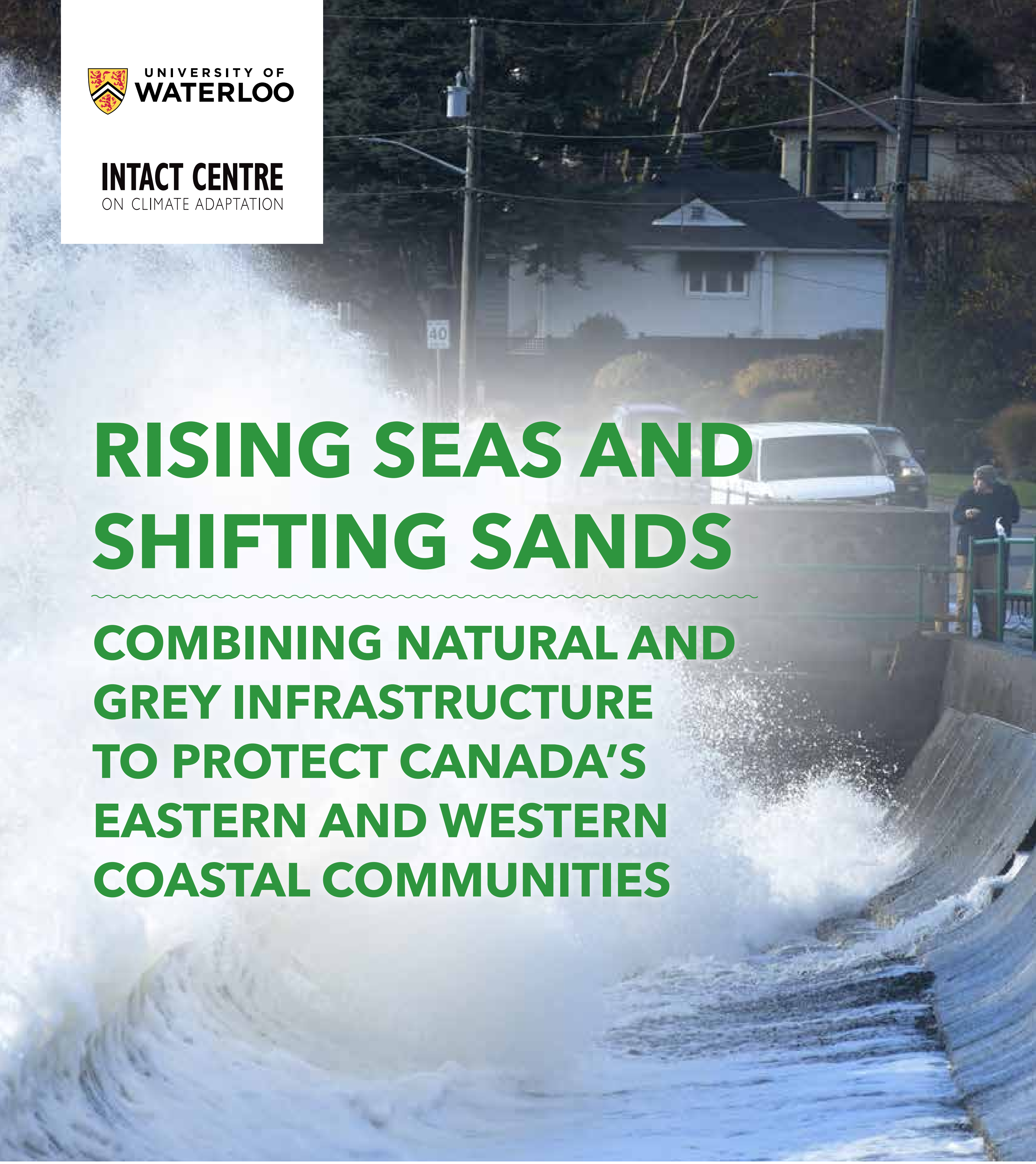

UNIVERSITY OF WATERLOO

INTACT CENTRE ON CLIMATE ADAPTATION

RISING SEAS AND SHIFTING SANDS

COMBINING NATURAL AND GREY INFRASTRUCTURE TO PROTECT CANADA'S EASTERN AND WESTERN COASTAL COMMUNITIES

Supported by:

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Joanna Eyquem P.Geo. ENV SP. CWEM. CEnv.

December 2021

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For information about this report, contact Joanna Eyquem: joanna.eyquem@uwaterloo.ca

