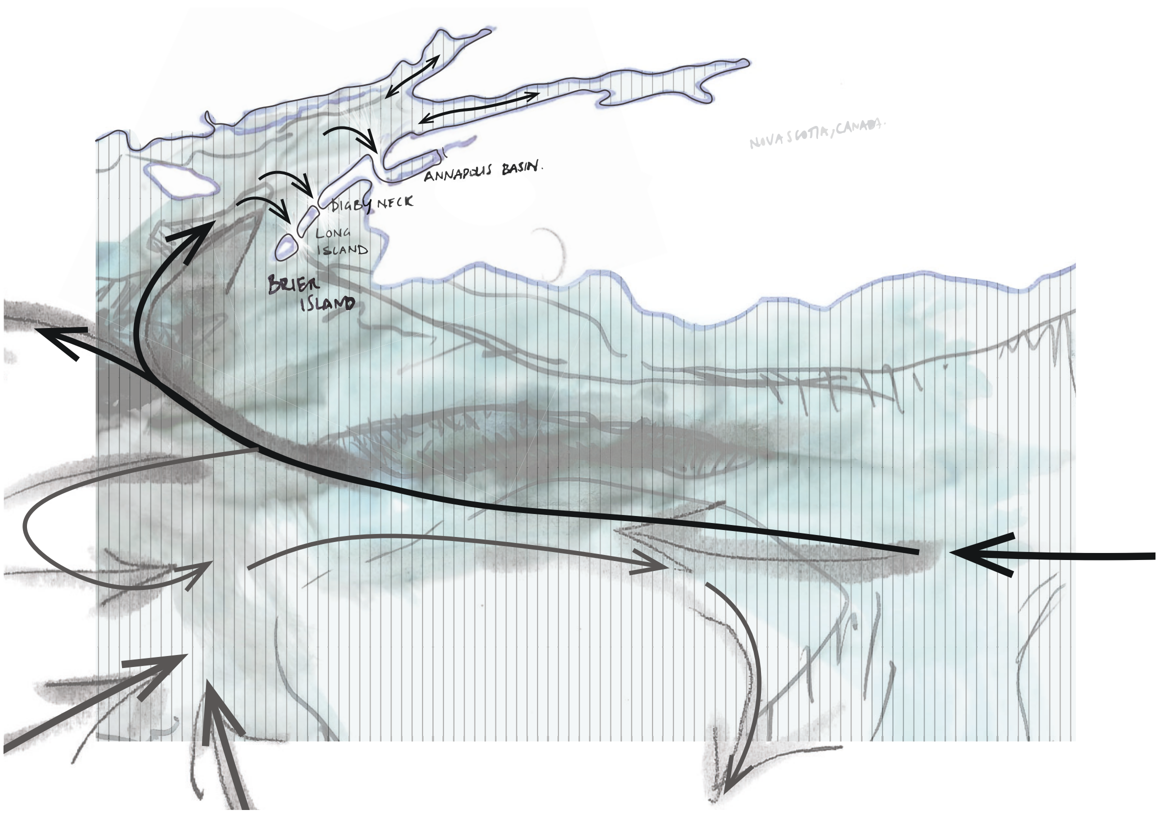


Sketch showing the resonance, like in a bottle, that occurs as tidal fluctuations are pushed in and out of the Bay of Fundy. The form contains the power of the tides pushing against its boundaries. Three unique moments exist along N.S. coastline where water flows through this threshold.

the sediment flow and creates more opportunities for sound dampening.

Pathways

The Bay is a popular site for marine life because the drastic tidal movements create a well-mixed water channel and productive underwater ecosystem. You can find rich supplies of krill, squid, young herring, pollock and mackerel attracted to the nutrient flow that feeds the bay. The most endangered whale species in the world, the North Atlantic Right Whale have historically spent summers circulating in the bay and spending time near the entrance where a critical protection zone has been established for them (Brillant and Trippel 2010, 355-364). The main threat to this population are ship strikes and entanglements with fishing gear, both



Tides flow into the Bay with extreme force. Unique energetic passageways exist where the water is pushed through land that exists as a threshold to contain the volume of water in the Bay and these include: the space between Brier Island and Long Island, Long Island and the Digby Neck, and the channel into the Annapolis Basin.

of which increase in frequency as the density of ship traffic associated with the Bay of Fundy increases.

In addition, the powerful tidal fluctuations move sediment more easily in the bay, and this reverberates acoustic feedback as bedrock is exposed. Every 12 hours, about 100 billion tonnes of water flows into the Bay of Fundy (FORCE n.d.). Along Nova Scotia's northwest coastline at the entrance to the Bay of Fundy, 3 energetic passageways exist where the tidal fluctuations are pushed through. These unique moments are the spaces between Brier Island and Long Island, Long Island and the Digby neck, and the channel into the Annapolis Basin.

Vessels and Materiality

Important to the interactions between actors, are the material composition of the vessels that contain the points of intersection. These material properties have repercussions for the type of acoustic experience that is perceived by the whale.

The Channel(s) and Reflectivity

Exposed bedrock beneath a thin layer of sand that has been washed away by the tide (Khines 2005).

Bedrock is a hard material in the ocean environment that, when exposed, is responsible for reflecting sound along the ocean floor. Reflective materials do not absorb sound particles, but due to their dense structure they reflect the particles out from the source of impact (Eagen 1972, 54). On land, hard materials like concrete, metal, and wood are considered reflective because they are not porous and have dense fiber orientation that prohibits particles from being absorbed. The Denge sound mirrors in the UK were originally designed to alert British army of incoming enemy aircraft. The form of the mirror is an instance of reflective

Denge Sound Mirror in the UK (Scott 2009).

materials used to concentrate environmental sounds as an early example of radar designed by the military. The mirrors were constructed with concrete, a hard surface used in a curved shape to increase the surface area available for reflection of sounds travelling through the air towards them. In the ocean, reflection along the sea floor facilitates acoustic feedback that is required to navigate the marine environment for whales and marine crafts using sonar.

A large source of reflection in the ocean environment is the surface due to the molecular composition differences between water and air. The ability of the surface to reflect sound can be impacted by the roughness associated with weather events or high winds. This reflection contains sound within the body of water and can scatter the reflected particles if the surface is variable.

The Basin(s) and Dampening

Sand provides a dampening effect for sound that is angled towards its surface (Siskopoulos 2014).

In contrast, building materials can be defined by sound absorption coefficients which determine incident sound energy dampened by the material. The coefficient normally varies between 0.01 and 0.99, and materials with high coefficients (above 0.20) are considered sound-absorbing. For dampening materials, or sound-absorbing, these coefficients are determined by thickness, density, high porosity, and loose fiber orientation (Eagan 1972, 37). Underwater, the dampening ability of a material determines sound transmission and quality of acoustic feedback. These impacts are site driven and determined by topography of the sea floor, sediment distribution and cover, depth and surface roughness (Bolghasi et al. 2016, 275-287). These dampening effects can also be applied to architectural spaces by introducing vegetation outside and porous materials inside to absorb sound and create a quieter environment for occupants. For this project, architecture can also take inspiration from the basins by considering the application of porous materials in thoughtful acoustic design that is critical of the ways visitors make and observe sound in space. By allowing some spaces to be noisy while others are quiet, when large rooms would all characteristically be treated with dampening materials, we are more aware of the intersections between program spaces in the building and the noise we are creating. This also heightens the experience of being in one of the rooms that is designed as a quiet space after leaving some of the noisy gathering areas.

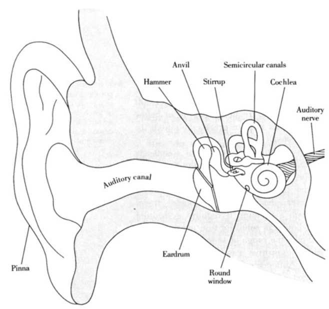
Understanding the power of reflective and dampening materials presents opportunities to purposely design unpleasant or disorienting auditory interactions for visitors to simulate an experience of the whale experiencing ship traffic.

The Bay and Reverberation

Reverberation is the amount of time that a sound remains audible, and we can use this concept in designing spaces by paying attention to the interior listening experience. Rooms that use hard materials to create reflective surfaces with greater distances between sound sources and walls will have more reverberation time, which means the sound will remain audible for longer. This is because the larger and more reflective the enclosure is, the sound that is travelling away from the source will have more opportunities to bounce off the surfaces in the room. In Seyðisfjörður, Iceland the Tvísöngur sound sculpture was created by German artist Lukas Kühne to naturally amplify five-tone harmonies that

Tvísöngur sound sculpture in Iceland (Leclerc 2019).

are an Icelandic music tradition through the domed form of the design. The form of each of the five concrete domes have a separate resonance, so each dome increases the strength or duration of one of the five musical tones associated with Icelandic harmonies to naturally amplify the music. This creates an experience that can be observed alone, or by consuming the domes together. This example illustrates how reverberation can be used to create pleasant listening experiences, but in large spaces too much reverberation can begin to multiply and create distracting sounds. This excessive sound can be unpleasant for programs like a classroom or office space.



Cross section of human inner ear (Pihlajamäki 2009).

Scientist holding the inner ear of a Humpback whale bone that washed up on shore in Massachusetts (Rimer and Colarossi 2019).

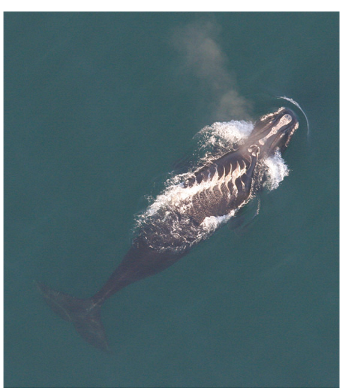
We can also understand reverberation by looking at different scales of acoustic forms. An example of a small form is the human outer ear that is funnel shaped to collect sound and amplify it towards the inner ear. Once sound reaches the fluid of the inner ear it is transmitted through vibrations in the cochlea. The elongated shape of the ear canal is our most personal example of a reverberant space that concentrates sound towards the inner ear to allow us to hear even quiet sounds around us (Eagen 1972, 50-62). The inner ear of the humpback whale evolved to be much smaller than ours because the assigned task of alerting the body to gravitational forces and head movements are both somewhat irrelevant to the whale's life underwater (Thean, Kardjilov and Asher 2017, 249-261). Their cochlea has developed the ability to hear underwater by responding to the vibration of water molecules instead of air molecules. The size of the whale cochlea can fit in the palm of a human hand, but their ability to perceive is sensitive to reverberation of acoustic feedback in their environment that is impacted by

PAUSE Pavilion in Iran (Ghaffari 2017).

suspended particles, surface conditions, sea floor qualities, and ocean depth.

Reverberation needs will differ based on program, but low reverb contributes to better conversational qualities, while higher reverb creates more pleasant listening for a music experience. Curved surfaces dissolve focus on the sound origin because sound reflects along smooth concave surfaces easily without interference. This leads to higher reverberation time when the materials are finished with a hard material like plaster to increase reflectivity. For the PAUSE Pavilion in Iran, designer Amir Ali Ghafari used brick and steel alternatively to create an experience that is delineated by reflective and dampened experiences of sound and light. His design intent for the pavilion was meant to draw visitors in with pleasing mirrored light displays, but then using a reverberant interior space and materials to create an auditory experience of the creek running beside the building. This is an example where a designed space is used to amplify the listening experience of natural sounds to create an intentional listening experience of something that would otherwise go unnoticed.

Conflicts



North Atlantic Right Whale struck by ship and left with propeller wounds (EcoHealth Alliance 2011).

Informed by the topography and material characteristics of the vessels in the Gulf of Maine, Zones of Conflict have been identified where ramifications for the whales are influenced by these underwater forms.

A collision between a North Atlantic Right Whale and a ship is an example of conflict between actors that was documented by drone footage in the Gulf of Maine. Although the risk is great, the whale must attempt to find food, and this forces them into these precarious interactions with fast-moving ships as they travel through marine habitat areas. Collisions symbolize a greater network of conflict zones between marine migration, acoustic disturbances, and points of research in the gulf, and these key zones will be used to create a design strategy for this proposal.

