ASSESSING THE SUITABILITY OF LIVING SHORELINE TECHNIQUES FOR COASTAL EROSION IN PRINCE EDWARD ISLAND, CANADA.

by Erin Nelson

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Abstract

Assessing the suitability of living shoreline techniques for coastal erosion in Prince Edward Island, Canada.

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Coastal erosion rates on Prince Edward Island (PEI) are increasing due to climate change. Wave action continuously works on the unconsolidated till and sandstone banks, eroding and receding coastlines, while nourishing beaches and estuaries. This causes intensified risk to properties, infrastructure, and humans. Hard engineered structures are common, short-term, solutions to coastal erosion. These structures disrupt the natural land-water interaction as wave energy is deflected at the structure and dispersed to adjacent areas, increasing erosion. Living shorelines are used as alternatives to hard structures by incorporating natural materials, such as vegetation, to provide coastal protection. Living shorelines are long-term methods for coastal erosion. These adaptations act as wave energy barriers and sediment traps, slowing erosion rates. Certain characteristics and baseline conditions such as vegetation, geology, geomorphology, sediment, and differing exposure types are required for living shoreline techniques to reap their intended benefits. Tools to assess site suitability for living shorelines, available online or through documents, are critiqued. The critique is based on how well the tool characterizes PEI, signifying how useful it would be if used as an assessment resource for the suitability of living shorelines. A multicriteria evaluation was conducted in ArcGIS Pro to identify segments of the shoreline that were suitable, moderately suitable, and unsuitable for implementing living shorelines. This model was tested using 31 field sites surveyed between July-August 2021. With this information, governments and coastal property owners will be able to determine whether or not their property would benefit from installation of living shorelines.

Acknowledgements

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Contents

CHAPTER 1: Literature Review

1.1 Setting the Stage for PEI

As the climate changes, seas are rising across the globe. Rising seas cause various hazards and risks to coastal areas. Flooding and erosion are two of the main hazards caused by global sea-level rise (SLR). Flooding causes permanent and/or periodic inundation of land, while erosion causes permanent changes to coastal areas (Oppenheimer, *et al.*, 2019). Both hazards are predicted to be more frequent as time moves forward (Oppenheimer, *et al.*, 2019).

Prince Edward Island (PEI), a province located on the east coast of Canada, is experiencing high rates of coastal erosion. Nationally, when reviewing the economic impacts in regard to the percentage of total land area, PEI is the most at-risk province for coastal erosion (Lemmen *et al.*, 2016). PEI is primarily composed of soft rock – sandstone and mudstone (Holman & Robb, 2021), and glacial till soils nearing the surface (Whiteside, 1950). These materials erode at a fast rate, more so when there is weathering action acting on the material, such as freeze thaw cycles and wave action (Figure 1.1).

Figure 1.1. Sites in Prince Edward Island experiences high rates of erosion. The left photo was taken at Thunder Cove Beach in Darnley, PEI. The right photo was at the parking lot of the East Point Lighthouse in East Point, PEI.

A large percentage of communities within PEI are coastal. Coastal communities are the most impacted by erosion and/or coastal flooding, both of which endanger the safety of the community occupants and put infrastructure at risk. In 2014, the visualized risk of coastal flooding was brought to the public's attention, by Dr. Adam Fenech of the University of Prince Edward Island's Climate Lab, using the coastal impact visualization environment (CLIVE). CLIVE showed that within the next 90 years (at the time of release) over 1000 residential homes, multiple garages, barns, and gazebos, 17 lighthouses, and 146 commercial buildings would be lost to the stark effects of climate change (Fenech, 2014). Not to mention the $50 million dollars of road infrastructure that would be washed away and awaiting repairs (Fenech, 2014).

Hard armouring of coastlines can pose more damages to the coastline as large storm events can damage the hard armour which is not resilient. Hard armouring of the coastline ruins habitat and results in the eventual loss of dunes and beaches. This type of armouring does not make any of the previous at-risk infrastructure mentioned any more protected to the impacts of erosion. In PEI, roughly 5% of the coastline has been armoured primarily by hard structures (Davies, 2011). Shifting protection methods from hard armour to more natural approaches, such as living shorelines, is one impactful way to mitigate against these coastal hazards that are amplified by climate change. At the same time, natural approaches provide environmental, social, and economic benefits. Determining/identifying potential suitable sections of the PEI coastline for the application of nature-base solutions is crucial for implementation and is to be assessed within this thesis. Understanding why some areas of a shoreline may be suitable while others are not, is important as well. Tools are available to help assess the characteristics of sites. Determining the best tool for PEI's unique characteristics will be the first step when planning for nature-based solution projects in the future as they become a more popular protection method.

1.2. Nature-based Solutions

Nature-based solutions (NbS) are actions implemented into an environment that take a natural approach to protect, sustain, manage, and restore both natural or anthropogenically modified environments and ecosystems in the face of a changing climate (International Union for Conservation of Nature, 2021). NbS have the ability to harness natural processes and mimic natural features/systems that are beneficial to people and the built environment. Anthropogenically modified environments and ecosystems are shaped by human activity and their side effects (Western, 2001). Historically, these side effects were the hallmark of human evolutionary success, though today, these side effects are negative, and harming the continuous evolution of Earth's biodiversity (Western, 2001). The term "nature-based solutions" is an umbrella concept for other terms such as ecological engineering, green or blue infrastructure, the ecosystem approach, and ecosystem-based adaptation or mitigation. (Osaka, *et al.*, 2021). The guiding principle of NbS is that ecological features are integrated within the design of the protective structures – whether it be an addition to a previously existing defense structure or a newly planned one (Morris, *et al.*, 2017). NbS can be implemented in a diversity of climatic regions. NbS can range from conservation and management of forests to restoration of wetlands to biochar burial to the conservation and restoration of peatlands (Osaka, *et al.*, 2021). The European Commission (2015) has stated that there are as many as 310 potential implementation measures that fall under the "nature-based solutions" categorical criterion.

Problems occur when stating what "natural and nature-based features" (NNBF) are and what are not. Although these environmental solutions are based specifically from the environments they are located in, there can still be an argument to what is considered to be natural or "nature-based" (Osaka, *et al.*, 2021). With the emerging literature being produced, there are many different ways NbS have been categorized. One method goes from hard engineering structures with little to no ecological integrity, to hybrid (a combination of both hard and soft), to soft – solely focusing on natural materials. Another method states that a better way to classify the gradient of NbS is by characterizing the methods by either "more engineered" or "less engineered" (Osaka, *et al.*, 2021). Martin *et al.* (2015) and Osaka *et al.* (2021) agree upon a three-tiered approach. Type 1 includes little to no human interaction with the natural environment; Type 2 involve some human interaction which involves "enhancing or diversifying existing ecosystem or agricultural lands" (Osaka, *et al.*, 2021); Type 3 involves creating a new ecosystem that did not exist prior to management. Type 3 NbS can also include man-made materials, causing the solution to be hybrid which other sources may consider not within the NbS realm (Gomez Martin, *et al.,* 2021). An example that may be argued is that a green roof created with natural features, should not be included within NbS as it does not include as many species as a similar counterpart would in nature making the area less biologically diverse (Osaka, *et al.*, 2021).

According to the International Union for Conservation of Nature (IUCN), NbS are implemented in order to provide co-benefits to both human well-being and biodiversity of environments (IUCN, 2021). NbS provide ecosystem services such as carbon sequestration, additional habitat fisheries, water quality, etc., which aid in the restoration and rehabilitation (Bridges, *et al.,* 2021). The same natural solutions also address problems such as food security, water security, disaster risk, and social and economic development (IUCN, 2021) that target human well-being. In addition to solving environmental and social issues, NbS are known to be cost-saving and cost effective as compared to more traditional approaches (European Commission, 2021). Cost-savings refer to the preventative care that decreases costs (Goodell, *et al.,* 2009). For example, if a marsh is being depleted, proper restoration will provide cost-savings as co-benefits are noted such as increased habitat. Cost-effectiveness is when costs are put towards something because the benefits are sufficiently large over the lifetime of the project, even if the implementation is more expensive than alternatives (Goodell, *et al.,* 2009). To put the cost-effectiveness into perspective, the City of Philadelphia found that the net-present value for their implementation of green-infrastructure to control storm water ranged from $1.94-$4.45 billion USD over a 40-year period (European Commission, 2021). This is compared to grey, or unnatural, infrastructure to combat this same issue, though it only provides $0.06-$0.14 billion USD over the same time period (European Commission, 2021). NbS solutions are considered to be cost-effective due to their increase resilience to changing conditions which results in lower maintenance costs and the economic value of the co-benefits they provide.

Challenges can arise with the implementation of NbS, as well. One of the problems that NbS experience are time lags (Figure 1.2) (Giordano, *et al.*, 2020). After an NbS is implemented into a system, for some, it takes time for the full range of benefits to be realized. Figure 1.2 shows the soft engineered structures – reefs, sediment barriers, and wetlands – require the most time of those mentioned to provide full intended benefits. Reefs will break waves and reduce energy at the shoreline providing immediate benefits for shoreline protection. Although true, it will take time for the reef to be colonized by oysters, macroalgae, etc. which provide the habitat, fishery, water quality and climate change resilience benefits. Even with a newly planted marsh, it will still have some immediate protective value though will increase over time. On the other hand, a benefit only recognized over a long-term time period would be the restoration of biodiversity within a location. (Giordano, *et al.*, 2020).

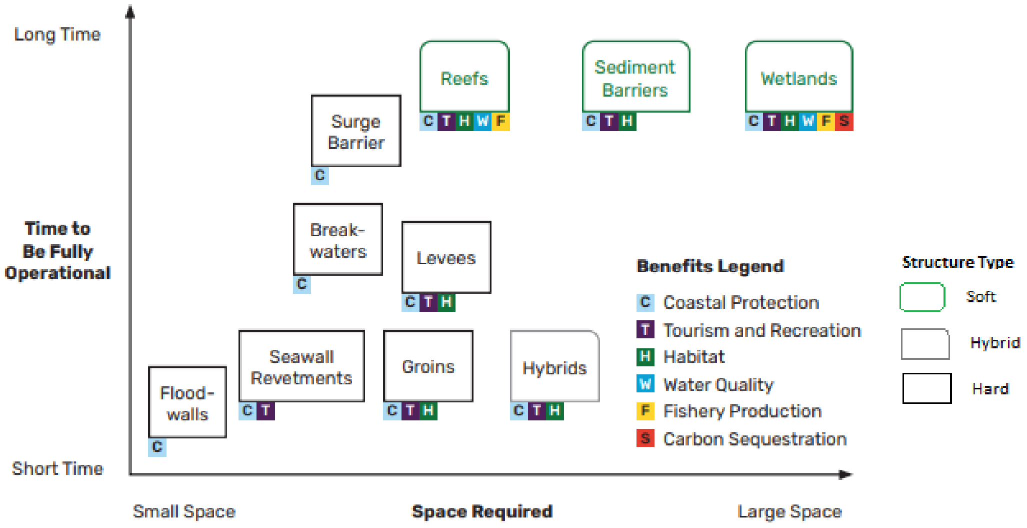


Figure 1.2. A diagram showing both hard, hybrid, and soft engineered structures if regards for their time to be fully operational and amount of space that is required. Benefits with each are also listed for each structure (modified from Bridges, et al., 2021).

When coastlines experience an increased rate of erosion, those implementing a protective structure may opt for a quicker return period from the hard engineered structures to reap fully intended benefits. Wetlands provide large amounts of benefits to an area as compared to a seawall (Figure 1.2). It may seem to be beneficial to introduce a protective structure that provides the full range of benefits for protection from the first day of implementation, though the long-term negative effects are not always understood. Bulkheads and rip rap interrupt the interaction between the water and the shoreline (Prosser, *et al.*, 2019). These structures can amplify energy at unprotected adjacent shorelines as the deflected energy is directed and added to these areas. The deflection of the wave energy also causes scouring of the ocean floor resulting in increased turbidity near the structure and can interrupt the natural flow of sediments to shorelines causing degradation (Prosser, *et al.*, 2019). Scouring can also cause the loss of beach if one were to exist at the location which then causes destabilization of the structure over time. This interruption is an addition to the degradation that wave energy causes alone – without the hard structure.

1.3. Living Shorelines

The term "living shoreline" is a type of natural or nature-based framework that uses vegetation native to the area in order to protect the shoreline from impeding erosive action (Bridges, *et al.*, 2021). Natural shorelines provide water quality and erosion protection, improved habitats for wildlife, and act as a wind barrier to open-water wind fetch (Rideau Valley Conservation Authority, 2021). It is crucially important to restore natural shorelines as it is commonplace to protect what you can – including sensitive environments. Without surface water sinks such as shoreline vegetated areas, surface water containing herb/pesticides, vehicular fluids, salt, gravel, etc. would run straight into the nearest water body (Rideau Valley Conservation Authority, 2021). If this were to happen, these effects would create negative downstream effects for other environmental characteristics as well, such as biodiversity and habitat loss for shoreline, and water fauna and flora.

This type of solution first requires a footprint that is dominated by native elements in the location. These elements include tidal flats, seagrass beds, intertidal marshes, mangroves, reefs, vegetated banks/buffers, or a combination of the multiple elements. Living shoreline projects usually happen to include components of physical modification too – whether it be the removal of hard structures, addition of sediment, or regrading of a bank. Typically, living shoreline projects are completed within estuaries (Figure 1.3), bays, tributaries, and sheltered parts of the coastline (National Oceanic and Atmospheric Administration, n.d.). Within the NNBF review, it states that “living shorelines often include a structure parallel to and along the waterward edge of the shore to buffer it against incoming wave energy” within higher wave energy situations (Bridges, *et al.*, 2021).

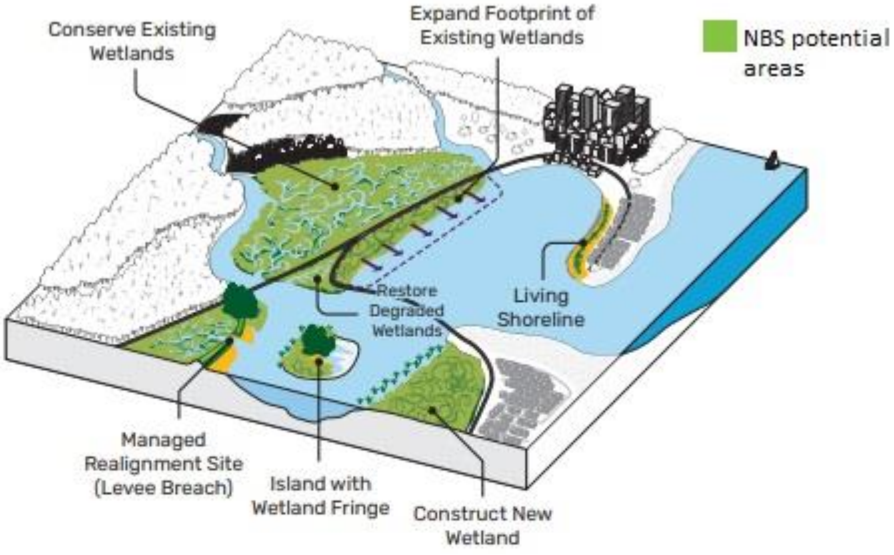


Figure 1.3. NbS options for an estuary (modified from Bridges, et al., 2021).

In the 1990s, Piver’s Island in North Carolina, home to the NOAA Beaufort Lab, was experiencing excessive erosion of the sandy beach on the coast (NOAA, n.d.a.). The case study from NOAA focused on the implementation of a living shoreline on a portion of the shore. In March of 2000, NOAA planted roughly 500 square meters of *Spartina alterniflora* along with oyster sills. In addition to constructing oyster sills in 2000, during the summers of 2000, 2006, and 2007, oyster shells were placed below the marsh elevation at the outer edge of the mudflat in order to avoid the softer sediment. Since the installation of these living shorelines, they have performed well against large storms. In 2011, Hurricane Irene provided storm surge levels of 1.39m, ~1.0m greater than the predicted high tides and wind gusts up to 70 mph to Piver's Island (Currin, 2012). After the hurricane, sites that were eroded on Piver's Island were the lands directly behind seawalls, a vertical bank beyond a stone retaining wall, and minor amounts on vertical banks inland of sandy portions of the beach. Within the two planted marshes on the island, during Hurricane Irene, one site captured 2-13mm, and the other captured 0.5-4mm of sediment on the marsh surface (Currin, 2012). Between March and September 2011, the accretion of sediment over the planted marsh surface with a sill and a natural fringing marsh without a sill, were analyzed (Figure 1.4). The marsh with a protective sill as a barrier to wave action, located in PIW, allowed for sediment accretion in the marsh. This is the opposite of what was noted in its natural marsh counterpart where the surface elevation change was decreased in the PIN location (Figure 1.4). The net change in marsh surface was measured by surface elevation tables. Benchmarks were placed in 2004 and are continuous analyzed at the PIW Lower, PIW Upper, PIN Lower, and PIN Upper sites. Changes were measured within the adjacent surface elevation with an accuracy of +/-2 mm as a measurement. This loss may not be an actual "loss" but rather a compaction of sediment – though time scale can also be a factor here as the (Currin, 2012).

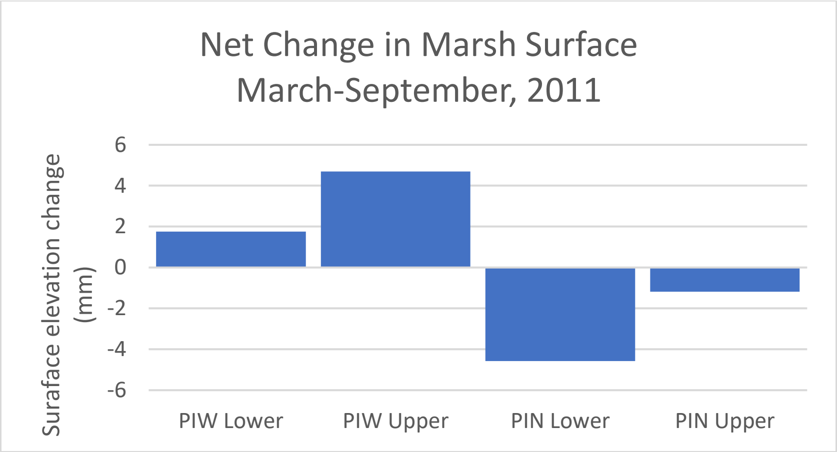


Figure 1.4. Net changes in the marsh surface elevation between a planted marsh with sill (PIW) and a natural fringing marsh (PIN). Lower refers to the near seaward edge of where the Spartina alterniflora is present. Upper refers to the inland edge of the Spartina alterniflora *(modified from Currin, 2012).*

In September of 2018, Hurricane Florence progressed over Piver's Island. The storm surge associated with Florence was 2-5 ft (0.6-1.5 m) with 75mph (121 km/h) winds from the north east direction (NOAA, n.d.a.). After 72 hours the storm passed and limited erosion was noted to the marsh itself or to the unvegetated land beyond the planted marsh. Since then, the oyster reefs have greatly improved the height of the marsh along with providing support to a living reef. Due to accretionary ability of the marsh, the living shoreline continues to accrete landward, expanding the total area of the marsh and the benefits with it (NOAA, n.d.a.).

A different study in Chesapeake Bay, Virginia was conducted using 13 different sites with pairs of natural marshes and living shorelines. The attributes that were studied were nekton, invertebrates, plants, herons, terrapin, and soil (Isdell, *et al.*, 2021). Living shorelines are similar to their natural counterparts (fringing marshes) in all functional aspects with the exception for a lag in soil composition – carbon, nitrogen, phosphorus (Figure 1.5). The lack of soil in comparison to natural fringing marshes is because of the use of clean soils when implementing the living shoreline. Clean soils in this study refer to sand fill that has a high bulk density, and low organic content. As time progresses, potentially greater than 25 years (Craft, *et al.*, 1999), it is expected that this attribute, too, will resemble natural fringing marshes due to the rapid plant growth and organic accumulation. In some cases, such as the nekton metrics, the Z-scores were slightly positive indicating that the anthropogenically installed living shoreline had a better outcome than the natural counterpart (Isdell, *et al.*, 2021). The Z-score is “the numerical measurement that describes a value’s relationship to the mean group of variables” and the value is measured in units of standard deviation (Hayes, 2021). A Z-score of zero indicates that there is no difference, while -1 or 1 indicate the value is either one standard deviation away negatively or positively (Hayes, 2021).

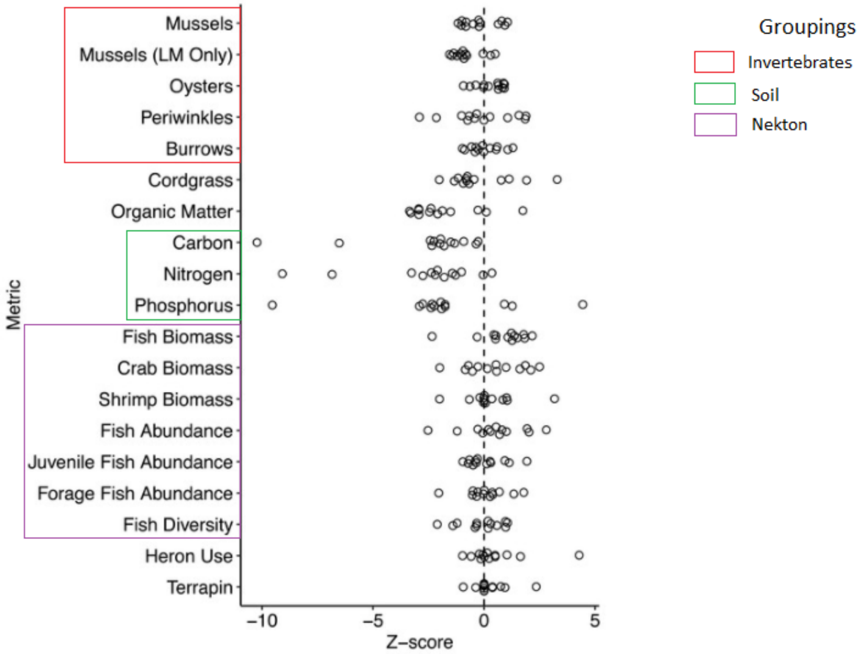


Figure 1.5. Pair-level Z-scores for the ecological metrics (modified from Isdell, et al., 2021).