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Enda Murphy, P.Eng.; Senior Research Engineer, Ocean, Coastal and River Engineering, National Research Council Canada
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Scott Adams, P.Eng.; Manager of Public Works, City of Charlottetown
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Matthew Armstrong, P.Eng.; Coastal Engineer, Baird and Associates
Rowland Atkins, P.Geo.; Self-employed (formerly Golder)
Christopher Benosky, PE., CFM.; Vice President, AECOM
Jason Bernier, P.Eng. PMP.; Vice President, Earth & Environment, CBCL Limited
DG Blair, Executive Director, Stewardship Centre for BC
Ursule Boyer-Villemaire, Project Manager, Adaptation, flood and natural & climate risks management, Ouranos
Jan Brownridge, Vice President Western Region Munich Reinsurance Company of Canada, Munich Re Canada
Alex Brunton, Ph.D.; Coastal and River Environmental, Baird and Associates
Robert Capozi, Director, Climate Change Adaptation, Climate Change Secretariat, Department of Environment and Local Government, Government of New Brunswick
Bridget Carle, Vice President | Public Sector Solutions, Swiss Re
Adam Cheeseman, Director of Conservation, Nature NB,
Charmaine Chiu, Intern, Climate Action Planning, Engineers and Geoscientists BC
Angela Danyluk, Senior Sustainability Specialist, City of Vancouver
Michael Davies Ph.D.; P.Eng.; President, Coldwater Consulting Ltd.
Tjasa Demsar, Climate Adaptation Coordinator, City of Surrey
Cheryl Evans, Director, Home Flood & Fire Protection, Intact Centre on Climate Adaptation
Blair Feltmate, Ph.D.; Head, Intact Centre on Climate Adaptation
Raelene Fewer, Director of Research and Development, Helping Nature Heal Inc.
Lisa-Marie Gagnon, urbaniste; Project Manager, Ville de Percé
Kevin Gallant, P.Eng.; Engineer / Researcher, Anqotum Resource Management
Shilo Gempton, MCIP., LPP.; Planner, Regional Planning, Planning & Development, Halifax Regional Municipality
Cherie Grey, Global Lead, Sustainability & Market Development, Swiss Re
Frédéric Haché, Chargé de projet en développement durable, Valorès
Mitchell Hahn, Inspector of Dikes / Head Flood Safety Section (BC), Government of British Columbia
Robin Hawker, RPP., MCIP.; Climate Resilience Associate, Integral Group (formerly Kerr Wood Leidal Associates Ltd)
Cindie Hébert, Ph.D., P.Eng.; Professor of Engineering, University of Moncton
Debra Hickey, Project Engineer, Parks Canada

Thomas James, Ph.D.; Research Scientist, Natural Resources Canada and School of Earth and Ocean Sciences, University of Victoria
Amir Ali Khan, Ph.D., P.Eng.; Manager, Water Rights, Investigations, and Modelling Section, Water Resources, Department of Municipal Affairs and Environment, Newfoundland and Labrador
Danker Kolijn, P.Eng.; Senior Coastal Engineer & Project Manager, DHI (formerly CBCL Limited)
Vincent Lambert-Song, BRACE Project Coordinator, New Brunswick Environmental Network
Jeannie Lee, P.Eng.; Flood Management Engineer, City of Vancouver
Sean Lee, P.Eng.; Assistant Director of Engineering & Operations, City of Fredericton
Taylor Legere, Manager, Intact Centre on Climate Adaptation
Kelly Loch, Green Shores Projects Coordinator, Stewardship Centre for BC
Vanessa Lueck, JD, Ph.D.; Researcher-in-Residence Coastal Adaptation, Living with Water, Pacific Institute for Climate Solutions
Tamsin Lyle, P.Eng.; Principal, Ebbwater Consulting
Jordan Matthieu, P.Eng.; Project Manager - Coastal Engineering, WSP
Keyvan Mahlujy, P.Eng.; Senior Principal Coastal Engineer, Golder
Bernard McDonell, Flood Specialist, Ministry of Forests, Lands and Natural Resource Operations, Government of British Columbia
Reid McLean, GIS Data Analyst, Government of New Brunswick
Caroline Metz, Manager Director, Economics and Resiliency, Intact Centre on Climate Adaptation
Shannon Miedema, Energy & Environment Program Manager, Planning & Development, Halifax Regional Municipality
Michelle Molnar, Technical Director, Municipal Natural Assets Initiative
Eric Morris, P.Eng.; Senior Coastal Engineer, Kerr Wood Leidal Associates Ltd
Natalia Moudrak, Managing Director, Climate Resiliency Leader, Public Sector Partnership, Aon
Marina Moudrak, Researcher, Intact Centre on Climate Adaptation
Charlotte Olson, P.Geo., PMP.; Manager, Infrastructure Habitat Development, Port of Vancouver
Phil Osborne, Ph.D., P.Geo.; Principal, Senior Coastal Geomorphologist, Golder
Matt Osler, P.Eng.; Senior Project Engineer, City of Surrey
Qi (Vivian) Peng, Junior Planner, Southwest New Brunswick Service Commission
Harshan Radhakrishnan, P.Eng.; Manager, Climate Change and Sustainability Initiatives, Engineers and Geoscientists BC
Lewnanny Richardson, Species at Risk Program Director, Nature NB
Jean-François Rolland, FCSLA.; Project Director, AECOM
Sybil Seitzinger, Ph.D.; Executive Director, Pacific Institute for Climate Solutions
Al Souid, PhD., PE., CFM.; Associate – Water Resources, Environment & Infrastructure, Wood
Amir Taleghani, P.Eng.; Senior Flood & Drainage Planning Engineer, City of Vancouver (formerly Kerr Wood Leidal Associates Ltd)
Danika Van Proosdij, Ph.D.; Chair of Geography, Faculty of Arts, Geography and Environmental Studies, Saint Mary's University
Sarah Van Veen, Former Co-op Student, Intact Centre on Climate Adaptation
Derek Williamson, Coastal Engineer, Baird & Associates
Régis Xhardé, Ph.D.; Oceanographer, Water, Tetra Tech
Queenie Yip, P.Eng.; Senior Flood Safety Engineer, Ministry of Forests, Lands, Natural Resources and Rural Development, Gov of BC