Zone of Conflict 1

The whale comes closer to the surface of the water when they ascend from the deeper, more protective plain below, gaining proximity to ship propellers that disrupt environmental feedback (Hill et al. 2017, 558-573). Ships heading to and from the Boston area increase noise produced by the stream of traffic crossing these migration paths over the channels. This stream is intensified by traffic associated with the Halifax port. These extensive pathways make the whale vulnerable to ship collisions, especially when the impact of

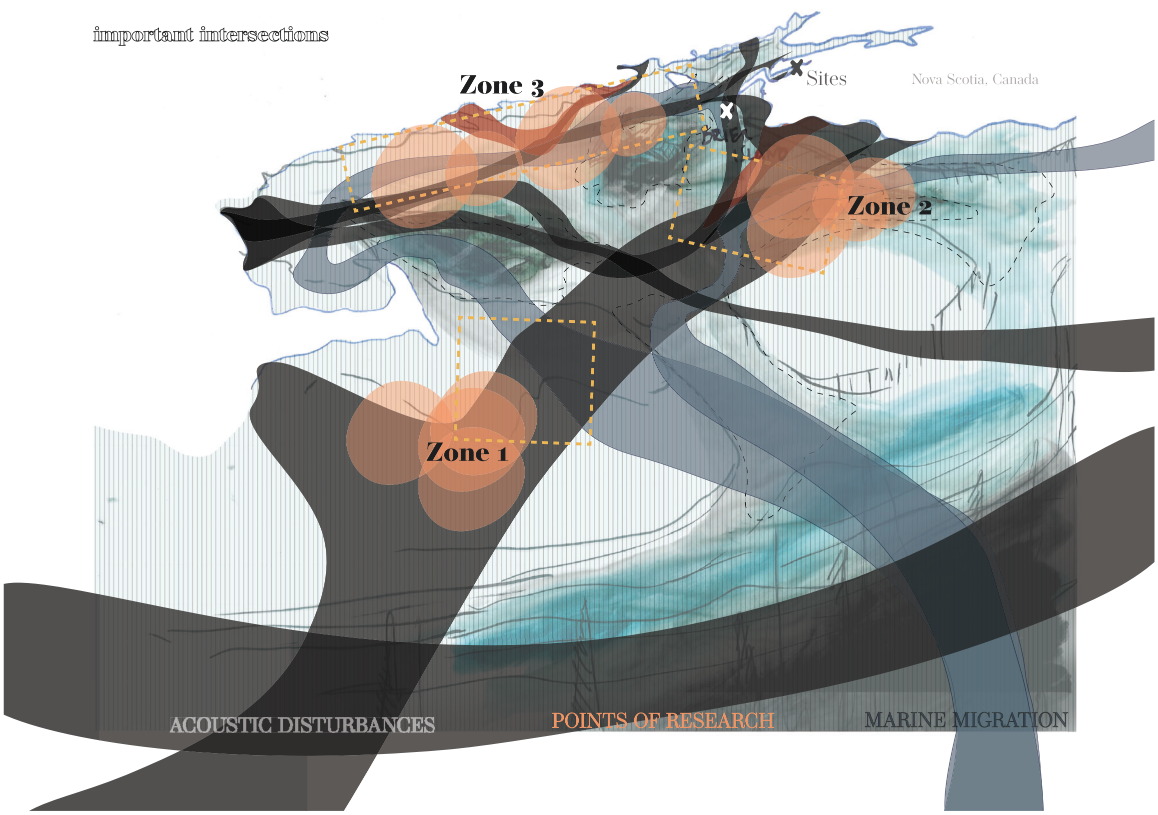


Diagram of conflict zones identified in the Gulf of Maine.

noise on their navigational abilities is considered. The whale finds a zone with plenty of food but stops feeding when in the presence of ship propeller noise, a response with dire consequences if traffic continues to expand (Dybas 2018, 6-11).

Passive acoustic gliders monitor areas south of Rhode Island Sound, a strait of water off the coast of Rhode Island, and east of Cape Cod Bay. This data provides important insight into how many whales are entering the gulf on their migration routes, along with individuals who bypass the channels eastward along the southern border of Georges bank. It also creates a hub for data collection that is important as climate change shifts the distribution of food sources and migratory timelines for different species. Accurate data on how many individuals and their distribution is crucial for informing noise and speed regulations on the shipping industry.

Zone of Conflict 2

The whale moves across the Northeast Channel towards the Scotian Shelf to seek out the popular feeding zone as productive waters are brought in from the Labrador Current. Georges Basin is situated between Georges Bank and Browns Bank, and at the mouth of the Northeast Channel - interrupting the dense stream of ship noise before the whales continue towards the shelf. The Humpback and Blue whales sometimes bypass the gulf entirely and continue northeast towards Newfoundland & Labrador. These alternative paths introduce the risk of collision from ship traffic porting in the southwestern tip of Nova Scotia, as well as the streams headed for the Halifax area. Additionally, ships travel across the whale’s migratory path when they enter through the Hawkesbury passage. There is a very dense and consistent stream of ship traffic that mirrors the whale's trajectory as they make their way along the Scotian Shelf towards the Gulf of St. Lawrence.

Zone of Conflict 3

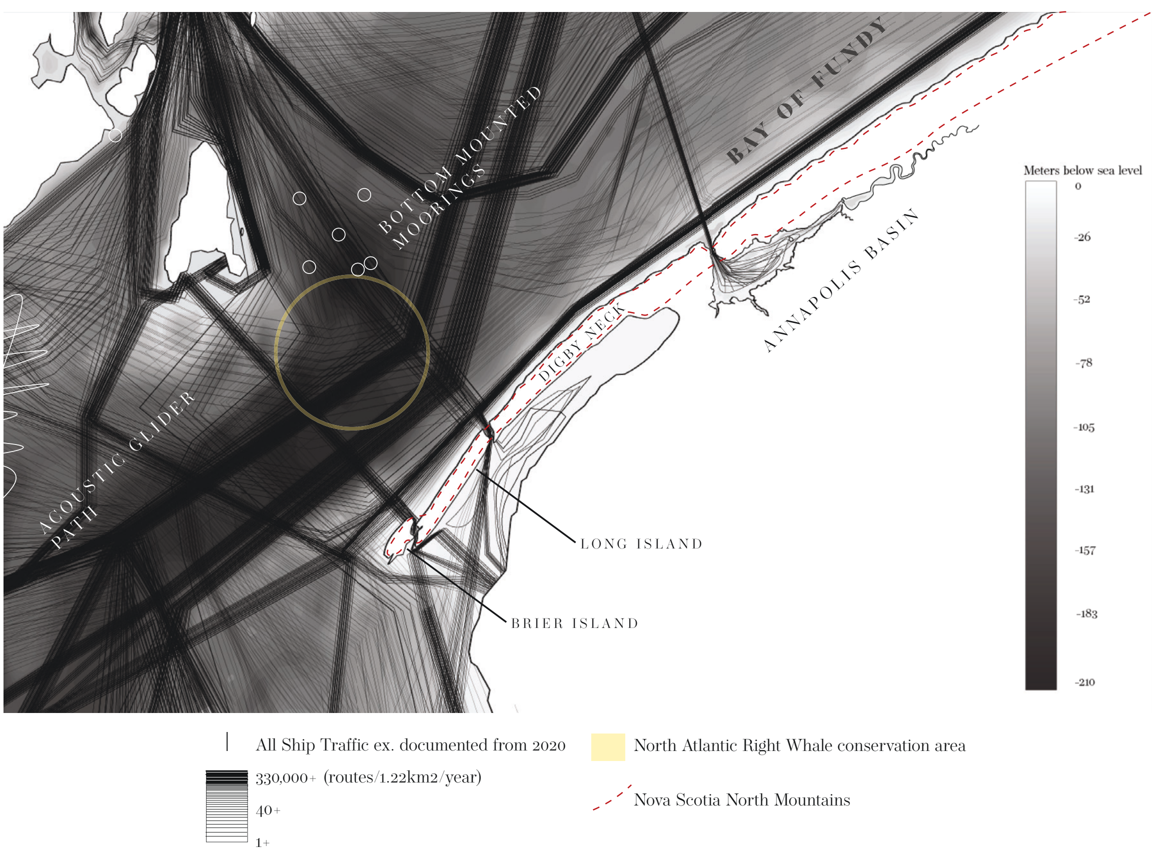
The whale migrates towards the Bay, but experiences conflict from various streams of ship traffic moving between ports stationed along the gulf's coastline. The sources and directions of noise are muddled this close to the bay due to the shallow water and proximity of ports. The whale finds food towards the Bay of Fundy's entrance while ships occupy the surface as they travel to and from the Saint John, New Brunswick port.

The bay has always been a productive zone where whales could gather and feed in the spring and summer months, growing their fat stores in preparation for their southern migration in the winter. With increasing densities of ship traffic, they have become treacherous places where collisions are more frequent, and disturbances are incessant.

Chapter 4: Design

Sites of Conflict in Nova Scotia

The acoustic composition of the Bay of Fundy is informed by the northwestern coastline of Nova Scotia and the North Mountains that create a hard edge along the Bay’s volume. There are a series of cuts in this edge - between Brier Island and Long Island, Long Island and the Digby Neck, and the channel into the Annapolis Basin - that can be considered anomalies acoustically. These moments allow both water



Passive Acoustic monitors are stationed at the entrance to the Bay to record whales that travel this far north. The data can be used to designate critical areas that should be protected by slower ship speed limits. This map contrasts the placement of these monitors with the global shipping maps that show how dense ship traffic is within the Gulf of Maine. The density of ship traffic at the entrance to the gulf is an example of conflict between ships and whales that has the potential to result in a collision (data from Marine Traffic 2020).

and ships to flow between protected areas behind the mountains and the Bay.

Brier Island

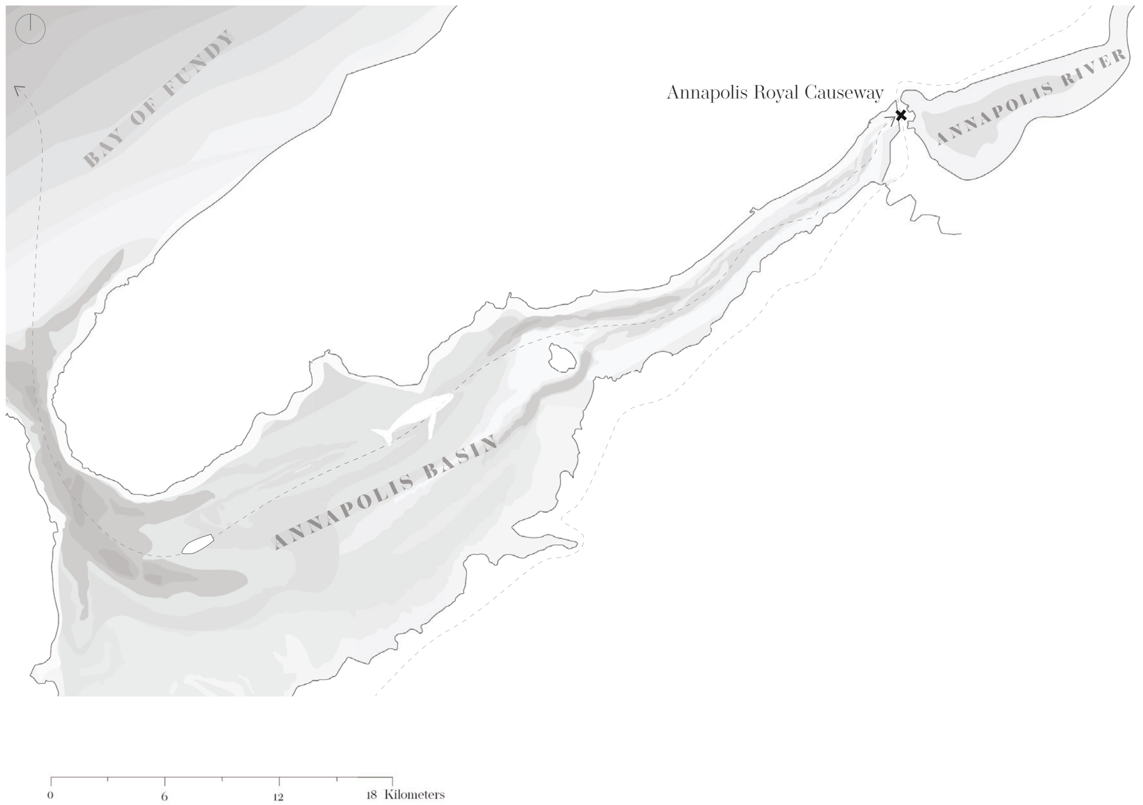
The energetic passageways along Nova Scotia's northwestern coastline allow ships to pass through the islands of the Digby neck, and bring visitors to Brier Island from ferries. Although ship access is facilitated by this flow, the protection of the whales in this area is important to Brier Island which hosts a small community that depends on whale watching as a pinnacle of ecotourism on the island. The map above (page 39) highlights a conservation area for the endangered North Atlantic Right whale that is contrasted by dense ship traffic. Providing access for researchers conducting fieldwork in protected areas is important for the populations of whale that frequent this area, contributing to the health of the North Atlantic Right whale and the Brier Island whale watching industry that is supported by them.

Annapolis Royal

Annapolis Royal Tidal Generating Station (Gielkens 2008).

Analysis of channels into the Gulf can be transferred to the energetic passageways off the Bay that connect the actors to the Annapolis Basin. The channel allows tidal fluctuations to enter the Basin and introduced a station for tidal energy generation to Annapolis Royal, a town bordering the Basin and river.

In 1984 the Tidal Generating Station in Annapolis Royal, N.S. began producing tidal energy for around 4500 homes. A causeway was constructed to control the tidal flow through two channels separating the Annapolis Basin from the Annapolis River. This increased bank erosion and created problems for marine life. In 2004, a disoriented humpback



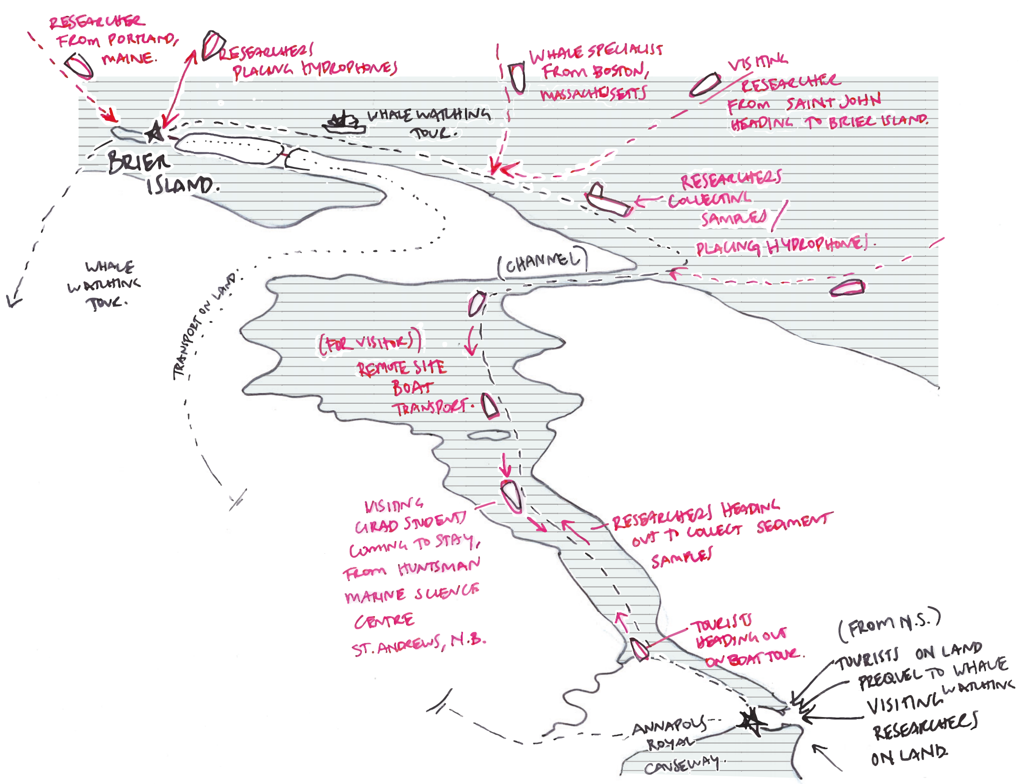
Map depicts where the Humpback whale travelled inland and swam through the Annapolis Royal Tidal Station dams and became trapped in the head pond, or the Annapolis River.

whale travelled inland, moved through one of the channels and became trapped for several days in the head pond of the tidal station. This was despite the use of high frequency sound being projected underwater to elicit avoidance responses from marine life before they were drawn through the turbine and killed (Gibson, Jamie and Myers 2002, 778). Crowds flocked to the site from all across Nova Scotia as the entire province was aroused by the chance to see a whale in such close proximity.

