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Managing Natural Assets
to Increase Coastal Resilience

Pointe-du-Chêne

New Brunswick



Pilot Study June 2021





Invest in Nature

This work is being supported by the David Suzuki Foundation, which is a member of the Municipal Natural Assets Initiative. The two organizations are collaborating on this project.

The David Suzuki Foundation (DSF) is a national, bilingual non-profit organization working to conserve and protect the natural environment and help create a sustainable Canada through evidence-based research, education and policy analysis. DSF is exploring and promoting the services that nature provides to our societies. Learning to understand, measure and manage nature-based solutions can help make better decisions about how we interact with nature and provide new justifications for protecting and restoring natural spaces.

The Municipal Natural Assets Initiative (MNAI) is changing the way municipalities deliver everyday services, increasing the quality and resilience of infrastructure at lower costs and reduced risk. The MNAI team provides scientific, economic and municipal expertise to support and guide local governments in identifying, valuing and accounting for natural assets in their financial planning and asset management programs, and in developing leading-edge, sustainable and climate resilient infrastructure.

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SUMMARY

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Communities all along Canada's coasts are facing infrastructure challenges. The structures that people originally built to protect their settlements from storm surges are showing their age, especially as they try to protect against bigger and more frequent storms that climate change is causing.

To address these challenges, the David Suzuki Foundation and the Municipal Natural Assets Initiative piloted the Coastal Resilience project in the Town of Gibsons, B.C. and Pointe-du-Chêne, New Brunswick. This report focuses on Pointe-du-Chêne. The project developed and tested a Coastal Toolbox (CT) model to determine what key advantages exist, if any, to implementing natural asset solutions in coastal areas of that community.

As of the 2016 federal census, Pointe-du-Chêne was home to 716 residents and 390 private dwellings. There were about 1,000 structures in the community in 2017 based on building footprints provided by the Southeast Regional Service Commission (SERSC). It is also a destination for tourists and recreational users of nearby Parlee Beach, a provincially protected park. With recent hurricanes and storms, the community has experienced large-scale flooding and coastal erosion that have affected buildings and beaches (e.g., in 2000, 2010 and 2019).

The Coastal Resilience project's two objectives were to:

1. Provide Pointe-du-Chêne and SERSC with a quantitative assessment of the benefits that coastal natural assets can offer for flood and erosion protection from coastal storms.
2. Develop and pilot a modelling tool (the Coastal Toolbox, or CT) that coastal communities can further refine so they could understand and compare alternative natural asset management solutions to storm surge and coastal erosion.

With input from a stakeholder group, the project team developed a list of 11 natural asset management options and assessed them against a set of criteria. Based on those considerations, the team identified five options for modelling:

- Dune improvements
- Beach nourishment
- Shoreline planting
- Eelgrass planting
- Submerged structures

The project team then took the following five steps:

1. Identified and selected coastal protection options for modelling
2. Incorporated coastal protection options in Coastal Toolbox
3. Specified sea level rise assumptions and constructed design storms
4. Developed simulation modelling using the Coastal Toolbox
5. Evaluated results and estimated benefits

With the CT, the project team determined that enhancing coastal natural assets can successfully reduce erosion impacts but would have a relatively small effect against floods, which could require managed retreat instead. Another key finding is that the cost advantages of natural assets are more from their ability to protect against smaller, more frequent storms than from the large, infrequent storms that typically receive the most attention.

Flood protection benefits:

Flood estimates from the CT indicate that, compared to erosion, flooding is a much costlier hazard for Pointe-du-Chêne. For the individual natural asset options assessed, those applied to the Parlee Beach NW segment consistently generate the greatest long-term avoided flooding benefits in absolute costs.

Given the impacts from flooding, even small improvements can have significant cost savings. Flooding is the greatest storm-related threat to the community, with total projected flood damages over a 100-year period exceeding \$182 million (2020 CDN). While natural asset enhancements would only provide a one to four per cent improvement in flood mitigation, the associated cost savings are in the \$1.4 to \$7.6 million range. This means natural asset solutions for flood management should be recognized, particularly considering the co-benefits they can offer, like habitat provision, aesthetic appeal and erosion protection.

Erosion reduction benefits:

Erosion results from applying the Coastal Toolbox in Pointe-du-Chêne indicate shoreline planting generates the greatest long-term benefits from avoided erosion costs (\$10.89M), followed by beach nourishment (\$9.55M) and dune improvement (\$8.22M).

The project team determined that total potential losses from erosion are approximately \$19 million over a 100-year time horizon. Solutions like shoreline planting, dune improvement and beach nourishment applied along all segments of Parlee Beach could reduce damages by 40 to 60 per cent, for a cumulative benefit of \$8 to \$11 million.

Overall, this pilot study demonstrated that:

1. The CT is a rapid and easy-to-use tool that is sufficient for high-level initial screening and for quantifying the benefits associated with coastal natural assets.
2. There are challenges associated with applying a generic tool to different types of coastlines; at its current stage of development, the CT will be most applicable to areas with sandy shores.
3. Current applications of the CT will likely still require local knowledge and external professional expertise for some key modelling steps.
4. The CT tool offers a valuable learning and assessment framework.

Local governments wishing to consider using the CT should review the full technical guidance document as well as the results from the Town of Gibsons pilot. Current applications of the CT will likely still require combining local knowledge with professional expertise for some key modelling steps. The resulting screening will help determine whether to proceed with more detailed investigation and research related to natural asset approaches.



INTRODUCTION

PHOTO: WIKI COMMONS - GRAND PARC

NATURAL ASSETS

What are municipal natural assets

The term *municipal natural assets* refers to the stock of natural resources or ecosystems that a municipality, regional district or other form of local government could rely on or manage for the sustainable provision of one or more local government servicesⁱ.

Why manage natural assets

A growing number of local governments recognize that it is as important to understand, measure, manage and account for natural assets as it is for engineered ones. Doing so can enable local governments to provide *core* services such as stormwater management, water filtration and protection from flooding and erosion, as well as *additional* services such as those related to recreation, health and culture. Outcomes of what is becoming known as *municipal natural asset management* can include cost-effective and reliable delivery of services, support for climate change adaptation and mitigation, and enhanced biodiversity.

How to manage natural assets

Local governments have numerous ways to manage natural assets. The Municipal Natural Assets Initiative (MNAI) uses methodologies and tools rooted in standard asset management, and provides a range of advisory services to help local governments implement them. MNAI has developed the methods and tools with significant investments, piloting, refinement, peer review and documentation of lessons in multiple Canadian provinces. MNAI's mission is to make natural asset management a mainstream practice throughout Canada, and in support of this, for local governments to accept and use the methodologies and tools in standard ways across the country.

ⁱ mnai.ca/media/2018/02/finaldesignedsept18mnai.pdf

Many MNAI tools to-date have focused on surface water quality and quantity. The development of a tool called the Coastal Toolbox (CT) is a first attempt to extend the natural assets methodology to coastal issues. The CT was piloted in Pointe-du-Chêne, New Brunswick, and in the Town of Gibsons, B.C. Results from the former are the subject of this report.

CT development was made possible with funding and project support made available through the David Suzuki Foundation; overall project coordination by MNAI; and support from a technical team.

POINTE-DU-CHÊNE, NEW BRUNSWICK

Pointe-du-Chêne, New Brunswick, is a topographically low-lying coastal community with open exposure to the neighbouring Northumberland Strait (Figure 1). The community has experienced large-scale flooding and coastal erosion with recent storm and hurricane cycles (Figure 1). Surrounding structures and the local wharf and marina have required expensive restoration following these storms (Figure 2) (CBC News 2010). As of the 2016 federal census, Pointe-du-Chêne was home to 716 residents (a 6.3 per cent decrease since 2011) and 390 private dwellings. There were more than 1,000 structures in the community in 2017 based on building footprints provided by the Southeast Regional Service Commission (SERSC). Pointe-du-Chêne is also a destination for tourists and recreational users of nearby Parlee Beach, a provincially protected and managed park.



Fig. 1: Project area overview, Pointe-du-Chêne, New Brunswick.



Fig. 2: Examples of recent flooding, coastal erosion and wave damage in the vicinity of Pointe-du-Chêne.

Source: Daigle, R. 2011.

Policy/governance context

Climate adaptation planning is being actively pursued in the Pointe-du-Chêne local service district to help mitigate damages from forecasted sea-level rise and increased severity and frequency of storms. With efforts led by New Brunswick's Southeast Regional Service Commission (SERSC), local governments recognize the importance of understanding, measuring, managing and accounting for coastal natural assets. These assets have the potential to provide significant economic benefits to local governments by mitigating floods and erosion, reducing long-term maintenance costs compared to hard/grey alternatives, and providing co-benefits such as habitat conservation or improvements to local park and recreation areas. The region sees more than 900,000 visitors per year, many of whom come to enjoy Parlee Beach and the wharf (Chouinard and Martin 2006).