As living shorelines are becoming a more popular method to protect shorelines, their benefits are being noted. Not all benefits are achieved in every project, as each implementation is different; e.g., geographically or due to local environmental conditions. Some of the potential physical benefits corresponding to living shorelines are protective benefits (Bridges, *et al.*, 2021). Erosion reduction and sediment trapping can occur on small or large spatial scales. Even a five-meter length strip can reduce the rates of erosion as the vegetation acts as a barrier to water movement and a sediment sink as suspended particles are removed from the water as the water velocity is reduced (Currin, 2012). A global review competed by Narayan *et al.* (2016) concluded that salt marshes are 72% effective of reducing wave heights. They also found that tidal wetlands and mangroves are three times cheaper to implement compared to alternative submerged breakwaters for the same level of protection.

As with any coastal protection methodology, living shorelines have some drawbacks and limitations. For instance, livings shorelines are not recommended for all locations of a shoreline. The National Oceanic and Atmospheric Administration (NOAA) states success rates with living shorelines are lower when the sites are adjacent to open ocean (NOAA, n.d.a.). This may be due to the fact that open ocean depths are much greater than estuarine areas as they have a greater slope offshore, not suitable for plant growth. Other limitations are high wave energy, proximity to navigational channels, surrounding built infrastructure, desired use of waterfront area, high bluffs, and steep shoreline morphologies (Currin, 2019).

1.4. Tidal Wetlands

Tidal wetlands are a key coastal ecosystem that is conducive to living shoreline methods because the environmental conditions and coastal processes that contribute to the establishment of tidal wetlands are also favourable for living shorelines. Tidal wetlands are described as “flat, vegetated areas that are subject to regular flooding by the tides” (Connecticut Department of Energy and Environmental Protection, 2018). The vegetative roots and rhizomes in tidal wetlands, known as the below ground biomass (Leonardi *et al*, 2018), can be one metre deep, typically on a shelf, and provide stability for the shore when storms occur as they bind together sediments (Bridges, *et al.*, 2021). There needs to be enough time for the vegetation and associated root systems to establish so they do not wash away with the excess water and wave energy.

Waves dampen as they come into contact with the shoreline vegetation – more specifically the plants with stiff stems – known as the above ground biomass (Leonardi *et al*, 2018). Three important factors to consider when discussing wave dampening during storms is the vegetation stems flexibility, diameter, and length (Leonardi *et al*, 2018). Storm conditions may cause flexible plant stems to lie horizontally along the substrate as the movement of the water flattens them. Though this decreases the wave dampening ability of the wetland, studies have shown that the flattened plants protect the substrate from erosion (Leonardi *et al*, 2018). Suspended sediments are deposited due to decreased flow velocities and altered flow patterns through vegetation and are then deposited within the wetland vegetation onto the substrate causing accretion of the bed level elevation (Bridges, *et al.*, 2021).

Tidal wetlands and living shorelines, that include a constructed wetland, have the ability to withstand sea level rise under certain conditions. Global-scale studies have found that 20-90% (low SLR to high SLR projections, respectively) of wetlands will be lost during the 21st century (Schuerch, *et al.*, 2018). Blankespoor, *et al.* (2014) found that 68% of wetlands found in 86 developing countries globally are at risk of loss in the 21st century. This statement does not account for developed countries, yet is still considered a global analysis – both the global north and south are considered (Blankespoor, *et al.*, 2014). Studies that use similar methods have been noted to not account for two important variables – the accommodation space and the failed realization of local-scale biological feedback mechanisms. Accommodation space refers to the vertical and horizontal space where fine sediments can accumulate and provide an area for wetland vegetation to grow (Schuerch, *et al.*, 2018). As an example, Raabe and Stumpf (2016) found that the low-lying areas along the “Big Bend” on the Floridan coast, were being transformed into marsh land over the last 120 years. As some marsh areas are being lost to open water along with permanent inundation, the landward retreat converts more forested area into marshes than the amount of marsh lost. The Big Bend does not conflict with humans or infrastructure and the increase in overall tidal marsh area is beneficial. This is not the case for the majority of global marsh areas. When there are anthropogenic influences on the coastal land and infrastructure, lateral movement of marshes inland poses threats to both humans and infrastructure (Raabe & Stumpf, 2016).

Biological feedback mechanisms, may be of high importance to the persistence and loss of tidal wetlands in the face of SLR and climate change. Increased inundation due to SLR can cause vegetation to die and the decomposition can cause collapse of the marsh substrate resulting in a quicker wetland loss than by SLR alone. The sensitivity of wetlands to SLR may decrease in the future. As climate change warms our planet, the increased abundance of CO_2 and warmer temperature, along with mid-range rates of SLR occurring, may lead to increased rates of vegetation productivity and wetland accretion (Spencer, *et al.*, 2016). Limitations for these to occur also depend on anthropogenic factors, such as coastal squeeze and coastal development (Spencer, *et al.*, 2016).

As NbS and natural marshes/wetlands are important for helping the environment adapt to climate change, it is important to know which areas can be enhanced or which areas would be suitable areas for NbS to be implemented. Tools are a way to take lessons learned from successful living shoreline projects to inform decisions for future projects. The research on living shorelines is available for what conditions and features we need in order to implement these structures. Tools are a way to go from understanding what needs to be present at a site and what actually is present in the area of interest before a decision is made.

1.5. Assessment Tools for Living Shorelines

Various interactive tools, guidelines, and checklists are available to assess which type of living shoreline is best suited for an area, it is important to understand the baseline conditions that a site needs to meet. Living shorelines will not work in all conditions, so having a list of crucially important characteristics described within a tool, guideline, and/or checklist is needed for proper guidance.

A variety of interactive living shoreline design tools, guidelines, and checklists have been revied in order to evaluate their suitability and applicability for use on Prince Edward Island, Canada (Table 1.1). Although the intended use is primarily based on different living shoreline techniques, other NbS adaptations are included within some of the tools.

Table 1.1. Tools for living shoreline techniques.

Title	Origin	Interactive	Guideline	Checklist
Decision Tree	Atlantic Climate Adaptation Solutions Association (ACASA)	X		
Living Shorelines Applicability Index	Woods Hole Group	X		
Shoreline Decision Support Tool	Virginia Institute of Marine Sciences	X		
Marine Shoreline Design Guidelines	Washington Department of Natural Resources		X	
Living Shoreline Engineering Guidelines	New Jersey Department of Environmental Protection		X	
International Guidelines on Natural and Nature-Based Features for Flood Risk Management	US Army Corps of Engineers		X	
Shoreline Evaluation Sheet	CB Wetlands and Environmental Specialists			X

In order to determine whether or not a tool can adequately inform the siting, design, and/or installation of a living shoreline, a locally informed assessment needs to be completed on the tool. The "International Guidelines on Natural and Nature-Based Features for Flood Risk Management" tool contains the most comprehensive list of living shoreline criteria, as it was used to understand the criteria needed in a natural approach which includes living shoreline. Table 1.2 shows the criteria outlined by the NNBF (Bridges, *et al.*, 2021) for the baseline conditions that must be met for successful living shorelines.

Table 1.2. Crucial criteria to account for when implementing or planning for a living shoreline project stated by the NNBF tool (Bridges, et al., 2021).

Category	Criteria
Vegetation	Upland type, composition, diversity, abundance
Geology/geomorphology/sediment	Sediment supply, site position, bulk density, grain size distribution, OM composition, elevation
Other	Light/shading, wave energy, current energy salinity, fauna

A useful tool, known as the “Tool Evaluation Criteria” by Workforce EdTech (2021), was used to help indicate what characteristics should be considered when analyzing the practicality of a tool. The tool was originally created as a guide to determine whether or not a technological tool or resource fits within what a program is intended for. The following topics are what the Tool Evaluation Criteria focuses on: proven effectiveness, accessibility, affordability, user experience, user support and communication, data, privacy and security, and longevity (EdTech, 2021).

The amount of light the area receives is crucial for plant health and will help the living shoreline to flourish (Currin, 2019). The uplands, too, must be vegetated by native gasses so minimal shade impacts the marsh vegetation growth (Mitchell & Bilkovic, 2019). Ideally, implementation of living shorelines would be in areas where the uplands are lower in elevation, so that natural retreat of the marsh can occur over time. Vegetation should be compared to what the expected and typical regional benchmarks for species composition, diversity, and abundance (Bridges, *et al.*, 2021). In areas where cliffs or bluffs are present, the sediment supply is the crucial factor for marshes to thrive as they accrete vertically. Before plants can even be established, the wave and current energy has to be low enough for the plant to stabilize and grow. This is when the position of the site and geomorphology are important. In regards to soils, the bulk density, grain size distribution, organic matter composition, and salinity, resistance to erosive forces are important factors to consider (Bridges, *et al.*, 2021). Without proper consideration of these parameters, a living shoreline that is implemented may not survive due to the lack of baseline conditions.

Of lesser importance, but still a notable factor in baseline conditions for living shorelines, are fauna. Crabs and other macroinvertebrates may play an important part for the soil formation and the stability for the deposition in new sediments through bioturbation (Bridges, *et al.*, 2021). The bioturbation by crabs causes an increase of the nutritional quality of organic matter in sediments both in mudflats and salt water, hindering the areas availability of plant nutrients and dissolved oxygen (Fanjul, *et al.*, 2015; Merriam-Webster, n.d.). On the other hand, anthropogenic interventions may be needed to control herbivorous fauna, such as snail and birds, for the establishment or re-establishment of marsh vegetation (Bridges, *et al.*, 2021). Without control, the herbivorous fauna will eat the plants before they can fully become stabilized (Bridges, *et al.,* 2021).

Other types of tools that provide guidance for other aspects of living shorelines aside from implementation are available as well. Some of these focus on land use planning for capacity building, policy and planning frameworks, and regulatory and land use change tools. Land use planning for capacity building tools focus on engaging the community, stakeholders, and others with interest or knowledge in understanding the environment and cultural significance of an area (Manuel, *et al.*, 2016). Capacity building is a key factor when in the beginning stages of an implementation plan of a coastal adaptation strategy. Policy and planning framework tools involve governments at all levels – municipal, provincial, and federal – in order to guide the uses of the land and other related activities. Related activities, such as watersheds and environmental resources, are also governed by the policy and planning frameworks. These are official plans that are dedicated to communities. Regulatory and land use change tools include other tools that govern land use, the subdivision of land, change in land use, or ownership of the land. Incorporated municipalities and provincial governments are the only ones who can use these tools, though if wanted, advocation by non-incorporated municipalities can be done in order to have these tools available for them as well (Manuel, *et al.*, 2016). These tools described are outside the scope of this project.

Multicriteria analyses (MCA) are a different way to make decisions or determine areas that are suitable for living shorelines. An MCA is a highly structured approach that considers all possibilities within the data (matrices) to evaluate their outputs at the same time (Nautiyal and Goel, 2021). Criteria can be weighted individually to emphasize its sensitivity to inputs, or all criteria can be weighted equally so no criteria have a greater influence than another. In more recent years, combining geographic information systems (GIS) with MCA has been common, too. The main driver behind the push for MCA and GIS is the need to make geographic information technology more relevant for addressing planning and management problems (Malczewski, 2018). The combination also allows for the visualization of complex issues which aids in communication, understanding, and informed participation in decision making.

1.6. Encouragement for the Implementation of NbS

Protecting shorelines using hard armouring methods is still commonplace. In a study based in various counties from North Carolina by Gittman *et al.* (2020), it was found that 58% of survey respondents had hard armouring as their property's protection method, 36% had unaltered or "natural" shorelines, and 6% had living shorelines. This study recognizes the influence of types of property armouring on neighboring properties. The results of the study show that property owners are aware of the benefits of living shorelines, though the benefits are outweighed due to social pressure or simply to replicate what neighboring properties have installed. Another issue that hinders the use of living shorelines is the fact that property owners value their property's aesthetics more than the damages to the ecosystem – even when they understand how damaging hard armour is along with the time it would take to restore to a natural state (Gittman, *et al.*, 2020).

In order to boost the popularity of NbS as an alternative method to hard armour, there needs to be some form of encouragement. It is suggested that the focus of these encouragements should be on high value properties in residential areas that are not armoured (Stafford, 2020). It is also suggested that these residential areas, along with business zones located on the coastline, should have some sort of intervention program specialized for them. The program would be targeted for these type of areas as they would be the most likely to armour their shoreline due to neighboring influences. The goal of these programs is to aid in distributing information and design ideas for living shorelines, or hybrid infrastructure (Stafford, 2020). The implementation of one hard structure in an area has a direct influence on what neighboring properties install causing a cascading effect for shoreline armouring (Scyphers, *et al.*, 2020). The information and guidelines regarding implementing living shorelines needs to be readily available and explained at a level that all property owners can grasp. On the other hand, most environmental problems today cannot be solved by simply informing people of the consequences (Scyphers, *et al.,* 2014). In more complex environmental situations, understanding the driving forces behind attitudes and motivations are necessary to change the trajectory from hard armouring to living shorelines (Scyphers, *et al.,* 2014).

Another method to influence coastal property owners to choose living shoreline techniques is by understanding the unknown social and economic dimensions. Decisions are influenced by cognitive factors such as values and beliefs held within the environment, or wealth or housing age (Scyphers, *et al.,* 2014). Many coastlines and coastal communities are developed with residential housing. Associations such as the Home Owners Association (HOA) have largely impacted what communities can and cannot do. An example – not related to living shorelines – is the impact HOAs have on diversity of plant and bird species (Lerman, *et al.*, 2012). Lerman *et al.* (2012) it was found that neighborhoods with HOAs had a greater diversity of plants and birds. If there were to be an association that determined what was not allowed to be constructed on shorelines – hard armouring of shorelines per se, and recommended/forced constructions of living shorelines, perhaps an influx of species diversity would be noted on the shoreline and surrounding areas as well. As everyone within the neighborhood would have to comply, values and belief systems may change in favour of living shorelines, creating a trickle-down effect for other surrounding residential areas. This research highlights the areas along the coastline where living shorelines are suitable – the first step in the right direction for getting governments and property owners talking and thinking about the implementation of living shorelines.

1.7. Purpose and Objectives

In order to implement living shorelines that are appropriate for the PEI context, we need to understand which portions of the coastline are suitable for these nature-based designs. In order to do so, we will:

1. Determine general site selection criteria for the application of living shoreline techniques,
2. Compare existing tools based on suitability to PEI context,
3. Develop an index of suitability ranges for PEI for application of living shoreline techniques, and
4. Test site suitability output for living shorelines on PEI within Queen’s County

CHAPTER 2: Study Area

Prince Edward Island (PEI) is a province situated within Atlantic Canada, surrounded by the Gulf of St. Lawrence to its north, and the Northumberland Strait to its south. The coastline of PEI is characterized by bluffs, cliffs, low plains, sand dunes, and wetlands (Davies, 2011). The north and south shore of PEI differ in exposure, geology, and geomorphology.

2.1. Demographics

PEI has twenty-nine municipalities which provide land use planning for approximately on 10% of the island region (Government of Prince Edward Island, n.d.a). The population of PEI is ~142 000 (Government of Prince Edward Island, n.d.a) distributed within three counties (Table 2.1).

Table 2.1. Population by county within Prince Edward Island (Government of Prince Edward Island, n.d.a)

County	**Population**
Queens	~82 000
Kings	~17 000
Prince	~44 000

The on-site assessment for this study focuses on the coastline of Queens County (Figure 2.1). The communities within Queens County are primarily coastal or within close proximity to coasts. Charlottetown, the capital of PEI, is located within Queens County and is a low-lying, coastal city. Other communities outside of the Queens County zone are primarily coastal as well. The province has 42.5% of the provincially owned land dedicated to agriculture (Government of Prince Edward Island, n.d.a). From the 2016 Census, it was recorded that PEI had 1353 operable farms that focused on growing crops and raising livestock. The primary crops are potatoes and other vegetables, fruit, grains, oilseeds, and organic produce. The primary livestock farmed in PEI are beef and dairy, hog, poultry, and honeybees.

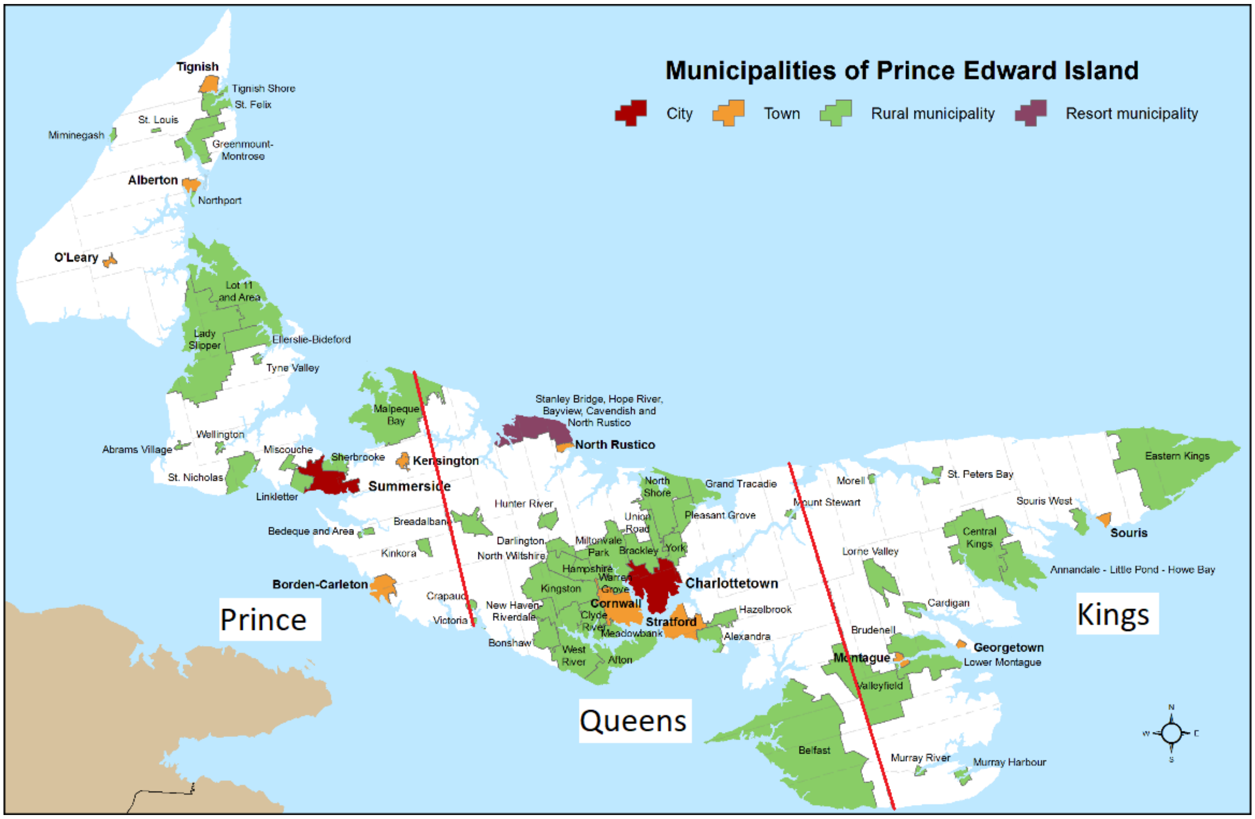


Figure 2.1. Municipalities of Prince Edward Island. The text highlighted in white are the county names, and the red lines note the county boundaries (modified from Hwy43, 2017).

2.2. Site Locations

Thirty-one 20m segments were assessed for suitability of NbS in fourteen coastal areas (Figure 2.2). Six coastal areas were located on the north shore, and eight were located on the south shore (Table 2.2) based on the criteria of locations that were within Queens County and had a coast type of till, found from the “Coastal Erosion and Shoreline Classification in Stratford, Prince Edward Island” report by O’Carroll (2010). Appendix A presents detailed maps for specific sites.

Table 2.2. Locations visited along the north and south shores of PEI.

Shore	Location
North	Phyllis Kennedy; Seawood Estates; Cavendish; Doyles Cove; Rustico; Savage
South	Argyle Shore; Canoe Cove; Camp Seggie; QEH; Tea Hill; Young's Marsh West; Mount Buchanan; Gascoigne Cove

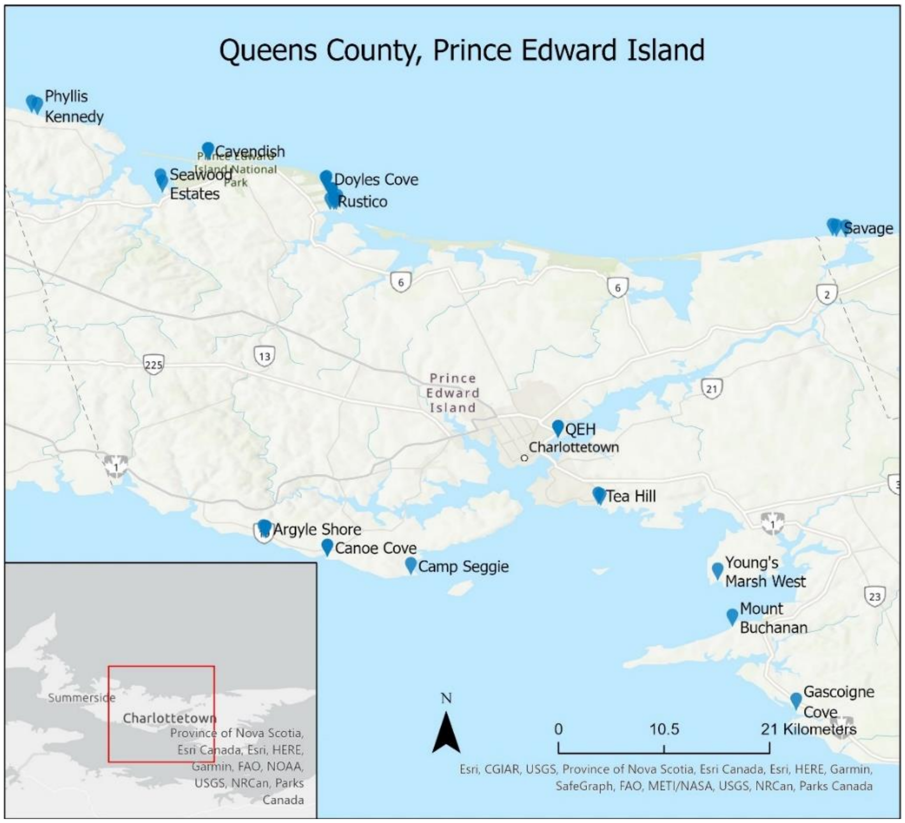


Figure 2.2. Map of locations that were assessed during field work in Queens County, PEI.