In 2019 the station was decommissioned due to substantial marine mortality and a major mechanical failure. Today it attracts tourists as it was once one of the only tidal generating stations in North America. The aquatic environment around the site has begun to recover for marine life. Before decommissioning, energy generation from the station was a source of anthropogenic noise on the site. Although the causeway remains as a blockage of what once was, today there is no sound above or below the surface of the water produced by this program.

Proposal for Sites of Conflict

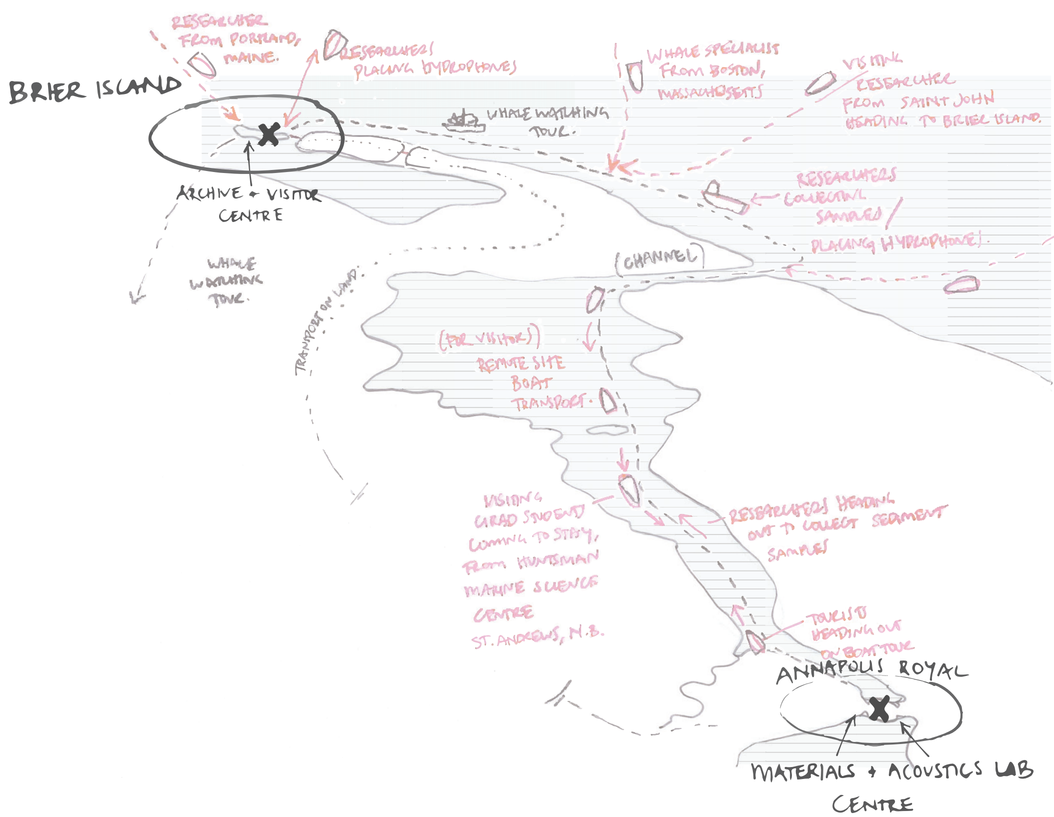
A connection between the Annapolis Royal causeway and Brier Island exists through stretches of land and 2 ferries that bridge the gaps between for visitors to each site. In the spirit of the whale's journey in the gulf, this project translates zones of conflict and creates new points of research. The project facilitates more research flow onto both sites with the benefit of using each location to connect researchers and tourists.



Sketch outlining the new streams of research flowing to both sites, facilitated by proposing a relationship between the two and along the Gulf of Maine's extensive coastline.

On the Annapolis Royal causeway, a Materials and Acoustics Lab introduces the concept of acoustic disturbance to visitors interested in the underwater ocean environment. Researchers coming to the site for placements, seminars, and lectures can now arrive by boat from various institutions bordering the Gulf.

The remote Brier Island site is used for researchers to conduct fieldwork and deposit hydrophones throughout the bay and gulf. Additionally, a water link is created to transport tourists to Brier Island, extending the pre-existing whale watching experience on the island. The proposal is to expand our human understanding of local soundscapes and reveal underwater sounds that exist without our inherent ability to hear them.



Relationship between the Annapolis Royal Causeway site and Brier Island site demonstrates the facilitation of visitor and information flow to both through a water link.

Annapolis Royal Causeway Site 1

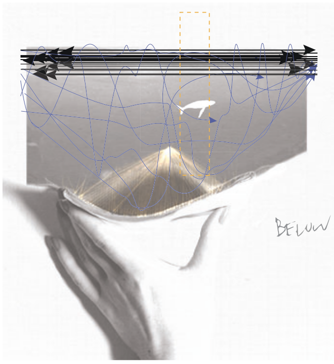
The Channel(s) and the Bay

The Annapolis Royal soundscape is characterized by interactions of ambient sounds, including those from wind, tidal changes, seabirds overhead, and anthropogenic noise introduced by car traffic.

Annapolis Royal key plan site placement on the causeway.

In the Gulf, the channels are areas of dense traffic and contain intersections between whales and ships. On the causeway, the Materials and Acoustics lab are designed to recreate these disorienting acoustic experiences between visitors above and researchers below. Sounds produced by visitors are translated to those below with unintended consequences. For this project, visitors take on the role of the ships while researchers embody the whales. In response to this interaction, visitors to the research centers come to

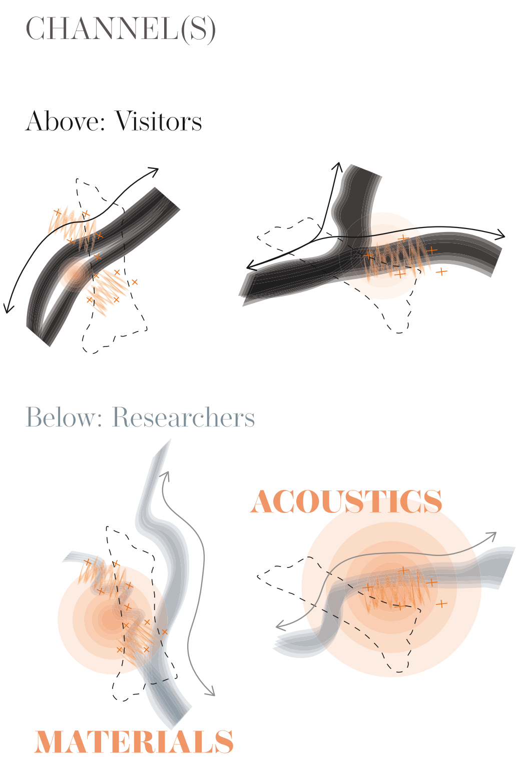
The exterior soundscape of the Annapolis Royal site is characterized by winds off the basin, seabird calls through the air, and car traffic across the causeway.

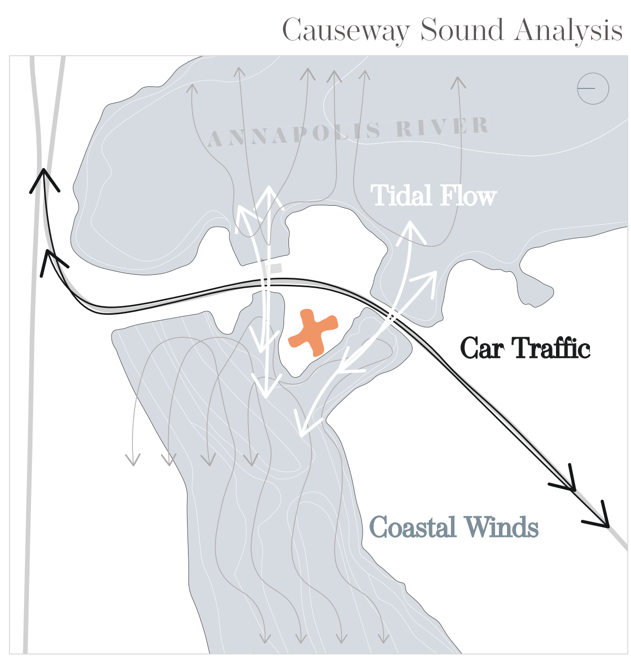


Introducing the concept of the channels to the Annapolis Royal causeway by creating a distinction between the visitor flow (ships) above and the researcher flow (whales) below.

understand their acoustic impact to those below through experiential learning, a novelty that ships circulating the ocean do not have.

Acoustic research can also be 'played' inside the building with operable components that allow sound to be heard without context. In the conflict zones identified, the paths of the whales, ships, and researchers interact in layered sectional relationships. The two program buildings on the Annapolis Royal causeway translate acoustic relationships between visitors above and researchers below that integrates non-porous materials like steel and glass to reflect movement and sound transmission inside the spaces.



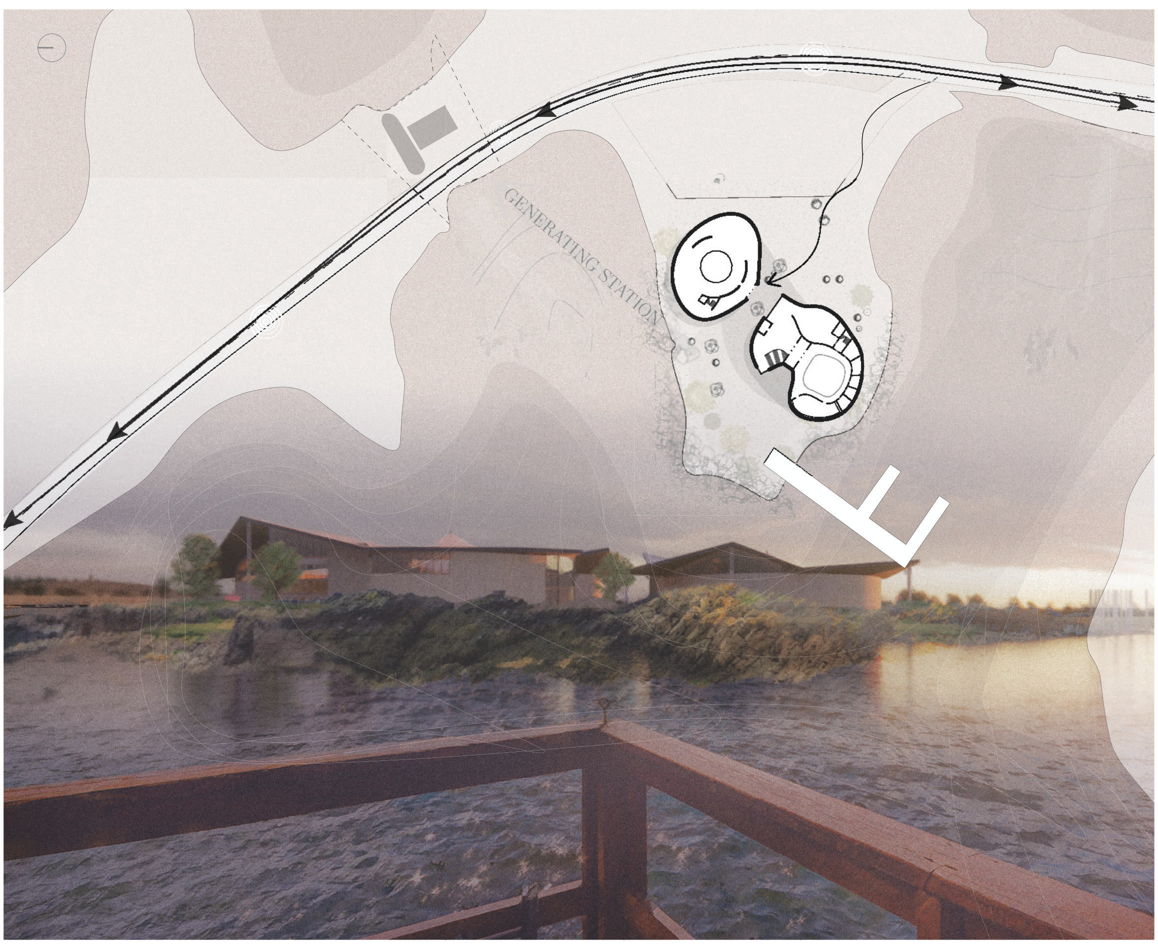


This presents the opportunity to introduce sound created by each group in disorienting and unexpected ways in the spaces where crossovers occur to aid in the contextual learning used in the buildings.