Canadian coastal management for flood and erosion mitigation overlaps with multiple marine jurisdictions, so in addition to the SERSC, provincial and federal governments set regulations and laws (e.g., New Brunswick Coastal Areas Protection Policy, Canadian Fisheries Act, Canadian Shipping Act, etc.) and contribute important resources, data and expertise that support adaptation planning (e.g., New Brunswick departments for provincial parks, geological survey, tourism, heritage and culture, climate change, environment and local government; Natural Resources Canada (NRCAN), Environment Canada, Department of Fisheries and Oceans

Canada [DFO]). Other community organizations and non-government organizations (NGOs) like the Shediac Bay Watershed Association, Greater Shediac Sewerage Commission, Southeast Planning Review and Adjustment Committee and the Nature Conservancy also play important roles. For an overview of jurisdictional considerations relevant to marine and coastal planning in Canada, see Section 3.1 and Appendix C of the Technical Guidance Document.

Natural asset of interest

In Pointe-du-Chêne, Parlee Beach is the dominant feature at the coastal interface (where land and ocean realms meet), stretching across the community's entire exposed coastline. Large, vegetated dunes and foreshore features along the beach already provide natural flood and erosion protection, while also contributing to the aesthetic appeal of one of the most attractive recreational beaches in the province. Parlee Beach itself is the main natural asset of interest for this pilot, with several enhancements to the beach considered in scenario modelling.

Project Objective(s)

The project team set out to develop an initial screening and quantification tool, called the Coastal Toolbox (CT), that could, with the accompanying Technical Guidance Document, be used independently by any community before deciding to invest in more detailed studies. Coastal processes are complex, and at its current stage of development the tool will be more applicable to some communities than others. Current applications of the CT will likely still require combining local knowledge with professional expertise for some key modelling steps. Regardless, the tool provides useful high-level screening and offers a valuable learning and assessment framework for coastal communities interested in exploring natural assets alongside conventional grey infrastructure projects and other strategies to promote coastal resilience.

The two primary objectives of this pilot are to:

1. Supply the Southeast Regional Service Commission (SERSC) of New Brunswick and participating stakeholder groups with a quantitative assessment of the benefits coastal natural assets can offer for flood and erosion protection from coastal storm surges in Pointe-du-Chêne.
2. Develop and pilot a modelling tool that can be refined for further use in coastal communities that wish to understand and compare alternative natural asset management solutions to storm surge and coastal erosion.



METHODS

PHOTO: TRACEY MCDONALD

OVERVIEW

As part of this study, the project team identified and inventoried coastal natural assets near Pointe-du-Chêne, linked these to ecosystem service provision, and then quantified the supplied flood and erosion benefits over a 100-year time horizon using the CT to capture a typical coastal planning time horizon. The tool examined how natural assets such as eelgrass, dunes and beach foreshores can provide flood and erosion protection under different management scenarios and climate change considerations (e.g., sea-level rise and increasing storm severity/frequency).

Methods focused on comparing modelled storm and erosion protection benefits of various natural asset management options with and without those management options applied. Comparisons of management options were based on avoided damage costs (in 2020 CDN \$), as well as using non-monetary metrics, including lost beach volumes from erosion and the number of flooded structures.

As a high-level assessment and learning tool, the model is based on one-dimensional transects (or lines that are drawn on maps that extend from offshore to the coastal floodplain). It does not consider cross-cutting effects from wind and waves that are more complex and computationally intensive than a two-dimensional model would provide, nor does it consider dynamic effects like sediment transport over time, which might replenish the eroded volumes indicated by the CT. Pointe-du-Chêne should consider these characteristics when interpreting results from the model. The CT was designed as a rapid first-pass assessment that minimizes processing time while still permitting a general indication of coastal protection benefits from natural assets and supporting community learning about how those assets can affect coastal processes.

Five steps were taken in the project:

1. Identification and selection of coastal protection options for modelling
2. Incorporation of coastal protection options in Coastal Toolbox
3. Specification of sea level rise assumptions and construction of design storms
4. Simulation modelling using the Coastal Toolbox
5. Evaluation of results and estimation of benefits (addressed in Section 3)

Each step is summarized below; a more detailed description is in the Technical Guidance Document.

STEP 1: IDENTIFICATION AND SELECTION OF COASTAL PROTECTION OPTIONS FOR MODELLING

Natural asset management strategies require a multi-disciplinary, team-based approach. The MNAI process therefore begins with an initial engagement session with community representatives from across a range of disciplines. During the spring, summer and early fall of 2020 (April, June, September) the project team held three multi-stakeholder workshops to discuss, identify and prioritize existing coastal natural assets, and to isolate the most promising candidate management options that would reduce damages from storms and provide other co-benefits such as habitat conservation or improvements to local parks and recreation areas. These workshops included local residents as well as participants and experts from the SERSC (planning, geomatics, GIS), the Shediac Bay Watershed Association, Greater Shediac Sewerage Commission, Southeast Planning Review and Adjustment Committee, Government of New Brunswick, New Brunswick Provincial Parks, New Brunswick Geological Survey, New Brunswick Tourism, Heritage and Culture, New Brunswick Climate Change Secretariat, New Brunswick Environment and Local Government, Natural Resources Canada (NRCAN), Environment Canada, Department of Fisheries and Oceans Canada (DFO), Parlee Beach Provincial Park and the Nature Conservancy of Canada. This larger group is referred to hereafter as the stakeholder group.

Workshop outputs included:

- Identification of the geographic region of interest and important areas of focus
- A detailed understanding of the flood and erosion problems Pointe-du-Chêne faces and important coastal processes
- Itemization of existing coastal natural assets in Pointe-du-Chêne and identification of asset management alternatives for modelling
- Itemization of available data and identification of outstanding data needs and knowledge gaps

The stakeholder group assisted the project team in identifying 11 options for modelling, each focusing on conserving or enhancing offshore and inland natural assets along Parlee Beach. To shortlist five options, a set of selection criteria was co-developed with project participants that considered the potential for each option to provide focal services (i.e., flood and erosion protection) and other co-benefits, as well as its overall implementation and modelling feasibility (Figure 3). In evaluating the options based on these criteria, considerations included whether reliable precedents exist, whether specific co-benefits of interest would be supplied by the option such as aesthetic appeal, habitat provision, runoff management, water quality regulation; whether significant engineering or design limitations exist, and whether the Coastal Toolbox is capable of simulating the option. Note that some options that did not make the shortlist are inherently difficult to model but could be quite feasible to implement and should therefore not be discarded as candidate management alternatives (e.g., tidal pond restoration to improve lagoon drainage). The five selected options included dune improvements, beach nourishment, shoreline planting, eelgrass planting and submerged structures, with managed retreat also making the shortlist as a sixth option that was not modelled (not a natural asset but is worthy of mention due to its high relevance to this case study).

Option Name	Flood & Erosion Protection	Other Benefits		Feasibility			Modelling
		Co-Benefits	Climate Change Adaptability	Community Implementability	Asset Policy & Planning Relevance	Achievable Cost	Modelling Feasibility
Current and Future-Climate Baselines							
1. Parlee Beach							
2. Point near wharf							
Adapting Parlee Beach for Coastal Protection under Current Conditions and Projected Climate Change							
Pb1. Dune improvement	H	M		H		H	x
Pb1a. Beach nourishment	M	L		H		H	x
Pb2. Shoreline planting A	M	M		H		H	x
Pb3. Shoreline planting B	M	H		M		H	x
Pb4. Eelgrass planting	L	M		M		H	x
Pb5. Tidal pond restoration	M	H		M		L	
Pb6. Submerged structure	H	H		L		H	x
Pb7. Managed retreat	H	H		L		L	
Enhancing the Point for Coastal Protection under Current Conditions and Projected Climate Change							
P1. Shoreline armouring	M	L		M		M	
Development Pressures that Reduce Coastal Protection under Current Conditions and Projected Climate Change							
D1. Marsh loss	M	L		M		L	

Fig. 3: An example of the criteria-based selection matrix used to identify a shortlist of top priority natural asset management alternatives.

STEP 2: INCORPORATION OF OPTIONS INTO COASTAL TOOLBOX

The approach to evaluating each natural asset option for Pointe-du-Chêne varied depending on the type of natural asset. Some options could be easily assessed using the CT by simply varying the standard parameter settings (e.g., dune height, beach width). Other options required the use of proxies like increasing the grain size parameter to represent added stability from shoreline planting. To capture a range of cost estimates, the model was confronted with multiple “variants” of the same management option using a set of “tunable” model parameter settings. Figure 4 illustrates the main parameters that are tunable in the CT and locates each of the five options (six including managed retreat) from offshore to inland along a schematized profile.