2.3. Geology and Geomorphology of Prince Edward Island.

PEI is located in the Maritime Basin region which was created during the final assemblage of Pangea (Gibling, *et al.*, 2008). This sedimentary basin was tectonically dynamic for 120 million years (Gibling, *et al.*, 2008). PEI was formed in the latest Carboniferous age to the earliest Permian and is underlain by characteristic gently warped clastic “redbeds” that were deposited during that time age (Ziegler, 2011). The term “redbeds” refer to the stratigraphy of the island due to the inclusions of iron-oxide within the sediment causing a red hue (Holman, 2021). The notable crescent shape of PEI is due to the melting of glaciers. As the glaciers, that were overtop of what is now PEI melted, the relief of pressure caused isostatic rebound. This rebound was more apparent in the Northumberland Strait region causing the crescent shape (Holman, 2021). What was left behind, over top of the redbeds, was glacial till, sandstone and shale (Mathew, *et al.*, 2010). PEI is broken up into five geological formations: Orby Head, Hillsborough River, Kildare Capes, Egmont Bay, and Miminegash (Figure 2.3). Figure 2.4 shows examples of what the outcropping of formations looks like for the Orby Head Formation and the Kildare Capes formation. The Hillsborough River formation has effectively no outcropping visible on the island. No photos of the Egmont Bay and Miminegash formations were found within personal photosets, therefore are not displayed. The distinct formations were noted first in 1989 by van de Poll and they were assessed in correspondence with fossils found dating back to different periods of time causing stratigraphy of each formation to differ (Ziegler, 2011).

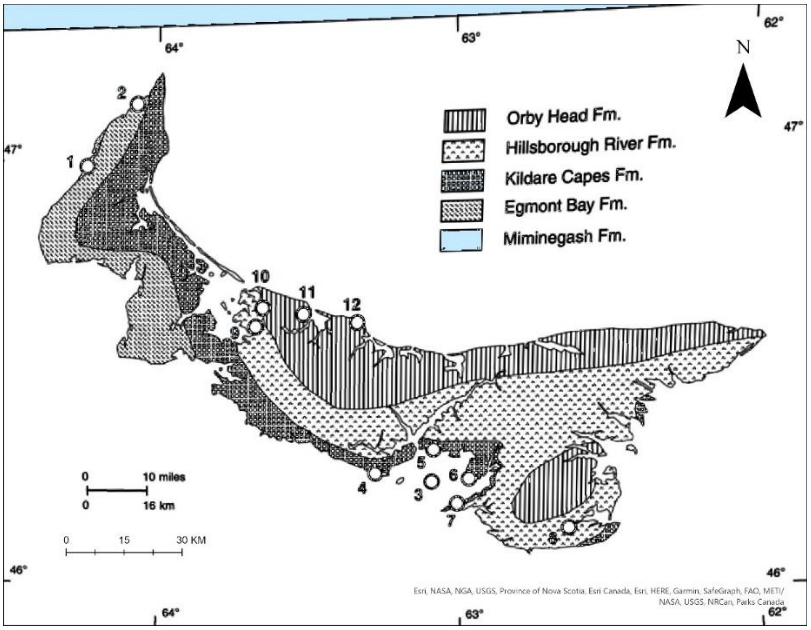


Figure 2.3. The five geological formations of PEI (modified from Ziegler, 2011).

Figure 2.4. A) Orby Head formation at Cape Tryon, PEI. B) Kildare Capes formations at Rice Point, PEI.

2.3.1. North Shore – Queens County

The entirety of the geology of north shore within Queens County on PEI is part of the Orby Head formation (van de Poll, 1989) (Figure 2.4.a.). The best view of this formation is along the northern coast at Cape Tryon. The age of this formation is not well documented as fossil evidence is lacking. It is suggested to be within the Artinskian age, and that the youngest sedimentary rocks found are from no later than the late Early Permian. The basal contact of this formation is not exposed on PEI, and is arbitrarily set just below the basal conglomerates (van de Poll, 1989).

The north shore shoreline of PEI that is of importance to this project is dominated by sand dunes (Davies, 2011) in open coast areas of the Gulf of St. Lawrence. Within the estuarine environments of PEI, wetlands are the dominant shoreline feature. The open coast within the Queens County boundary experience low to moderate tidal ranges both in coastal areas and estuaries. These values are measured at 0.50-0.80m above mean sea level by the higher high water, large tide (HHWLT) tidal time series (Davies, 2011). The north shore subdivisions of interest are Malpeque, Cavendish, Brackley, Tracadie, and St. Peters. These subdivisions are classified by their annual average net longshore transport rates and the direction of transport. No numeric values of transport are given with these subdivisions, only dozens of different arrows within the cells. An important note to make is the transport rates are potential rates, if the sediment supply was unlimited. Along the open coasts, the transport rate is larger compared to the estuarine coasts as the wave heights are greater and the relative angle of the shoreline on the open coast is more exposed to the oceanic conditions. This makes open coastal areas more susceptible to erosion, while estuaries tend to be depositional environments causing accretion.

The main sources of sediment for beaches, dunes, and wetlands, on the north shore are from the sandstone cliffs and bluffs that experience ongoing erosion (Davies, 2011).

Maximum wave heights determined for the north shore were as high as 4-6m during peak storm activity (Davies, 2011). The open coastlines and estuarine areas are then subdivided by different classifications for each region and are either classified as a bluff, cliff, low plain, sand dune, or wetland (Table 2.3, Table 2.4). Cavendish, Brackley, Tracadie, and the St. Peters subdivisions are known as “bights”, and are relatively shallow (Davies, 2011). The National Oceanic and Atmospheric Administration (NOAA) (n.d.b.) defines bights are as a “long, gradual bend or recess in the shoreline that forms a large, open bay”. “Bights” are also known to cause navigational difficulties as they tend to be shallow, a hazard for ships and boats (NOAA, n.d.a.).

Table 2.3. North shore coastline classification chart percentage for littoral cells of importance within Queens County (Davies, 2011).

Coastline	Bluff (%)	Cliff (%)	Low Plain (%)	Sand Dune (%)	Wetland (%)
Malpeque	2.1	20.9	2.1	74.4	0.5
Cavendish	0.0	47.4	0.0	52.6	0.0
Brackley	2.6	37.1	1.3	56.7	1.3
Tracadie	5.5	69.9	4.7	19.6	0.3
St. Peters	3.4	2.2	1.4	93.0	0.0

Table 2.4. North shore estuary classification chart percentage for littoral cells of importance (Davies, 2011).

Estuary	**Bluff (%)**	**Cliff (%)**	**Low Plain (%)**	**Sand Dune (%)**	**Wetland (%)**
Malpeque	5.9	12.8	15.4	11.8	54.2
Cavendish	3.1	39.9	3.5	5.9	47.6
Brackley	2.1	27.2	5.1	6.2	59.4
Tracadie	4.8	17.2	3.0	13.9	61.1
St. Peters	7.5	19.3	8.2	14.0	50.9

2.3.2. South Shore – Queens County

The south shore of PEI within Queens County is primarily characterized by cliffs (Davies, 2011). These cliffs can be composed of till or sandstone materials. The shoreline within the Queens County region is primarily formed from the Kildare Capes formation (Figure 2.4.b.) and partially the Hillsborough River formation (subsection Wood Islands Member), on the southeast part of PEI (Figure 2.3). The Kildare Capes formation can be seen in an outcropping setting between Port Borden (now known as Borden-Carleton) to Rice Point (van de Poll, 1989). The lowermost exposure is rhyolite which overlies the distinctly finer grained material of the older Egmont Bay formation. Due to the high erodibility of the upper part of the Kildare Capes formation, surficial deposits are all that is left of that particular formation. The Kildare Capes formation is the earliest Permian unit of the PEI redbeds. The small portion of the Hillsborough River formation that is within Queens County, is known as the subsection named the “Wood Islands Member”. Van de Poll (1989) stated that the Hillsborough Bay formation has virtually no exposure on the open coasts, and what you are seeing exposed on the coastline are characteristics of basal conglomerates. The Wood Islands Member is suggested as being from the Early Permian age (van de Poll, 1989).

The south shore of PEI is situated within the Northumberland Strait. The highest tides on PEI are found along the south shore within Queens County – near Tryon and the entirety of the Hillsborough Bay. During storms, peak wave height was averaged between 1-2m (Davies, 2011). Sediment transport within the Queens County portion of the south shore is generally an order of magnitude lower than that of the north shore (Davies, 2011). This is primarily due to the lesser exposure of wind waves within the Northumberland straight as compared to the gulf. The south shore subdivisions that will be of interest are Tryon, Hillsborough, and Southeast (Table 2.5, Table 2.6).

Table 2.5. South shore coastline classification chart percentage for littoral cells of importance (Davies, 2011).

Coastline	**Bluff (%)**	**Cliff (%)**	**Low Plain (%)**	**Sand Dune (%)**	**Wetland (%)**
Tryon	8.9	70.6	16.0	4.1	0.4
Hillsborough	8.5	51.9	13.5	5.8	20.4
Southeast	5.6	66.2	7.8	18.6	1.8

Table 2.6. South shore estuary classification chart percentage for littoral cells of importance (Davies, 2011).

Estuary	**Bluff (%)**	**Cliff (%)**	**Low Plain (%)**	**Sand Dune (%)**	**Wetland (%)**
Tryon	9.4	16.9	38.6	4.5	30.5
Hillsborough	3.1	19.0	4.6	0.4	73.0
Southeast	2.8	12.6	16.1	7.0	61.5

The shores along the north and south of PEI differ. By comparing the coastal areas on the north and south shore, we can understand just how different they are (Figure 2.5). Similarly, we can do the same for the estuarine areas along the north and south coasts of PEI (Figure 2.6). Coastal areas, which are exposed to more open-ocean conditions, are characterized by much different shoreline classifications. The north shore is dominated by sand dunes, while the south shore is dominated by cliffs (Figure 2.5). The estuarine classifications for the north and south shore within Queens County are dominated by wetlands, which have almost exactly the same percent cover (Figure 2.6).

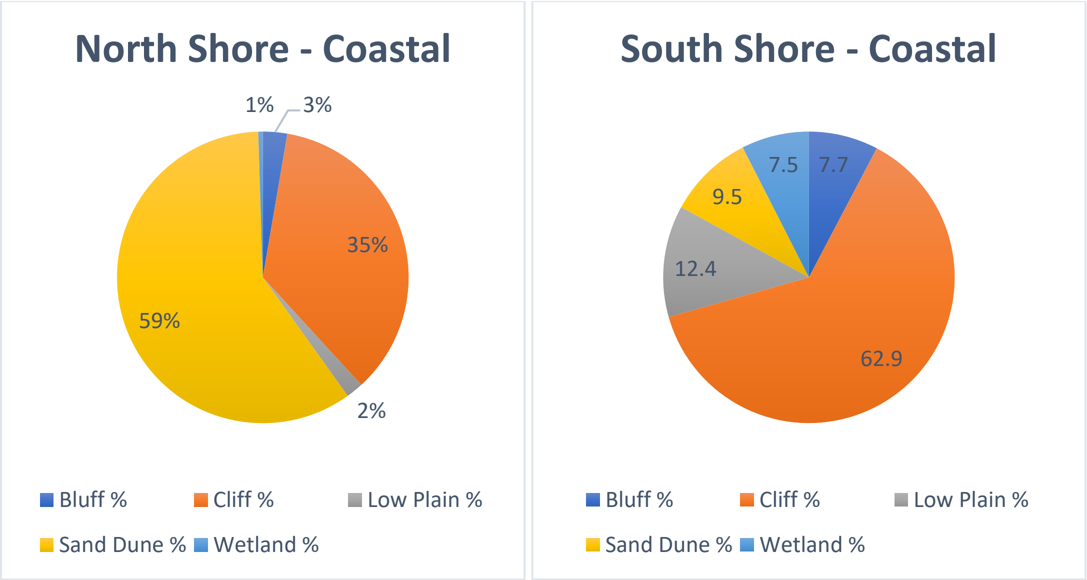


Figure 2.5. Classification comparisons for the north and south shores, regarding coastal areas within Queens County, PEI

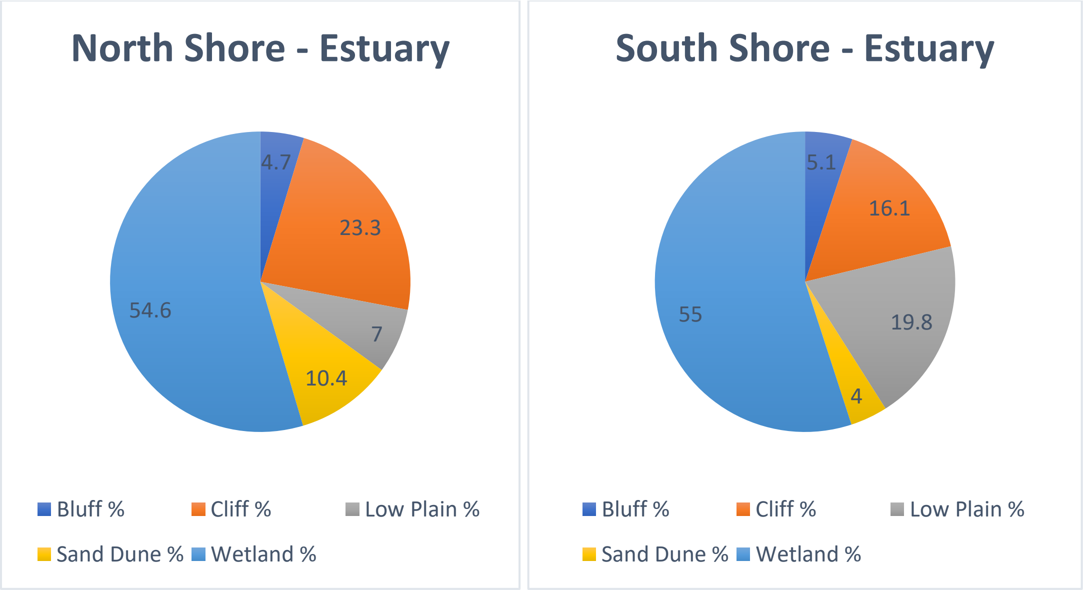


Figure 2.6. Classification comparision for the north and south shores, regarding estuarine areas within Queens County, PEI.

2.4. Climate and Climate Change Vulnerability

PEI is located within the Atlantic Maritime ecozone (ESTR Secretariat, 2014). One large influential factor for this ecozone is the proximity to the ocean. PEI has a mild maritime climate which is also influenced by proximity to water. In regards to climate, the warm waters of the Gulf of St. Lawrence on PEI's north side, has a strong influence on climactic regimes (Government of Prince Edward Island, n.d.b). The proximity of bodies of water to PEI has an effect on precipitation regimes, meaning higher amounts of precipitation. PEI, on average, receives approximately 890mm of rain and 290mm of snow, annually. The average temperature in winter is -9°C and 19°C in summer (Government of Prince Edward Island, n.d.b). As the winter and summer months differ between above and below zero degrees Celsius (along with the fluctuation above and below zero degree Celsius in the winter) freeze-thaw cycles are a regular occurrence. Freeze-thaw cycles refer to temperatures dropping below zero, causing ice crystals to exert pressure within the pores of the materials they reside in, causing the material to become disrupted which may lead to cracking within the material (Camuffo, 2019). The expanded cracks in the material allow for precipitation to infiltrate further into the cracks the next time, repeating the same processes, and expanding the crack further. Below zero temperatures also play a role in how much ice coverage the bodies of water surrounding PEI receive during the winter months.

In a typical year, the amount of ice coverage in the Gulf of St. Lawrence is roughly 33% during the second week of February (Yarr, 2021a). In 2021, the amount of ice coverage during the second week of February was only 1% (Yarr, 2021a). As global temperatures rise, this trend of less sea ice is expected to become more prevalent. For the south shore of PEI, along the Northumberland Strait, the lack of ice is a concern. Ice coverage cools down the water in the strait which plays a factor long into the summer months, which are responsible for thriving oyster reefs (Yarr, 2021b). Without these cooler water temperatures, the health and productivity of the oysters are at stake along with their economic benefits (Yarr, 2021b).

The coastlines of PEI become more vulnerable to erosion when sea ice is not present. As wind speeds pick up in the fall and winter months (Figure 2.7), the wave climate and wave energy of the neighboring bodies of water surround PEI become larger. Going from summer to winter, the temperature of the atmosphere decreases at a faster rate than the water temperatures causing weather systems to form (Davidson-Arnott, *et al.*, 2019). Weather systems, such as major storms and hurricanes, create large waves (Davidson-Arnott, *et al.*, 2019) which increases the wave energy for this time of the year which in turn impacts erosion. Without ice cover there is nothing keeping the churning sea from contact with the coastline (National Snow & Ice Data

Centre, n.d.). When sea ice is present, the build up of ice at the toe of the bank acts as a protective barrier between the waves and the coastline.

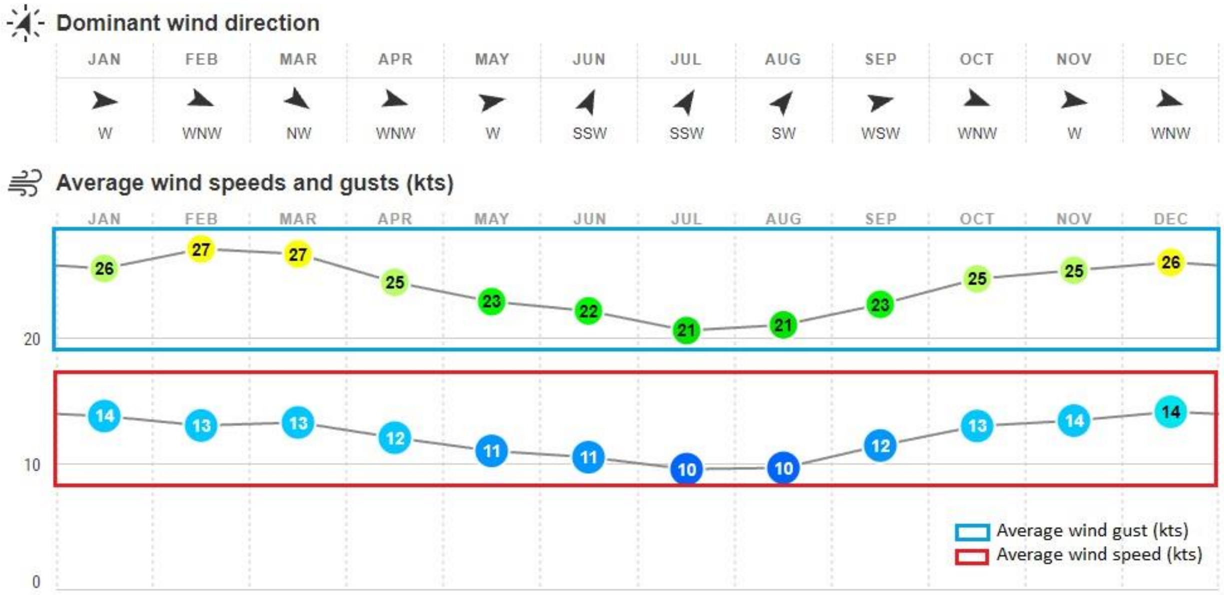


Figure 2.7. Average wind speeds (kts) and directions from East Point/Prince Edward Island observed from November 2008 until November 2021 (modified from Wind Finder, 2021). This data was the closest weather station with historical data in Queens County.

Climate change vulnerability affects other characteristics of PEI as well. Accelerated coastline erosion rates and increase in the amount, duration, and frequency of coastal and freshwater flooding for low lying areas are major risks. The average erosion rate for PEI between 2000-2010 was found to be 40 cm annually (Webster, 2012) (Table 2.7). Comparing this value to the historical average erosion rate on PEI between 1968 and 2010 being only 28cm annually shows alarming rates of increased erosion (Table 2.7). The locations in Table 2.7 that are within Queens County are North Rustico, St. Peters, Wood Islands, and Charlottetown. According to the trajectory climate change is presenting now, we expect these trends to continue and to continue to heighten the risk to coastal areas.

Table 2.7. Average erosions rates on Prince Edward Island between 1968-2010 and 2000-2010 (modified from Webster, 2012).

Location	**Average Erosion Rate 1968-2010 (cm·a^{-1} ± 1 Standard Deviation)**			**Average Erosion Rate 2000-2010 (cm cm·a^{-1} ± 1 Standard Deviation)**		
Entirety of PEI	28	±	127	40	±	119
Tignish	23	±	64	46	±	73
Malpeque	51	±	116	101	±	265
North Rustico	16	±	69	31	±	120
St. Peters	84	±	316	43	±	82
East Point	17	±	58	71	±	74
Souris	0	±	33	24	±	61
Wood Islands	24	±	162	30	±	84
Charlottetown	10	±	59	32	±	123
Borden-Carleton	15	±	68	29	±	199
Summerside	22	±	66	26	±	118
West Point	30	±	52	54	±	59
West Coast	24	±	36	51	±	57

Coastal flooding from rising sea levels, storm surge, and large amounts of precipitation over an acute time period are a large risk now and more so into the future for PEI. The Government of Prince Edward Island (2021) classifies post-tropical storms as a risk currently and a larger risk for the future (Table 2.8). A notable post-tropical storm Dorian occurred in September of 2019. Both the north and south shorelines within all three counties had severe flooding throughout (Jardine, *et al.*, 2021). Local infrastructure was threatened by flooding as some locations had flood levels in excess of 3.4 m as a result of storm surge (Jardine, *et al.*, 2021). PEI currently lacks the number of tide gauge stations needed in order to be prepared for future conditions. PEI only has one tide gauge that gives real-time tides, and 23 additional stations that give tidal predictions (Government of Canada, 2022). Tide gauges can be used to predict the frequency of future large post-tropical storms; identify high risk areas; identify areas where flooding is likely to occur in future storm/SLR conditions; to provide documentation from storms that occur (Fenech, *et al.*, 2017). For future preparedness, additional tide gauges should be installed throughout different locations around PEI.