Lecture rooms inside the venues provide space for colleagues and researchers to gather in Nova Scotia and provide insight into the acoustic disturbances facing local whale populations. The venue allows researchers studying material properties of sea floor topography and acoustical oceanography to benefit from community outreach and collaborative lecture opportunities.

Site Placement

Sited across the highway from the decommissioned generating station, the Material and Acoustic labs are separated into two program buildings on the causeway to use the space between as a second degree of separation between the sounds produced by each program. The site



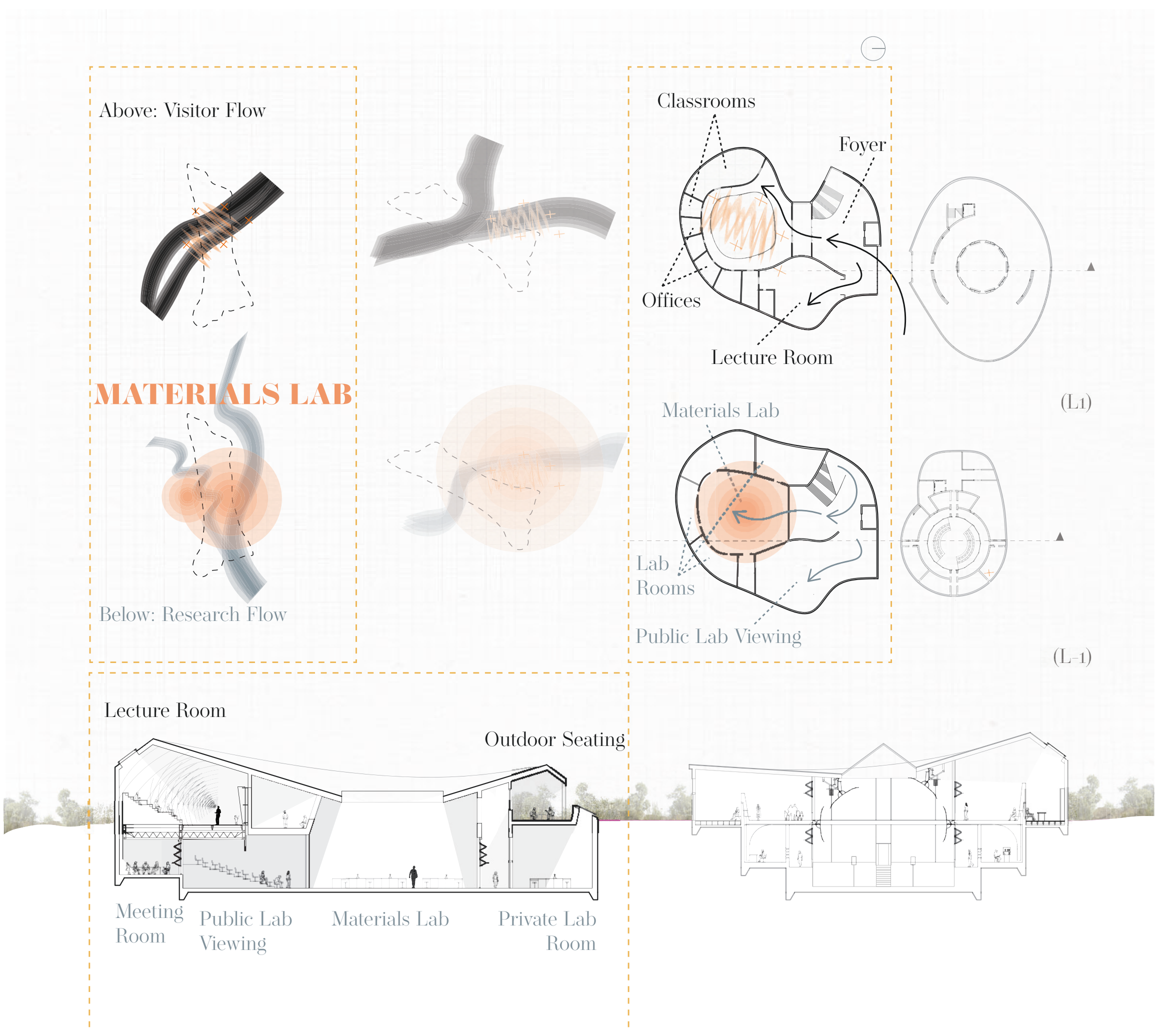
A gap between the two lab buildings creates a protected zone between the buildings on the site.

placement gives visitors an eastern view of the Generating Station where they can see the dams created in the causeway's construction. The chosen site provides context for the issues at hand by transforming the causeway - what has been an acoustic barrier between ocean and river, between silence and noise, between calm and chaos – into a productive point of intersection that educates local industries, communities and draws visitors.

The building shelters visitors from street traffic by setting back towards the water and guiding them into the south side not facing the highway. On the exterior, porous materials like wood evoke feelings of shelter and rest created by the position of the buildings which protects visitors on the

Visitors coming to the labs are ushered between the program buildings where they experience focused views of the water and boats coming to and from the site.

exposed site. The entrances to both labs are blocked from the highway traffic and face views out towards the Digby neck where visitors can watch boats coming in and out of the site. The gap between the two program buildings focuses the visitor's experience of the water, and introduces more protected areas for vegetation to break the coastal wind off the basin. The breeze carries seabird calls and soft sounds of the water crashing on the shore. Guests can see and hear the massive tidal fluctuations that occur four times a day as car noise is blocked by the building itself.



Relationship between Above and Below in the Channel(s) and the Bay reflect relationships between visitors (above) and researchers (below) in program buildings on the site.

Materials Lab

Inspired by the dynamic sea floor composition of the bay, the first program building is a Materials Lab designed for research on the sediment composition and distribution feeding the Bay from the Gulf of Maine and beyond. The upper floor is open to the public and brings tourists and locals to connect with researchers studying material properties of sea floor topography, sediment transport, and geo-mechanics. This intersection between the science community and public outreach for tourists visiting the site offers benefits for the visitors, the researchers, and the whales. There are designated spaces for visitors to see and hear research as it is being done, both directly and indirectly through the design. In lower floor of the materials lab building, visitors have access to a viewing area where they can watch sediment samples being analyzed from the sea floor of the Bay of Fundy and Gulf of Maine.

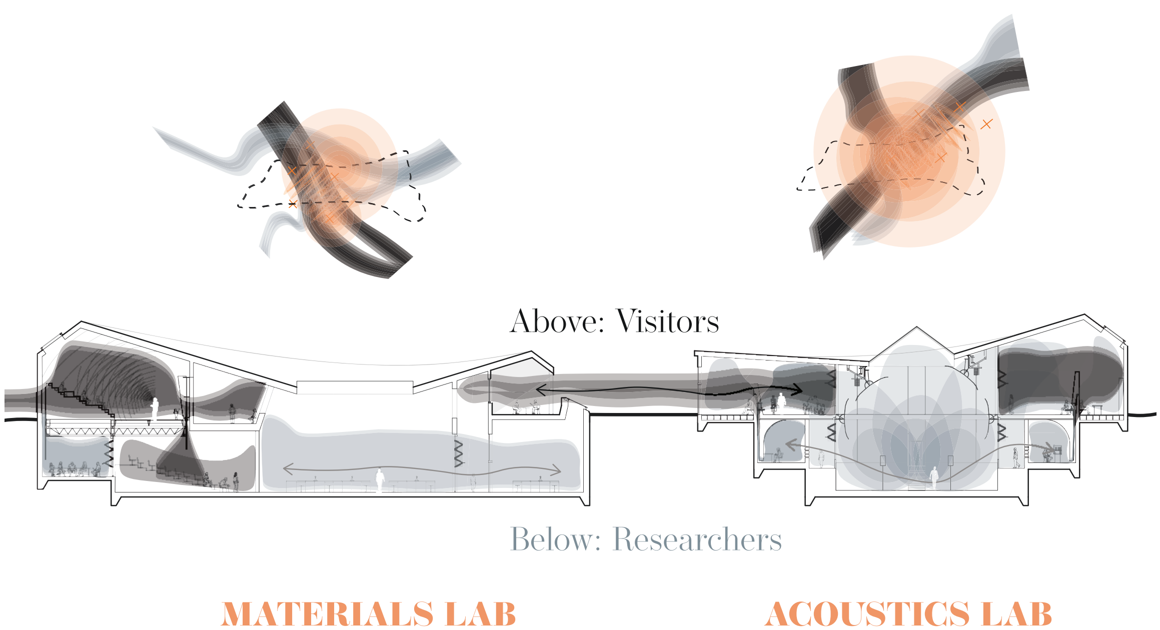


Diagram showing circulation through the Materials and Acoustics labs. In both buildings, visitor traffic (ships) occupy the upper floor, while researchers exist below (whales). Blue and black clouds illustrate the potential acoustic interactions that may invade other spaces through different thresholds. These moments are designed into the building through operable components.

Actors on the Site

The Visitor in the Materials Lab

Section A shows the acoustic relationship between a group of people in this public viewing area and researchers working in the Materials lab. The group is watching a researcher analyze sediment deposits from the Gulf of Maine to better understand the distribution of sediment in the Bay. There are rock and sediment samples scattered throughout the lab. The work in the lab is quiet, however, overhead a child is running a stick along aluminum fins in the lecture hall as their parents attend an informal community meeting for residents of Annapolis Royal.

The lab viewers below can hear the discussion as though the group above is in the room with them, but the tinging of the metal from the child provides just enough noise to muffle distinct voices. Those viewing the lab room start to talk amongst each other and slowly the tinging stops - the child has taken notice of their conversation and stops making noise.

She’s trying to listen.

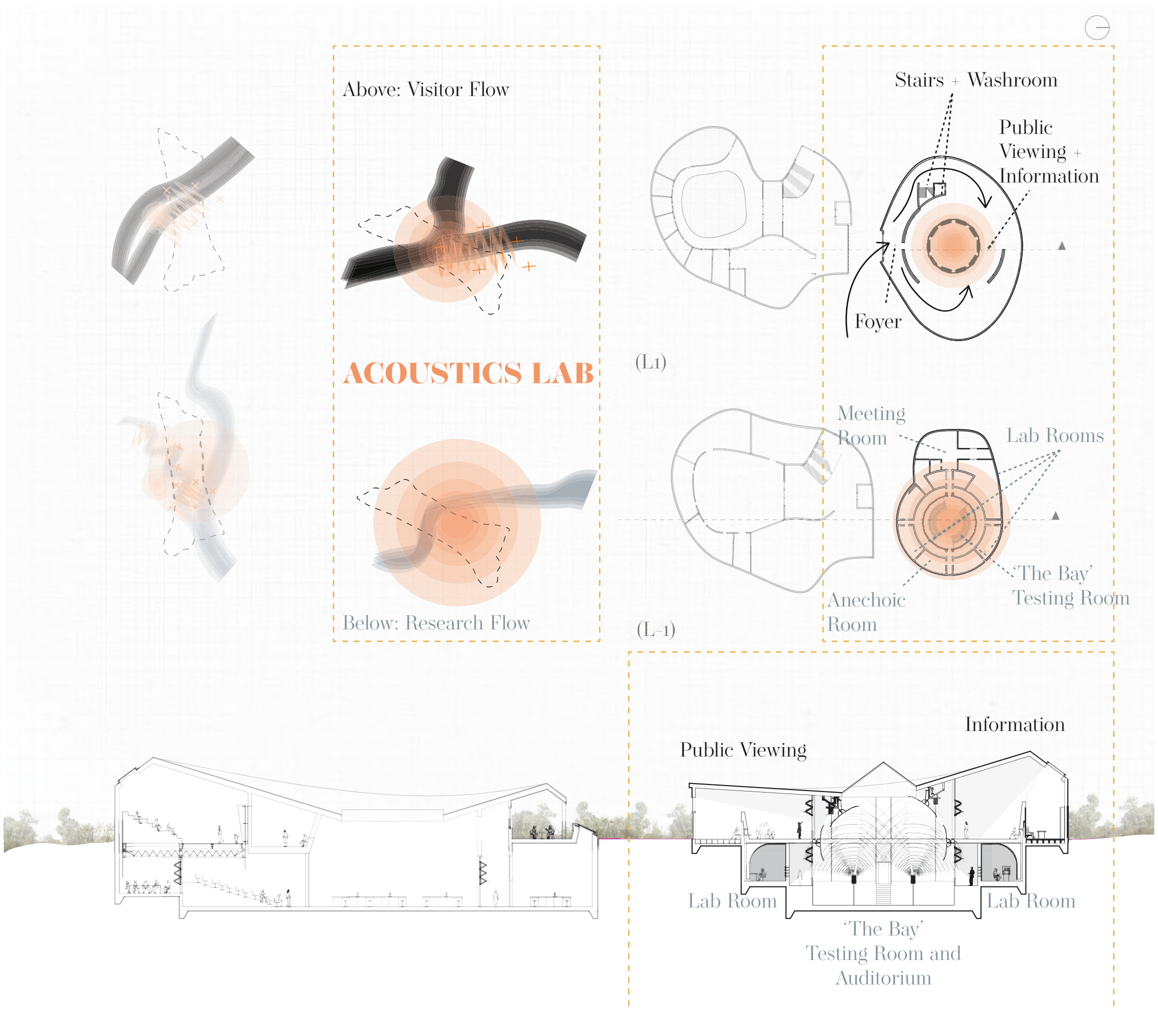
Moments described in Section A: Like the whale who is not in direct proximity to the source of noise or in control of the disturbance, people in the viewing area are impacted by sound that disturbs their experience, but they are unable to modulate.

Section A through the lecture room and public viewing area into the Materials Lab. The viewing area is an opportunity for visitors to descend and experience the acoustic impact of other visitors above, or from the perspective of the ‘whale’ (researchers) below.