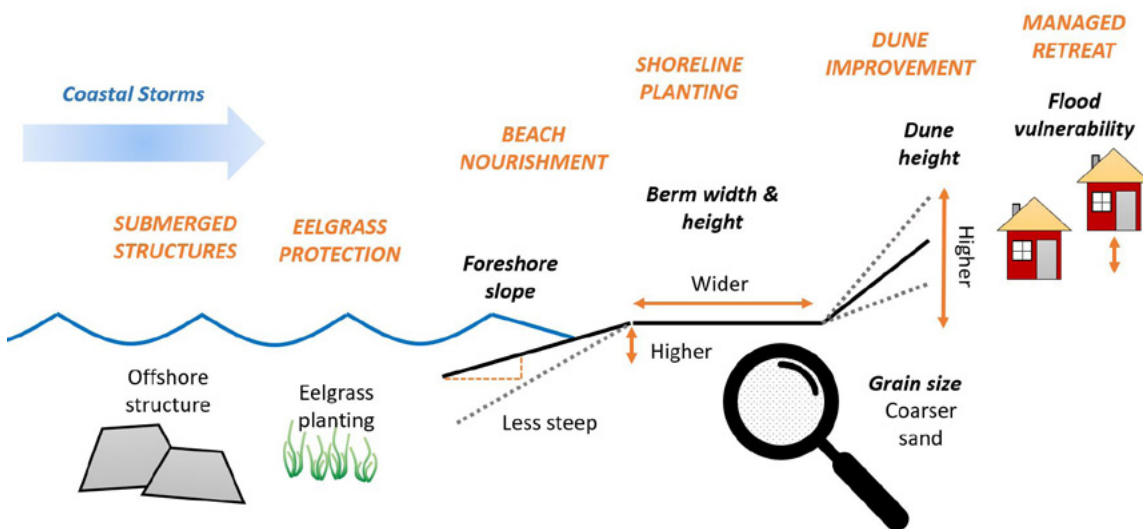


Figure 4: A schematic locating natural asset options along a cross-section from offshore to inland.

Tunable parameters in the CT that can be modified to evaluate flood and erosion impacts are also shown (e.g., foreshore slope, berm width, berm height, grain size, dune height).

Table 1: Parameter settings used for baseline simulation modelling and a range of model variants.

Settings in black font represent baseline conditions, while settings in red font represent different variants of the natural asset options explored. The Beach Nourishment option is unique since it involves multiple tunable parameters. For this option, all possible combinations of the parameter settings shown were tested (i.e., foreshore slope, berm height, berm width).

	Dune Improvement	Shoreline Planting†	Beach Nourishment	Eelgrass Planting	Submerged Structures
Foreshore slope*	2%-7%	2%-7%	2%-7% 1%, 5%, 9%	2%-7%	2%-7%
Berm height*	0.5-1m	0.5-1m	0.5-1m 0.5m, 1m, 1.5m	0.5-1m	0.5-1m
Berm width*	5-20m	5-20m	5-20m 5m, 10m, 20m	5-20m	5-20m
Dune height*	1-2m 1m, 3m, 5m	1-2m	1-2m	1-2m	1-2m

	Dune Improvement	Shoreline Planting [‡]	Beach Nourishment	Eelgrass Planting	Submerged Structures
Grain size	200 µm [†]	200 µm [†] 100µm, 2mm	200 µm [†]	200 µm [†]	200 µm [†]
Eelgrass patch width	NA	NA	NA	200m	NA
Structure distance offshore	NA	NA	NA	NA	300m
Structure depth	NA	NA	NA	NA	3-4m Chart Datum
Structure height	NA	NA	NA	NA	1.5, 5m
Structure width	NA	NA	NA	NA	5, 10m
Land value (erosion)	\$50/m ²	\$50/m ²	\$50/m ²	\$50/m ²	\$50/m ²
Structure value (flood)	Total assessed value less assessed land value, distributed proportionally by footprint area in cases with multiple structures				
Depth-damage estimates	U.S. HAZUS – filtered for salt water, short duration flooding from USACE – New Orleans. We used curves for one- and two-storey residential building structures only.				
Discount rate	5%				

* Baseline parameter values vary by beach segment. For example, the foreshore slope is 2% at Parlee Beach NW and 7% at Parlee Beach SE (see Appendix).

† Baseline grain size represents “fine sand”.

‡ Changes in grain size are used as a proxy to represent beach stability benefits provided by shoreline planting.

STEP 3: SEA-LEVEL RISE AND DESIGN STORMS

The project team evaluated the performance of the five selected natural asset options under an assumed sea-level rise (using emissions scenario RCP 8.5ⁱⁱ), specific tide level assumptions and using different “design storm” scenarios. Coastal flooding and erosion at Pointe-du-Chêne are primarily driven by a combination of “still water levels” and wave impacts (wave run-up), where the former term is used to describe average water surface elevation including contributions from tides, storm surges and sea-level rise. Wave run-up is used to describe the shoreward movement of waves produced by waves immediately along the shoreline. It is therefore important to conduct simulations across a range of storm frequencies/intensities to provide a stronger basis for short- and long-term planning. Our design storm scenarios included the following parameter value settings:

ii The RCP8.5 Representative Concentration Pathway for the global high-emissions climate change scenario adopted by the International Panel on Climate Change. RCP8.5 was chosen in this study as a more conservative benchmark for mitigation and planning.

Table 2: Storm scenarios.

Parameter	Settings			
Sea-Level Rise (constant across all scenarios)	0.38m* (2070 RCP8.5)			
Tides	Lower low-water large tide	0.7m Chart Datum		
	Mean sea level	1.0m Chart Datum		
	Higher high-water large tide	1.7m Chart Datum		
		1-year storm	10-year storm	100-year storm
Storms	Recurrence frequency	Annual	Decadal	Centennial
	Significant wave height	1.5m	2.0m	2.5m
	Peak wave period	4.9s	5.5s	5.9s
	Storm surge elevation	0.75m	1.40m	1.90m

* Based on RCP 8.5 for 2070. We selected the 2070 sea-level rise horizon because 50 years (2020-2070) is a typical lifespan for a coastal infrastructure project and it is also a strategic mid-point for our modelling, which covers a 100-year time horizon.

Please refer to the Appendix and the Technical Guidance Document for further details about these parameters and their settings.

STEP 4: SIMULATION MODELLING WITH THE COASTAL TOOLBOX

Using the Coastal Toolbox, each design storm was simulated over 100 years with and without each of the five natural asset options across all natural asset parameter combinations. The CT was built by modifying the open source InVEST Coastal Protection Module from Stanford University's Natural Capital Project with the assistance of the model's original architect, Greg Guannel.

The InVEST Coastal Protection Model runs as a tool within ArcGIS to estimate how different habitats reduce nearshore wave energy and coastal erosion. The model accepts a baseline scenario and a proposed scenario to facilitate comparison. Unfortunately, this model has been discontinued by the InVEST team as of 2017 due to its dependence on ArcGIS, but they intend to migrate the tool to its standalone platform. As this model was best suited to allow interested municipalities to assign credible values to flood and coastal erosion protection provided by their shoreline and nearshore vegetated ecosystems without needing to outsource any aspect of the analysis, it was adapted to the Canadian environment.

The finished tool is a package of ESRI toolboxes built for use in ArcGIS Pro with some supplementary R Shiny functionality (a web application that allows the user to build interactive web apps). The CT calculates wave propagation, beach retreat and flood levels, and allows users to develop a first-pass estimate of damages from flooding and erosion.

The toolbox comprises six main components (Figure 5) including: a) a cross-shore profile generator that creates a set of transects (or cross-sectional slices, perpendicular to the coast at specified intervals), b) the natural/built asset scenario, which can be constructed uniquely

for each profile, c) a wave/storm simulator, d) a flood estimator that builds a two-dimensional flood extent by interpolating flood depths between profiles, e) a coastal erosion estimator, and f) an avoided costs and damages estimation for floods and erosion.