On a chronic time-scale, over the past 100 years (1911-2011), the city of Charlottetown has succumbed to 36 inches of SLR (Fenech, *et al.*, 2017). Predictions state within the next 100 years, the sea level in Charlottetown will rise by an additional 100cm (1m) (Fenech, *et al.*, 2017). This one-meter SLR prediction will severely impact a large portion of Charlottetown (Figure 2.8) and large portions of the coast throughout the province.

Figure 2.8. A spatial map showing a moderate-low hazard flooding scenario for 2100, coloured in yellow (Government of Prince Edward Island, n.d.c).

Table 2.8. Climate hazards for Prince Edward Island and their corresponding risks as score now and predicted for 2050 (modified from Government of Prince Edward Island, 2021).

Climate Hazard	Scenario	Current Risk Rating (Score)	2050 Risk Rate (Score)
Coastal erosion	Acceleration of the historic erosion rate	Medium (9.2)	High (15.3)
Post-tropical storm	Multi-day post-tropical storm with heavy rain, storm surge, and wind making landfall in Queens County	High (14.1)	High (14.1)
Heat wave	Three consecutive days with temperatures over 29°C	Medium (7.0)	High (11.7)
Heavy precipitation and flooding	100 mm rain event in 24 hours	Medium (8.4)	High (11.2)
Severe ice storm/freezing rain	Multi-day severe ice storm/freezing rain event in winter	High (12.3)	Medium (9.2)
Earlier, warmer springs	Earliest onset of spring temperatures by two weeks affecting key species	Low (4.4)	Medium (8.8)
Seasonal drought	Months-long severe summer drought affecting the entire province	Medium (7.4)	Medium (7.4)

Not only do the loss of these lands pose physical risks to property and infrastructure, but also risks to the economy and health of humans. The main losses that are experienced by the economy due to erosion and other climate change factors are tourism and recreation, and agricultural, fisheries, and aquaculture (Government of Prince Edward Island, 2021). Other economic losses can be noted in real estate markets, insurance industries, and private homeowners as there are fewer properties for municipalities to derive income tax from. In terms of human health, the loss of land and altered coastal processes can have a widespread negative impact to mental health as there is a lost sense of place. This could be caused from smaller instances where someone’s daily work commute is altered, to as large as displacement of residence (Government of Prince Edward Island, 2021). From a different standpoint, pollution from damages to infrastructure, such as damaged sewer systems, or access to routes for medical services cut off are heightened risks for human health as well.

Over the summer of 2021, The PEI Watershed Alliance (PEIWA), in partnership with the City of Charlottetown, Town of Stratford, and Lennox Island First Nation, implemented four living shoreline pilot projects, a type of NbS. The living shorelines were installed as part of the broader Community-based Climate Action on PEI project which was funded through the Environment and Climate Change Canada's (ECCC) Climate Action and Awareness Fund (CAAF) (Charlottetown, 2021). These projects were installed along shorelines near the Queen Elizabeth Hospital (QEH) in Charlottetown, at Tea Hill Park, Stratford, on the Stratford waterfront, and at Lennox Island. This report focuses on the QEH and Tea Hill Park sites. The QEH living shoreline installation began with the removal of the existing gazebo and gabion basket wall conducted by the Department of Transportation and Infrastructure. The bank was then graded and native vegetation was planted. Haybales, shore parallel logs, and native plants were used to protect the natural bank on either side of the former gabion wall. For the Tea Hill Park project, the small eroding bank face was protected with haybales and logs to increase the resilience of the shoreline. Native trees, shrubs, and perennials were planted extending from the shoreline into the upland to create a vegetated buffer along the shoreline to help infiltrate runoff. The shoreline access was upgraded to a woodchip path to reduce foot traffic impacts to the shoreline. Within the coming years, it is intended that the vegetation will flourish in the area and lessen the amounts of coastal erosion experienced.

CHAPTER 3: Methods

3.1. Determine Site Selection Criteria

3.1.1. Pre-Site Visit

Thirty-one sites were identified in Queens County, Prince Edward Island (PEI) based on locations found within Queens County that had a coast type of till. The "Coastal Erosion and Shoreline Classification in Stratford, Prince Edward Island" report by O'Carroll (2010) was used as a guide. The O'Carroll (2010) report contains information regarding erosion rates for the assessed sites. Sites were labeled in maps that were included in the report's appendix, each with a unique ID and a point symbol. The map points and their IDs correspond to tables within the appendices giving quantitative and qualitative data for each site (Table 3.1). Any sites that had their coast type as "till" were recorded because till was the selection criterion (Table 3.1). Wetlands were not included in this as the focus was on the highly erodibility of the till banks. These were the sites to be used for the suitability analysis.

Table 3.1. An example table listing qualitative and quantitative data for different sites within the appendix (modified from O'Carroll, 2010).

Site ID	**General Location**	**Exposure**	**Coast Type**	**Easting Coordinate (m)**	**Northing Coordinate (m)**
F103	Bacon Cove W	Strait	Marsh	*383439.02*	*678091.18*
F104	Bacon Cove E	Strait	Marsh	*383922.78*	*678083.98*
F105	Holland Cove, Rocky Point	Strait	Till	*389416.64*	*681529.46*
F106	Ferguson Point, West River	Estuary	Sandstone	*386490.16*	*683413.14*
F107	York Point, North River	Estuary	Till	*387609.34*	*686546.84*

Different living shoreline feasibility assessment tools were reviewed to determine if they were suitable for a PEI context. Some of the tools were interactive, prompting users to answer a sequence of questions on-line. Others were guidelines that aided in the selection and implementation of different living shorelines, or checklists containing different criteria in order to assess site conditions. Each tool had their own set of criteria, making each unique. Throughout the assessment process, the pooled criteria from all tools tended to fall under different sets of categories. The categories were biotic, hydrodynamic, geophysical, soils, erosion rates, exposure, infrastructure, shore armouring, and data that is unmeasurable in the field (Table 3.2).

Table 3.2. Table that characterizes shore armouring criteria between interactive tools, guidelines and checklists. The green highlighting recognizes the inclusion of the parameter within the tool, guideline, or checklist.

Shore Armouring		**Neighboring property armouring**	**Type of armour**	**Condition of armouring**	**Structure elevation**	**Artificial shellfish reefs**	**Barriers to water movement**
Tools	ACASA		🟩	🟩	🟩		
	Woods Hole Group						
	VIMS		🟩				
Guidelines	WDFW						
	NJDEP						
	NNBF	🟩	🟩				🟩
Checklists	CBWES	🟩	🟩	🟩			🟩

After the pooled criteria was organized into tables, the quantitative criteria were recorded for use when conducting site visits. Table 3.3 displays the quantitative criteria that was to be measured during site visits.

Table 3.3. Quantitative criteria for measurement in the field.

Site Info	**Dimensions (m)**	**Slopes (°)**	**Directions (°)**
ID	Shoreline length	Backshore	Shoreline orientation
Date	Shoreline width	Foreshore	Wind direction
Time	Backshore width	Intertidal	
	Nearshore width	Bank	
	Bank height		

Five different zones were measured or characterized in the field – the shoreline, backshore, foreshore, nearshore, and intertidal zone. The shoreline width measured a combination of both backshore and foreshore, with the potential of the nearshore if it was observable. The backshore for this study is the width of the shoreline between the toe of the bank to the high-water line mark or where the sediment significantly changed materials (Figure 3.1). Because research was done at low tide, high-water marks were noted by debris lines on the shoreline – the most prominent being considered the transition between backshore to foreshore. The foreshore area is the width between the high-water line mark or change in sediment characteristic to the most notable berm or change in slope along the shoreline towards the water (Figure 3.1). The intertidal zone was the area between this berm and the lowest water elevation at the lowest tide. The intertidal zone for many of my sites was expansive and was not quantitatively measured. The nearshore according to this research was the area within the intertidal zone where SAV was present at low tides. These shoreline areas are defined slightly differently throughout different literature. Both the definitions characterized in this thesis and in the Davies (2011) report were kept consistent.

Figure 3.1. Photo characterizing the backshore and foreshore areas within a shoreline. A nearshore (area containing SAV) is not present in this photo, though it does exist.

3.1.2. Site visit

Sites were visited within two hours of low tide to analyse the greatest portion of shoreline. At each site, a 20m transect was measured parallel to the shoreline (Figure 3.2) that exhibited similar characteristics throughout to determine consistency. The characterstics were bank height, bank slope, bank material, and the amount of vegetation on the bank face (Figure 3.3.). Three shore-perpendicular subsections were then established per site, arranged along the 20m transect of the shoreline at 0 m, 10 m, and 20 m intervals.

Figure 3.2. Example of a 20m transect. Sub-transects measured at 0m, 10m, and 20m.

Figure 3.3. A coastal bank showing consistent conditions throughout the 20m transect.

Along with recording the quantitative data, photos were captured at each subsection throughout the 20m transect. Photos included were one directly facing the bank when standing on the shoreline in line with the subsection, one directed at the water when standing at the toe of the bank, and two photos directed at each side of the bank when standing at the toe of the bank (Figure 3.4).

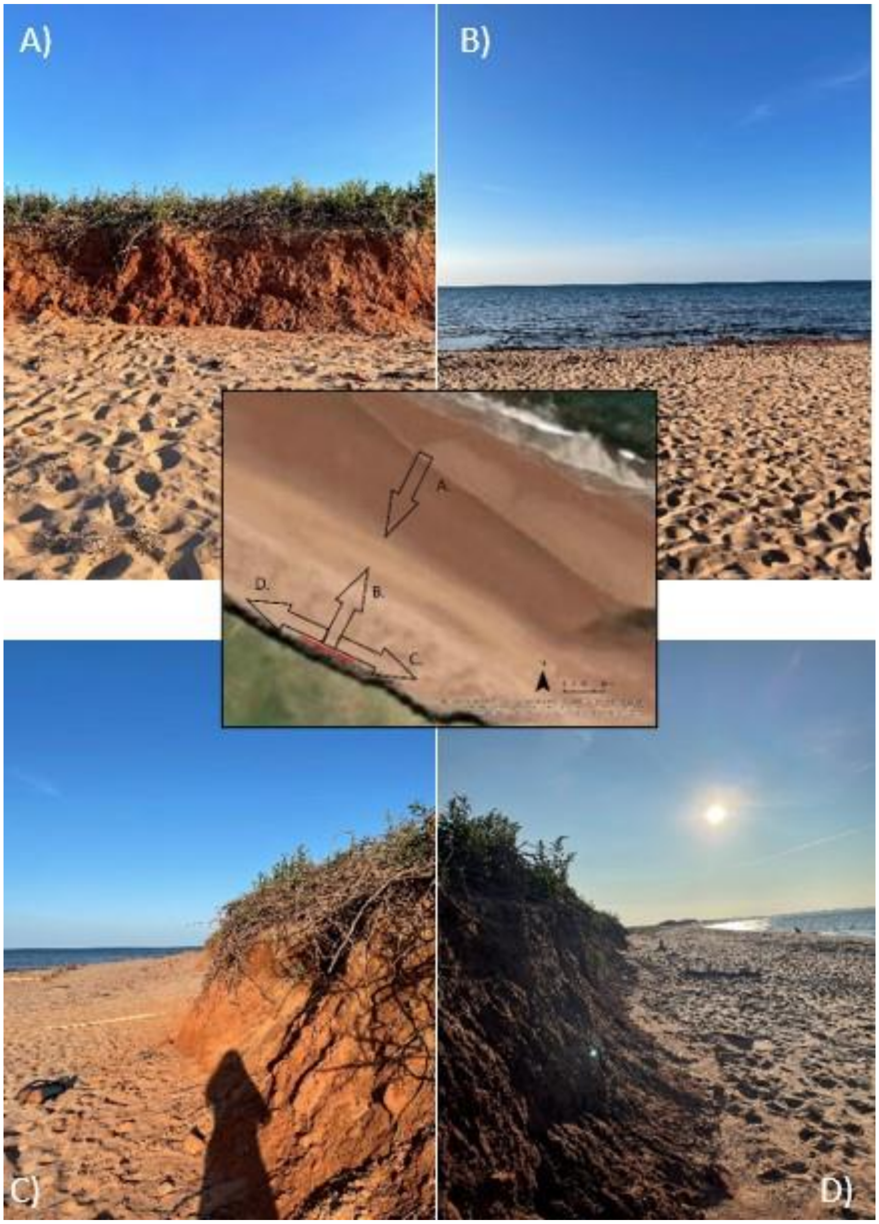


Figure 3.4. An example of site photos from Cavendish Campground West directed in all four directions to be taken at all three sites within the 20m transect.

A 15cm pencil was placed in the sediment on the backshore, nearshore (if present), foreshore, and intertidal zone and photos were taken at each shoreline zone (Figure 3.5). The pencil was used as a qualitative measure to determine sediment size differences along the shoreline and between sites. As the size of the pencil is uniform throughout the photos, the sediments can be compared between the pencil in the photos and different sediments from different sites.

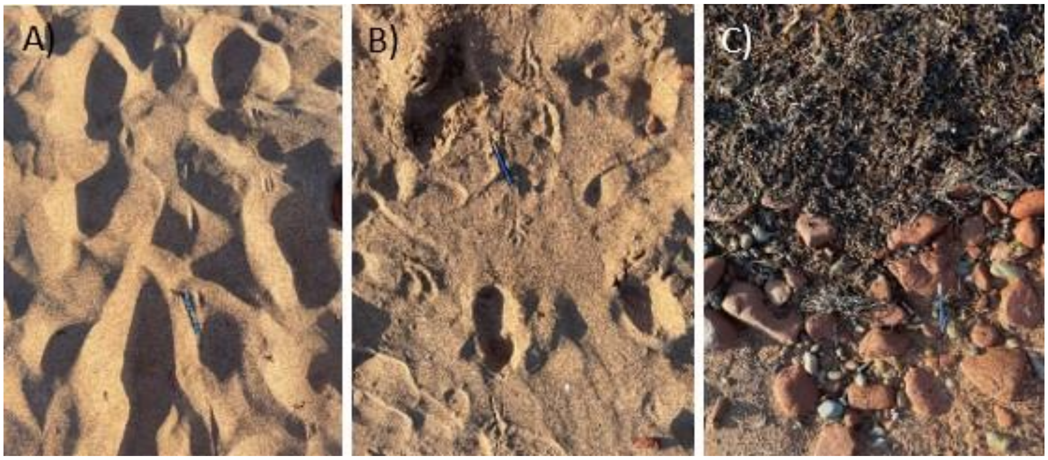


Figure 3.5. An example at the Cavendish Campground West site of grain size and grain characteristic photos taken at three sites within the perpendicular subsection of shoreline. Note the blue pencil in each photo. A) Backshore B) Foreshore C) Intertidal zone.

Qualitative observations at each subsection of the transect during the site visits were made. The observations noted were shoreline vegetation, nearshore submerged aquatic vegetation (SAV), presence of animals, presence of endangered/threatened species, and sediment grain size. Another important qualitative observation that was made was if the bank itself had vegetation growing on it – vegetation that was part of the bank and stabilized (Figure 3.6). These sites were noted as being “reference” sites. If pieces of sod from higher elevations were present on the bank face due to erosion or slumping, but not originally established on the bank face, it was not referred to as being a reference site.

Figure 3.6. A bank located in Rustico Bay Centre composited of till that has vegetation growing in the bank, known as a reference site.

3.1.3. Post-Site Visit

After the site visits were conducted, an excel table was made containing each site name and their corresponding coordinates from recorded field data. A shape file was then created by bringing the standalone table into the map on ArcGIS Pro. This allowed for easy visualization of the sites on the interactive ArcGIS map.

Of seven tools assessed, the three interactive tools were used after site visits were completed. The information gathered during site visits were used in the interactive on-line and off-line tools to produce results for each site. The interactive tools used were the “Decision Tree” by Atlantic Climate Adaptation Solutions Association (ACASA), the “Living Shorelines

Applicability Index" by the Woods Hole Group, and the "Shoreline Decision Support Tool" by the Virginia Institute of Marine Sciences. The results were from the interactive tools were compared to one another for each site.

3.2. Tool Comparison

The seven different tools were assessed using an MCA approach. Each tool's purpose is different due to the focus of its intended output. Some of the tools assessed give direct living shoreline outputs as per a response to inputs, while others give users information regarding potential solutions to coastal erosion and/or flooding hazards an area may face. This following section described how the tool is used, who created it, and states whether or not direct outputs or inferences are given.

3.2.1. Provides Outputs

The tools that are capable of providing outputs as a response to inputs are used in conjunction with the data collected during site visits. Once the information requested from the tools is input, the tool gives unique outputs. By using these tools, we then understand what outputs are possible by the interactive tools we are assessing.

Atlantic Climate Adaptation Solutions Association (ACASA) – The ACASA tool, the "decision tree", requires users to select an answer or multiple (depending on the question) that best suits the site in question by providing options in a multiple-choice format. Once completed, users receive a "Decision Tree Results" page. This page is used as a reference to determine which NbS and/or engineered structure is best suited for the site in question.

Web address: https://atlanticadaptation.ca/en/acasa/user

Virginia Institute of Marine Sciences (VIMS) – The VIMS tool, the "shoreline decision support tool", requires users to select certain answers for the first four (4) multiple-choice questions, to continue. Selecting "no" for the first four questions, if they do not apply to the site in question, allows you to continue to the next, more site specific, questions. After submitting the answers, a printable results page appears with the most suitable living shoreline/engineered structure method to protect the shoreline.

Web address: https://cmap2.vims.edu/LivingShoreline/DecisionSupportTool/

Woods Hole Group – The Woods Hole Group's tool, the "living shorelines applicability matrix", was created in excel. The answers for the site in question were to be selected from the drop-down menu options. As each question was answered, the values for the characterized protection methods changed. These changes altered the suitability of the method by outputting a value of "likely", "possible", or "unlikely". The results are analyzed in the matrix when all questions are answered.

Web address: https://www.northeastoceancouncil.org/wp-content/uploads/2018/12/Final_StateofthePractice_7.2017.pdf

3.2.2. Guidelines

Guidelines are created to guide users to an appropriate method to protect shorelines. Guidelines are not site specific, though similar characteristics of an area can be helpful when creating projects for a new location.

Washington Department of Fish and Wildlife (WDFW) – The WDFW "marine shoreline design guidelines" is a tool that provides a structured process to help determine the best solution to manage coastal erosion at a site, based on the site conditions and processes that occur at the site.

The guidelines do not provide outputs, though potential designs for living shorelines and/or other methods to protect a coastline are available with relevant information within the guideline.

Web address: https://wdfw.wa.gov/sites/default/files/publications/01583/wdfw01583.pdf

New Jersey Department of Environmental Protection (NJDEP) – The NJDEP's "living shorelines engineering guidelines" is used as a guide to ensure that the living shoreline projects are built to the expectation of the State of New Jersey under Permit 24. No outputs are given, though there are recommended living shoreline and/or other methods of shoreline protection information given.

Web address: https://www.nj.gov/dep/cmp/docs/living-shorelines-engineering-guidelines-final.pdf

Natural and Nature-Based Features (NNBF) – The NNBF document is used as a guide to understand the important characteristics of nature-based solutions for flood risk management. No outputs are given using this document, though there is lots of relevant information for coastal areas, processes, and types of shoreline managements.

Web address: https://ewn.erdc.dren.mil/?page_id=4351

3.2.3. Checklists

CB Wetlands and Environmental Specialists (CBWES) – The CBWES checklist, the "shoreline evaluation sheet", guides users in what to look for when conducting a site visit for potential living shoreline projects. The checklist provides no outputs.

3.3. Assessment Framework

An assessment framework was created in excel in order to determine which tool, guideline, or checklist is most suitable for a Prince Edward Island context. Four different tables were created, each with their own categorical criteria within. The categories were accessibility, reproducibility, characteristics, and scientific rigor found from the Workforce EdTech (2021) website. Accessibility refers to how well a tool is laid out for users of all abilities to gain benefits from. If a tool is reproducible, it means that if someone were to go to the field and collect data from the same location, that the tool would output those same findings again. A tool that is characteristic in this sense, refers to a tool that has inputs/outputs that are reflect the conditions of PEI. Scientific rigor was determined by the descriptions of tool criteria, the success with the use of the tool (e.g., demonstrated examples), and the number of available outputs the tool offers.

To use the framework, each criterion had to be characterized by a number to complete an MCA – either two (2), one (1), or zero (0). Two would be the most desirable threshold, and zero the least desirable threshold (Table 3.7). To understand what these values refer to in the context of this assessment, definitions of each threshold were described for each criterion (Appendix B). The definitions were referred to in order to give a proper numeric value for the criteria from the tool, guideline, or checklist. Each criteria table was scaled to 25% to ensure that they all received the same weight of importance when the results were tallied. A “totals” table (Appendix B) was used to incorporate all final values for each four of the tables for the tools, guidelines, and checklists. The summation of these values resulted in an answer that determined whether the tool was a good fit for PEI or not. Since the values were normalized, the tool, guideline, or checklist with the percentage closest to 100% was the most valuable of those investigated.

Table 3.7. Example of the thresholds given to different tools, guidelines, and checklists by criteria. The normalized values for this category of interactive tools, guidelines, and checklists out of 25% are shown in the bottom row.

Scientific Rigor							
Criteria	**Tools**						
	ACASA	**Woods Hole Group**	**VIMS**	**WDFW**	**NJDEP**	**NNBF**	**CBWES**
Descriptions for Criteria	1	2	2	2	2	2	0
Success in Results with Use	N/A	2	2	1	N/A	2	2
Tool Output	1	4	4	3	2	4	2
Normalized (% of 25)	**6**	**25**	**25**	**19**	**13**	**25**	**13**

3.4. Modified Index

The three most applicable tools for the PEI context were noted for living shoreline outputs. The criteria and their corresponding options and/or thresholds that were found in two or more of these tools were included in a table. This showed the differences and similarities between the thresholds of each tool.

An MCA to determine site suitability was needed. In order to begin to create the site-suitability analysis, each threshold in each field had to be coded with a corresponding numeric value. These values corresponding to the criteria thresholds were then summed together to produce a total value for the specific location segment. The higher the value, the more suitable a location for implementation of a living shoreline.