Executive Summary

Victoria, British Columbia

Coastal flooding and erosion are a direct threat to the health and safety of people living in coastal communities, and cause damage to local infrastructure and property. The majority of Canada's coastal population are located along the East (Atlantic) and West (Pacific) coastlines, where sea levels are rising due to effectively irreversible climate change.[1] Action is required **NOW** to manage the growing risks to coastal communities.

This report describes how Canada can scale-up the use of nature-based solutions, in tandem with grey infrastructure, to protect communities along the East and West coastlines.

Importantly, action must consider natural processes along the coast to a greater extent than has occurred to date. Reduction of flooding and erosion at one site, if not carefully designed, can cause instability further along the coast and degradation of coastal ecosystems on which communities depend.

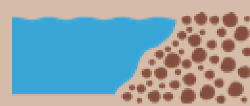
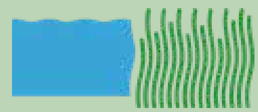
Canada does not yet have a strategic planning framework or standard classification of approaches for coastal risk management. Coastal risk management responses identified by the Intergovernmental Panel on Climate Change (IPCC) include **Protection**, **Accommodation**, **Retreat** and **Avoidance**, as well as non-intervention.[2] A suite of options should be appraised to select appropriate approaches along Canada's East and West coasts.

Coastal protection measures can be divided into two key categories:

- **Grey Infrastructure:** hard, engineered coastal protection measures, and;
- **Nature-Based Solutions:** measures that depend on, or mimic, natural systems to manage flood and erosion risk,[3] that may be a) predominantly sediment-based, such as adding sediment to beaches through beach nourishment, or b) predominantly vegetation-based, such as saltmarsh restoration.

Table 1 presents an overview of different coastal protection measures utilized in Canada according to the above classification. Each of the measures has associated advantages and disadvantages, and different measures can be combined to fulfill multiple objectives within coastal communities.

Table 1: Overview of coastal protection measures utilized in Canada

Grey Infrastructure	Underutilized Nature-Based Solutions	
	Predominantly sediment-based	Predominantly vegetation-based
		
• Seawalls • Detached / Nearshore Breakwaters • Attached Breakwaters / Headlands • Submerged Breakwaters / Reefs • Permeable Revetments* • Impermeable Revetments* / Retaining Walls • Groynes • Storm Surge Barriers / Tidal Sluices • Sea Dikes / Embankments / Levees	• Dynamic Revetment* / Cobble Berm • Submerged Sills / Perched Beach • Beach Nourishment • Island Restoration or Enhancement	• Dune Restoration or Stabilization • Cliff Stabilization / Revegetation • Salt Marsh and Coastal Wetland Restoration • Submerged Aquatic Vegetation • Bioengineering - Coir Rolls (made of coconut fibre) • Bioengineering - Natural Fibre Blankets

* Revetments are sloped coastal treatments used to protect the coastline.

Nature-based solutions, in particular, have a vital role to play in managing coastal flood and erosion risk in Canada. International experience and guidance demonstrate that these measures not only provide protection against coastal flooding and erosion, they also deliver multiple benefits, including improved biodiversity, carbon sequestration and storage, enhanced wellbeing and opportunities for recreational activities.

Three courses of action are recommended to scale-up the use of nature-based solutions for coastal protection in Canada:

1. **Develop national standards to support consistent evaluation of the benefits of nature-based solutions when comparing infrastructure options**, including for coastal protection. This should include minimum requirements, regional-specific standards, engagement with Indigenous people and recommended methodologies for reflecting the financial value of benefits provided by nature-based solutions.
2. **Develop national monitoring standards for coastal protection measures, focused on nature-based solutions.** This should include

consideration of minimum monitoring requirements, as well as how monitoring should be tailored to document performance against project-specific objectives. Funding for long-term monitoring and engagement with Indigenous people could be considered as minimum monitoring requirements.

3. **Build capacity to finance and deliver nature-based solutions by engaging the private sector.** Public-private partnerships can potentially assist in financing, delivering, monitoring, and maintaining nature-based solutions. The insurance industry can also assist in managing construction risks and offering innovative insurance products that provide funds to restore natural features protecting the coastline, should they be damaged during extreme events.

The outcomes of these actions will help governments and other organizations make robust management decisions regarding coastal flooding and erosion along Canada's East and West coastlines.

Perhaps the greatest challenge in Canada, and globally, in preparing for climate change and sea-level rise along the coast, is a limited sense of **urgency to act**. For around the past 6,000 years, global sea-level has remained relatively steady.[4] This makes the recent, comparably rapid rise in sea-level caused by human-induced climate change less easy to grasp. Decision makers in Canada must realize, sooner rather than later, that the sea level of the past will not be the sea level of the future, and prepare coastal communities accordingly.