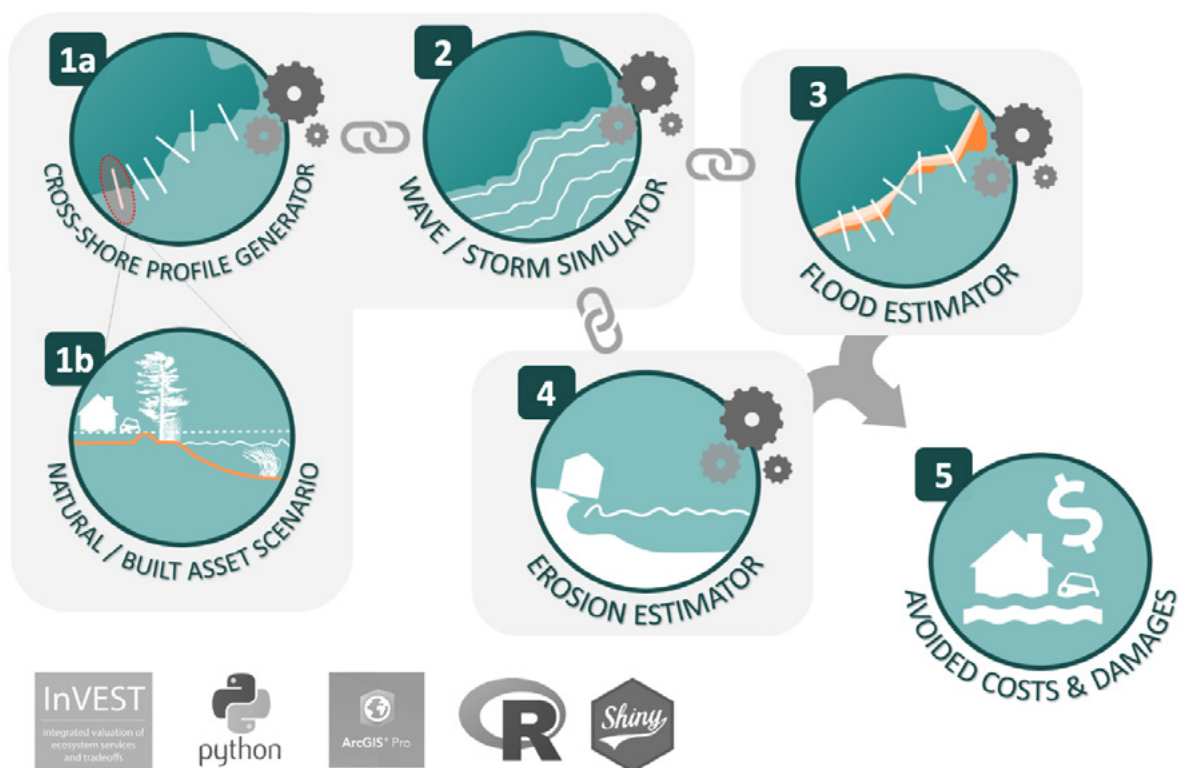


Figure 5: Conceptual diagram of the main components and workflow of the Coastal Protection Benefits Toolbox.

Built using the open source InVEST Coastal Protection Module and adapted for use in ESRI ArcGIS Pro with supplementary tools using R Shiny. The steps in this model workflow are described in more detail in the Technical Guidance Document.

Several input datasets are required for the application of the CT, many of which will vary in terms of quality and availability depending on the local government. For this pilot, input data shown in Table 3 were prepared in collaboration with the SERSC and other project partners. Further details about the compilation of these datasets are available in Appendix A, as well as the Technical Guidance Document.

Table 3: Input datasets for application of the Coastal Protection Benefits Toolbox

Dataset	Details
Coastline	A spatial polyline demarcating the coast extending along Pointe-du-Chêne and Parlee Beach from the wharf to Belliveau, excluding sections with rip-rap.
Seamless Topographic-Bathymetric Digital Elevation Model	A continuous water-free elevation surface created by merging existing Canadian Hydrographic Service bathymetry data with municipal LiDAR data. See the Appendix for more details.

Dataset	Details
Building footprints	Spatial polygons of all structures in Pointe-du-Chêne and the Bluffs with attributes including footprint area, assessed value and building type. Note that individual properties ("households") will often have more than one structure. See the Appendix for more details.
Depth-damage curves	Functional forms representing the relationship between flood depth and structure damages for different building types. Used for estimating flood damage costs. For this pilot, U.S. HAZUS depth-damage curves for USACE New Orleans were used. See the Technical Guidance Document for more details. Note that these curves estimate damage to structure only (not contents).
Shoreline/foreshore beach attributes	Foreshore slope, grain size (D50), berm width, berm height and dune height. See the Appendix for more details.
Sectionalized representation of Parlee Beach	A spatial polygon of Parlee Beach split into beach foreshore segments based on general geomorphic differences, breakpoints and natural features. See the Appendix for more details.
Historical storms, water levels, wind and wave conditions and sea-level rise scenarios	Static water levels, stormwater levels and sea-level rise levels from various data sources. Used to derive design storm parameters. See the Appendix for more details.

Table 4 lists the final indicator outputs available from the CT, including main indicators and supplementary indicators. For erosion, the cost of beach loss (\$) is calculated using the beach retreat distance (m). For flooding, the costs of flood damages (\$) are calculated using the number of buildings inundated and the depth of inundation (m), which is derived from total flood levels (m) approximated using wave run-up levels (m).

Table 4: Indicator outputs from the CPBT

Hazard	Main Indicators	Supplementary Indicators
Erosion	<ul style="list-style-type: none"> • Beach retreat distance (m) • Cost of beach loss (\$) 	<ul style="list-style-type: none"> • Beach loss/damage (m3)** • Wave attenuation (%) • Erosion index score (0-5)*
Flooding	<ul style="list-style-type: none"> • Wave run-up levels (m) • Total flood levels (m) • Buildings inundated (#) • Cost of flood damages (\$) 	

* The erosion index score is calculated as the beach retreat distance relative to the beach size.
0 (<1%), **1** (1 – 25%), **2** (25-50%), **3** (50-75%), **4** (75-100%), **5** (>100%).

** The beach loss volumes we report are calculated as the product of retreat distance, berm height and length of the beach along the coastline. If the modelled retreat distance was greater than the berm width, the reported volume is simply a product of the berm width, height and length of the beach along the coastline.

For each natural asset option, the cost of beach loss and flood damages were calculated over a 100-year time horizon across all tunable parameter settings and combinations, omitting any settings that produced an asset condition worse than the baseline (e.g., we did not propose reducing the dune height at a given beach). Because a 100-year time horizon was used, each design storm occurs, on average, 100 times (one-year storm), 10 times (10-year storm), and one time (100-year storm) during the simulated period. These return periods represent storm intensities along a probability distribution and are not actual storm occurrence frequencies in any given year. The CT provides cost outputs in “present value,” which means they are discounted annually (five per cent discount rate) then summed to get a cumulative, discounted amount over the full time horizon. This discounting is standard practice by economists to capture the fact that people value one dollar today more than they value one dollar in the future. For erosion, damages from beach loss that would occur at mean sea level only (not high or low tide, a limitation of the model) were estimated using 2020 assessed land values per m² to estimate damage costs (see Appendix). For flooding, average damage estimates from floods at low tide and high tide relied on 2020 assessed building values. For reporting purposes, the average damage cost estimates across all parameter combinations for each natural asset option along with result ranges across the different model variants are reported and shown in Appendix A – Data Acquisition and Processing. These ranges represent the minimum and maximum estimates across all parameter combinations. The final outputs, avoided costs, are simply the difference in costs between the baseline condition (no action) and a given natural asset option. This value represents the long-term (100-year) advantage, if any, from implementing the natural asset alternative.

Note that the wave attenuation indicator shown in Table 4 is a useful secondary output to the main flood and erosion indicators. While it was not the case for this pilot study, the CT’s erosion estimates are inaccurate for certain types of shoreline (e.g., see the Gibsons, B.C., companion study). In these cases, the wave attenuation metric can be used as an indirect proxy for assessing the effectiveness of a given management option with respect to erosion protection. This output is an indicator of erosion-reduction potential. The erosion index score is also a useful supplementary metric that permits comparisons across studies and beach sites. This indicator provides a relative score based on the ratio between the estimated beach retreat distance and the beach size (**0** (<1%), **1** (1 – 25%), **2** (25-50%), **3** (50-75%), **4** (75-100%), **5** (>100%)).



RESULTS

PHOTO: TRACEY MCDONALD

EROSION-REDUCTION BENEFITS

Erosion estimates from the CT suggest a strong potential to reduce erosion vulnerability along Parlee Beach using natural asset options such as dune improvement, beach nourishment and shoreline planting. Results are reported for these three natural asset options in Table 5. Despite being shortlisted for analysis, and although the stakeholder group indicated that conditions offshore of Parlee Beach are favourable for submerged vegetation (or kelp seeding), eelgrass planting and submerged structures had lower implementability ratings for the Pointe-du-Chêne case and are more theoretical in terms of their application. As such, erosion benefits are reported separately for these two natural asset options. These more theoretical options were modelled based on their ability to reduce wave energy from storms. Investigations of these options primarily sought to understand their overall feasibility for further consideration, and to provide a model “proof of concept.”

Table 5: Summary of erosion-reduction benefits

for three of five selected natural asset options with results reported for each individual beach segment in which the asset option is implemented as well as in total (i.e., if it were implemented across all segments). Dollar values are in millions (CDN 2020), annually discounted at five per cent over a 100-year time horizon.*