Detail view of operable dampener surrounding the 'Bay' room.

Acoustics Lab and The Bay

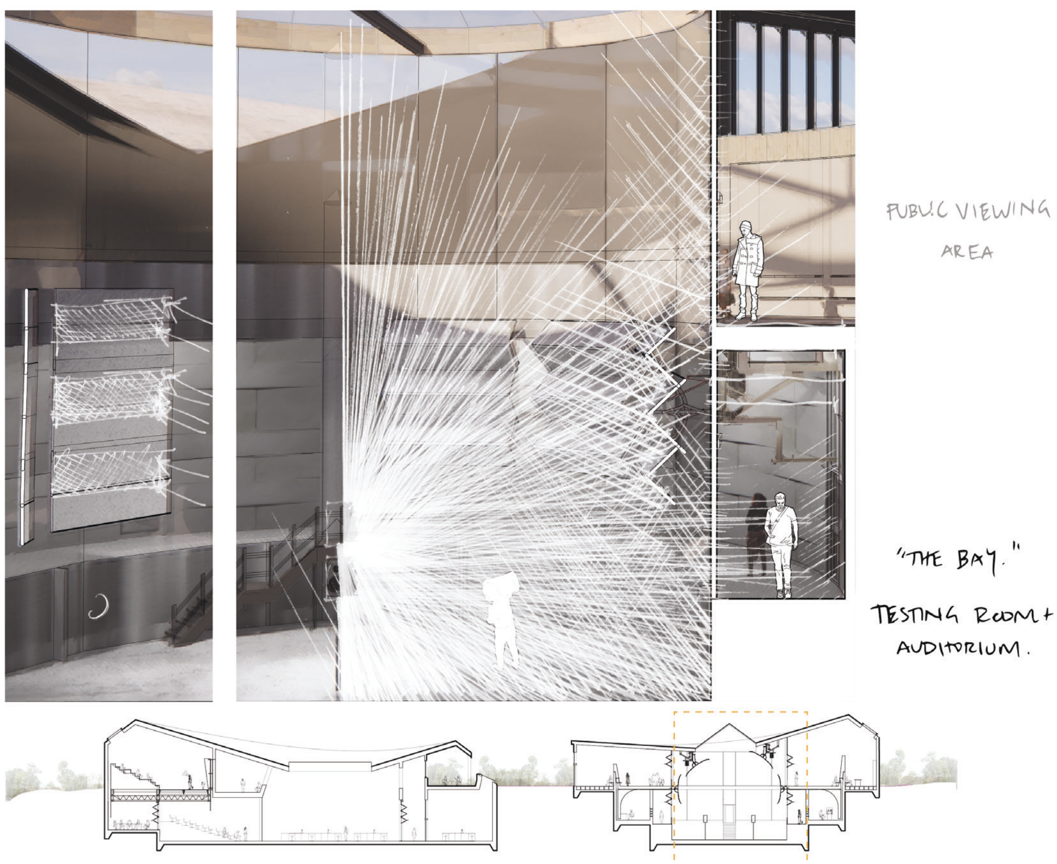
Acoustic material testing requires a space with design considerations that are critical to the success of the testing. The second program building is a space specialized for researchers studying sound absorption, acoustic transmission, and acoustic attenuation of materials, specifically in a room called 'the bay'. The bay has operable components that allow program needs to shift the interior acoustic experience. Around the room, dampeners flex and flatten to change the reflectivity of sound inside the room. The dampeners are operated by inhabitants, unfolding to



The Bay is a room in the Acoustic Lab that is observed by visitors above. Due to the nature of acoustic testing, research can be heard throughout the entire building – although not immediately understood by those visiting the building without context.

create more pleasant and intimate conversational volume for small groups of researchers. Operable seating also can be adjusted to create more texture inside the room to absorb some reverberation during quiet discussions between groups of colleagues. The task of flexing and flattening the

Visitors engaging with the public viewing area seating can hear broadcasted hydrophone recordings from lab room below.



Detail section showing an interaction between the public viewing and acoustic testing in ‘The Bay’.

operable dampeners allows occupants to understand the impacts of wall composition on the acoustic experience inside a large space.

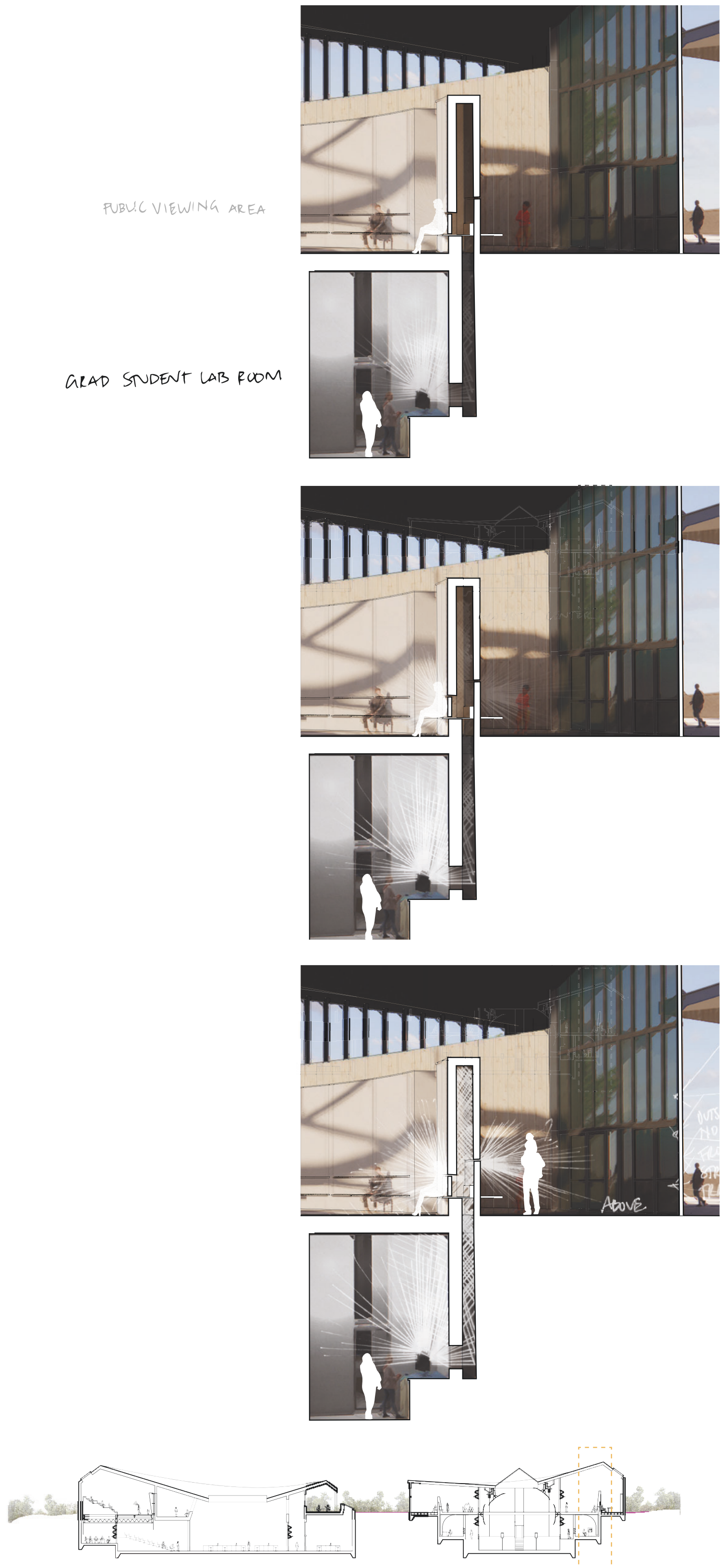
The bay is a place that visitors will have access to when public events and lectures are taking place. During these times the space will transform as dampeners flatten to amplify the information back to the guests, while unfavorable reverberation is dampened by increased seating and bodies in the room – much like the flow of sediment in the Bay, groups of people will flow in and out of the space impacting reverberation. Outreach lectures serve to educate visitors on the current research being done in the province and how it impacts the species of whales who frequent the Gulf of Maine.

The Visitor in the Acoustics Lab

Section B is in the Acoustic Testing Lab. It shows a woman interacting with an operable channel between researchers below working in their office, and seating above.

In the viewing area, a woman notices what looks like a bench seat - she pulls the seat out so she can sit down and notices sounds coming from below. She can hear a researcher listening in to an acoustic monitor placed off the coast. Ambient ocean sounds flood through the channel and out the space the woman has created by interacting with the seat.

She also notices a shelf above, out of curiosity, she pulls this out as well. The sound gets louder now and she can hear it broadcasting out the other side of the bench.



Section B showing an interaction between the public viewing area seating and lab room below in the Acoustics Lab. This experience reflects a complicated relationship between those above and below where impact and awareness are not always understood.

Brier Island Site 2

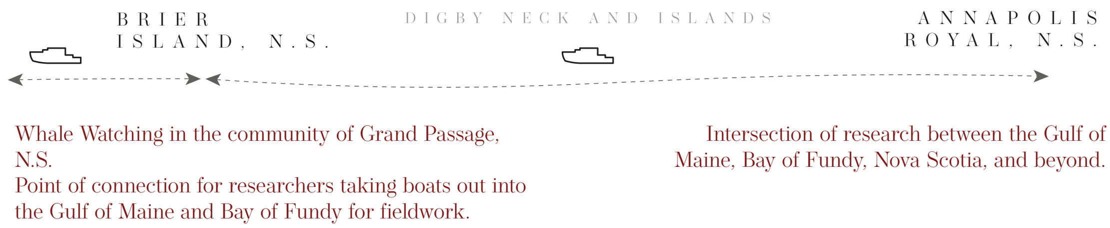


Diagram illustrating the relationship between research/fieldwork on the Brier Island and Annapolis Royal sites.

Whale Watching

Brier Island key plan shows site relationship to the Bay of Fundy (left) and Long Island, which provides ferry access for those driving from the mainland.

Moving down the Digby neck, Brier Island is the remote point for fieldwork between researchers working in the gulf. This site can also foster a relationship between the whales and visitors to Nova Scotia.

Brier Island is a small, rugged landscape located at the entrance to the Bay of Fundy from the waters of the gulf, which gives it a prime location to observe marine species and their relationships to the bay, gulf, and the Atlantic Ocean. According to the Passive Acoustic Cetacean Map, researchers have already placed bottom-mounted mooring, surface buoys, and gliders to monitor marine population activities in these areas (Passive Acoustic Cetacean Map 2022). This also makes the island a great point for whale watching businesses to originate with tours heading out from the island and in the bay and gulf.

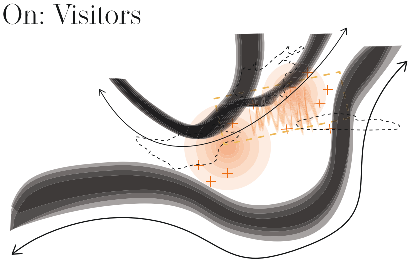
Proposal

The whale watching industry of Brier Island is well developed and provides an opportunity to see the animals in their natural environment - hearing them, however, has been more challenging. When analyzing the soundscape of this popular whale watching site, there are important feature sounds that exist below the ocean's surface that can elevate this experience.

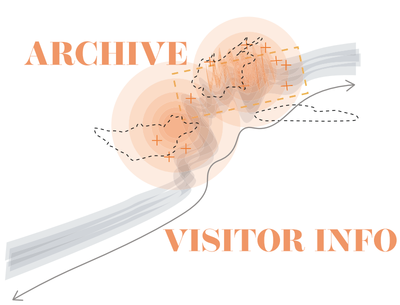
An archive in Brier Island with local recordings of marine life collected by passive acoustic monitoring throughout the Gulf of Maine are stored here and visitors can broadcast feature sounds that make this site unique and important. The experience of uncovering marine communication happening below is inspired by the form and material characteristics associated with the basins and their ability to dampen disturbing noise. The vessel's role on this site is to dull the chaotic intersections between ships ON and the whale's experience BELOW.