Chapter
1

Canada's Coastline in a Changing Climate

Storm waves off the north shore of Prince Edward Island

Canada's climate is warming twice as fast as the global average and this warming is effectively irreversible.[5] The changing climate is having widespread and worsening effects on both human and natural systems along the coastline.[6] In 2019, coastal communities were identified as one of the top six areas of climate risk facing Canada.[7]

Canada's diverse and dynamic coastline is the longest in the world.[8] The biodiversity, beauty and resources of the coast contribute significantly to the culture, economy, and identity of the country and traditional ways of life.[9]

Coastal Communities

1 of top 6 areas of climate risk in Canada

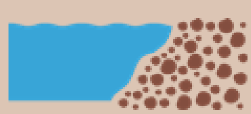
However, coastal communities are exposed to hazards, including flooding and coastal erosion, that will become more frequent and intense as a result of climate change. These hazards pose a direct threat to the health and safety of people, and may cause damage to coastal infrastructure and property. Action is urgently required to manage the growing risks to coastal communities, while working with natural processes along the coast. If not carefully designed, measures to reduce flooding and erosion at one site may cause instability further along the coast and degradation of coastal ecosystems on which communities depend.

A range of alternative strategic approaches should be considered in managing coastal flooding and erosion, including **Protection**, **Accommodation**, **Retreat**, **Avoidance**, and Non-intervention (see Section 2.1).

This report outlines the range of practical measures that can be used to protect coastal communities on Canada's East and West coasts from flooding and erosion. Coastal protection measures include:

Grey Infrastructure
Hard, engineered coastal protection measures

a.



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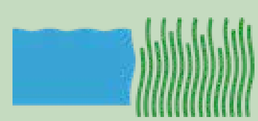


Nature-Based Solutions
Measures that depend on, or mimic, natural systems to manage flood and erosion risk,[10] and may be a) predominantly sediment-based or b) predominantly vegetation-based

The report is divided into four key parts. Chapter 1 (this chapter) introduces coastal hazards and vulnerabilities along Canada's East and West coastlines and the impacts of climate change, Chapter 2 provides an overview of international approaches to coastal risk management, Chapter 3 describes measures used in Canada to reduce flooding and erosion in coastal communities, and Chapter 4 discusses practical steps that are required for Canada to scale-up the use of measures that work with nature to deliver coastal protection, alongside multiple other benefits.

The report focuses on the East and West Coast Regions (Figure 1). It does not specificially address the unique challenges facing coastal communities in Canada's North coast region, which are significantly different to those along the East and West coastlines.

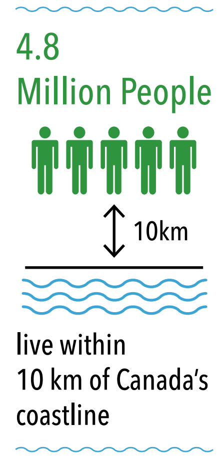
The report is designed to inform stakeholders in Canada involved in funding, design, implementation, management and insurance of coastal protection measures and their communities, including:

- Coastal communities, including Indigenous communities;
- All levels of government;
- Infrastructure designers, owners and managers;
- Industry and governmental associations;
- Institutional investors, pension funds, banks and other project financing institutions;
- Insurers (property and casualty; life and health; marine and re-insurance)
- Credit rating agencies;
- Commercial and residential real estate owners and managers; developers and homebuilders;
- Non-Governmental Organizations; and
- Academic institutions

Figure 1: Canada's West, North and East Coast Regions (adapted from Lemmen, et.al., 2016)[11]

1.1 Canada's Coastal Population

In 2016, nearly 4.8 million Canadians, representing 13.5% of the population, lived within ten kilometres of Canada's coastline.[12] Most of these people were living in Canada's East and West Coast Regions, which form the focus of this report (Figure 1). Within the East and West Coast Regions, populations are particularly concentrated within ten kilometres of the coast in the provinces of British Columbia, Nova Scotia, Newfoundland and Labrador, and Prince Edward Island (Table 2).



People living near the coast benefit from the ocean and its resources, including through employment and recreational activities. They, and many others, also enjoy the services provided by the ocean and coastal ecosystems, often referred to as "ecosystem services", including fish and seafood, opportunities for tourism and recreation, and wider societal benefits such as climate regulation and carbon storage.[13] These important services may be impacted by climate change, and consequently those living along the coast are likely to be greatly affected.

Table 2: Canada's coast and coastal population, 2016 (Source: Statistics Canada, 2021)[14]

	Coastline (km)	Total population (people)	Population within 10 km of coast (people)	Share of provincial population living within 10 km of coast (%)	Share of Canada's population living within 10 km of coast located within the province (%)
Canada	**247,007**	**35,151,728**	**4,755,541**	**13.5**	-
British Columbia	26,507	4,648,055	2,981,321	64.1	62.7
Nova Scotia	8,122	923,598	754,012	81.6	15.9
Newfoundland and Labrador	25,940	519,716	454,093	87.4	9.5
New Brunswick	2,732	747,101	242,035	32.4	5.1
Prince Edward Island	1,371	142,907	138,142	96.7	2.9
Quebec	15,699	8,164,361	147,138	1.8	3.1
Other provinces and territories	166,635	20,005,990	38,799	-	0.8

1.2 Coastal Hazards in a Changing Climate

Coasts are dynamic environments. The coast is shaped by ongoing natural processes, such as sediment erosion and deposition, which may be more pronounced during extreme weather events, such as storms. In the longer-term, change is also driven by adjustments in the relative levels of land and sea.