Long-term benefits from avoided costs (Cumulative 1-,10- & 100-year storms over a 100-year time horizon)						Other indices (short-term) (single 10-year storm example)			
Natural Asset Option & Implementation Beach Segment	Total cost		Difference (%)	Avoided Costs	Avoided Costs - Model Variant Range	Erosion Index (0-5)		Volume Loss (m³)	
	Without Action	With Action				Without Action	With Action	Without Action	With Action
Dune Improvement									
Parlee Beach NW	\$2.15	\$1.09	50%	\$1.06	\$0.86 - 1.27	3	2	5,000	3,800
Parlee Beach Main	\$4.09	\$2.83	31%	\$1.27	\$0.80 - 1.74	4	4	12,200	11,100
Parlee Beach SE	\$2.88	\$1.82	37%	\$1.06	\$0.76 - 1.36	5	5	8,300	7,000
Belliveau	\$9.91	\$5.07	49%	\$4.83	\$2.12 - 6.82	5	3	20,500	15,200
TOTAL	\$19.03	\$10.01	47%	\$8.22	\$4.54 – 11.19	-	-	-	-
Shoreline Planting									
Parlee Beach NW	\$2.15	\$0.90	58%	\$1.26	\$1.08 - 1.44	3	2	5,000	4,100
Parlee Beach Main	\$4.09	\$2.10	49%	\$1.99	\$0.80 - 3.19	4	4	12,200	11,400
Parlee Beach SE	\$2.88	\$1.38	52%	\$1.5	\$0.53 - 2.48	5	5	8,300	8,200
Belliveau	\$9.91	\$3.77	62%	\$6.14	\$3.89 - 8.38	5	4	20,500	17,600
TOTAL	\$19.03	\$8.15	57%	\$10.89	\$6.30 – 15.49	-	-	-	-
Beach Nourishment									
Parlee Beach NW	\$2.15	\$1.39	35%	\$0.77	\$0.44 - 1.18	3	2	5,000	5,300
Parlee Beach Main	\$4.09	\$1.85	55%	\$2.24	\$0.80 - 3.97	4	3	12,200	7,400
Parlee Beach SE	\$2.88	\$1.22	58%	\$1.66	\$0.53 - 2.82	5	5	8,300	4,500
Belliveau	\$9.91	\$5.03	49%	\$4.88	\$2.12 - 8.42	5	3	20,500	16,900
TOTAL	\$19.03	\$9.49	50%	\$9.55	\$3.89 – 16.39	-	-	-	-

*Several limitations associated with the erosion model should be considered in interpreting these results. We have highlighted some of these limitations at the end of this report but readers should also refer to the Guidance Document for more detail. These avoided cost estimates should be viewed as coarse first-pass estimates only. The important information to take away from this table is the relative differences between with/without alternatives.

Table 5 shows that, applied across all beach segments, shoreline planting generates the greatest long-term benefits from avoided erosion costs (\$10.89M), followed by beach nourishment (\$9.55M) and dune improvement (\$8.22M). These benefits can vary by up to -40 per cent and +70 per cent depending on the variant of each natural asset option that is applied.

While combined natural asset options would likely provide even greater benefits — for example, by including dune improvement and shoreline planting in the same model run —

combined options were not performed for this pilot study. For the individual natural asset options assessed, those applied to the Belliveau Beach segment consistently generate the greatest long-term benefits in absolute costs. In relative terms (% difference column), among all beach segments, Parlee Beach NW sees the greatest benefits from dune improvement, Belleveau from shoreline planting and Parlee Beach SE from beach nourishment. Also, among all beach segments, Parlee Beach Main sees the fewest benefits from dune improvement and shoreline planting, and Parlee Beach NW from beach nourishment.

Differences across beach segments occur due to their unique characteristics. For example, dune improvement benefits are more limited at Parlee Beach Main because established large dunes at that beach segment limit the extent to which improvements can be made under the range of parameter settings tested. Absolute erosion benefits for Belliveau Beach are larger due to its larger size relative to the other beaches.

Another key finding not shown in Table 31 is that over the 100-year time horizon, smaller, more frequent storms (e.g., annual recurrence frequency) tend to account for a larger portion of avoided costs than the larger, less frequent storms (e.g., 10-year and 100-year recurrence frequencies). For example, decreasing the foreshore slope at the main section of Parlee Beach from about 0.05 to 0.01 is projected to decrease erosion by ~2,400 m² for the one-year storm and over ~5,200 m² for the 100-year storm. However, if the valuation is extended to a 100-year time horizon, the cumulative erosion from the reoccurring one-year storm events would quickly surpass the initially high erosion projections from a single one-in-100-year storm event.

For each natural asset option, erosion index scores and beach loss/damage volumes for a single 10-year design storm (averaged across variants for each option) are also reported. Absolute volume losses are largest at Belliveau Beach and Parlee Beach Main. In relative terms, beach nourishment at Parlee Beach SE provides the most improvement (46 per cent decrease in beach loss) of any option at any of the beach segments. The erosion index scores add context to volume losses by communicating results relative to beach segment size. For example, the largest shifts in the erosion index occur at Belliveau via dune improvement and beach nourishment (scores shift from 5 to 3). So even though Belliveau may see lower relative improvements from these natural asset options compared to some of the other beach segments, when total beach segment size is considered, those options provide more significant benefits (in relative terms) when applied to the Belliveau Beach segment.

Eelgrass planting: As an additional input to the CT, a hypothetical eelgrass patch off Parlee Beach was created with a width of 200 metres. Modelling results suggest that eelgrass patches could reduce wave heights by approximately 25 per cent, but these benefits would be diminished during storms occurring at high tides or storms with lower probability of occurrence (higher surge), as the wave dissipation is directly dependent on the waves “feeling” the vegetated sea bed to dissipate energy. Because this natural asset option is so theoretical, avoided cost estimates from erosion protection are not reported.

Submerged structures: A hypothetical, 1.5-metre tall by five-metre wide submerged structure positioned 300 metres offshore from Parlee Beach about three to four metres (chart datum) underwater was created. Modelling results suggest such a structure could reduce wave heights by 20 per cent during storms at low tide but would provide no noticeable protection from storms occurring at mean sea level or high tide. If the structure size were increased to five metres tall by 10 metres wide, wave heights could be reduced by up to 40 per cent, but constructing these features would be a massive infrastructure undertaking. Smaller structures positioned closer to shore could have other benefits such as sediment retention and accretion, but the CT is only able to estimate wave height reductions.

FLOOD-PROTECTION BENEFITS

Flood estimates from the CT indicate that, compared to erosion, flooding is a much costlier hazard for Pointe-du-Chêne. A single storm can cause damages anywhere from \$0.1 to \$42.9 million and, in a finding that is consistent with other flood vulnerability studies for Pointe-du-Chêne, one 10-year storm could inundate almost half the community (Table 6). Cumulatively over the 100-year time horizon, damage costs were estimated by the CT to total \$184.2 million in present value (Table 7). In the current implementation of the CT, the mechanism by which natural assets reduce flooding is by reducing localized wave run-up heights during storms. Reducing wave run-up heights in turn reduces local water levels, flooding depths and corresponding flood damages. Natural asset options applied at any of the beach segments will have zero or relatively minor impact against flooding in the region. However, in cases where flood protection benefits do occur, the avoided costs from these relatively small improvements (one to four per cent), are within range of those from erosion. This occurs because, under all scenarios, the total damage cost to structures from floods is much higher than the total damage cost from land loss due to erosion.

Table 6: Structure damages from a single storm in Pointe-du-Chêne...

across a range of storm-induced water levels. The types of storm (1-yr, 10-yr, 100-yr) that could produce each stormwater level are also shown.

	Water Level		Structure Damage Summaries				Storm Type**
	Chart Datum (m)	CGVD2013 (m)	Flooded Structures (#)	Median Flood Depth (m)	Median Structure Damage (\$)	Total Damage Cost (\$ Millions)*	
High Tide	1.7 (HHWLT)	0.1	2	0.4	\$0	\$0	
Storms	1.75	0.15	8	0	\$9,738	\$0.1	1-yr storm
	2	0.4	52	0.1	\$8,137	\$0.4	
	2.25	0.65	134	0.2	\$12,934	\$1.7	
	2.5	0.9	228	0.4	\$20,005	\$4.6	10-yr storm
	2.75	1.15	349	0.5	\$22,416	\$7.8	
	3	1.4	436	0.6	\$25,612	\$11.2	
	3.25	1.65	544	0.8	\$27,415	\$14.9	100-yr storm
	3.5	1.9	649	0.9	\$30,834	\$20	
	3.75	2.15	763	1.1	\$33,974	\$25.9	
	4	2.4	892	1.2	\$35,695	\$31.8	
	4.25	2.65	968	1.4	\$38,923	\$37.7	
	4.5	2.9	1,025	1.6	\$41,891	\$42.9	

*Structural damage estimates are the sum of damages across all flooded structures in Pointe-du-Chêne, where damages for a single structure are derived from flood depth, structure value and the depth-damage curve assigned to the building type. Note that these values represent damages to structures from a single storm and are not aggregated over any time horizon.

** Water levels represent the potential flood water levels (above LLWLT, 0.4m) from an individual storm. Ranges reflect a combination of mild and extreme flood damages as a result of tidal elevation during the storm (+0.7 to +1.7m), SLR (+0.38m), storm surge (+0.75 to +1.9m) and runup (+0.43 to +0.65m).



Figure 6: A still water level flood map of Pointe-du-Chêne

for a 10-year storm modelled by the CT. The total water level is 3.48 metres chart datum (1.88m CGVD2013). This value includes: +1.7-metre high tide (HHWLT), +1.4-metre storm surge, +0.38-metre sea-level rise. Storm wave run-up (not included) is also likely to increase the water level at the shoreline by up to 0.65 metres.

Table 7: Summary of flood-protection benefits for three of five selected natural asset options

with results reported for each individual beach segment in which the asset option is implemented. "All-segment totals" are not provided since flood-protection benefits are not localized like erosion reduction benefits; each row represents total damages across the entire community. Dollar values are in millions (CDN 2020), annually discounted at five per cent over a 100-year time horizon.