To perform a desktop analysis in GIS and an on-site analysis, the criteria were separated between what values could be easily found on-site and which needed to be determined through a more specialize spatial analysis, found in the geodatabase given by Davies (2011). The criteria were tidal range, wave energy, backshore material, foreshore material, bank composition, and shoreline type from hydrological and physical categories. Spatial data from acquired geodatabases and data from the Government of PEI that were compatible with ArcGIS Pro were used in both analyses. Both quantitative and qualitative data were used in the desktop analysis. Thresholds for the modified index were created based on the thresholds given within the top three tools. The values given by the three tools had to be altered to match the same units as shown in the data layers acquired. The threshold groups were suitable; moderate; and not suitable.

The on-site analysis criteria were primarily qualitative (Table 3.8). This data had to be input into the field table manually as the on-site data collected were not included in any of the geodatabases or layers found. One field was created per criterion, and populated using the information provided by the data collected in the field. As these fields did not contain thresholds per-se in the tools analysed, inputs were considered “suitable”, “moderate”, and “not suitable” and were subject to knowledge based on living shorelines from the guidance documents. This data was amalgamated in ArcGIS with the desktop data using the “spatial join” tool. The point data from the on-site analysis were matched by the closest linear data found within the desktop analysis within 5m. This allowed for maximum data for each location visited in the field.

Table 3.8. Biotic, geophysical, erosional, exposures, infrastructure, and shore armouring in regards to the site level analysis.

Category	**Criteria**
Biotic	Nearshore SAV; Vegetation on bluff/backshore; Shellfish reefs
Geophysical	Foreshore dimensions; Natural features protecting against erosion; Slope of shoreline
Erosion	Type of erosion; Cause of erosion
Exposure	Fetch; Storm Exposure
Infrastructure	Type of infrastructure; Shoreline uses; Type of access
Shore Armouring	Neighboring property armouring; Type of armour; Condition of armour; Barriers to water movement

For both desktop and on-site analysis, new fields were created which allowed for coded values to be set while keeping the original field and acquired data. Thresholds or values that were considered “suitable” were coded with a value of “2”; those considered “moderate” were coded a value of “1”; those considered “not suitable” were coded a value of “0”. The on-site analysis had some criteria that were based on presence and absence, and therefore only were coded as “suitable” or “not suitable”.

Living shorelines are not possible or required at every location. For example, locations with rocky shorelines make it impossible and unnecessary to establish an living shoreline. A field named “POSS_IMPOSS” was created to host these impossible/unnecessary values. The locations where the filed “FSType” equals “Rocky” were selected using a query. A value of “1” indicated that there was the possibility of an NbS to be implemented, while the values noted as “0” signified areas where it is not possible to accommodate an NbS. Locations with null values were coded as “99” in the “POSS_IMPOSS” field as they were inconclusive.

Lastly, a field was created named “SUIT_UNSUIT”. This field dictates whether a section of shoreline will be suitable or not for the implementation of an living shoreline adaptation and by what degree. Each field with their coded number values were added together to produce a total result. These results were then visualized by symbolizing both line and point data using graduated colours. Suitable values were shown in green, moderately suitable in orange, unsuitable in red, and impossible/unnecessary in light grey. Areas where null values were present were coloured in dark grey, representing inconclusive.

3.5. Model Site-Suitability Output

Modeling sites where living shorelines were suitable in PEI started by querying the desktop and field data for the ranges were living shorelines were deemed suitable. The “impossible/unnecessary” range within the suitability index was noted when a foreshore type was rocky and was set to equal zero from the MCA output. The range of other values (suitable, moderately suitable, unsuitable) were determined by dividing the maximum total output value (12) by three as three categories are possible with numeric values that do not equate to zero (Table 3.9). The range of suitable areas for the desktop data was determined to be 9-12 from the “SUIT_UNSUIT” field as it was the group that had the highest numeric values meaning it was the most suitable range, when dividing the highest value possible by three. The field data that was suitable was determined to be 30-46 from the “SUIT_UNSUIT” field. Again, the total possible numeric value for this analysis (46) was divided by 3 to make the same four groupings as the on-site analysis (Table 3.9).

Table 3.9. Suitability ranges for MCA analysis in GIS

	Desktop	On-site
Impossible/unnecessary	0	0
Unsuitable	1-4	1-15
Moderately suitable	5-8	15-30
Suitable	9-12	30-46

After selecting the suitable areas, two new tables for the desktop and on-site analyses were created to host the suitable data. The data was presented on the interactive map. In both analyses, the “frequency” analysis tool was used to determine the different matrix combinations that occur considering all applicable attributes and counting how many times each appear. This analysis tool also computed a summation of the shoreline length accounted for within each matrix in a column named “LENGTH”. The data was then organized in a descending order to easily show which combination of appears most on PEI coastlines.

The other ranges (moderate, unsuitable, impossible/unnecessary, and inconclusive) were queried from the total data and frequency tables for each of these ranges were created. These were each exported as excel files. The “LENGTH” column was summed to calculate how much of the total shoreline fell within each category.

CHAPTER 4: Results

4.1. Baseline condition criteria for the application of living shoreline techniques

Baseline conditions are conditions that need to be met to implement an adaptation technique in a specific location. An ideal tool encompasses all baseline conditions. The NNBF tool is the most in-depth work which accounts for multitudes of different research and literature making it the most comprehensive, overarching nature-based and living shoreline guideline. The criteria in the NNBF tool were divided by geology/geomorphology/sediment, vegetation, and "other" categories (Table 4.1). Each tool when compared to the NNBF lacked crucial baseline criteria for living shorelines.

Table 4.1. Baseline condition criteria divided by category from NNBF.

Baseline Condition Category	**Criteria Included**
Vegetation	Upland type; Composition; Diversity; Abundance
Geology/geomorphology/sediment	Sediment supply; Site position; Bulk density; Grain size distribution; Organic matter composition; Elevation
Other	Light/shading; Wave energy; Current energy; Salinity; Fauna

In the vegetation category, upland type and diversity was not included in any tool other than the NNBF tool. The VIMS tool had one of four vegetation criteria (abundance), the WDFW tool had two of four (composition and diversity), and the CBWES tool also had one of four (composition). In the geology/geomorphology/sediment criteria, the ACASA tool had one of six (sediment supply), the Woods Hole Group tool had one of six (elevation), the WDFW tool had one of six (grain size distribution), and the CBWES tool had one of six (grain size distribution). No mention of site position, bulk density, or organic matter composition were included in any of these tools aside from the NNBF tool. The "other" category was the most populated in terms of criteria that the tools included for baseline conditions (Table 4.2).

Table 4.2. Baseline conditions not associated with vegetative and/or geologic criteria by tool – 'x' representing inclusion.

Tool	**Other**				
	Light/Shading	**Wave Energy**	**Current Energy**	**Salinity**	**Fauna**
ACASA					
Woods Hole Group		x	x		
VIMS	x				
WDFW		x			x
NJDEP	x	x	x	x	
NNBF	x	x	x	x	x
CBWES					

4.2. Comparison of the different tools

A good tool is one that has easy access for all users. It should provide clear descriptions for the different criteria, explaining what the output or resulting information means for a full understanding. The tool should account for all types of users with potential varying abilities, as well (Appendix B). In addition, a good tool should provide evidence of success and outputs. The criteria used for this section of comparison primarily comes from the "Tool Evaluation Criteria" tool created by WorkForce EdTech (2021).

The Woods Hole Group tool was found to be the most successful. Both Woods Hole Group and ACASA were awarded over half of the possible points for this category (Table 4.3). The Woods Hole Group is the most successful due to ability to backtrack without losing previous inputs, no need for registration requirements, photos detailed captions, and its method of being interactive with the user. A value of "N/A" for the "backtracking abilities" criteria, means that no outputs or results are given. None of the tools included in this study have audio availability, and only ACASA offers more than one language (Table 4.3).

Table 4.3. Assessment of accessibility between tools.”2” means most suitable, “1” moderately suitable, and “0” not suitable.

Accessibility							
Criteria	**Tools**						
	ACASA	**Woods Hole Group**	**VIMS**	**WDFW**	**NJDEP**	**NNBF**	**CBWES**
Backtracking Abilities	1	2	1	N/A	N/A	N/A	N/A
Internet Requirements	0	1	0	1	1	1	1
Registration Requirements	0	2	2	2	2	2	2
Instruction Ease	2	1	2	0	1	1	1
Languages Offered	1	0	0	0	0	0	0
Photos to Aid Descriptions or Questions	2	2	0	2	1	1	0
Audio Availability	0	0	0	0	0	0	0
Method	2	2	2	1	1	1	0
Tool Output	8	10	7	6	6	6	4
Normalized (% of 25)	**13**	**16**	**11**	**9**	**9**	**9**	**6**

The most reproducible tool is a tool that is sensitive to differing inputs, available information regarding the criteria, and is easy to reproduce results. The VIMS tool is the most reproducible with 21/25 points awarded (Table 4.4). VIMS has information available regarding the input meaning and also is easily reproducible. Its sensitivity isn’t the most desired as it only scores a value of 1, though it is still sensitive to some of its inputs. “N/A” values for sensitivity meant that the tool is not interactive. “N/A” values for the data collection reproducibility are due to the non-interactive method of the tool, meaning it is not known if the results would be the same. Both the NJDEP and NNBF tools do not acquire any form of reproducibility. The score of zero was based on the fact that the information needed was difficult to acquire, and the tool provided no results, guidelines, or recommendations (Table 4.4).

Table 4.4. Assessment of reproducibility between tools. .”2” means most favoured option, “1” mediocre, and “0” least favoured.

Reproducibility							
Criteria	**Tools**						
	ACASA	**Woods Hole Group**	**VIMS**	**WDFW**	**NJDEP**	**NNBF**	**CBWES**
Sensitivity	2	1	1	N/A	N/A	N/A	N/A
Information Availability	1	1	2	1	0	0	2
Data Collection Reproducibility	1	1	2	N/A	N/A	N/A	N/A
Tool Output	4	3	5	1	0	0	2
Normalized (% of 25)	**17**	**13**	**21**	**4**	**0**	**0**	**8**

The term “characteristic” refers to the tool ability to reflect PEI conditions – how applicable a tool is for a PEI context. To reflect PEI well, a tool must include inputs that meet the characteristics of PEI, such as till banks or erosion processes. It must also consider multiple inputs from physical, biological, and social consideration criteria to be considered to have characteristic inputs that are representative of PEI. The resulting living shoreline output options also have to be characteristic of what can be installed in PEI. All tools are awarded over half of the possible points, with the NNBF and ACASA tools being the highest at 23/25 points (Table 4.5). The NNBF tool is only lacking from the characteristic of PEI point – it does not provide a large amount of information and guidance to properly reflect PEI characteristics. The ACASA tool lacks points in the baseline condition criteria, as well as all other tools, except for NNBF which the baseline conditions were based on. All tools represent physical and biological considerations nicely, with multiple being addressed in each tool.

Table 4.5. Assessment of how a tool reflects PEI characteristics.”2” means most favoured option, “1” mediocre, and “0” least favoured.

Characteristics							
Criteria	**Tools**						
	ACASA	**Woods Hole Group**	**VIMS**	**WDFW**	**NJDEP**	**NNBF**	**CBWES**
Characteristic of PEI	2	2	1	0	0	1	2
Physical Considerations	2	2	2	2	2	2	2
Biological Considerations	2	2	2	2	2	2	2
Social Considerations	2	0	0	0	2	2	2
Baseline Conditions	1	1	1	1	1	2	1
Output Options	2	1	1	1	0	2	N/A
Tool Output	11	8	7	6	7	11	9
Normalized (% of 25)	**23**	**17**	**15**	**13**	**15**	**23**	**19**

A scientifically rigorous tool is one that is not biased and has a design method that is controlled well. Control in this case results in descriptions that are available for easy input of values that all users will understand. Both extremes are found in this category (Table 4.6). The input of “N/A” in this category means that it is unknown if there have been successful projects implemented with this use of the tool. The Woods Hole Group, VIMS, and NNBF tools account for all possible points at 25 making these tools the best candidate for use (Table 4.6). The ACASA tool is the weakest tool for scientific rigor, with only 6/25 points due to lack and inconsistent descriptions of criteria options.

Table 4.6. Assessment of scientific rigor between tools. .”2” means most favoured option, “1” mediocre, and “0” least favoured.

Scientific Rigor							
Criteria	**Tools**						
	ACASA	**Woods Hole Group**	**VIMS**	**WDFW**	**NJDEP**	**NNBF**	**CBWES**
Descriptions for Criteria	1	2	2	2	2	2	0
Success in Results with Use	N/A	2	2	1	N/A	2	2
Tool Output	1	4	4	3	2	4	2
Normalized (% of 25)	**6**	**25**	**25**	**19**	**13**	**25**	**13**

Table 4.7 shows the cumulative results between all categories for each tool analyzed. This does not account for the baseline conditions criteria mentioned previous. The results show that the tool best suited for PEI’s use when viewing all categories equally is the Virginia Institute of Marine Sciences (VIMS) tool.

Table 4.7. Cumulative results for all four categories assessed for each tool.

	ACASA	**Woods Hole Group**	**VIMS**	**WDFW**	**NJDEP**	**NNBF**	**CBWES**
Accessibility	13	16	11	9	9	9	6
Reproducibility	17	13	21	4	0	0	8
Characteristic	23	17	15	13	15	23	19
Scientific Rigor	6	25	25	19	13	13	0
TOTAL (/100)	**58**	**70**	**71**	**45**	**36**	**57**	**46**

4.3. Modified index for PEI of suitability for application of living shoreline techniques.

The ACASA, Woods Hole Group and CBWES tools represent PEI best for characteristics out of the total seven tools previously analyzed (Table 4.8). These three tools provide answers within that directly link to the characteristics of PEI, and hence, are awarded a value of “2” (Table 4.8).

Table 4.8. Blue-shaded cells are the three tools that represent PEI characteristics the best.

Tools	ACASA	Woods Hole Group	VIMS	WDFW	NJDEP	NNBF	CBWES
Characteristic of PEI	2	2	1	0	0	1	2

The GIS package, layer and field name criteria information needed is found within appendix (Appendix C). Living shoreline suitability is based off of the information from these GIS packages, layers, and field data (Table 4.9; Table 4.10). The list of criteria was based off what was found within the three most characteristic tools. Each tool had their own unique groupings and thresholds for the criteria.

Table 4.9. Suitability ranges from desktop analysis for hydrological and geophysical criteria.

Criteria	Suitable (2)	Somewhat (1)	Not suitable (0)
Tidal range	<0.9m	0.9-2.7m	>2.7m
Wave energy	<0.61	0.61-1.52	>1.52
Backshore material	Plain, Marsh	Dune	Cliff
Foreshore material	Sandy, Marsh		Rocky
Bank composition	All		
Shoreline type	Low Plain, Bluff	Wetland, Sand dune	Cliff

Table 4.10. Suitability ranges from on-site analysis for biotic, geophysical, exposures, infrastructure, and shore armouring.

Criteria	**Suitable (2)**	**Somewhat (1)**	**Not suitable (0)**
Nearshore SAV	Persistent	Sparse	Non-existent
Vegetation on bluff/backshore	Yes	Moderate	No
Shellfish reefs	Yes	Moderate	No, Unsure
Foreshore dimensions	Wide (>30m)	Narrow (<30m)	None
Natural features protecting against erosion	Yes; No		
Slope of shoreline	<20°	20-33.3°	>30.3°
Type of erosion	Caused by a single event that will naturally recover	Ongoing continuous erosion; Non-reversible caused by a single event	Ongoing that poses danger
Cause of erosion	Slope failure originating at top	Undercutting by waves	Runoff/precipitation/freshwater
Fetch	<1.5 km	1.5-8.0 km	8.0< km
Storm exposure	Protected	Moderate	Exposed
Type of infrastructure	Park; Road; Trail; Building		
Shoreline uses	None	Recreation	Commercial
Type of access	None	Footpath; Stairs; Boardwalk	Wharf
Neighboring property armouring	Yes; No		
Type of armour	Soft; None	Hybrid; Hard	
Condition of armour	Very good; Good; N/A	Fair; Minor repairs needed	Major repairs needed; Collapsed; Remnant
Barriers to water movement	Permanent sandbar; Breakwater	Causeway; Culvert; Dyke; Bridge; None	Shoreline armouring; Dam; Groyne

4.4. Modeled site suitability output for living shorelines on PEI within Queen's County

Based off the GIS analysis, the total length of PEI's shoreline was calculated to be 3279 km. Of the total length, approximately 35% of the coastline is suitable for living shorelines according to the desktop analysis (Table 4.11; Figure 4.1). The moderate range does not mean unsuitable, therefore, up to 67.4% of the total coastline may be able to host these adaptations with some unnatural intervention. Impossible/unnecessary sections of coastlines are those that have a rocky foreshore and make up 6.3% of PEIs coastline (Figure 4.1.a). Inconclusive sections, 26.3% of PEI coastline, are those that are lacking the important criteria, such as soil type or foreshore type, stated by the three most suitable tools for showcasing characteristics of PEI. Unsuitable sections of coastlines were not identified as rocky foreshores were accounted for already in the "impossible" index – all other foreshores that contain data are not rocky (Figure 4.1.b). This means that all other shoreline sections acquire more than enough points (>4) to have them considered as a "moderate" suitability or higher (Table 4.11).

Table 4.11. Shoreline suitability for the implementation of living shorelines in PEI.

Suitability index	**Shoreline length (km)**	**Percentage (%)**
Suitable	1130.7	34.5
Moderate	1078.9	32.9
Unsuitable	0.0	0.0
Impossible/unnecessary	207.9	6.3
Inconclusive	861.5	26.3

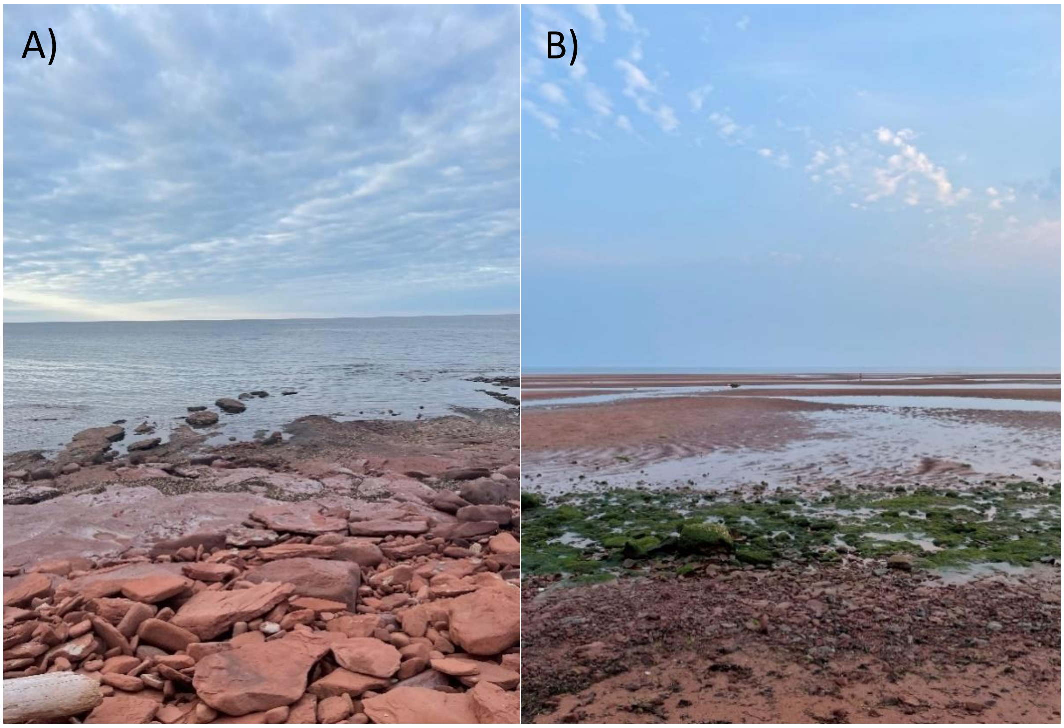


Figure 4.1. A) Example of a rocky foreshore making it impossible/unnecessary to implement a living shoreline; B) Sandy/muddy foreshore where a living shoreline could be implemented

Within the suitable sections of coastlines, over half of the suitable sections were wetland (Table 4.12). Low plain and sand dunes were the next best shore types for implementation of living shorelines. Till bluff and sandstone cliff areas are shown not the best suited for the living shoreline techniques considered in this study.

Table 4.12. Suitable shorelines data for living shorelines divided by shore type for PEI.

Shore type	Shoreline length (km)	Percentage (%)
Bluff	52.71	3.2
Cliff	10.15	0.6
Low plain	233.05	22.4
Sand dune	181.94	17.5
Wetland	652.82	56.3

Viewing the colour-coded coastline map (Figure 4.2), it clearly shows that the north shore of the island is more suitable for living shorelines as compared to the south shore. Both the coastal tips of PEI – west and east – are coded in purple meaning that living shorelines are areas are impossible/unnecessary based on the desktop exercise. The estuaries on both the north and south shore have significant data that is inconclusive, depicted in the dark grey colouring, especially in the Charlottetown region (Figure 4.3). Though true, the north side estuaries are more suitable than the south shore for living shorelines suitability.