Flooding and erosion are natural processes that are fundamental to the function of coastal ecosystems. However, *risks* arise along the coast when coastal *hazards*, such as flooding and erosion, interact with *exposed* and *vulnerable* people, infrastructure, or ecosystems (see Box 1 for definitions).

Box 1

Definitions: Risk, Hazards, Exposure and Vulnerability

Risk: The potential for adverse consequences for human or ecological systems. In the context of climate change impacts, risks result from dynamic interactions between climate-related hazards with the exposure and vulnerability of the affected human or ecological system to the hazards.

Hazard: The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources.

Exposure: The presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected.

Vulnerability: The predisposition to be adversely affected. Vulnerability encompasses sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

(Source: IPCC, 2021)[15]

This chapter describes how the changing climate is increasing the severity and frequency of coastal flooding and erosion along much of Canada's marine coasts, with a focus on the West and East Coast Regions.

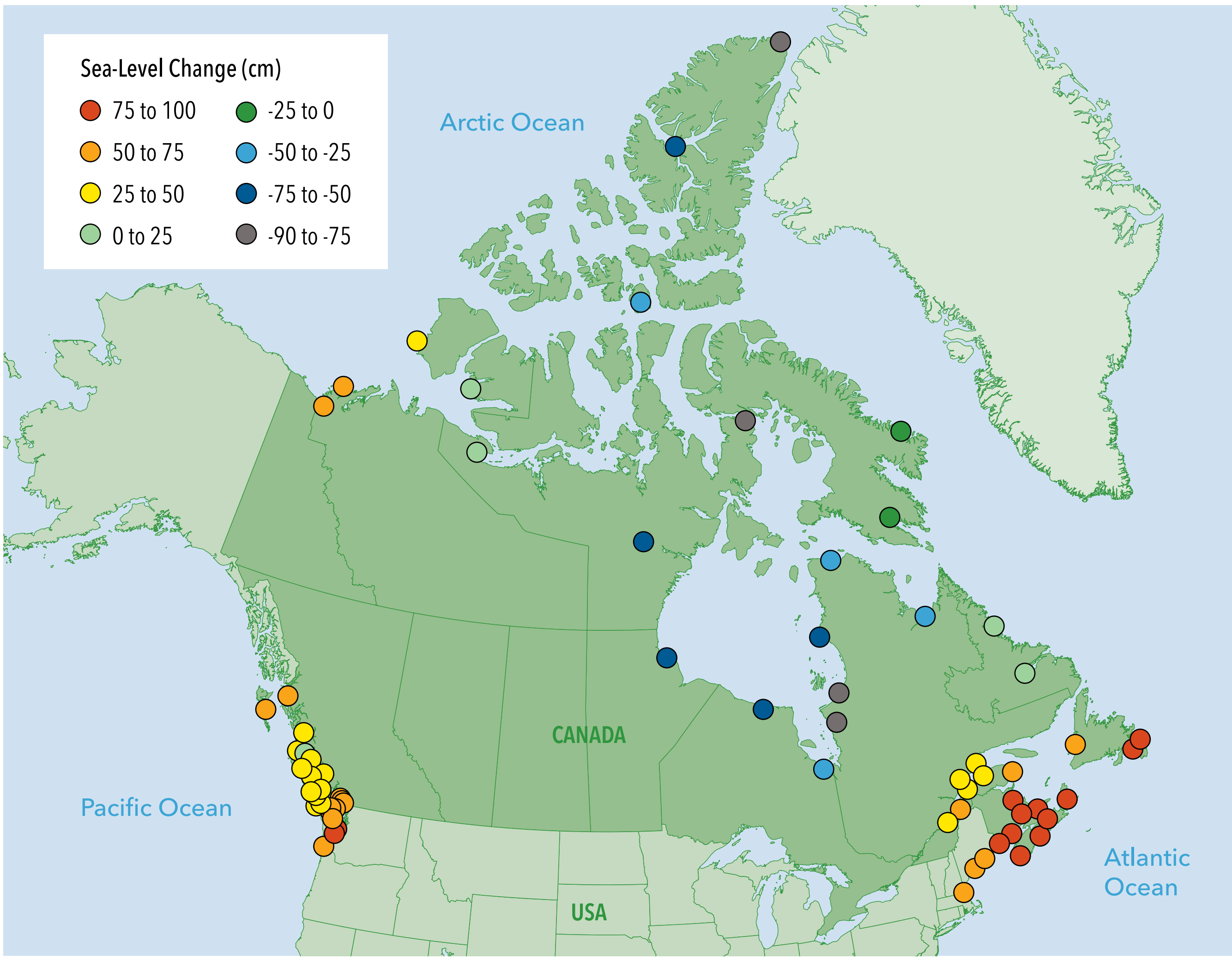
1.2.1 Extreme Water Levels and Coastal Flooding