Long-term benefits from avoided costs (Cumulative 1-,10- & 100-year storms over a 100-year time horizon)				
Natural Asset Option & Implementation Beach Segment	Total cost		Avoided Costs	Difference (%)
	Without Action*	With Action**		
Dune Improvement				
Parlee Beach NW	\$184.2	\$176.6	\$7.6	4%
Parlee Beach Main	\$184.2	\$184.2	\$0	0%
Parlee Beach SE	\$184.2	\$184.2	\$0	0%
Belliveau	\$184.2	\$184.2	\$0	0%

Shoreline Planting				
Parlee Beach NW	\$184.2	\$176.6	\$7.6	4%
Parlee Beach Main	\$184.2	\$184.2	\$0	0%
Parlee Beach SE	\$184.2	\$184.2	\$0	0%
Belliveau	\$184.2	\$184.2	\$0	0%
Beach Nourishment				
Parlee Beach NW	\$184.2	\$176.6	\$7.6	4%
Parlee Beach Main	\$184.2	\$180.8	\$3.4	2%
Parlee Beach SE	\$184.2	\$182.8	\$1.4	1%
Belliveau	\$184.2	\$180.9	\$3.3	2%

*Assumes an investment frequency for damage repair that is consistent with the design storm return periods (e.g., annual investments for one-year storms, decadal investments for 10-year storms, centennial investments for 100-year storms). Note that this assumption may result in overestimates of total damage costs because individual homeowners are likely to intervene in structural repairs with mitigative action or retreat.

** "With action" results are for beach-specific actions with impacts calculated globally. For example, improving dunes at Parlee Beach NW only reduces the total flooding damage cost for the entire study area by four per cent. Flood management actions are beach-specific but damage summaries are not.

STUDY LIMITATIONS



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The sub-models comprised by the Coastal Toolbox make several simplifications and assumptions that limit the representation of various complex coastal processes. The toolbox is well suited to coarse-scale evaluations of the relative value and approximate cost differences of alternative coastal natural asset design scenarios for Pointe-du-Chêne. However, the following key limitations should be considered during analysis and interpretation of results:

- Complex hydrodynamic flow structures and wave-propagation patterns are not represented, such as the flow around Shediac Harbour and the tidal exchange at the lagoon east of Belliveau Beach.
- Similarly, the flood maps are based on the “bathtub” model approach, which assumes very little spatial variation in the water levels and does not consider the actual flow dynamics. This approach usually provides a conservative estimate of the area flooded (i.e., it represents an underestimate). Wave evolution is modelled along individual profiles (1D); therefore, processes such as longshore drift and sediment transport are not accounted for in the outputs. The model assumes target beaches to be longshore-uniform, meaning that complex features such as narrow inlets, estuaries and points cannot be accurately captured. While a large winter storm may indeed produce erosion estimates similar to quantities estimated by the CT, beaches may also regenerate in the summer and possibly show additional accretion from longshore drift and onshore sediment transport driven by smaller waves and tidal currents.
- The 1D shoreline profiles assume that the storm’s angle of attack is perpendicular to the shoreline section. Therefore, neighbouring features adjacent to a profile will not interact with the wave model to provide coastal protection. The modelled storm simulations should be customized for an area of interest to represent the dominant exposure aspect to the beach (e.g., a south-facing beach should be modelled with northerly winds).

- The model provides a simplified estimate of beach loss (retreat) after a storm for each profile, but it does not estimate sediment accretion, seasonal changes to a beach or any other type of cut/fill sediment transport estimates along a profile.

A further consideration is that the CT is not capable of modelling all natural asset management alternatives. During stakeholder engagement, additional flood-mitigation options were identified that incorporate natural assets but were not feasible to assess with the toolbox. These options should be explored further with external tools and expertise. For example, a continuous dune could be established around Parlee Beach that acts to divert water around the community toward the harbour. This feature could be coupled with a project that improves drainage from the tidal lagoon and reduces water levels around the most vulnerable low-lying section of the community.



CONCLUSIONS

PHOTO: TRACEY MCDONALD

Erosion results from applying the Coastal Toolbox in Pointe-du-Chêne indicate shoreline planting generates the greatest long-term benefits from avoided erosion costs (\$10.89M), followed by beach nourishment (\$9.55M) and dune improvement (\$8.22M). These results were consistent across all beach segments. For the individual natural asset options assessed, those applied to the Belliveau Beach segment consistently generate the greatest long-term avoided erosion benefits in absolute costs. In relative terms, among all beach segments, Parlee Beach NW sees the greatest benefits from dune improvement, Belleveau from shoreline planting and Parlee Beach SE from beach nourishment.

Flood estimates from the CT indicate that, compared to erosion, flooding is a much costlier hazard for Pointe-du-Chêne. For the individual natural asset options assessed, those applied to the Parlee Beach NW segment consistently generate the greatest long-term avoided flooding benefits in absolute costs.

This pilot study demonstrated the utility of the Coastal Toolbox as a comparatively rapid and easy-to-use tool that is sufficient for high-level quantification of benefits from coastal natural assets. It also emphasized the challenges associated with developing a generic tool that is applicable across many community contexts where coastlines differ dramatically. The project team set out to develop a coarse, first-pass screening model that could, with the Technical Guidance Document, be used independently by any community before deciding to invest in more detailed studies. But coastal processes are complex, and at its current stage of development the tool will be more applicable to some communities than others. Current applications of the CT will likely still require combining local knowledge with professional expertise for some key modelling steps. Regardless, the tool provides a useful high-level screening and offers a valuable learning and assessment framework for coastal communities interested in exploring natural assets alongside conventional grey infrastructure projects to promote coastal resilience.



NEXT STEPS

PHOTO: TRACEY MCDONALD

Refinements to the Coastal Resilience framework and model should be pursued. Pointe-du-Chêne and/or MNAI and DSF may refine project results through sensitivity analysis, model adjustments to recognize a wider range of beach types, and expanded economic analysis.

Several assumptions are associated with the baseline parameter estimates, and a useful next step would be to examine the impact of these assumptions on results by performing various sensitivity analyses. For example, the erosion model's cost estimates rely on a median assessed value for land located near the coast (\$50/m²). In reality, land values can vary considerably, so adjusting this amount by ± 20 per cent would provide an uncertainty range for consideration. Similarly, to get building damage costs, the flood model relies on the total assessed value of each property, less the land value, which is then distributed proportionally by area in cases where multiple buildings are present (see Appendix). Since this proportional distribution may not be fully accurate, and since property prices can fluctuate, a ± 20 per cent adjustment would provide an uncertainty range that could be useful, for example, if there were a sudden increase in property values over a short time. In the project team's experience, the discount rate used to derive present values can have a significant impact on results and should also be varied. The default discount rate in the CT is five per cent but the Treasury Board of Canada (2007) recommends a social time preference rate of three per cent. Feedback from MNAI suggests this latter discount rate is preferred and should be adjusted up and down by two percentage points as a sensitivity analysis.

For depth-damage relationships, the U.S. HAZUS depth-damage curves from New Orleans were used. These relationships might vary in the Canadian context and these flood damage estimates do not consider non-structural damage like that to interior content, vehicles and public infrastructure such as utilities or bridges. Ideally, one would have access to Canadian-derived depth-damage curves. In the absence of these curves, additional sensitivity analysis can be performed by adjusting the U.S. curves (e.g., steepening or flattening, or

selecting curves from different depth-damage ensembles), and by including infrastructure in the analysis. The depth-damage curves are also an oversimplification of flood damage to structures. In many cases they may overestimate or underestimate flood vulnerability based on footprint elevation, freeboard and building features that may mitigate flood damage. This analysis is based on a high-resolution LiDAR-derived digital terrain model, but future extensions to the model should consider editing the topo-bathymetry under each structure to represent the exact elevation from survey data. In addition to these cost-related parameters, the CT sub-models themselves are based on a number of assumptions about physical processes related to storms, waves and erosion. As such, it would be useful to increase or decrease CT outputs by ± 20 per cent for a few key variables before performing the cost calculations (e.g., wave run-up, beach retreat distance, total flood levels). Other storm return intervals could also be explored. Lastly, given the comparatively large costs associated with flood damages in Pointe-du-Chêne, prioritizing sensitivity analysis for this hazard is recommended.

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APPENDIX A

DATA ACQUISITION AND PROCESSING

Area of Interest

At community engagement meetings, Parlee Beach and surrounding areas from the Pointe-du-Chêne wharf to the tidal estuary and the eastern extent of Belliveau Beach were identified as key areas of interest. For erosion, the CT used cross-shore profiles to assess all areas with sandy shores and erodible material, and excluded areas armoured with rip-rap as defined by spatial data for armoured shoreline received from the community. We further divided Parlee Beach into three sub-sections — Northwest, Main, and Southeast — for a total of four beach segments (including Belliveau Beach). For flooding, the CT assessed a larger area that included Pointe-du-Chêne and the Bluff and all areas around the wharf/marina. We excluded structures in the neighbouring community of Shediac. The backshore cutoff line for this exclusion stretched from the end of South Cove to the Horizon Trailer Park and then to the tidal estuary.