BASIN(S)

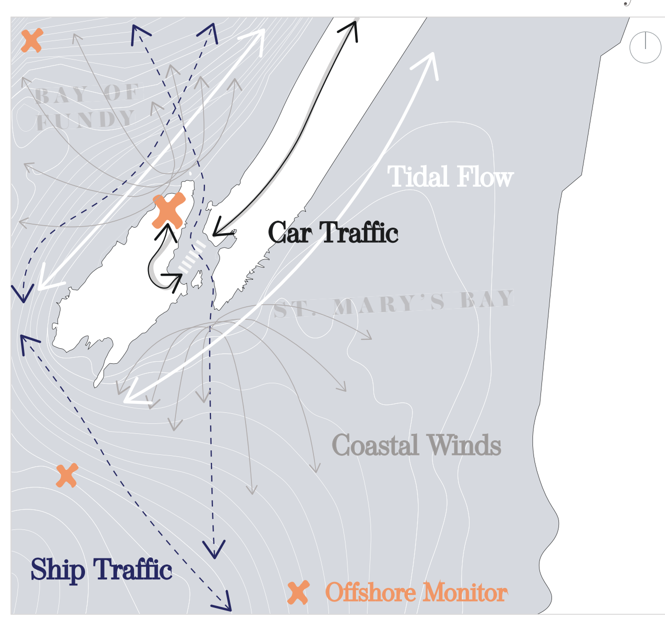
On: Visitors



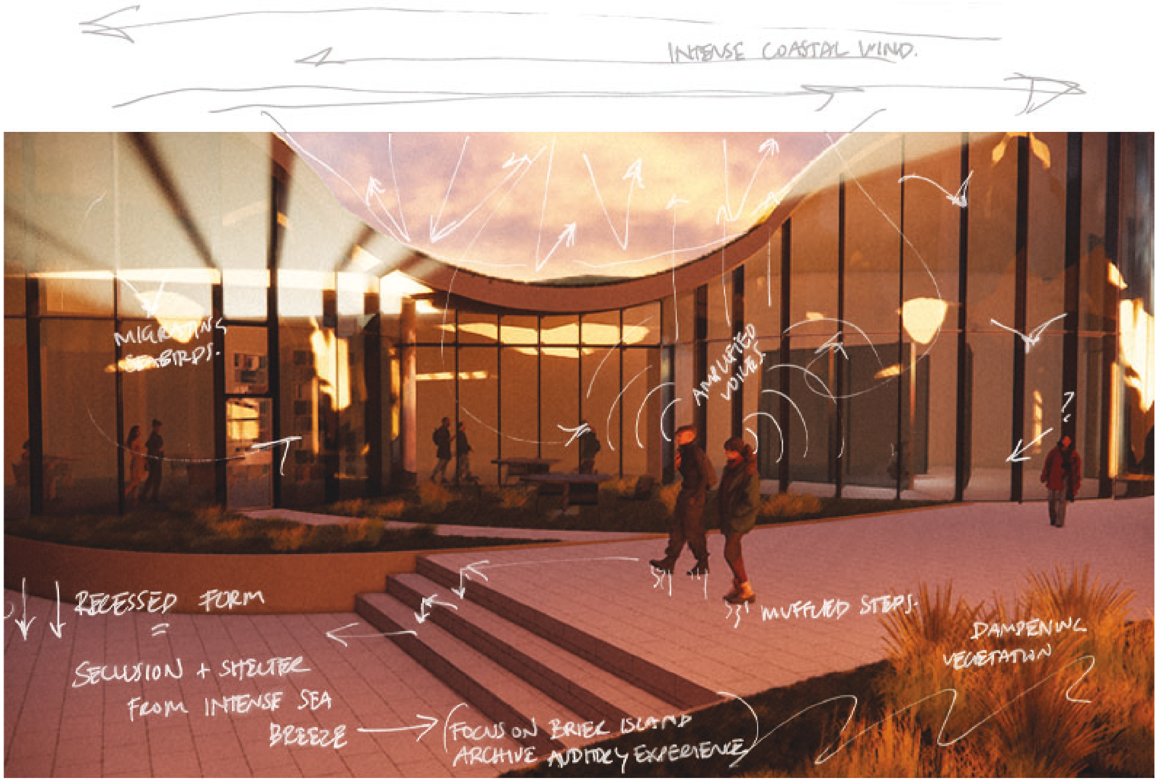
Below: Researchers + Visitors



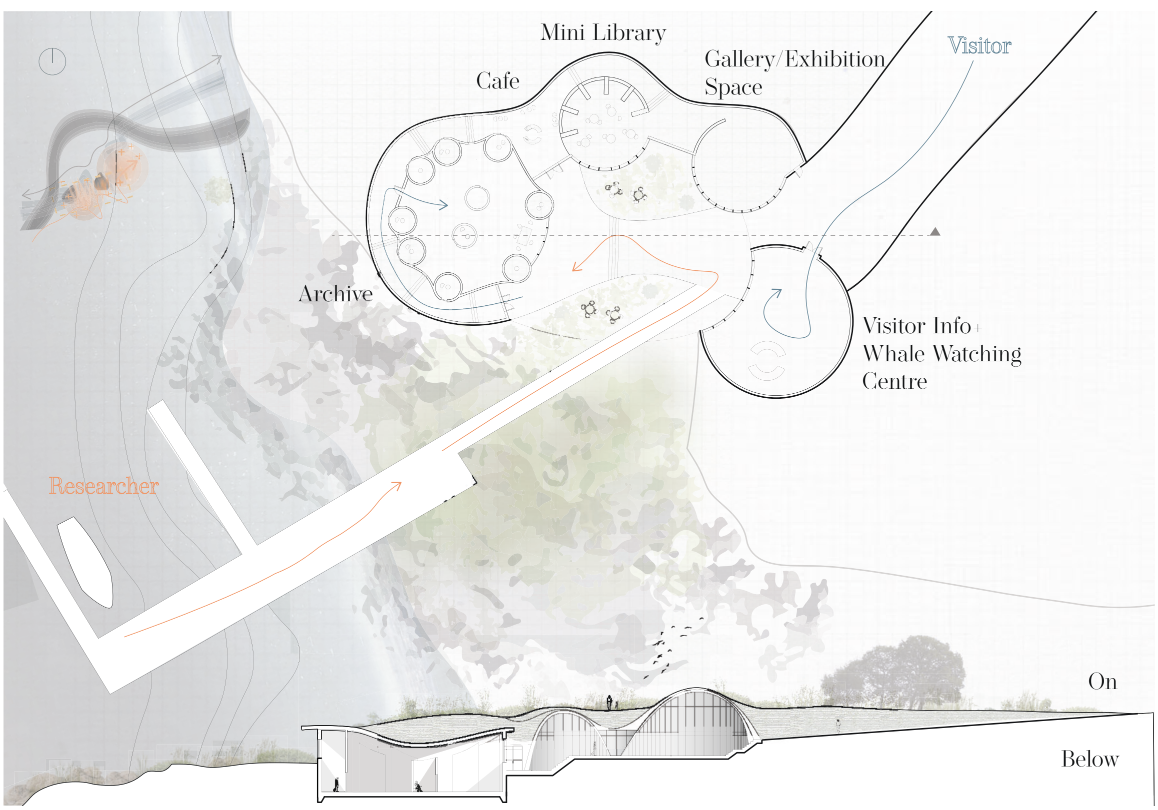
Island Sound Analysis



The basin(s) are translated to Brier Island by giving visitors on the site an opportunity to hear hydrophone recordings of whales below. Due to the recessed form of the proposal, powerful wind blows over the site so the experiencing of listening to revealed recordings is uninhibited. Brier Island key plan shows site relationship to the Bay of Fundy (left) and Long Island, which provides ferry access for those driving from the mainland.



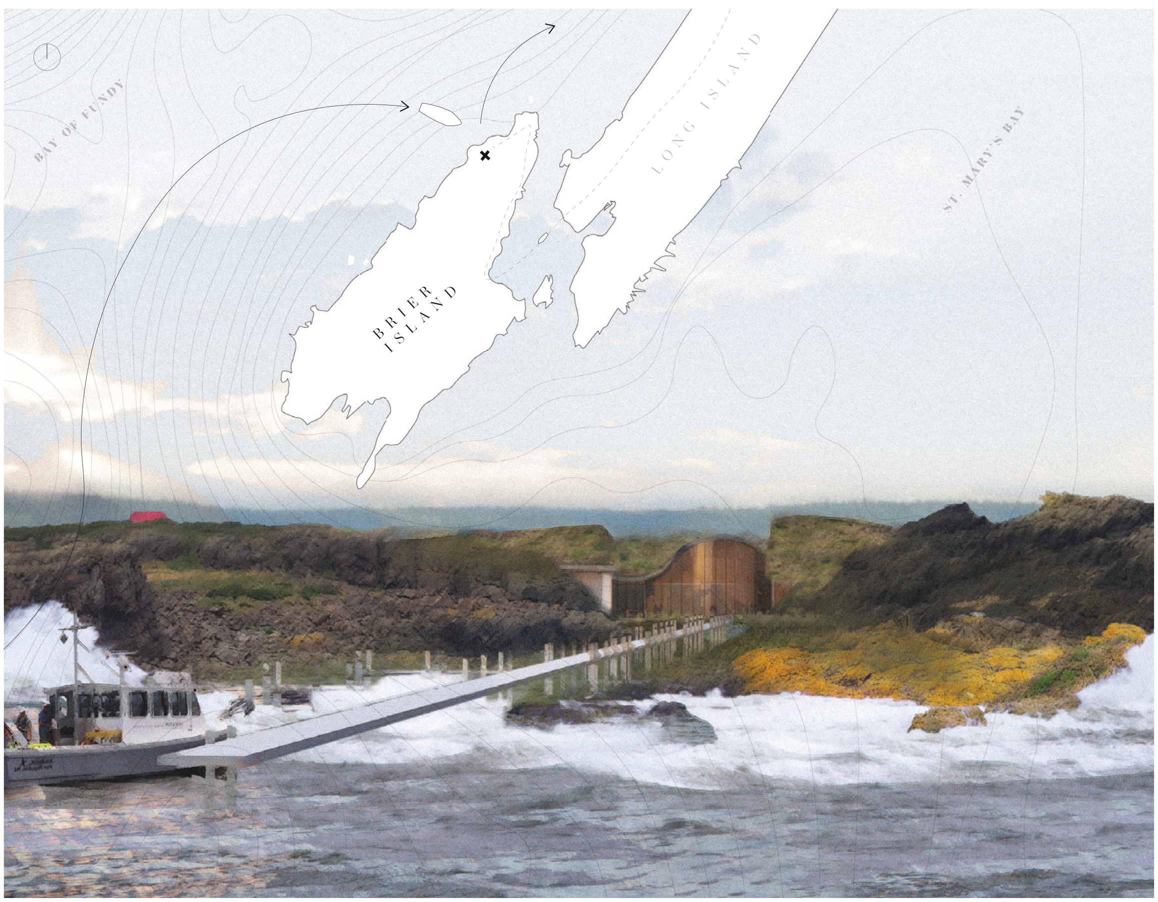
Sketch of the external soundscape experienced within the courtyard of the proposal on Brier Island. The form provides protection for visitors and dampening vegetation.



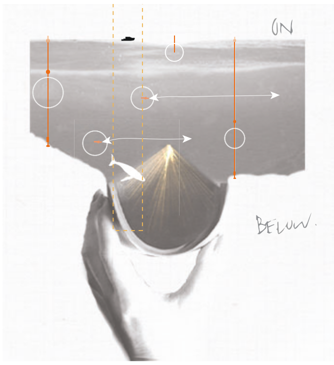
Plan and section outlining the experience for visitors On and Below the Brier Island archive.

The Basin(s)

The form of the archive is recessed into the landscape, sheltering occupants from the intense coastal winds on this exposed site. The interior courtyard uses vegetation as a dampening element by coating the ground surface and provides shelter from the wind by sinking visitors below the ground line. The shape also allows visitors to see both research and tour boats off the coast from a protected area within the courtyard. The building is a moment of calm after the journey that's taken to arrive on the site. While not site specific, the archive is fully site determined – sound is not generated, only translated between the ocean's recordings and visitors on land. Below, to accompany the archive on



Visitors to Brier Island can arrive by boat, an extension or addition to their whale watching tour. The dock also provides research access for those doing fieldwork in the area.



Introducing the concept of basin(s) to the Brier Island site by bringing the visitors (ships) below to hear the research flow (whales).

the site, there is also a cafe for visitors, a small library, and gallery/exhibition space.

The 'basins' are spaces in the archive where feature sound installations may be played, but the sound of human traffic is completely isolated. In these spaces, the visitor experiences specific sound displays to focus our attention on the auditory experience of tuning into the hydrophone offshore and minimizing outside distractions. Visitors can broadcast hydrophones separately in private vessels, or experience fragments of all the broadcasts together in the center of the room. To focus attention on the recordings and minimize distractions, concrete reverberates the audio and drowns sound created by foot traffic. These are moments intended