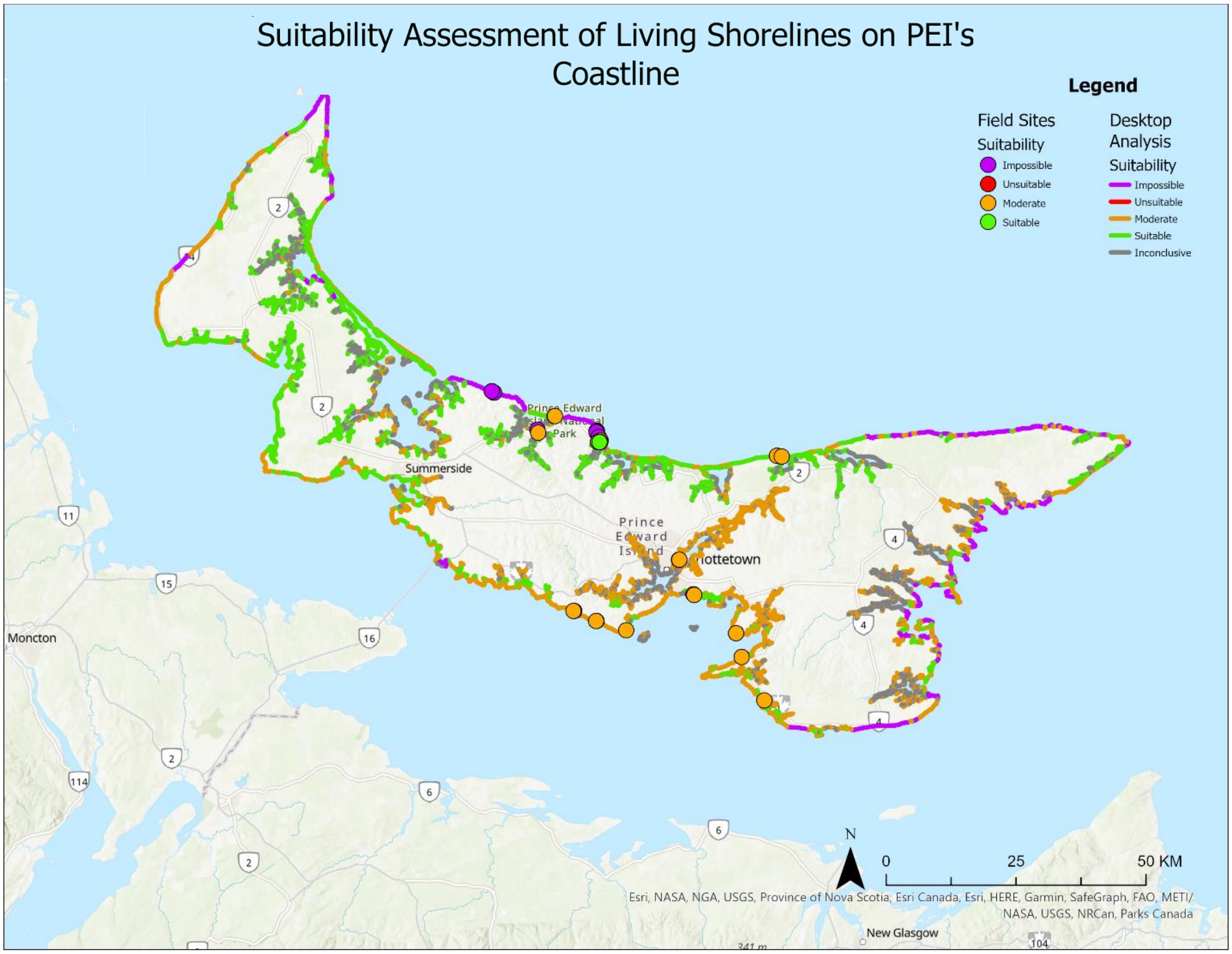


Figure 4.2. Line polygons and point data denoted in green and orange show where living shorelines are suitable or moderately suitable in PEI.

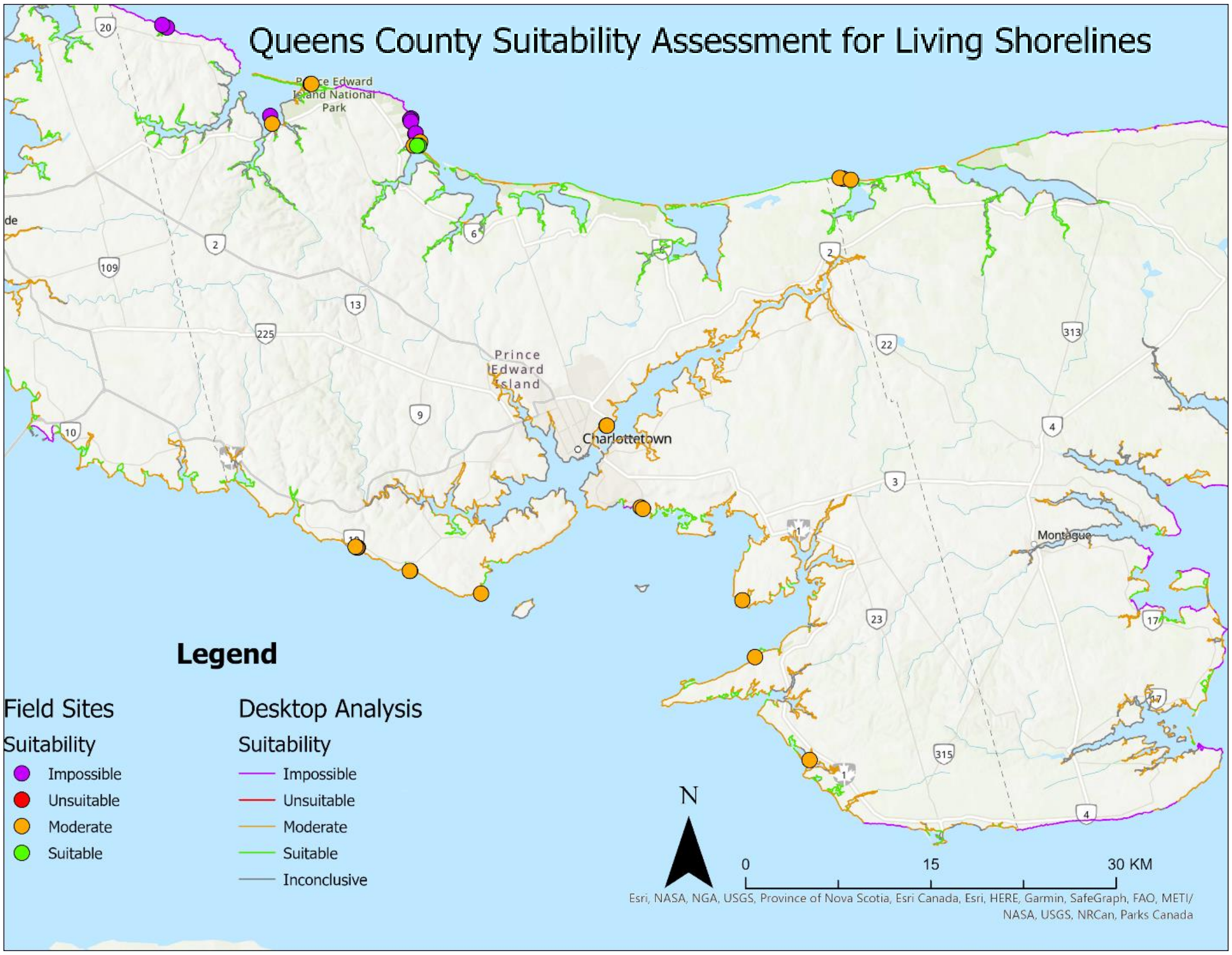


Figure 4.3. Queens County's coastline suitability breakdown.

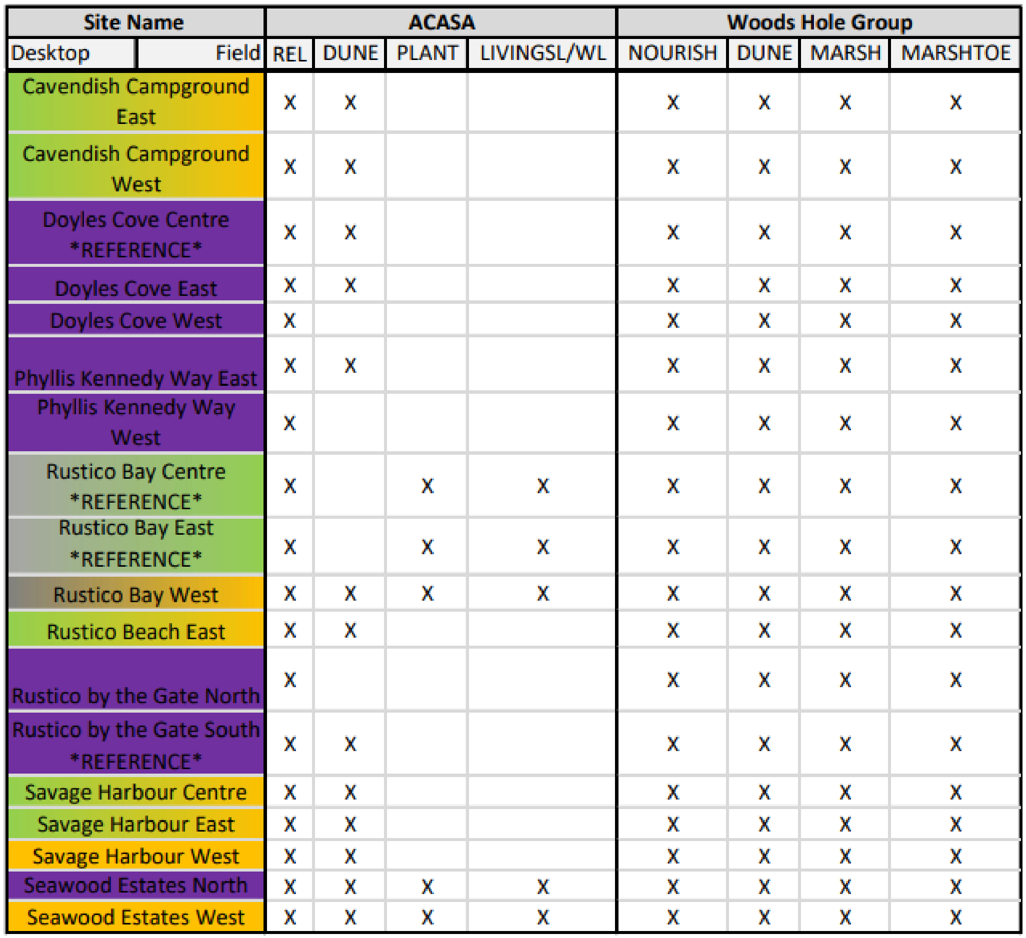
4.5. Comparison between tool results and GIS results

Comparing between tools, desktop analysis, and on-site analysis show outputs that vary with regard to what methods of NbS are suitable (Table 4.11; Table 4.12). The left most colour in the "Site Name" column corresponds to the colouring from the desktop analysis in the suitability maps. The right most colour in the "Site Name" column represents the suitability from the field analysis in the suitability maps. The ACASA and the Woods Hole Group tools gave outputs regarding the most suitable implementation techniques for an area. The CBWES checklist was not included in this table because it did not produce outputs. Though no outputs were given, it was used to inform the design of the Queen Elizabeth Hospital and Tea Hill Park living shoreline sites in Charlottetown and Stratford, respectively. The purpose of the GIS analyses was to produce suitability ranges, and not specify types of nature-based solutions.

For the tools examined, the most common outputs for the ACASA tool were the relocation of infrastructure and natural dune building, with relocation being the standard option for all sites (Table 4.13; Table 4.14). The Woods Hole Groups tool did not differ much between any of the sites. Along the north shore, each site was stated to be suitable for implementing beach nourishment, dune building, natural marsh creation/enhancement, and natural marsh creation/enhancement with toe protection as natural protection methods. The same was noted within the south shore locations, with the exception of QEH East and QEH west. These two locations did not support the implementation of a natural marsh creation/enhancement – these locations require the toe protection. ACASA and Woods Hole Group referred to living shorelines directly. The Woods Hole Group tool's output options regarding creation and enhancement of marsh/wetland and column titles refers to living shorelines. CBWES, as a checklist, did not produce any outputs (Appendix D). These are not mapped.

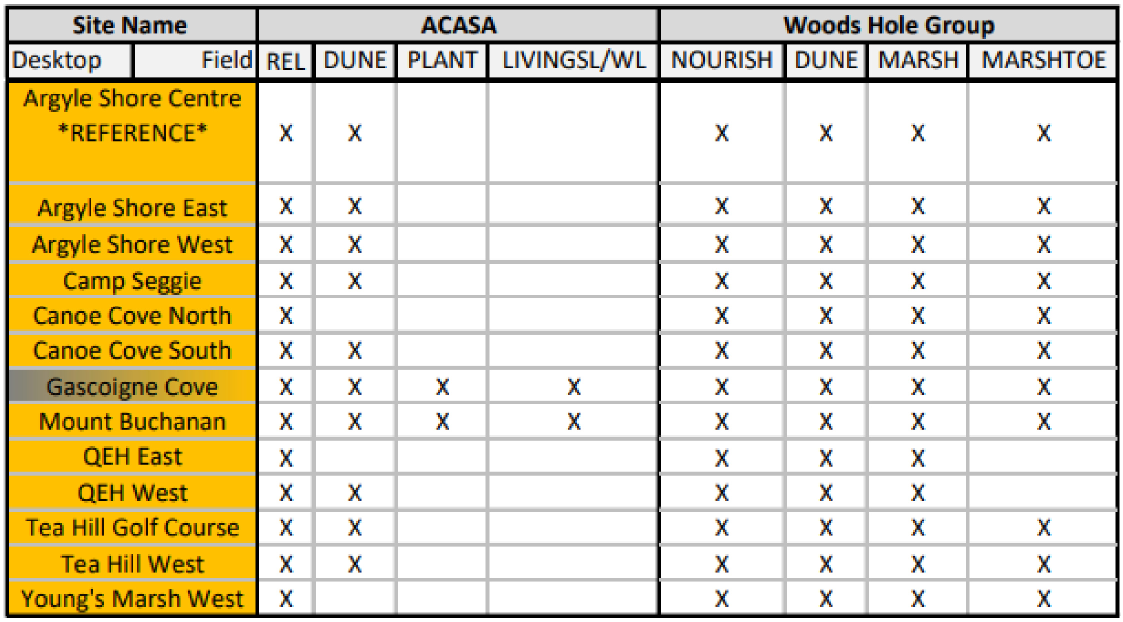
The north shore sites providing "impossible/unnecessary" outputs occurred both for the desktop and on-site MCA analyses (Table 4.13). No outputs were inconclusive within the on-site results. No values between desktop and on-site were the same with the exception of Savage Harbour West and Seawood Estates West. Any location that was output as "suitable" in the desktop analysis, was output as "moderate" in the on-site analysis. The south shore outputs had only "moderate" outputs for both desktop and field analysis with the exception of Gascoigne Cove (Table 4.12). This site had an output of "inconclusive" in the desktop analysis, and as "moderate" for the on-site analysis (Table 4.14).

Table 4.13. Comparison between the north shore adaptation outputs given by conducting GIS (desktop and field) analysis and tool outputs from the two best interactive tools (ACASA and the Woods Hole Group). Refer to Appendix D for descriptions of tool outputs. Green = suitable; orange = moderate; red = unsuitable; purple = impossible/unnecessary; grey = inconclusive



Site Name			ACASA				Woods Hole Group			
Desktop	Field		REL	DUNE	PLANT	LIVINGSL/WL	NOURISH	DUNE	MARSH	MARSHTOE
🟩	🟧	Cavendish Campground East	X	X			X	X	X	X
🟩	🟧	Cavendish Campground West	X	X			X	X	X	X
🟪	🟪	Doyles Cove Centre *REFERENCE*	X	X			X	X	X	X
🟪	🟪	Doyles Cove East	X	X			X	X	X	X
🟪	🟪	Doyles Cove West	X				X	X	X	X
🟪	🟪	Phyllis Kennedy Way East	X	X			X	X	X	X
🟪	🟪	Phyllis Kennedy Way West	X				X	X	X	X
▨	🟩	Rustico Bay Centre *REFERENCE*	X		X	X	X	X	X	X
▨	🟩	Rustico Bay East *REFERENCE*	X		X	X	X	X	X	X
▨	🟧	Rustico Bay West	X	X	X	X	X	X	X	X
🟩	🟧	Rustico Beach East	X	X			X	X	X	X
🟪	🟪	Rustico by the Gate North	X				X	X	X	X
🟪	🟪	Rustico by the Gate South *REFERENCE*	X	X			X	X	X	X
🟩	🟩	Savage Harbour Centre	X	X			X	X	X	X
🟩	🟩	Savage Harbour East	X	X			X	X	X	X
🟧	🟧	Savage Harbour West	X	X			X	X	X	X
🟪	🟪	Seawood Estates North	X	X	X	X	X	X	X	X
🟧	🟧	Seawood Estates West	X	X	X	X	X	X	X	X

Table 4.14. Comparing south shore outputs between GIS (desktop and field) and tool outputs (ACASA and the Woods Hole Group). Refer to Appendix D for descriptions of tool outputs. Orange = moderate; grey = inconclusive.



Site Name		**ACASA**				**Woods Hole Group**			
Desktop	Field	REL	DUNE	PLANT	LIVINGSL/WL	NOURISH	DUNE	MARSH	MARSHTOE
Argyle Shore Centre *REFERENCE*		X	X			X	X	X	X
Argyle Shore East		X	X			X	X	X	X
Argyle Shore West		X	X			X	X	X	X
Camp Seggie		X	X			X	X	X	X
Canoe Cove North		X				X	X	X	X
Canoe Cove South		X	X			X	X	X	X
Gascoigne Cove		X	X	X	X	X	X	X	X
Mount Buchanan		X	X	X	X	X	X	X	X
QEH East		X				X	X	X	
QEH West		X	X			X	X	X	
Tea Hill Golf Course		X	X			X	X	X	X
Tea Hill West		X	X			X	X	X	X
Young's Marsh West		X				X	X	X	X

The additional data collected with field visits allowed for a more intricate representation for areas to host living shorelines. Discrepancies were shown to be common when comparing desktop and field analyses. Due to the lack of soil and foreshore type information within the desktop analysis, to assess a site for living shoreline, a field visit is critical.

Site names followed by "*REFERENCE*" acknowledged that the majority of the bank face was vegetated. These sites should have the ability to host living shorelines as the vegetation shows that the bank is stable. Doyles Cove Centre, Rustico by the Gate South, and Argyle Shore Centre, should all be suitable for living shorelines according to the site visits. In the both the desktop and on-site GIS analysis, both Doyles Cove Centre and Rustico by the Gate South were analyzed to be impossible/unnecessary (Table 4.13 and Figure 4.4). Argyle Shore Centre was analyzed as being moderate in both desktop and on-site GIS analysis (Table 4.14 and Figure 4.5). Backshore material was not considered when classifying locations in the field as reference or not.

Figure 4.4. Both reference sites due to the vegetation growing within the bank face. A) Doyles Cove Centre; B) Rustico by the Gate South

Figure 4.5. Argyle Shore Centre reference site.

CHAPTER 5: Discussion and Conclusion

The goal of this project was to locate sections of coastline that would be suitable for living shoreline implementation. The best suited tool with nature-based adaptation outputs that reflect PEIs characteristics was determined. With the suitable sections mapped, and the best implementation options given, coastal property owners and governments can use this information as a guide to base their own living shoreline projects from. However, the desktop analysis does not replace the need to conduct a detailed site assessment in the field.

5.1. Tool Usefulness

5.1.1. Number of output options

The number of criteria a tool incorporates and its associated input options, leads to the number of outputs that are possible. The ACASA tool has 19 questions that all need to be answered, with multiple selections, to produce an output. Because of this, the ACASA tool shows variability in outputs between sites meaning it is sensitive to inputs, making the tool site specific. There are 11 different options associated with mitigating erosion, and an additional six options for adaptation that focus on erosion and flooding, together. In comparison, the Woods Hole Group tool only has eight input questions. The fewer criteria needed leads to fewer combinations from inputs for a site analysis. This leads to a tool that is not very sensitive to input options. Eight output options are available with the Woods Hole Group tool.

The application of the ACASA tool to the 31 sites assessed in this study, produced four different options. Using the Woods Hole Group tool for the same 31 sites produced identical outputs with the exception of two sites. Those two sites that differed from the rest were the same, and in very close proximity of each other. The four different options produced by the ACASA tool show that it takes more site-specific details into consideration than compared to the Woods Hole Group tool where the results were nearly homogenous. Yes, the sites did not differ too much as the area studied not large, but sites differed enough to differentiate between only two options. Hence, in the case of usefulness in the real world for decision making, ACASA is the better option to use.

5.1.2. Amount of human interaction required for implementation

Another perspective to look at the tools from is how much human interaction is required to implement and upkeep the recommended adaptations results. Osaka *et al* (2021) defines three different types of living shoreline adaptations based on the amount of human interaction required throughout the process. Type 1 involves very seldom to no interaction between humans and the shoreline area where the implementation will take place; Type 2 involves little human-shoreline interaction that requires humans to physically implement the installation method; and Type 3 involves lots of human-shoreline interaction during the life cycle of the living shoreline. The ACASA tool has Type 1 (relocate infrastructure) and Type 2 (dune building and plant stabilization) for human-shoreline interaction. Though for dune building, if you are building a dune on a shoreline where one does not exist already, hence you are creating a new ecosystem, this involves heavy human interaction which falls in a Type 3 category. This is true for the dune building category for the Woods Hole Group tool as well. The Woods Hole Group tool also has Type 2 (beach nourishment and wetland/marsh enhancement with and without toe protection). Type 3 is associated with wetland/marsh creation with and without toe protection.

The type of project being implemented and who is conducting the implementation determines the amount of human-shoreline interaction that is allowed or wanted. If property owners were looking for an living shoreline to be implemented to protect their property, provincial laws and regulations may hinder some of the options. Changes to shorelines have to be conducted through specific licensed contractors given by the Government of PEI or a Watercourse, Wetland, and Buffer Zone Activity Permit needs to be submitted prior to beginning alterations (DV8 Consulting, 2016). As the ACASA tool is made for use within the maritime provinces of Canada, it does give estimates on how much involvement governments have with its outputs.

5.1.3. Realistic tool outputs

Because the goal of the tool is to predict the best options for living shorelines, a part of NbS, it is also important to understand what outputs are considered "nature-based solutions". The majority of the results gathered are living shorelines included under NbS because of the use of natural materials. Dune building is a recommendation from both ACASA and Woods Hole Group and is a living shoreline if natural materials such as sand, sand fences, etc. are used. Though, in some cases for a dune to establish, additional "hard" materials such as a geotextile base are needed to establish dune growth (Leys & Bryce, 2016) creating an adaptation type that is not fully natural, though still considered a living shoreline. Beach nourishment, plant stabilization, restoration and/or creation of living shorelines or marsh/wetlands are NbS, as well. The "relocation" result given from ACASA, is also, a living shoreline. With relocation, there can be some misinterpretation as to why it is considered a living shoreline as no natural material is added to the coastline. Though true, relocation provides a larger area for the coastline to be eroded without damaging infrastructure previously at risk or putting human lives in danger (Seddon, *et al.*, 2020). Marsh creation/enhancement with toe protection is a living shoreline as long as the toe protection created is created with the intent of hosting natural organisms or it is made from natural materials. These natural materials could be natural fibre rolls, or shell bags such as oyster or mussel shells (Woods Hole Group, Inc, 2017).