Digital Elevation Model

We developed a seamless topographic-bathymetric digital elevation model (DEM) using bathymetric data from the Canadian Hydrographic Service (CHS) and topographic data from local high-resolution LiDAR data filtered to represent a digital terrain modelⁱ. We referenced these datasets to the Canadian Geodetic Vertical Datum 2013 (CGVD2013), then merged and interpolated them to generate a continuous surface model. The LiDAR topographic data covers the higher intertidal region, the bathymetry data covers the submerged area below low tide, and we derived the elevation for the intertidal region (between the datasets) using linear interpolation. We compared the final elevation model with the aerial images, nautical charts and previous regional flood studies to confirm that the derived DEM is representative of the area. We then converted the vertical reference datum of the dataset CGVD2013 to the chart datum used by DFO where the lower low water is 0 m. Lower low-water large tide (LLWLT) = 0.4 m for this specific area. The spatial resolution of the final raster was 1 m x 1 m, but we applied additional smoothing parameters in the erosion and wave-attenuation models.

Static Water Level and Storm Surge

Coastal static water levels include contributions from the astronomical tide, storm surges and sea-level rise. We obtained astronomical tide elevations from Fisheries and Oceans Canada Tide Tables, surge levels from the “Updated Sea-Level Rise and Flooding Estimates for New Brunswick Coastal Sections 2020” and sea-level rise scenarios from the Canadian Extreme Water Level Adaptation Tool (CAN-EWLAT). These predictions provide local estimates of future sea-level rise and account for local land subsistence.

ⁱ Provincial LiDAR obtained under an open government licence for New Brunswick; see: geonb.snb.ca/nbdem/

Table A-1: Tide elevations at Pointe-du-Chêne from DFO Tide Tables

Tide Elevations	Chart Datum (m)	CGG2013 (m)
Higher high-water large tide (HHWLT)	1.7	0.1
Higher high-water mean tide (HHWMT)	1.5	-0.1
Mean water level (MWL)	1.0	-0.6
Lower low-water large tide (LLWLT)	0.4	-1.2
Lower low-water mean tide (LLWMT)	0.7	-0.9
Recorded highest high water	2.9	1.3
Recorded lowest low water	-0.5	-2.3

Storm surge is an abnormal (non-tidal) rise (or fall) in the local water level due to the effect of wind and air pressure. When the air pressure is low and the wind is blowing from the sea to the coast, a rise in the water level is observed. Negative surges can also occur when the atmospheric pressure is higher than normal, or the wind is pushing the water offshore. Since this work focuses on flooding impact of the storm surges, we only considered positive surge values. Table A-2 and Figure A-1 show storm surge levels for the area.

Table A-2: Extreme storm surge levels at Pointe-du-Chêne.

Source: Updated Sea-Level Rise and Flooding Estimates for New Brunswick Coastal Sections 2020.

Return Period (years)	Residual (m)
1	0.75
5	1.20
10	1.40
25	1.60
50	1.70
100	1.90

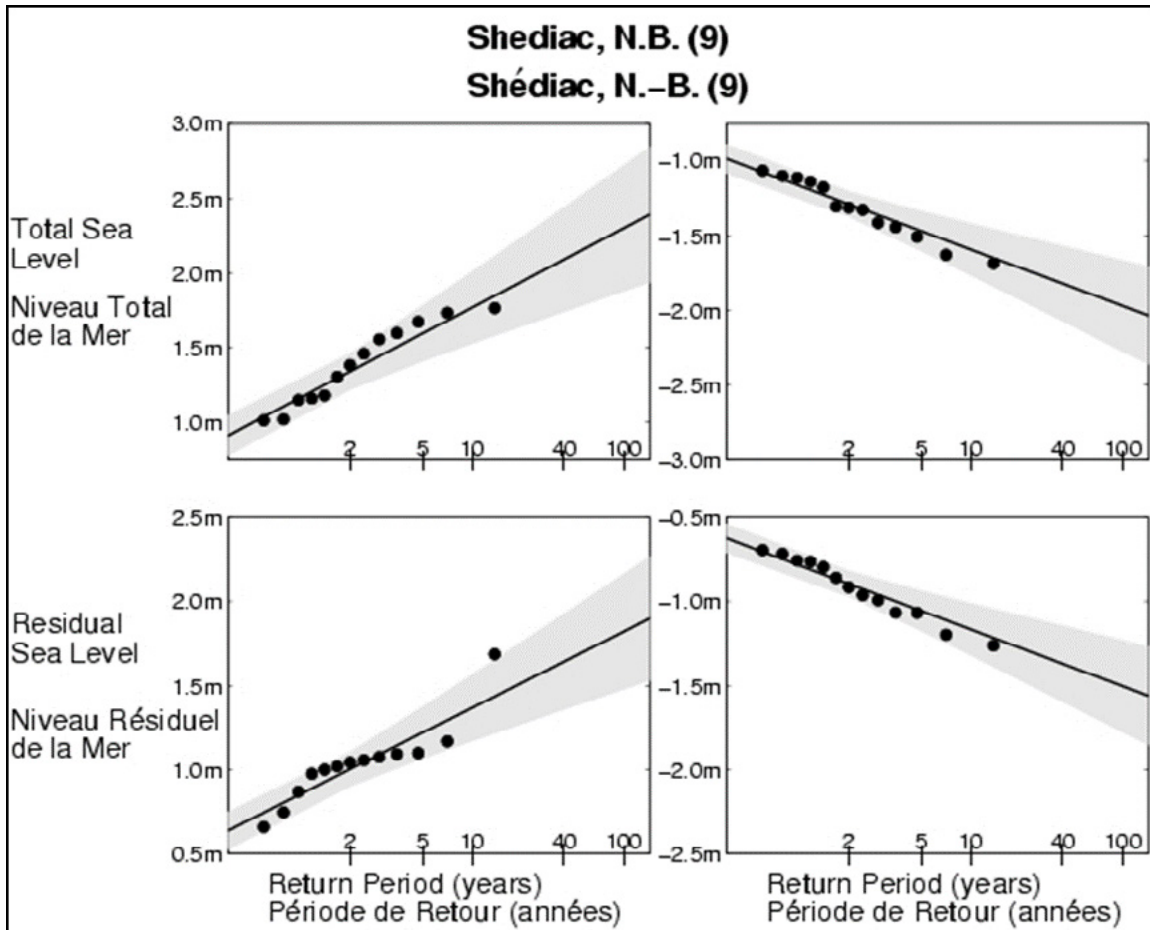


Figure A-1: Total sea levels and storm surge residual plots

Total sea levels (upper left) and storm surge residual (lower left) plots for Shédiac Bay from Bernier (2005). Grey shading represents the range of uncertainty for modelled results. Source: R.J. Daigle Enviro (2017)ⁱⁱ

Sea levels have been rising in the Maritimes since the end of the last Ice Age 10,000 years ago. The trend is expected to accelerate with climate change. Sea-level rise (SLR) projections for the area are summarized on Figure A-2 and Table A-3 (Greenan et al. 2018, based on James et al. 2014). For this study we considered the RCP 8.5 SLR scenario for the 2070 planning horizon.

ⁱⁱ The maximum water level recorded in Shédiac Bay (21 Jan 2000, 3.62 m above Chart Datum (CD) including a residual storm surge component of 2.0 m) is not plotted on the graphs because the Bernier (2005) analysis covers only the storms that occurred during period 1960-1999.

CAN-EWLAT, Shediac Bay, NB

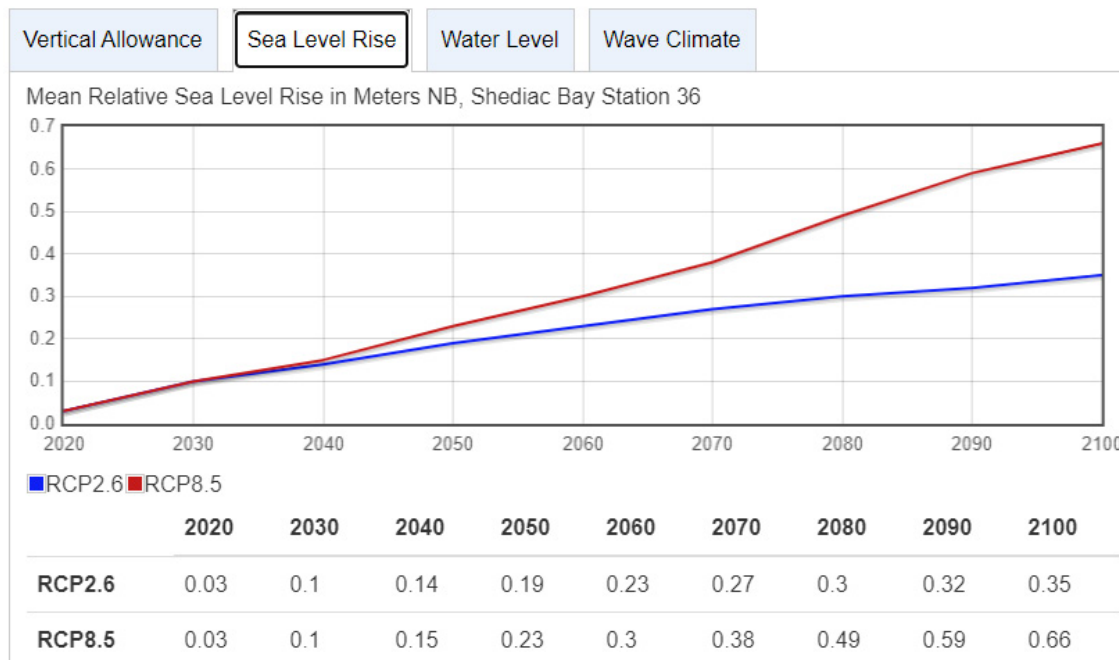


Figure A-2: Shediac Bay, NB Sea-level rise estimates for different emission scenarios.