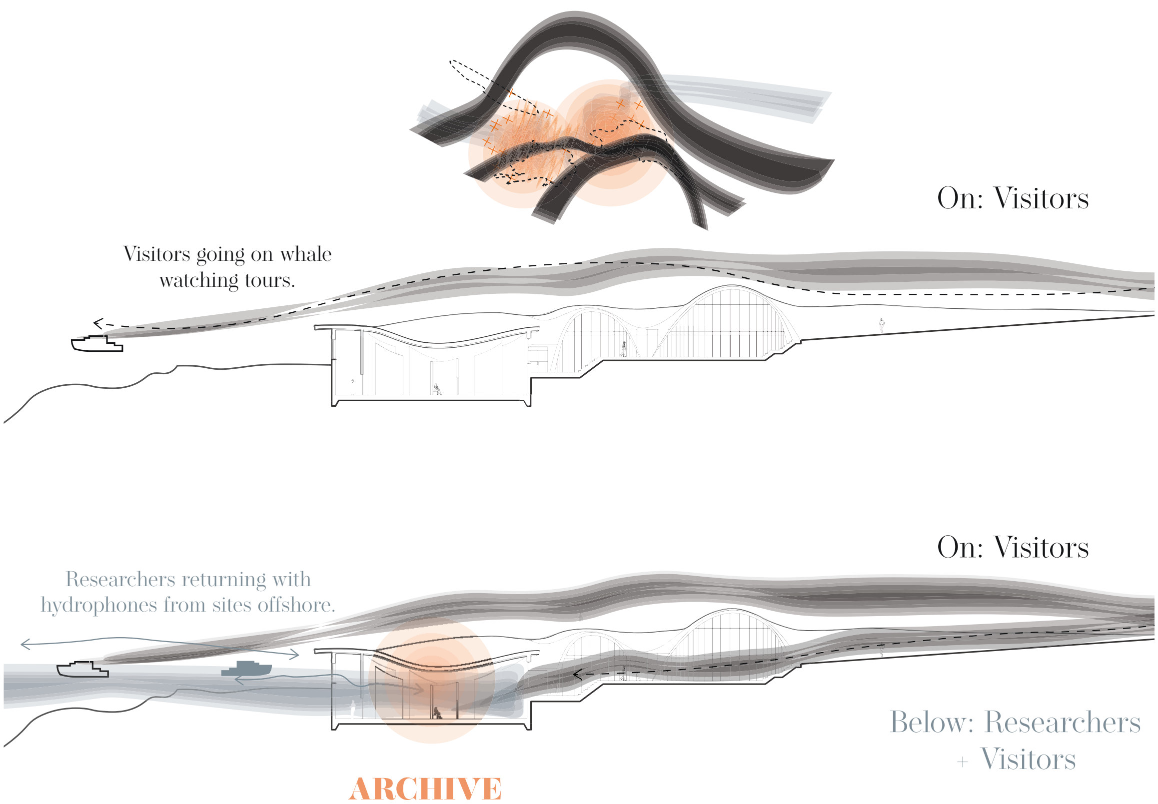


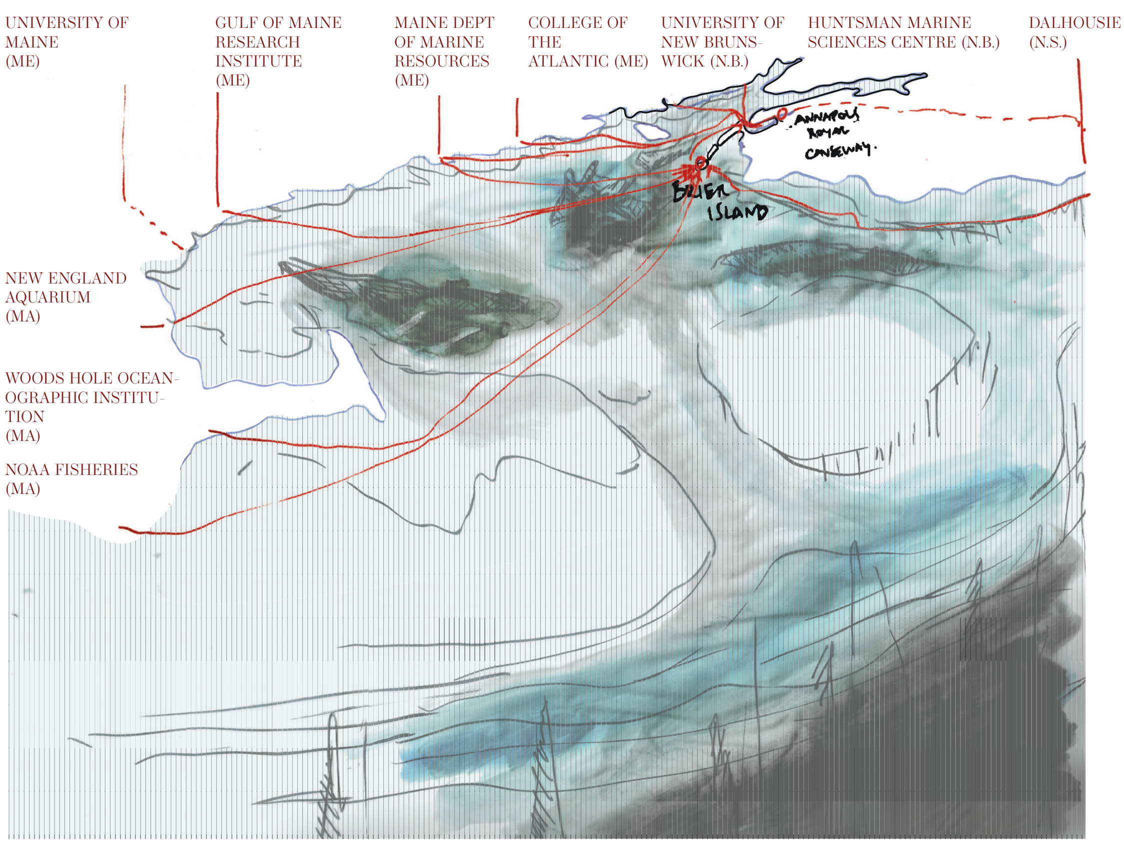
Diagram showing circulation through the archive. Due to the recessed form of the building, visitor traffic (ships) occupy the exterior around the building and the upper floor, while researchers returning from fieldwork enter below (whales) from the water. This building creates opportunities for visitors to access the spaces below and enrich the whale watching experience.

for the visitor to understand the impact of introduced noise on the listening experience.

Actors on the Site

The Researcher on Brier Island

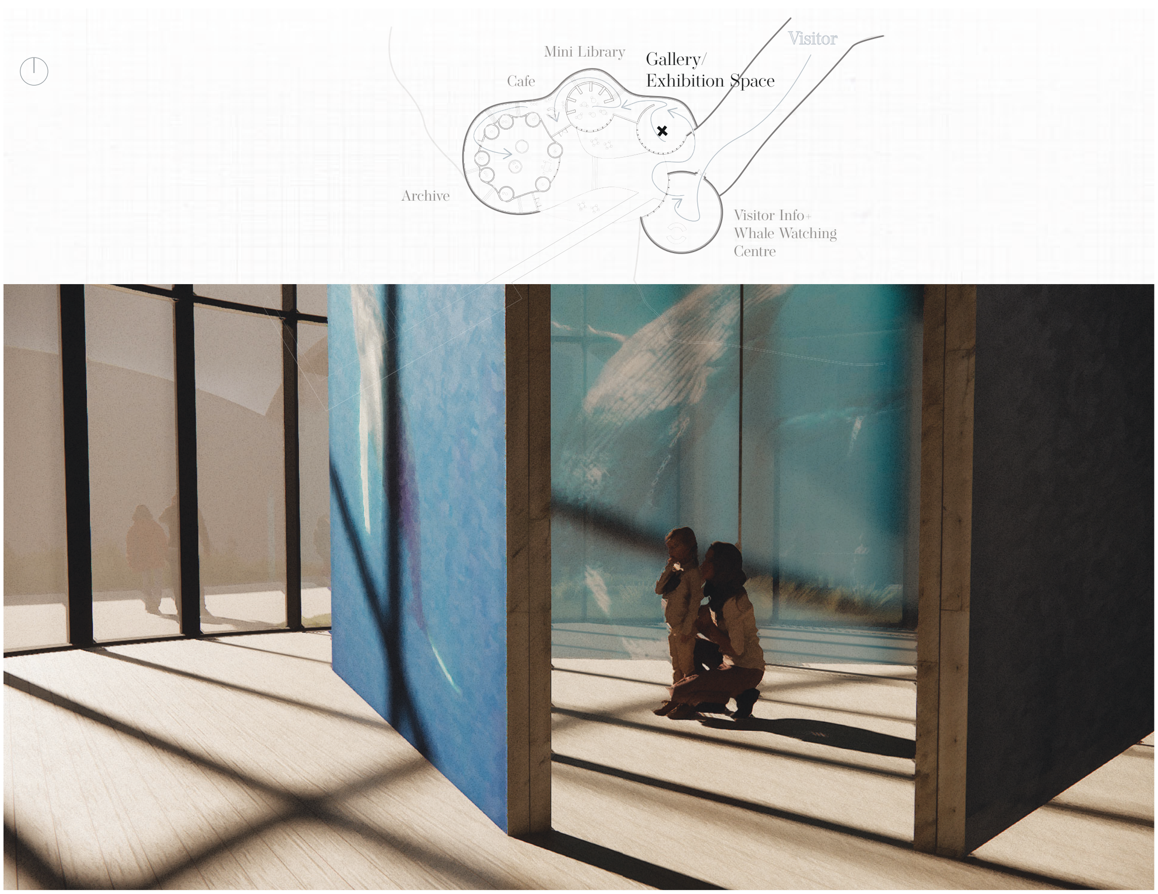
The researcher arrives by boat to Brier Island from the Huntsman Marine Science Centre in St Andrews, New Brunswick. They are attending a seminar at the Annapolis Royal Materials Lab, but first they are stopping at the Brier Island archive for a meeting about their work placing hydrophones off the coast of Grand Manan Island to measure effectiveness of a conservation area for North Atlantic Right whales, the most endangered whale species in the world. The other team's work also includes placing hydrophones



Sketch outlining the new streams of research flowing to both sites from various institutions with access to Brier Island from the Gulf of Maine's coastline.

on a site at the entrance to the Bay of Fundy, between the coast of New Brunswick and Nova Scotia.

The two research teams are collaborating by bringing their knowledge on sediment distribution, sound reverberation, the whale's migration pathway and population densities together to publish a paper on the importance of stricter speed limits for ships coming in and out of the Gulf during the spring and summer season. The venue offers a place for them to meet and discuss research while presenting opportunities to take excursions together for additional field world. Later in the week, they will be presenting their research in a public lecture hosted at the Annapolis Royal Acoustics Centre.

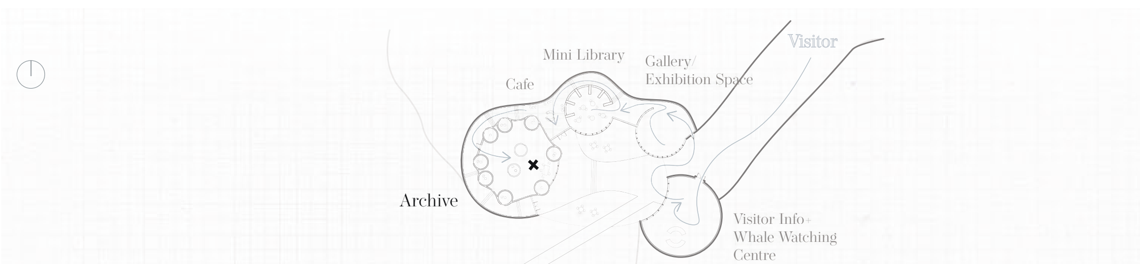


Visitor viewing an exhibition on local whale populations in the gallery of the archive on Brier Island.

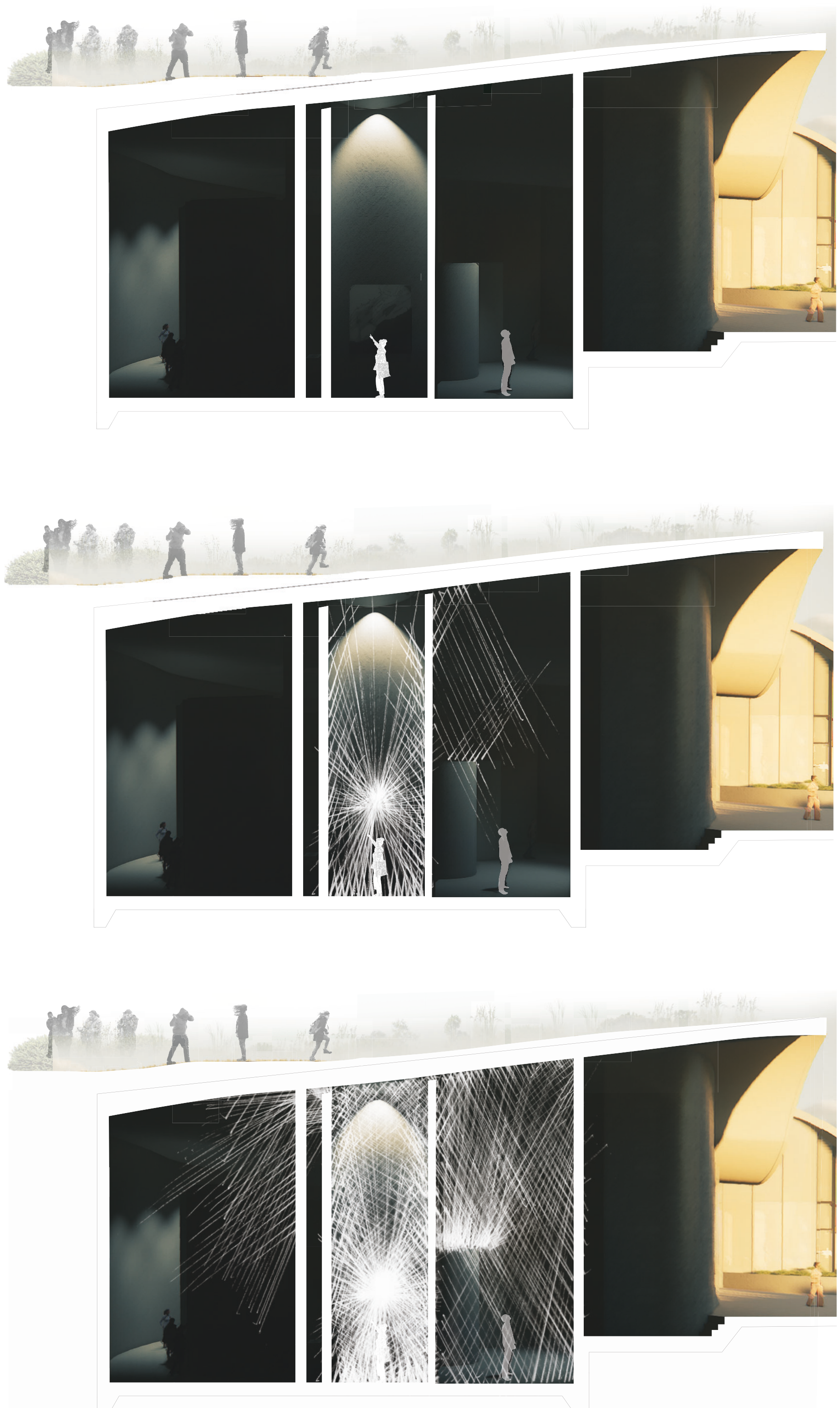
The Visitor on Brier Island

The visitor gets to Brier Island early on the day of their excursion with their family. After checking in with their tour group at the center, they visit the gallery which is hosting an exhibition on some local whales they will hopefully interact with later today.

Interested to learn more, their son heads to the library to look up the different whale species found in the area. The rest of the family gets a hot drink and then heads to the archive to broadcast whale calls from some of the hydrophones sited nearby.



Visitors having an auditory experience within the vessels of the archive. The visitors are transported to a space where the sounds of the whales below change their perception of the tour aboard the boat. The gallery is pictured in the background left of the image.