The tool outputs for the majority of the sites visited, gave techniques that would be appropriate for those areas. Between all of the outputs options resulting from the ACASA and Woods Hole Tool, all are feasible to implement in PEI. Relocation is an appropriate option at all sites (Figure 4.11 & Figure 4.12). No sites were unique enough that the infrastructure surrounding could not be relocated if necessary – if costs were not part of the problem. One issue with the outputs given by both ACASA and the Woods Hole Tool is dune building as a common output. Dunes require additional conditions that are not reflected in the tools. Dunes require a large supply of sand, a large beach that contains dry sand, onshore wind, and an obstacle for the dune to form against (Davidson-Arnott, *et al.*, 2019). In estuarine bays and areas where there is no onshore wind, and minimal dry sand, dunes should not form. According to ACASA, Rustico Bay West should be able to host dune building – along with all estuarine sites according to Woods Hole Group. Rustico Bay West, as an example, is a developed coastline with lots of infrastructure in close proximity. If a dune building implementation were to happen at this location regardless of these unfavourable conditions, and the winds just happened to be right, the sand would be lost again to the water as there is no space for the dune material to shift inland (Wootton, 2016).

Figure 5.1. Rustico Bay West location showing the infrastructure and uses of the area beyond the shoreline, not suitable for dune building as stated by ACASA and Woods Hool Group.

5.2. North vs. South Shore

Living shorelines are typically best suited in areas that are sheltered from the open ocean, such as bays, tributaries, and estuaries (National Oceanic and Atmospheric Administration, n.d.). Based on these criteria, few sections of PEI should be suitable for living shorelines when they are located on the exposed northern coasts. With the results found showing that segments of the open coast are moderately suitable for living shorelines, the previous statement is counteracted to a degree. The bays, tributaries, and estuaries definitely were notably better suited for the implementation of living shorelines on the north shore.

Looking at the GIS outputs in Figure 4.2, the areas of shoreline that are suitable on the north shore are more suitable than those on the south shore. This finding was not expected. It was excepted there would be more suitable areas along the south shore rather than the north because there is more open water on the north coast with the Gulf of St. Lawrence as compared to the south with the Northumberland Strait. Wave action tends to be more prominent on areas that have greater amount of open water, which is why the result was not expected. Perhaps the dominant wind direction that was not part of the multicriterial analysis resulted in these unexcepted results. The characteristics of the different coasts (e.g., different percentages of dunes, bluffs, etc.) also may have contributed to these results. Because the estuaries and tidal inlets on the north coast are more prominent, it may lead to a false sense of "the north coast being more suitable", as the suitable areas stand out in the estuaries and inlets, though the open coast itself is only moderate. Another reason why the north shore many have been more suitable than the south was due to the wide sandy beaches on the north shore that provide a buffer area to implement these living shoreline adaptations on.

As for the winds, lack of dominant wind direction criteria used in the analysis may have been an issue. Compensating for wind were fetch and exposure values. The fetch criteria used in the field analysis was calculated by five lines, evenly spaced radially, from each location to the nearest lands, then divided by five. This method doesn't account for which direction has more of an impact on the fetch, as all five lines are weighted equally. For exposure, it was a qualitative value (exposed, moderately exposed, protected) used from the ACASA tool that may not have properly been implemented in the field.

The large presence of dune areas as compared to rocky areas along the north shore (Figure 2.3 – Figure 2.6) may also be a reason why living shorelines are more suitable on the north shore. Larger estuaries, too, that are present on the northern shore which allow for conditions that can accompany living shorelines easily. In these estuaries, wave action is lessened and accretion ability of sediments can occur.

5.3. Bluffs characterizing reference sites

Areas that were located on shorelines that contained bluffs were only 3.2% of the suitable data – almost 53 km of shoreline (Figure 4.10). Till is highly friable and susceptible to erosive forces (Davies, 2011). As shorelines have land-water interactions (if no hard engineered structures and in place), the till bluffs are eroded when water interacts were their base. Because living shorelines and other NbS can have lag time to see fully intended benefits, segments of shoreline which are composed of till are not generally suitable for some types of adaptation techniques, as noted from our output percentage.

Reference sites are segments of shoreline that have till bank and an abundance of stable vegetation growing from the bank face. Reasons for these two characteristics to be juxtaposed may have to do with foreshore type. Rocky shelves at the toe of the banks, as seen in Doyles Cove Centre and Rustico by the Beach South (Figure 4.4), may dissolve some of the incoming wave energy from the open coast allowing the bank to be stable and host vegetation. Although Figure 4.11 considers these areas impossible/unnecessary for hosting living shorelines, the bluffs seem to be stable already. Another reason why vegetation may be able to grow on till banks is due to the type of water body that interacts with the shoreline. Estuarine areas, where wave action is not strong, may allow for a more stable till bluff. Water may rise and fall with the tides but not crash against it, eating away at the bank itself.

Comparing between a bluff that was 5m to one that was 10m, it is thought that it would be more likely that a living shoreline would be implemented on the 5m due to available space. To regrade a bluff to an acceptable angle of 30-35° on glacial till (Ottawa, n.d.) for vegetation to grow, a lower bank would take up less space beyond the shoreline, causing lessened impacts to the infrastructure around the shoreline if any. Though true, there is no correlation found between bluff erosion and bluff height (Buckler & Winters, 1983). The material eroded off the bank face is brought to the toe, and removed by wave processes no matter the height (Buckler & Winters, 1983). Another limiting factor to this is the presence of endangered bank swallow nests housed within these eroding till banks, which are not allowed to be disturbed.

5.4. Limitations to MCA and strength of model output

Although the use of an MCA is handy for planning and management, there are limitations to this type of analysis. One limitation is that just because an MCA is conducted for a site and provides outputs that seem to provide a comprehensive result, does not mean that it replaces the on-site visit. As seen throughout the desktop and on-site visits, the data within the geodatabase provided by Davies (2011) doesn’t consistently match what is actually in the field as it was conducted over a decade ago via desktop analysis. Material on the shoreline may have shifted since initial data were collected, or were misidentified during interpretation. As this geodatabase is primarily used throughout the desktop analysis, it leads the outputs to be incorrect in certain places. Because field assessments included foreshore types that were identified by the desktop criteria, some areas have been classified incorrectly. For example, Savage Harbour West is classified as “sandy” as per the desktop analysis. When conducting the site visit, the same area showed it to be a rocky foreshore area. This gives a false positive in the outputs, otherwise known as a type 1 error. Phyllis Kennedy Way East was classified as “rocky” when during the site visit it was clearly sandy material. This gives a false negative in the outputs, otherwise known as a type 2 error. The incorrect data within the geodatabase limits the correctness of the MCA. In the case of this study, if a type 1 error were to occur and not be recognized, time and money could potentially be wasted creating an implementation framework for an NbS where it simply cannot be used. In this case, type 1 errors are more dangerous.

Other limitations arise when using an MCA in conjunction with GIS. As each criterion is weighted, the data are based on quality and the expertise level of whomever is conducting the analysis (Gonzalez & Enriquez-de-Salamanca, 2018). This issue then becomes subjective to the weighted values and judgements can be different between different researchers causing discrepancies (Gonzalez & Enriquez-de-Salamanca, 2018). As the MCA conducted during this research contained all criteria weighted equally, the results may be skewed in a way that does not represent the results in the most correct manor. In reality, some criteria used would have more of an influential effect on whether or not a living shoreline could be implemented at a specific location. Chen (2010) gave weighted values that were dependent on a sensitivity analysis. The lesser weighted values were given to the criteria that were more stable throughout the study area, and higher weights for criteria that were not as stable. This allowed for differing visual representations within GIS to showcase just how much change would occur when sensitive criteria were given those higher weights in the MCA (Chen, 2010).

One reason for the inconclusive outputs in the MCA analysis is a result of having missing foreshore type data for a wide range of segments – known as data constraints (Gonzalez & Enriquez-de-Salamanca, 2018). This could be the result of a “sandwiching” effect. This would mean that the ends of a shoreline are stated as having X for their foreshore type, while the ones in the midsection (that are the same as the ends) do not have the foreshore type obviously stated. Another reason is that some soil types were given null values, leading to inconclusive outputs as soil type is an important criterion for suitable areas for living shorelines.

Shorelines are dynamic systems with sediment and materials always shifting within the shoreline. The incorrect classifications may also have to do with the shoreline break down. The section breakdown between the toe of bank to water, are slightly different from desktop analysis compared to what was used during the site visits. With the discrepancies between the two, the material shown in, say, the foreshore, might be different between the two methods which then give differing results. Problems occurring from these incorrect results are the outputs shown in the map. Locations, such as the ones mentioned that were found to be wrong, are coloured incorrectly in the map due to some outdated data from the geodatabase that they use.

5.5. Potential Challenges

Potential challenges may arise when implementing living shorelines in PEI. As these nature-based methods are not yet common implementation types in PEI, property owners may be hesitant to shift their methods from hard engineered structures as they are not familiar with living shorelines. When collecting field data during the summer of 2021, many sites had people out strolling the beaches, and many stopped to ask what was being measured/assessed. After speaking with some property owners, it was found that at the Argyle Shore East site, the amount of erosion that occurred over the winter was in the meters, according to the property owner. A brand new hard armoured structure of hard stones along the bank was just implemented a few days before, as a way to “protect” against erosion. The folks that were spoken to seemed to understand the downfalls to adjacent properties, potentially their own, with the implementation of hard engineered structures. Even though the understanding was evident, they thought that the neighbors would follow suit as a trend. This information aligns with the study by Gittman, *et al.*

(2020) stating that social pressures of the type of installment neighboring properties have a direct influence on those property owners adjacent.

Another challenge that nature-based solutions face in regards to coastal property owners is that all of the intended benefits are not seen instantaneously. This does not mean that no benefits are seen right away from day one of implementation. Many implementation methods include the use of native vegetation to protect the shoreline against erosion. Vegetation takes time to stabilize within an environment, therefore the benefits to an area may not be noted for a few months or years. The benefit of implementing natural structures not being seen instantaneously, may lead to a false sense of failure with the project. Because hard structures show a physical barrier between the shoreline and water, they are thought to provide instantaneous benefits by many. Proper education for coastal property owners about the time lag noted before benefits are reaped, and the multiple benefits when the living shoreline is stabilized is required for successful new initiatives (Cohen-Shacham, *et al.,* 2019). It is important that governmental and non-governmental groups take action and implement policies that will invoke change within implementation information. It is also important that these groups are not vague or overly defined with their definitions and frameworks, as that may lead to confusion or an overwhelming feeling. These feelings may deter those important stakeholders, such as coastal property owners, from using a living shoreline as their choice of protection (Cohen-Shacham, *et al.,* 2019). A spokesperson from Helping Nature Heal Inc., based out of Nova Scotia, says that within five years of implementation of living shorelines that no maintenance is typically needed and the system is self-sufficient (CBC News, 2015).

Although the cost of materials for living shorelines is said to typical be a more economical option when compared to hard structures, this may not always be the case in the grand scheme of things. In situations where hard structures already exist, removal of the material may be costly if fully shifting to a living shoreline. Hiring a contractor to determine the best adaptation technique for a specific segment of shoreline is also an expensive process. Property owners in PEI are in charge of all the expenses for upkeep of the stabilization methods required (DV8 Consulting, 2016). If the proposed project by the contractor fails, the property owner is still responsible for the clean-up of the remnant materials (DV8 Consulting, 2016). Of course, there are cheaper alternatives that still provide some protection that are not listed within the tools. Packing brush and branches at the toe of a bank is a natural, and usually cheap, way to disrupt the immanent energy from the waves crashing on the shore which cause erosion, were seen along some shorelines during site visits (McLean, 2015). The South Shore Watershed Alliance completed a living shoreline, created out of brush, in 2015 and thought it to be the first of its kind implemented on public land in PEI (McLean, 2015).

5.6. Potential for implementing living shorelines in PEI

The areas that had the best potential for implementing living shorelines in PEI from on-site analyses were Rustico Bay Centre and Rustico Bay East. These are the two areas that should be prioritized for ground truthing.

Because many of the suitability outputs for the sites on the north coast did not match between desktop and on-site MCA, it may be hard to identify areas that were not visited in the field. There are lots of suitable areas along the north shore within estuaries when using the desktop MCA, but a site visit and a run through the MCA with the field criteria as well, may show areas that are only now moderately suitable.

The south shore lacks suitable areas when compared to the north shore. Only one site, Gascoigne Cove, showed different outputs between the desktop and field analysis. Although, the outputs match, a site visit needs to be conducted regardless before a decision is made on where a NbS should be implemented.

5.7. Conclusion and Recommendations

Considering all the facts, it is found true that living shorelines are suitable in PEI. Of these suitable areas, nearly 60% are wetland shore types.

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Figure 5.2. An example of a marsh where NbS may be implemented.

The MCA is a useful evaluation of numerous criteria, though it is hindered by its limitations. The limitations that the MCA is obstructed by are the amount of data that is available, the correctness of the data used, and the equal weighting of all criteria used in this particular experiment.

The lack of encouragement and education for living shorelines in PEI is slowing the transition between hard engineered structures to these natural methods of erosion protection. The use of hard structures is still present today and the persuasive ability of neighboring properties is challenging to overcome. As coastal property owners continue to implement hard structures, neighboring coastal property owners tend to follow suit. There need to be more visible demonstration sites across PEI that show that these natural methods work and provide co-benefits to both humans and the environment.

The following considerations in implementing living shorelines in PEI are recommended…

- Always conduct a site visit before making decisions
- Engage a knowledgeable practitioner in the design and implementations of living shorelines
- Allow sufficient time and resources to undertake permitting and material sourcing
- Ground truth various sites located in the desktop analysis
- Weight the criteria used in the MCA according to its sensitivity
- Encourage governments, NGOs, and other organizations to prioritize education and workshops regarding living shorelines

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Appendices

Appendix A: Sites assessed in different locations

Figure A1. Argyle Shore sites that were assessed.

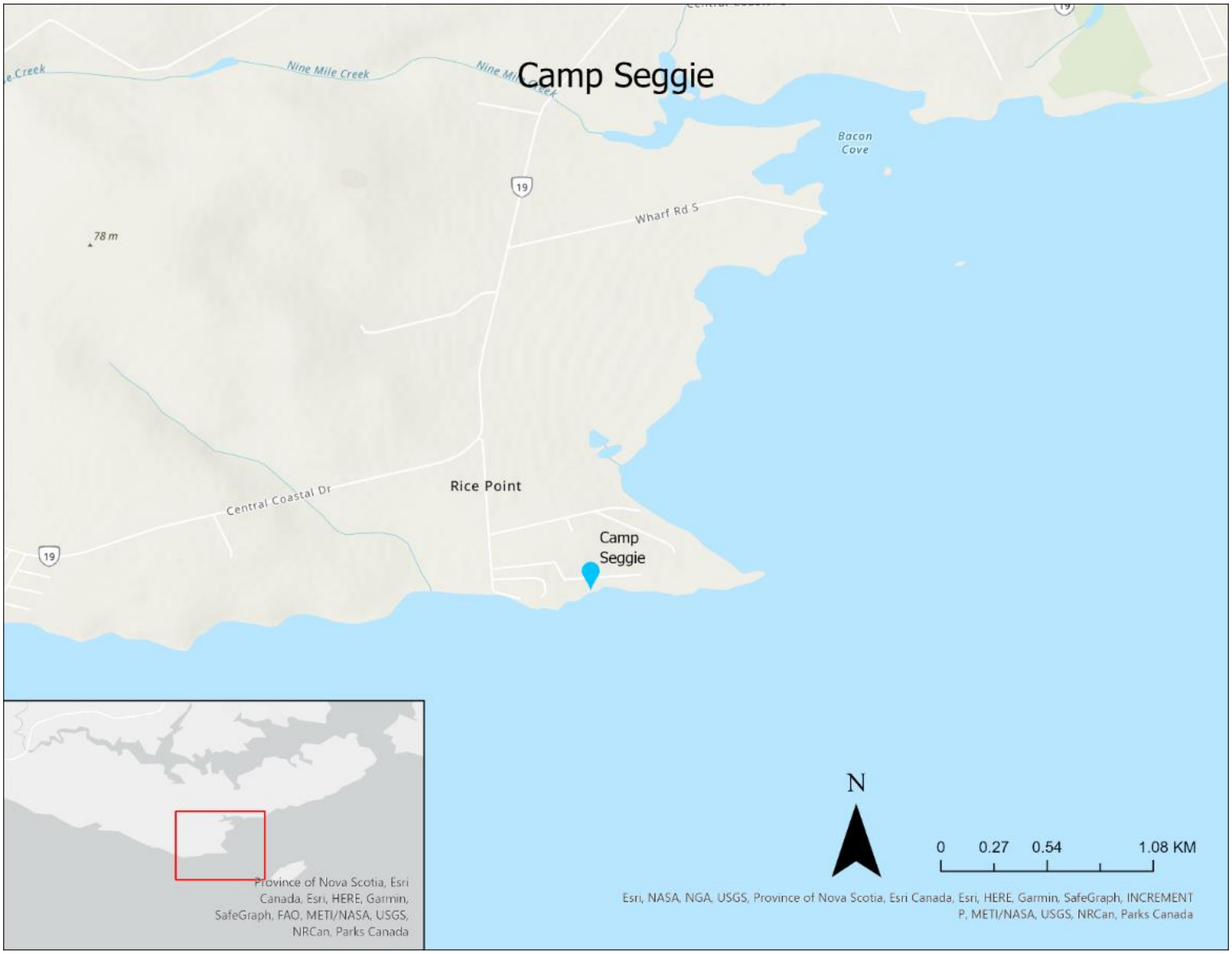


Figure A2. The Camp Seggie site that was assessed.

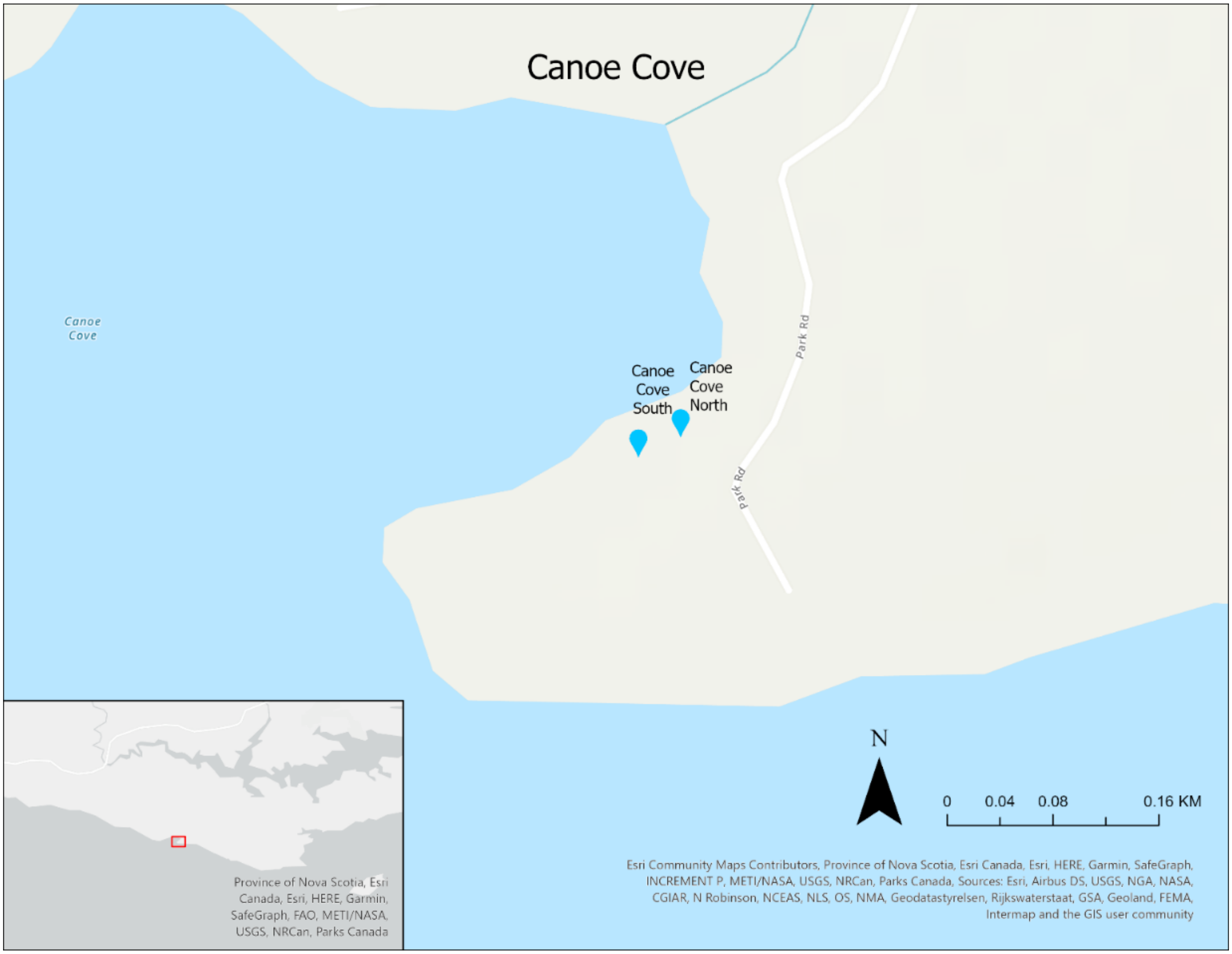


Figure A3. The Canoe Cove sites that were assessed.