Source: Canadian Extreme Water Level Adaptation Tool (CAN-EWLAT). Note: EWLAT provides local sea-level rise predictions with land subsidence corrections.

Table A-3: Sea-level rise at Shediac Bay.

Source: Canadian Extreme Water Level Adaptation Tool (CAN-EWLAT)

SLR Scenario	2020	2030	2040	2050	2060	2070	2080	2090	2100
RCP2.6	0.03	0.1	0.14	0.19	0.23	0.27	0.3	0.32	0.35
RCP8.5	0.03	0.1	0.15	0.23	0.3	0.38	0.49	0.59	0.66

Wave Conditions

We obtained representative wind and wave conditions for Pointe-du-Chêne from the Meteorological Service of Canada's MSC50 wind and wave model hindcast, which contains hourly time series of wind (speed, direction) and wave (height, period, direction) from January 1954 to December 2015. The dataset is a state-of-the-art hindcast; i.e., data are computed from all existing wind and wave measurements, re-analyzed, and input to a 0.1-degree resolution ocean wave growth model that includes the effect of depth. The MSC50 hindcast was developed by Oceanweather Inc. and is distributed by Environment Canada (Swaile et al., 2006).

We calculated extreme wind and wave conditions for one-, 10- and 100-year return periods using the Peaks over Threshold (PoT) analysis with Generalized Pareto Distribution (GPD) as fitting method. This method is based on the observation that the extreme tail of a distribution often has a rather simple and standardized form, regardless the shape of the central part of a distribution. We combined the results of this extreme value analysis with storm surge levels to determine the storm simulation parameters shown in Table A-4.

Table A-4: Storm simulation parameters

Return period (yrs)	Hs (m)	Tp (s)	Wind (m/s)	Tide (CD)	Surge (m)	SLR 2070 (RCP8.5 m)	Total WL
1	1.5	4.9	15.4	1.7	0.75	0.38	2.83
10	2.0	5.5	18.6	1.7	1.40	0.38	3.48
100	2.5	5.9	19.6	1.7	1.90	0.38	3.98

Foreshore Beach Attributes and Beach Loss Values

We split the study area's beaches into four sections based on geomorphic differences and natural breaks. The sections included Parlee Beach Northwest (NW) starting from the outlet of the tidal lagoon and ending at the corner of the gravel parking lot; Parlee Beach Main (main section of the beach) and Parlee Beach Southeast (SE) a smaller subsection defined by slightly steeper foreshore slopes; and Beliveau Beach behind the narrows. Other areas west of Parlee NW have a rip-rap cover. For the purpose of modelling we assumed this armoured area does not erode. For each beach segment, we determined the typical foreshore slope, grain size (D50), berm width, berm height and dune height (Table A-5).

The value of a section of beach is needed as an input for the erosion model. Determining the value of a beach is challenging, and many assumptions of the underlying modelling process may favour selecting a higher or lower value. For this pilot, we selected a beach value of \$50/m² based on an approximate median value of undeveloped land near the coastline (~\$25/m²-\$200/m²)



Figure A-3: Beach sections used for foreshore evaluation.

Table A-5: Beach sections and foreshore attributes

Section Name	Grain Size (mm)	Dune Height (m)	Berm Length (m)	Berm Height (m)	Foreshore Slope (rise/run)	Section Length (m)
Parlee Beach NW	0.1	2.0	10	0.5	0.020	514
Parlee Beach Main	0.2	3.0	10	1.0	0.055	568
Parlee Beach SE	0.2	2.5	5	1.0	0.070	261
Belliveau	0.1	1.0	20	0.5	0.050	596

Building Footprints and Structure Values

We performed all data analyses at the individual structure level rather than the property level to accommodate the use of depth-damage curves, which estimate percentage flood damages at the structure level. We multiplied these proportional damage estimates by the 2020 assessed values to get damage costs. In many cases, a given property had more than one structure. Therefore, the total structure count should not be compared to the total household count from 2016 census data. We defined structure values using census data by subtracting land values from total assessed values. For cases where secondary structures were present, we assigned values using the proportional footprint of each structure on a given property and the total structure value for the property (e.g., if the total structure value was \$100k and the property had one 10m² structure and one 15m² structure, then we calculated the value of these structures as \$100k*(10/25m²) and \$100k*(15/25).

Depth-Damage Curves

We assigned depth-damage curves using U.S. HAZUS records. We filtered the record set for salt water, short duration flooding from the USACE – New Orleans source. We assigned curve IDs to structures as follows: one-storey residential = UUID 147 and two-storey residential = UUID 163. We could not find suitable curves for the few commercial buildings on the wharf, so we assigned them either curves 147 and 163 as if they were residential. Final curve DDIDs were therefore RES1-147 and RES1-163.

Building footprint elevations are extracted as median values for each structure polygon from the underlying topo-bathymetric DEM and flood surface rasters during each model run. The terrestrial portion of this elevation surface was originally acquired as a digital terrain model from a recent LiDAR survey (i.e., vegetation is flattened and building and other artificial structures are flattened to represent a smoothed terrain surface). Visual evaluation revealed that the high resolution of this dataset still retained local grade elevations around built-up structures. The building footprints in this dataset therefore approximately align with the actual structure footprint elevations (at ground level), but local errors are certainly possible for some structures. Additional freeboard and other fine scale features may make certain structures more or less vulnerable to flooding than can be reasonably predicted by the elevation surface alone. In future developments of the CT it would be ideal for users to have a known building footprint elevation in the building layer which (if populated) updates the underlying data in the topo-bathymetric DEM to reflect the exact building elevations. These estimates do not reflect any long-term future changes to building codes and design improvements of the time horizon.

APPENDIX B

WORKSHOP PARTICIPANTS

Last Name	First Name	Role	Affiliation	Workshop		
				1	2	3
Allard	Karel	Marine Protected Area Coordinator	Canadian Wildlife Service		X	X
Baily	Matt	Decision Support System/ Tool Developer	ESSA Technologies Ltd			X
Bérubé	Dominique	Coastal Geomorphologist	New Brunswick Geological Survey	X	X	
Bornemann	James	Geomatics Manager	SERSC	X	X	X
Bourque	Zachary	Wetland Biologist, Region 3	Government of New Brunswick	X		
Brawn	Caity	GIS Specialist	SERSC	X	X	
Brooke	Roy	Executive Director	Municipal Natural Assets Initiative	X	X	X
Camarena	Amaury	Coastal Engineer	CBCL	X	X	X
Capozi	Rob	Climate Change Secretariat	New Brunswick Department of Environment & Local Government Division	X	X	X
Doiron	Sébastien	Director of Planning	SERSC	X	X	X
Donelle	Rémi	Manager	Shediac Bay Watershed Association	X	X	X
Frenette	Joey	General Manager & Head Operator	Greater Shediac Sewerage Commission	X		
Gould	Marci		New Brunswick Tourism, Heritage & Culture		X	X
Guyondet	Thomas		DFO (Moncton)		X	
Hébert	Jolyne	Project Coordinator	Shediac Bay Watershed Association	X	X	
Hunter	Garry		Hunter and Associates/Hunter GIS			X
LaFlamme	Christina	Wetland Biologist	Government of New Brunswick	X		
Long	Marc-André	GIS Specialist	SERSC			X
Love	Brandon	Climate Change Secretariat	New Brunswick Department of Environment & Local Government Division	X	X	X
Mallet	Michel	Park Manager	Parlee Beach Provincial Park	X		X
McInroy	Harry	Resident, Pointe-du-Chêne; Chair	Southeast Planning Review & Adjustment Committee; Greater Shediac Sewerage Commission	X	X	X
Molnar	Michelle	Ecological Economist	David Suzuki Foundation / Municipal Natural Assets Initiative	X		X
Morton	Cedar	Sr. Systems Ecologist	ESSA Technologies Ltd	X	X	X
Noseworthy	Josh	Director of Science, Atlantic Provinces	The Nature Conservancy of Canada	X		
Olson	Erica	Systems Ecologist	ESSA Technologies Ltd	X	X	X
Robichaud	Phil	Planner	SERSC	X	X	X
Sommerville	John	Policy Analyst	NRCAN	X		X
Tompkins	Josh	Project Executive	New Brunswick Provincial Parks	X	X	X



**DAVID SUZUKI
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Making Nature Count