Extreme water levels along the marine coast are a result of a combination of different processes, including storm surge, tides, and ocean waves. Future projections indicate that rising global sea levels and retreating sea ice will continue to cause changes in the frequency and magnitude of extreme water levels, which will impact Canada's coastlines.[16]

Relative sea-level change

Global sea levels are rising due to ocean thermal expansion and water delivered to the oceans from melting land-based glaciers, ice caps and ice sheets. Changes in sea level relative to Canada's coastline are also affected by vertical land motion (upward, called "uplift" or downward, called "subsidence") in response to the retreat of the last glacial ice sheet. [17]

Figure 2 shows projected relative sea-level change along Canadian coastlines at the end of the 21st century, assuming a "high carbon" greenhouse gas emissions scenario (RCP 8.5). Relative sea level is projected to rise along most of the East and West Coast Regions.



Projected relative sea-level changes shown at 2100 for the median of a high emission scenario (RCP8.5) at 69 coastal locations in Canada and the northern United States.

Figure 2: Projected relative sea-level change along Canadian coastlines at the end of the century (Source: James et al. 2014,[18] 2015[19]; Lemmen et al, 2016[20]).

The greatest rates of relative sea-level rise in Canada are projected to occur along the East (Atlantic) coast, in locations where the land is currently subsiding (red dots in Figure 2). This includes the coastline of New Brunswick, Prince Edward Island, the southern coast of Nova Scotia and the upper Bay of Fundy.[21] Along the Quebec coastline and eastern coast of

Newfoundland and Labrador, relative sea-level rise is projected to be greater than 50cm by under the "high carbon" scenario (RCP 8.5) (orange dots in Figure 2).

Along the West Coast, vertical motion rates vary from negligible values near Vancouver to uplift of almost 4 mm per year in the middle part of Vancouver Island, and smaller rates of uplift further north.[22] The largest relative sea-level rises by 2100 are projected to occur along the coast of the Fraser Lowland, southern Vancouver Island and the north coast.[23]

Where relative sea level is projected to rise, the frequency and magnitude of extreme high water-level events will increase. This will result in increased flooding, and potential for coastal erosion, that may place coastal communities at increased risk.

Further information relating to extreme water levels can be obtained using the "Canadian Extreme Water Level Adaptation Tool" (CAN-EWLAT).[24]

Storm surges

Storm surges are changes (rises or falls) in water levels occurring in response to the direct effects of wind and atmospheric pressure fluctuations during the passage of storms.[25] The low pressures and high wind speeds associated with intense storm systems typically result in positive storm surges (rises in sea level). These rises in sea level may cause coastal flooding, depending on their timing and magnitude relative to tides, and other effects such as storm waves.

Meet Cove, Nova Scotia

In some coastal regions, extreme storm surges can exceed 1 m above tide levels, and can lead to flooding when coincident with high tides. Wave effects, together with breaching or overtopping of coastal features and defences, can further exacerbate flooding. Where relative sea level is projected to rise, extreme high-water levels are expected to be even higher and more frequent in the future[26].

Changing Sea Ice Conditions in Atlantic Canada

Sea ice interacts with and affects waves and storm surges, which contribute to coastal flood hazards. While relatively low to moderate ice concentrations can result in increased storm surges relative to equivalent open-water conditions, higher concentrations and shore-fast ice conditions attenuate waves and storm surges, reducing their impacts on the shore.

In Atlantic Canada, some projections indicate that the Gulf of St. Lawrence will be free of winter sea ice by the end of this century. Reduced sea ice cover will result in longer open water fetches and increased wave heights and storm surges during winter.[27] More prolonged open water seasons will also result in increased exposure of shorelines to wave action and extreme water levels, increasing erosion in some areas.

1.2.2 Coastal Erosion

Coastal erosion is a natural process by which sediment is removed from an area and transported along or away from the coast, usually by wind, waves and/or currents. As described in the previous section, the dynamics of the coastal system are being affected by climate change. Sea level rise and reduction in seasonal sea ice cover is expected to increase coastal erosion as well as flooding, depending on the nature of the coastline.[28]

Human influence can also contribute to or accelerate coastal erosion. For example, the installation of hard coastal protection or erosion control measures, can reduce sediment supply to downdrift areas further along the coast. Where sediment supply is limited, this can result in, or accelerate, erosion along adjacent coastlines. A functional systems-based approach to coastal management must be adopted to avoid undesirable impacts elsewhere within the system.

1.3 Coastal Ecosystems

At least seven coastal ecosystem types are found along the East and West Coast regions of Canada, namely: estuaries; coastal sand systems; intertidal flats; salt marshes; cobble beaches;

cliffs/bluffs; and rocky shore ecosystems. Table 3 illustrates the features of these ecosystems and describes the potential impacts of climate change in terms of coastal flooding and erosion.