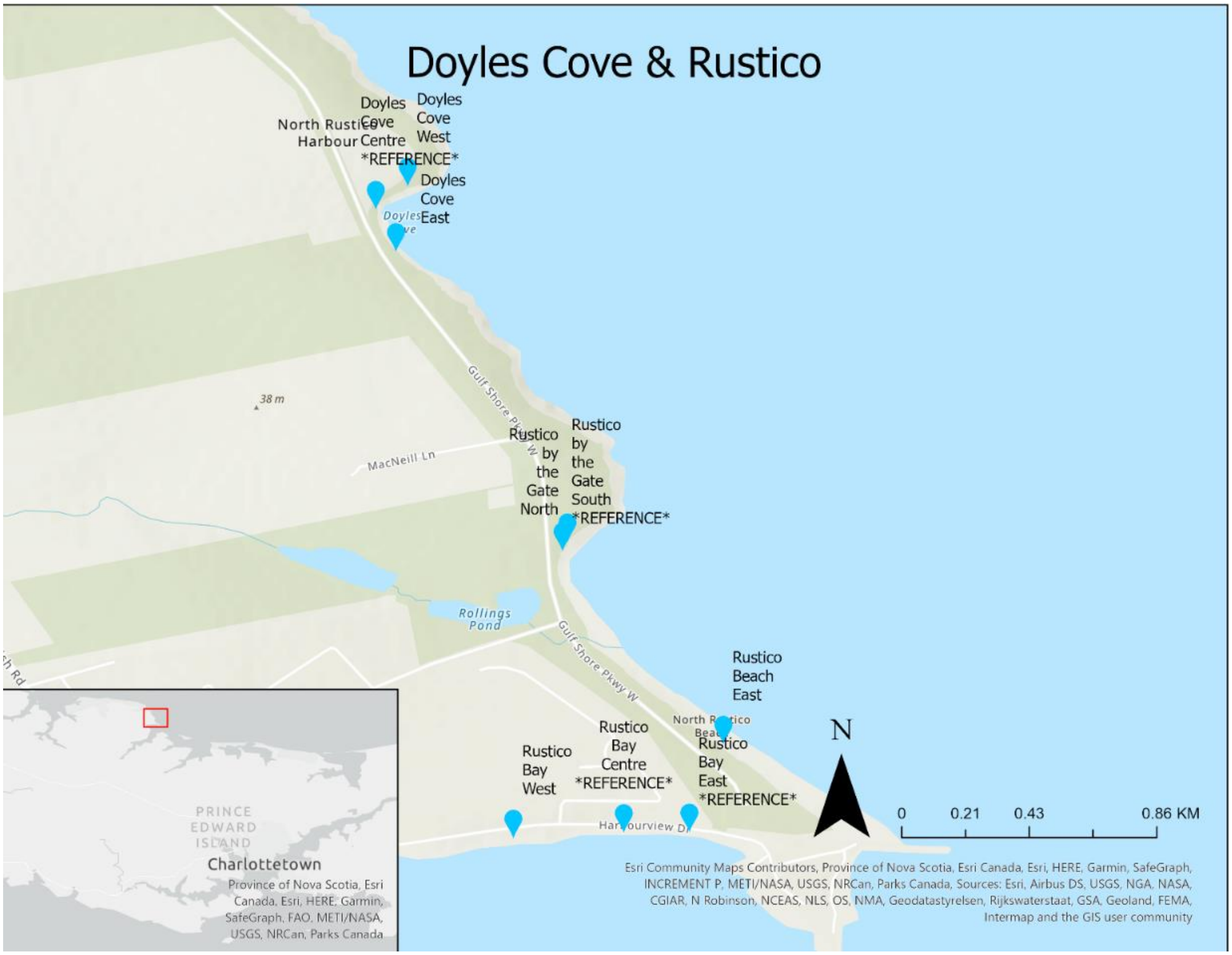


Figure A4. The Doyle’s Cove and Rustico sites that were assessed.

Figure A5. The Phyllis Kennedy Way, Seawood Estates, and Cavendish sites that were assessed.

Figure A6. The Queen Elizabeth Hospital (QEH) sites that were assessed.

Figure A7. The Savage Harbour sites that were assessed.

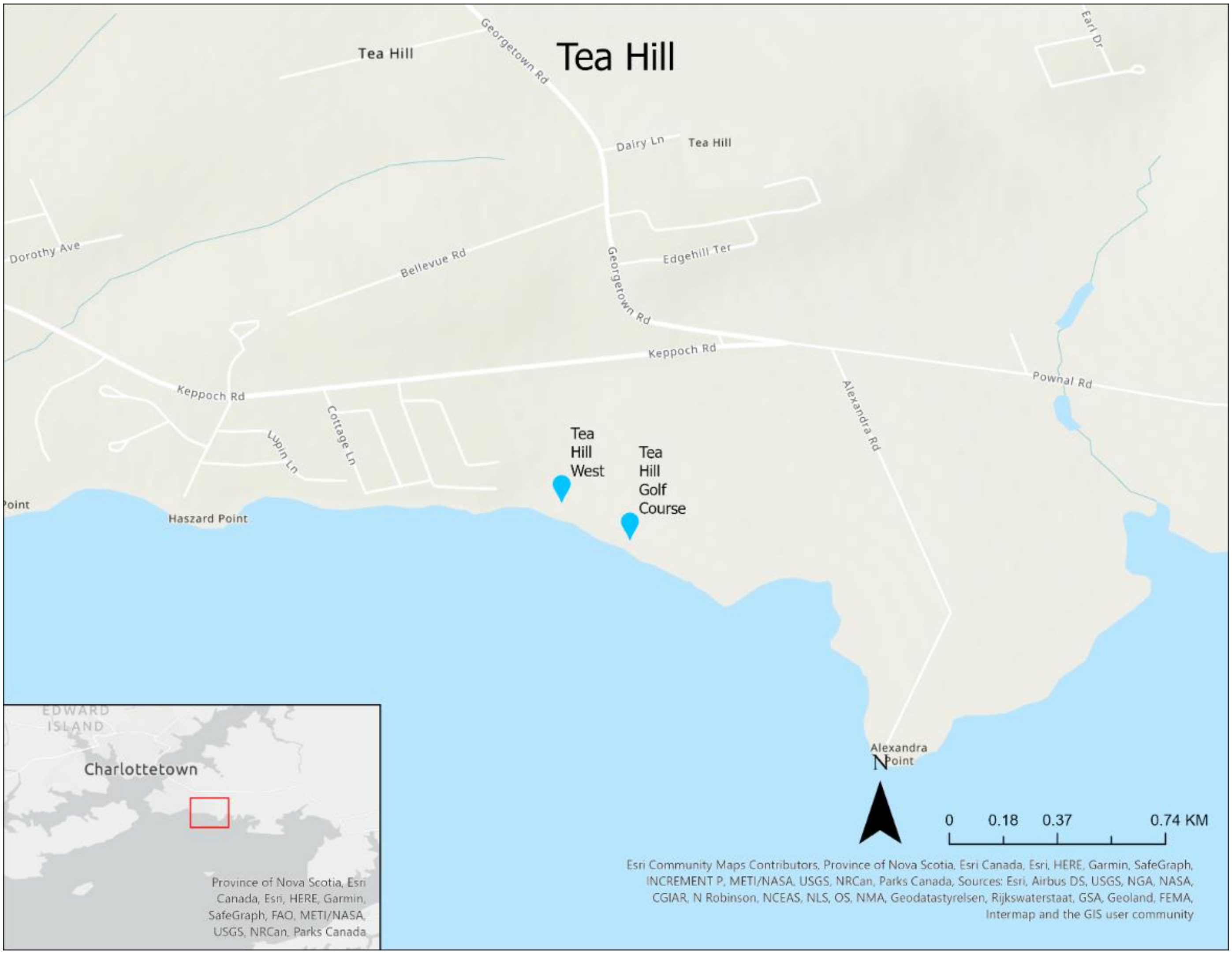


Figure A8. The Tea Hill sites that were assessed.

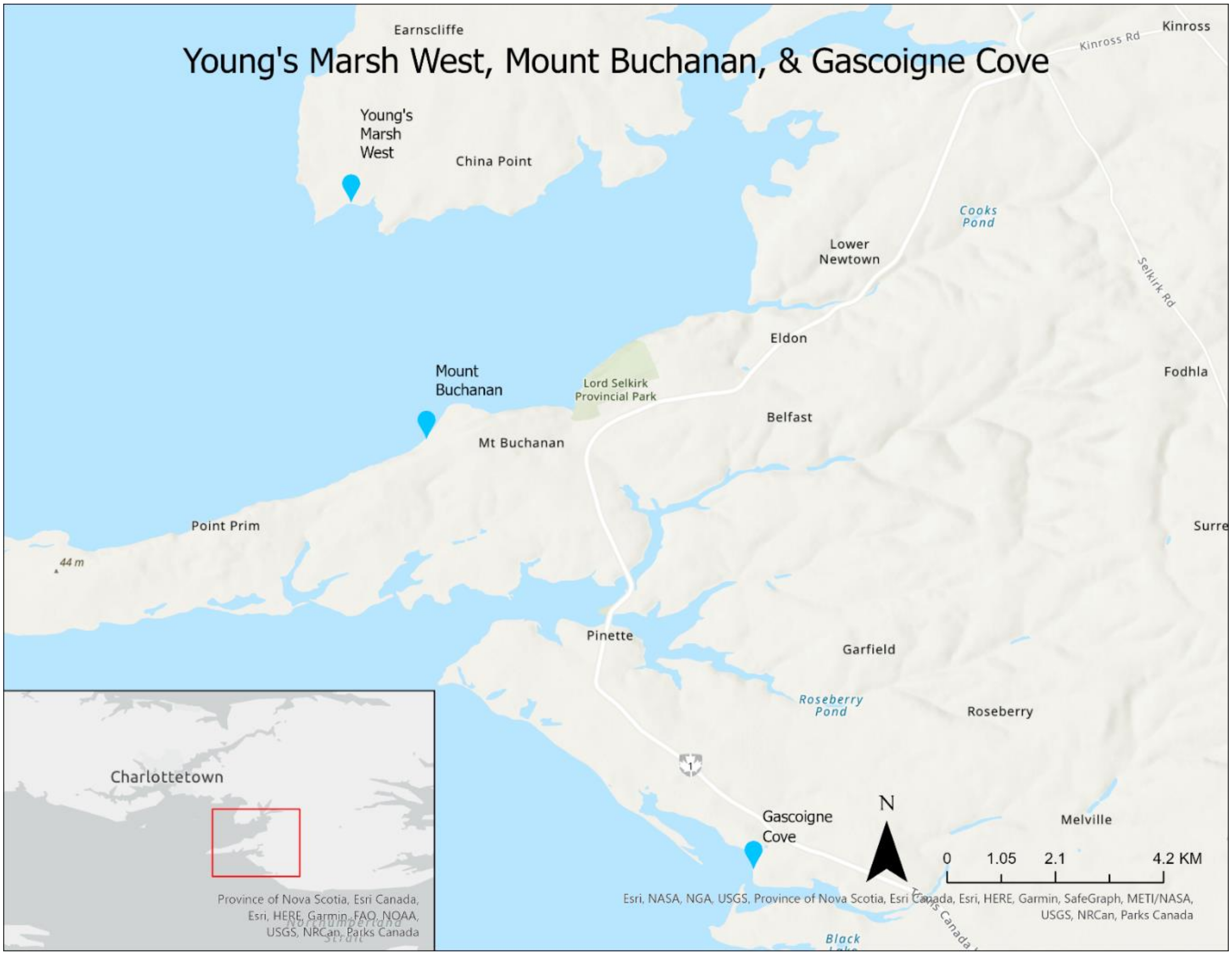


Figure A9. The Young's Marsh West, Mount Buchanan, and Gascoigne Cove sites that were assessed.

Appendix B: Tool assessment framework input descriptions

B1. Assessment framework inputs for the "accessibility" category

Parameter		Description	Answers		
Accessibility	Method of Interaction	Interactive with user or a guideline or checklist?	2 - interactive	1 - guideline	0 - checklist
	Instruction Ease	Does the tool provide instructions for the tool that are easy to follow?	2 - yes	1 - somewhat	0 - no
	Backtracking Abilities	Can you change a previous answer without losing work?	2 - yes, anytime	1 - yes, if its currently being worked on	0 - no
	Internet Requirements	Does the tool require internet to assess?	2 - no internet	1 - only to download	0 - yes, all times
	Registration Requirements	Do you need an account to use/access the tool? How difficult is it to create an account?	2 - no	1 - yes, easy to obtain	0 - yes, difficult to obtain
	Languages Offered	How many languages is the tool, guideline, or checklist offered in?	2 - >3	1 - two	0 - one
	Photos to Aid Descriptions or Questions	Are there photos to supplement descriptions?	2 - yes, when needed	1 - occasionally, could use more	0 - no, rarely

B2. Assessment framework inputs for the "characteristic" category

Parameter		Description	Answers		
Characteristic	Characteristic of PEI	Does the tool provide available answers that are characteristic of PEI? E.g., till banks	2 - yes	1 - somewhat	0 - no
	Physical Considerations	Does the tool take physical considerations into account?	2 - yes, multiple	1 - yes, one	0 - none
	Baseline Conditions	How many of the following does it involve: hours of light; sediment supply; wave energy; currents; site position; vegetation; elevation, fauna, grain size, bulk density, OM composition, salinity	2 - 7 to 12	1 - 1 to 6	0 - none
	Biological Considerations	Does the tool take biological considerations into account?	2 - yes, multiple	1 - yes, one	0 - none
	Social Considerations	Does the tool take social (e.g., governments, land use, etc.) considerations into account?	2 - yes, multiple	1 - yes, one	0 - none
	Output Options	How many output options do the tools have?	2 - 12 to 17	1 - 6 to 11	0 - 1 to 5

B3. Assessment framework inputs for the "scientific rigor" and "reproducibility" categories

Parameter		Description	Answers		
Scientific rigor	Success in results with use	Have other organizations use the tool and have had success with it? Were their answers characteristic of PEI?	2 - yes, success, characteristic	1 - some successes/characteristic OR some successes/uncharacteristic	0 - no, unsuccessful, not characteristic
	Descriptions for Criteria	Are descriptions provided for criteria useful? If there are photos, do the photos match what is being said within the description?	2 - yes, always	1 - sometimes	0 - no, never
Reproducibility	Data Collection Reproducibility	If someone else went out to the field, collected the same parameters, would they output the same result?	2 - yes	1 - likely	0 - no/unsure
	Sensitivity	Are any of the parameters sensitive to certain answers which can greatly change an output?	2 - multiple	1 - one	0 - none
	Information availability	Is the information the tool is asking for easy, okay, or hard to find?	2 - easy	1 - okay	0 - hard

B4. Final values from accessibility, reproducibility, characteristics and scientific rigor for assessed tools.

	ACASA	Woods Hole Group	VIMS	WDFW	NJDEP	NNBF	CBWES
Accessibility	13	16	11	9	9	9	6
Reproducibility	17	13	21	4	0	0	8
Characteristic	23	17	15	13	15	23	19
Scientific Rigor	6	25	25	19	13	25	13
TOTAL (/100)	**58**	**70**	**71**	**45**	**36**	**57**	**46**

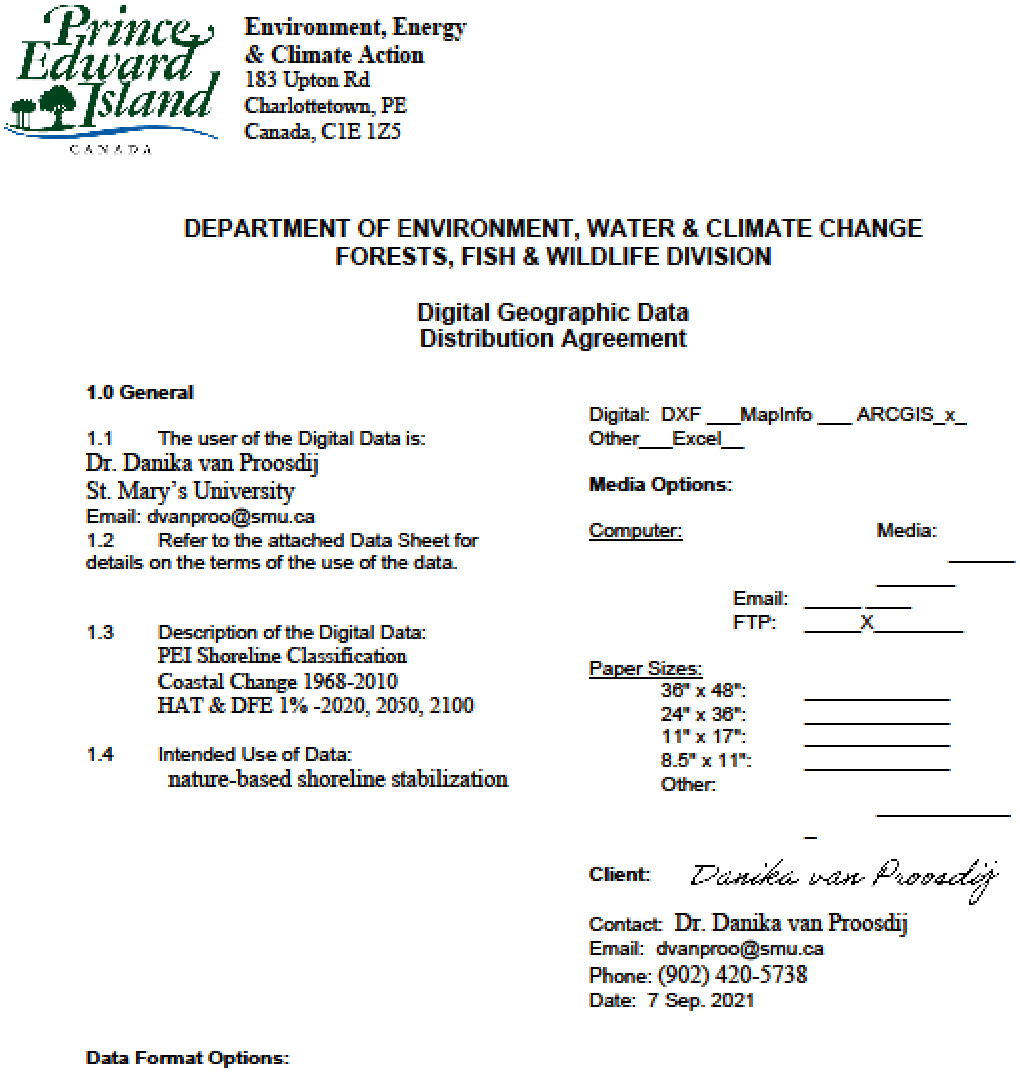
Appendix C: Desktop, on-site analysis criteria location information, and licensing agreement

C1. Desktop analysis information

	Criteria	**Source**	**Package**	**Layer**	**Field Name**
Hydro	Tidal range (MHHW-MLLW)	Government of PEI	PEI_Shoreline.gdb (Davies, 2011)	VCF	MHHW; MLLW
	Wave energy	Government of PEI	PEI_Shoreline.gdb (Davies, 2011)	VCF	Hs; Hsmax
Geophysical	Backshore material	Government of PEI	PEI_Shoreline.gdb (Davies, 2011)	VCF	BSType
	Foreshore material	Government of PEI	PEI_Shoreline.gdb (Davies, 2011)	VCF	FSType
	Bank composition	Government of PEI	Soils.shp	Soils	SOIL_CODE1
	Shoreline type	Government of PEI	PEI_Shoreline.gdb (Davies, 2011)	VCF	ShoreType

C2. On-site analysis information

	Criteria	**Source**	**Field Name**
Biotic	Nearshore SAV	On-site	NSSAV; NSSAV_Code
	Vegetation on bluff/backshore	On-site	Vegetation; Veg_Code
	Shellfish reefs	On-site	SFReef; SFReed_Cd
Geophysical	Foreshore dimensions	On-site	FSWidth; FSWidth_Cd
	Natural features protecting against erosion	On-site	ExistEroStr; ErStr_Code
	Slope of shoreline	On-site	SLSlope; SLSlope_Cd
Erosion	Type of erosion	On-site	ErosionTyp; ErType_Cd
	Cause of erosion	On-site	ErosionCse; ErCse_code
Exposure	Fetch	On-site	Fetch; Fetch_Code
	Storm exposure	On-site	Exposure; Expsr_Code
Infrastructure	Type of infrastructure	On-site	Infrstrctr; Infr_Code
	Shoreline uses	On-site	SLUses; SLUses_Cd
	Type of access	On-site	Access; Access_Cd
Shore Armouring	Neighboring property armouring	On-site	NeighbArmr; NgbArmr_Cd
	Type of armour	On-site	ArmrType; ArmrTyp_Cd
	Condition of armour	On-site	ArmrCond; ArmrCon_Cd
	Barriers to water movement	On-site	Barrier; Barrier_Cd



Environment, Energy & Climate Action
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DEPARTMENT OF ENVIRONMENT, WATER & CLIMATE CHANGE
FORESTS, FISH & WILDLIFE DIVISION

Digital Geographic Data
Distribution Agreement

1.0 General

1.1 The user of the Digital Data is:
Dr. Danika van Proosdij
St. Mary's University
Email: dvanproo@smu.ca

1.2 Refer to the attached Data Sheet for details on the terms of the use of the data.

1.3 Description of the Digital Data:
PEI Shoreline Classification
Coastal Change 1968-2010
HAT & DFE 1% -2020, 2050, 2100

1.4 Intended Use of Data:
nature-based shoreline stabilization

Data Format Options:

Digital: DXF ___MapInfo ___ ARCGIS_x_
Other___Excel__

Media Options:

Computer: Media: ______

Email: _____ ____
FTP: _____X________

Paper Sizes:
36" x 48": ____________
24" x 36": ____________
11" x 17": ____________
8.5" x 11": ____________
Other: ____________

Client: Danika van Proosdij

Contact: Dr. Danika van Proosdij
Email: dvanproo@smu.ca
Phone: (902) 420-5738
Date: 7 Sep. 2021

C3. Licensing agreement for the use of the PEI_Shoreline.gdb.

Appendix D: Output Definitions

D1. Definitions from ACASA and the Woods Hole Group for living shoreline adaptation methods and the codes used for the comparison tables.

Code	**Definition**
REL	Relocate infrastructure
DUNE	Dune building/natural coastal dune
MARSH	Natural marsh create/enhancement
MARSHTOE	Marsh creation/enhancement with toe protection
PLANT	Plant stabilization
LIVINGSL/WL	Living shoreline/wetland
NOURISH	Beach nourishment