Within the basin(s), a visitor broadcasts a hydrophone while the rest of the tour group experiences fragments of all the broadcasts together in the center of the room. To focus attention on the recordings and minimize distractions, concrete reverberates the audio and drowns sound created by foot traffic.

In the archive, the visitor enters a vessel and begins to press buttons on an interactive map that allow them to broadcast recordings from specific hydrophones located throughout the Gulf of Maine. The youngest daughter migrates to the center of the room, overcome with the experience of hearing all the sounds of different marine animals softly communicating all at once. The sounds reverberate within the double height space and are reflected off the concrete forms within the room. She wonders if this is what it sounds like to be in the ocean, swimming alongside the whales.

This view shows the archive, a tour and research boat above the surface of the water. Interactions between the whales, gliders, and the visitors can be viewed from this perspective. The visitor has had a norm shifting experience at the archive by interacting with the hydrophone broadcasts, and now views the experience of whale watching and interaction with other vessels on the water with a new perspective.

The archive is designed to create opportunities for reflection intended for the visitor to understand the impact of introduced noise on the listening experience. Later on the tour boat, the family remembers the call of the whales as they see a tail breach the surface. They are reminded of the sounds and the research happening beneath them, and the experience stays with them.

Chapter 5: Conclusion

Acoustic disturbances to the underwater environment can cause marine animals to alter their behavior, restrict their foraging abilities, lead to hearing loss, and can damage tissue (Andre 2021). The acoustic impacts are far-reaching and ultimately have consequences for marine industries and tourism as whale populations are affected. Until recently the impacts of acoustic disturbances were not widely researched, but current data started to alert researchers to impacts from excessive underwater noise from the worldwide shipping network. This type of data collected by researchers is crucial to instigating important

A future image of our relationship with whales where we understand and appreciate their ability to function acoustically underwater. Through contextual learning proposed by this thesis we can begin to understand things we cannot see, and for the benefit of the whale, this awareness can hasten legislative action for shipping routes to avoid migratory pathways and the enforcement of stricter vessel speed limits.

policy changes to protect marine species noise introduced by human activities. Industry leaders must facilitate a shift of societal norms by spreading awareness of the impacts of shippings. This education begins at a community level, but we must employ multi-scale engagement by using the research to correct misperceptions about noise underwater and innovate proposals for quieter shipping methods. In the context of this project sited in Nova Scotia, we should use the province's close relationship to the ocean and draw from the local whale watching community's own value system to educate tourists and advocate for changes to shipping routes and speed limits in the Gulf of Maine.

The two sites in Nova Scotia each have unique opportunities to educate tourists and draw on local communicates to further the spread of research. Visitors and residents alike must be aware of the path and activity of the whales in the Gulf of Maine so they can advocate for their provincial legislation to demand the reduction of noise levels at the source. Specifically, to protect the North Atlantic Right whale, shipping and fishing within the Gulf of Maine must be aware of traffic streams to account for excessive acoustic disturbances during active periods of marine migration. The impact of acoustic disturbances is critical, however, once the noise is halted then marine communication can flow freely once again. As climate change continues to impact the temperatures of the ocean, the migration pathways and critical habitat zones of different whale species will shift as well. This will make it even more crucial for researchers to monitor populations, as these changes may force whales to shift habitats faster than shipping legislation can be effected, which would be devastating for whales that cannot defend their place in the ocean.

References

Andre, Michel. 2021. Listen to the Deep. http://listentothedeep.com/acoustics/index.php.

Bolghasi, Alireza, Parviz Ghadimi, and Mohammad A. Feizi Chekab. 2016. “Sound Scattering From Rough Bubbly Ocean Surface Based on Modified Sea Surface Acoustic Simulator and Consideration of Various Incident Angles and Sub-Surface Bubbles Radii.” *Journal of Marine Science and Application* 15, no. 3: 275–287.

Brekhovskikh, L. M., and U. P. Lysano. 2003. *Fundamentals of Ocean Acoustics*. 3rd ed. New York: Springer.

Brillant, Sean W., and Edward A. Trippel. 2010. “Elevations of Lobster Fishery Groundlines in Relation to Their Potential to Entangle Endangered North Atlantic Right Whales in the Bay of Fundy, Canada.” *ICES Journal of Marine Science* 67, no. 2: 355-64.

Dybas, Cheryl. 2018. “Over the Hump.” *Oceanography* 31, no. 3: 6-11.

Eagan, M. David. 1972. *Concepts in Architectural Acoustics*. New York: McGraw-Hill.

EcoHealth Alliance. 2011. Photograph of North Atlantic Right Whale #3853 with Propeller Wound. South Carolina. https://oceana.ca/en/blog/right-whales-should-have-right-way-ships-ignoring-voluntary-slow-down-zone/.

Erbe, Christine, Arti Verma, Robert McCauley, Alexander Gavrilov, and Iain Parnum. 2015. “The Marine Soundscape of the Perth Canyon.” *Progress in Oceanography* 137: 38-51.

Ewing, M., B. C. Heezen, D. B. Ericson, J. Northrop, and J. Dorman. 1953. “Exploration of the Northwest Atlantic Mid-Ocean Canyon.” *Geological Society of American Bulletin* 64: 865-868.

FORCE (Fundy Ocean Research Centre for Energy). n.d. The Fundy Force. Last modified May 16, 2022. https://fundyforce.ca/.

Ghaffari, AmirAli. 2017. Photograph of a woman inside the PAUSE Pavilion. Afif-abad Garden, Shiraz, Iran. https://worldarchitecture.org/architecture-projects/hfzfe/the-pause-pavilion-project-pages.html.

Gibson, A., F. Jamie, and Ransom A. Myers. 2002. “Effectiveness of a High Frequency Sound Fish Diversion System at the Annapolis Tidal Hydroelectric Generating Station, Nova Scotia.” *North American Journal of Fisheries Management* 22, no. 3: 770-84.

Gielkens, Jan. 2008. Photograph of the Annapolis Royal Tidal Generating Station. Flickr. https://www.flickr.com/photos/25955360@N00/2818703698/in/photolist-5i5ApC-5i1fyR-5i1fq2-6vtuRx-9nCph7-4djLeh-4djQQS-4dfSdg-4djQZo-wyxywS-4dfRt4-8ZuYRW-4dfRUK-4dfRGv-akymPv-6RNG1h-k4ApYM-9NxRVo-bC8AFw-pw1eDa-xZtYS5-pkDWXk-5UyAoD-5UyzBx-dyNdvZ-dsTV7d-wwVfCC-dyNFb8-dyTGQN-8fDN68-dmq5w4-dmq9CS-pkDtzW-ePD7iH-f7Tf4L-VBxWRc-VBxVcv-VBxVvB-dsTHQe-UjUs9E-9QJ6Zx-UjUrQd-a8LnCC-2hNtDt-VBxVG8-VBxWfT-a8LkA1-VBxV-kM-VBxWBp-VBxW4a.

Godin, Oleg A., Nikolay A. Zabotin, and Valery V. Goncharov. 2010. “Ocean Tomography with Acoustic Daylight.” *Geophysical Research Letters* 37, no. 13.

Hill, Alex N., Caitlin Karniski, Jooke Robbins, Tom Pitchford, Sean Todd, and Regina Asmutis Silvia. 2017. “Vessel Collision Injuries on Live Humpback Whales, Megaptera Novaeangliae, in the Southern Gulf of Maine.” *Marine Mammal Science* 33, no. 2: 558-73.

Jing, Liu, Mingyang Liu, Chenchen Sun, Zhiwei Lin, Zhiping Feng, Shaobo Si, and Jin Yang. 2022. “Triboelectric Hydrophone for Underwater Detection of Low-Frequency Sounds.” *Nano Energy* 99.

Karnik, Pranjali. 2021. “Sensory Architecture: Sound - Creating Experience and Memory.” https://www.re-thinkingthefuture.com/designing-for-typologies/a3969-sensory-architecture-sound-creating-experience-and-memory/.

Khines, Megan. 2005. Photograph of bedrock exposed beneath sand on the beach. Wisconsin, Port Washington, U.S.A. https://www.flickr.com/photos/megankhines/40263765.

Leclerc, Pierre. 2019. Photograph of Tvisongur sound sculpture in Iceland. Seyðisfjörður, Iceland. https://fineartamerica.com/featured/tvisongur-sound-sculpture-iceland-pierre-leclerc-photography.html.

Manz, K., and M. Rössler. 2008. “The Mid-Atlantic Ridge.” United Nations Educational Scientific Cultural Organization. https://whc.unesco.org/en/activities/504/.

MarineTraffic. 2020. Marine traffic density maps surrounding Nova Scotia. https://www.marinetraffic.com/en/ais/home/centerx:-67.5/centery:43.3/zoom:7.

Masud, Numair, Laura Hayes, Davide Crivelli, Stephen Grigg, and Jo Cable. 2020. “Noise Pollution: Acute Noise Exposure Increases Susceptibility to Disease and Chronic Exposure Reduces Host Survival.” *Royal Society Open Science* 7, no. 9: 200172–200172.

Mentz, S. 2020. *Ocean*. New York, N.Y. Bloomsbury Publishing.

Merriam-Webster. n.d. “Vessel.” Accessed February 12, 2022. https://www.merriam-webster.com/dictionary/vessel.

Munk, Walter, Peter Worcester, and Carl Wunsch. 1995. *Ocean Acoustic Tomography*. Cambridge, U.K.: Cambridge University Press.

NOAA (National Oceanic and Atmospheric Administration). n.d. Passive Acoustic Cetacean Map. Accessed January 10, 2022. https://apps-nefsc.fisheries.noaa.gov/pacm.

NOAA (National Oceanic and Atmospheric Administration). 2020. Whale Alert app designed to show where whales are migrating in real time by sharing whale sightings. New England/Mid-Atlantic. https://www.fisheries.noaa.gov/resource/tool-app/whale-alert.

NSCC AORG (Nova Scotia Community College Applied Oceans Research Group). 2017-2019. Image of benthic data from the Bay of Fundy sea floor. Nova Scotia. https://cogsnscc.maps.arcgis.com/apps/Cascade/index.html?appid=df126acbb9e3472b9926a3344fec775a.

Nyborg, W. L. and I. Rudnick. 1948. "Acoustic Absorption in Sand and Soil." *The Journal of the Acoustical Society of America* 20, no. 597; https://doi.org/10.1121/1.1917021.

Parsons, E. C. M., Sarah J. Dolman, Michael Jasny, Naomi A. Rose, Mark P. Simmonds, and Andrew J. Wright. 2009. "A Critique of the UK's JNCC Seismic Survey Guidelines for Minimising Acoustic Disturbance to Marine Mammals: Best Practise?" *Marine Pollution Bulletin* 58, no. 5: 643-51.

Pihlajamäki, Tapani. 2009. Drawing of cross section of human ear. Helsinki, Finland. https://www.researchgate.net/figure/A-cross-section-of-the-human-ear-Different-parts-of-the-ear-can-be-seen-in-it-Adapted_fig2_267239829.

Rimer, Sara, and Jessica Colarossi. 2019. "A Dead Humpback, a Team of Scientists, a Race for Answers." The Brink. https://www.bu.edu/articles/2019/noise-pollution-in-the-ocean-affect-whale-ears/.

Schafer, R. Murray. 1993. *The Soundscape: Our Sonic Environment and the Tuning of the World*. Rochester, VT: Destiny Publishers.

Scott, Paul. 2009. Photograph of a Denge sound mirror taken in the UK. Lydd on Sea, England, UK. https://www.flickr.com/photos/26943652@N05/3919165466/.

Siskopoulos, Dimitris. 2014. Underwater image of the sandy sea floor. Genoa, Italy. https://www.flickr.com/photos/dimsis/14312758808.

Sonnichsen, Gary. 2010. *Discovering the Bay of Fundy's Seafloor.* Ottawa: Natural Resources Canada.

Staudinger, Michelle D., Katherine E. Mills, Karen Stamieszkin, Nicholas R. Record, Christine A. Hudak, Andrew Allyn, Antony Diamond, Kevin D. Friedland, Walt Golet, Meghan Elisabeth Henderson, Christina M. Hernandez, Thomas G. Huntington, Rubao Ji, Catherine L. Johnson, David Samuel Johnson, Adrian Jordaan, John Kocik, Yun Li, Matthew Liebman, Owen C. Nichols, Daniel Pendleton, R. Anne Richards, Thomas Robben, Andrew C. Thomas, Harvey J. Walsh, and Keenan Yakola. 2019. "It's about Time: A Synthesis of Changing Phenology in the Gulf of Maine Ecosystem." *Fisheries Oceanography* 28, no. 5: 532-66.

Thean, Tara, Nikolay Kardjilov, and Robert J. Asher. 2017. "Inner Ear Development in Cetaceans." *Journal of Anatomy* 230, no. 2: 249–261.

"The Threat from Vessel Strikes." n.d. Whale and Dolphin Conservation. Accessed June 22, 2022. https://us.whales.org/our-4-goals/create-healthy-seas/the-threat-from-vessel-strikes/.

Trowse, Greg, Moira Brown, Brad Whinney, and Chloe Malinka. 2014. "Observations of Marine Mammals in Petit Passage and Grand Passage, Nova Scotia and Adjacent Waters in the Eastern Bay of Fundy to Assess Species Composition, Distribution, Number and Seasonality." *OERA Interim Report, Marine Life Observations.* https://oera.ca/research/observations-marine-mammals-petit-passage-and-grand-passage-nova-scotia-and-adjacent.

Whale Center of New England. 2006. Whale and ship in the same image. Stellwagen Bank National Marine Sanctuary. https://www.flickr.com/photos/76145908@N08/31660389204.

Zhang, JianSheng, ShuYu Lin, Peng Liu, RunCai Miao, and WanMin Yang. 2008. "Sound Speed in Bubble Film of Ship Wakes." *Science in China Series G* 51, no. 1: 64–71.