Coastal landforms and habitats have previously adapted to rises in relative sea level by shifting further inland to a higher elevation (depending on the type of coast, wave dynamics and sediment supply). A key challenge is that infrastructure and communities are generally fixed in place and may limit the landward migration of coastal ecosystems. This may result in "coastal squeeze" whereby inter-tidal zone habitats are caught between rising sea levels and fixed infrastructure, for example sea walls.[29] Since coastal ecosystems often play a role in natural coastal protection by storing water and diffusing wave energy, their loss can also make coastal flooding and erosion worse in coastal communities.

Table 3: Flood and Erosion Impacts on Seven Common Coastal Ecosystems along East and West Coastlines of Canada (Source: Adapting to Climate Change in Coastal Communities of the Atlantic Provinces, Canada, 2016[30])

Ecosystem	Example	Impacts of Climate Change
Estuary An area where a freshwater river or stream meets the ocean.[31] Courtenay Estuary, Vancouver Island, British Columbia		• Low-lying and highly vulnerable to flooding. • Rising sea levels will increase flood extent and depth in already vulnerable areas. • Storm surges will increase inland reach and intensity of flooding. • Ecosystems are diverse and sensitive to change, including changes in mixing of salt and freshwater. • Many urban coastal communities are located at estuaries.
Coastal Sand Systems The terrestrial portion of beaches, spits, barrier islands and dunes in which sand is the dominant substrate.[32] Sand dunes, Prince Edward Island		• Rising sea levels will increase flooding and erosion in areas previously not exposed to water. • Storm surges may result in overtopping and flattening of coastal features as sediment moves landward or is carried offshore by ocean currents. • Sensitive to interventions that disrupt natural sediment movement.

Ecosystem	Example	Impacts of Climate Change
Intertidal flats Generally non-vegetated expanses of mud, sand or rock lying between high and low water marks.[33] Intertidal flats, Fundy National Park, New Brunswick		• Low-lying and highly vulnerable to flooding. • Rising sea levels will increase flooding and erosion in areas previously not exposed to water. • Wave action resulting from storm surges may result in movement of large volumes of material. • Sensitive to interventions that disrupt natural sediment movement.
Salt marshes Coastal wetlands that are flooded and drained by salt water brought in by the tides, with soil typically composed of deep mud and peat.[34] Rissers Beach Provincial Park, Nova Scotia		• Diverse habitats that are sensitive to change. • Rising sea levels may cause excessive sediment deposition, burying and killing vegetation. • Vegetation can also drown if not exposed to air during low tide. • Without vegetation, habitat may be degraded, reducing carbon sequestration and storage.
Cobble beaches beaches that are made up of glacial till and other rock materials from the sediment that accumulated along the coast when the glaciers retreated. Qualicum Beach on Vancouver Island, British Columbia		• Cobble material may shift inland in response to sea level rise. • Higher wave energy during storm surges may transport cobbles inland, potentially causing damage to infrastructure.

Ecosystem	Example	Impacts of Climate Change
Cliffs / bluffs Cliffs are vertical, or nearly vertical, rock exposures. Bluffs are broad, rounded cliffs. [35] Eroded cliffs, Cape Enrage, New Brunswick		• Sea level rise can lead to submergence of cliffs and bluffs and backshore flooding. • Higher wave energy during storm surges can exacerbate erosion both at the top and bottom of a cliff / bluff. • If the undercutting is significant, cliffs/ bluffs may fail.
Rocky shore ecosystems Coastal shores made from solid rock Blanc Sablon, Gulf of St. Lawrence, Quebec		• Sea level rise can lead to submergence of rocky shores and backshore flooding. • During storm surges, water can travel further inland. • Rocky shores may fail due to undercutting by increased wave action.

Chapter

2

Coastal Risk Management Around the World

Erosion on a coastal path, St Andrews, New Brunswick

According to the IPCC's "Special Report on the Ocean and Cryosphere in a Changing Climate", adaptation responses to coastal risks have been implemented globally mainly in response to existing coastal risk or experienced disasters.[36]

This chapter opens with an overview of international coastal adaptation responses and trends, followed by country-based case studies that illustrate evolving approaches to coastal risk management.

2.1 International Coastal Adaptation Responses and Trends

Six key types of adaptation responses were identified by IPCC, namely: No Response, Advance, Protection, Accommodation, Retreat and Ecosystem-based Adaptation (illustrated in Figure 3).

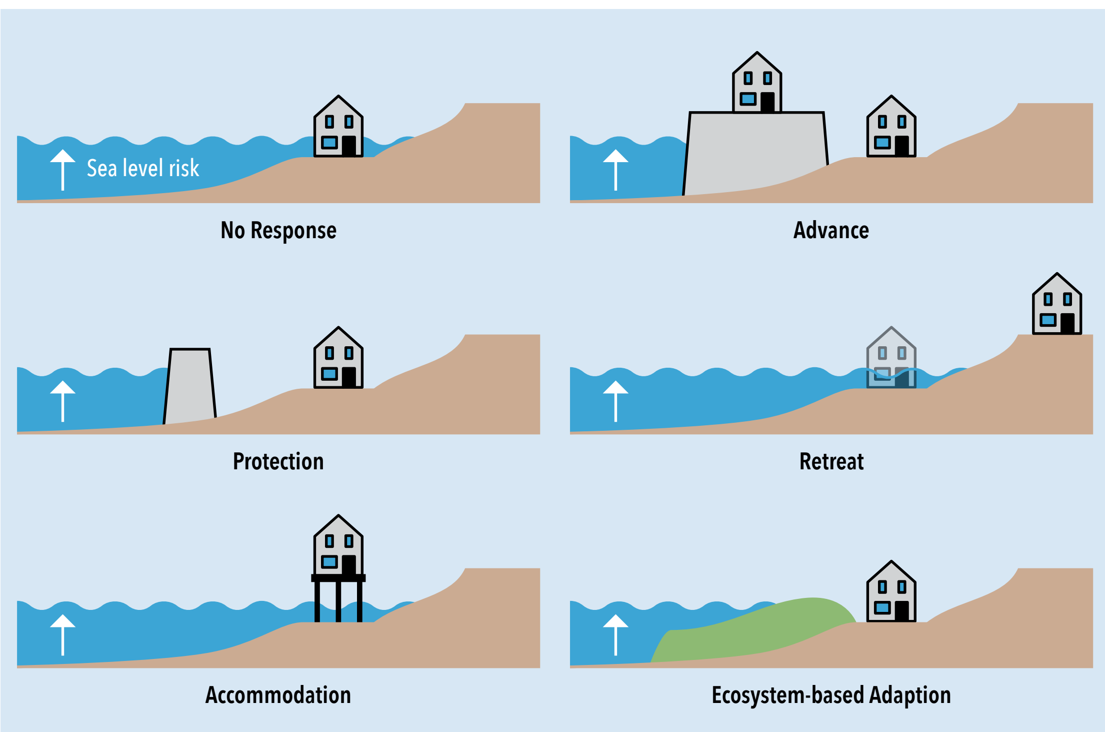


Figure 3 : Different types of responses to coastal risk and sea level rise (Source: Oppenheimer, et al. 2019)[37]

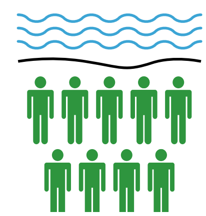
In reference to the different types of response, the report notes:[38]

- **Hard coastal protection measures** (dikes, embankments, sea walls and surge barriers) are widespread, concentrated particularly in northwest Europe, East Asia, and around many coastal cities and deltas. The application of **sediment-based protection measures** also has a long history
- **Accommodation** measures, such as early warning systems for extreme sea level events, are widespread.
- **Advance**, which refers to the creation of new land by building into the sea (e.g., land reclamation), has a long history in most areas where there are dense coastal populations.
- **Retreat** is observed but largely restricted to small communities or carried out for the purpose of creating new wetland habitat
- **Ecosystem-based adaptation** is continuing to gain traction worldwide, providing multiple co-benefits, but there is still low agreement on its cost and long-term effectiveness.

The IPCC report also states, with high confidence, that "well-designed coastal protection is very effective in reducing expected damages and is cost efficient for urban and densely populated regions".[39]

In 2018, a study of the economic robustness of protection against 21st century sea-level rise also concluded that it is economically beneficial to protect 13% of the global coastline, a proportion which encompasses 90% of the global floodplain population.[40] It should be noted that this study did not consider social and environmental costs and benefits, which add to the overall value of interventions and should also be taken into account in decision-making.

Protecting 13% of global coastline



affects 90% of the global floodplain population

While "grey" infrastructure and sediment-based protection measures have a long history, experience in the design, implementation and management of vegetation-based protection has been gathering pace internationally since around 2000. Building on this experience, in 2021, subject matter experts from across the world came together to publish the "International Guidelines on Natural and Nature-Based Features for Flood Risk Management", drawing on expertise from the United States Army Corps of Engineers, the Rijkswaterstaat Ministry of Infrastructure and Water Management in the Netherlands, and the Environment Agency in the United Kingdom among many others, including organizations from Canada.[41] These guidelines cover the use of nature-based solutions for coastal flood protection, including beaches and dunes, coastal wetlands, islands, reefs and submerged aquatic vegetation. The trend towards the use of measures that work with natural processes is evident in several of the county-based case studies that follow.

2.2 Country-Based Case Studies

The following sections provide an insight into approaches to coastal risk management in the Netherlands, England, Japan, the United States of America and Australia.

Two common themes are increasing recognition of the need for coastal protection measures to work with natural processes and the selection of measures that deliver multiple benefits while protecting communities from coastal flooding and erosion.

2.2.1 The Netherlands –Working with Natural Sediment Processes

The Netherlands is a low-lying, flood prone country located in a delta. With 350 km of coastline, nine million residents living in coastal areas and vast regions located below the mean sea level, it is severely exposed to coastal risks. However, the country is also a source of extensive experience and innovation in approaches to coastal protection.

Coastal flood and erosion protection in the Netherlands is governed by the Delta Programme Commissioner.[42] The first Delta Committee was established after the dramatic storm surge of 1953 and provided direction for engineering works to protect areas that had been damaged. The Second Delta Committee, however, was not commissioned in response to a disaster, but to provide direction on how to protect the Netherlands against the expected impacts of climate change, including sea level rise. The 2008 recommendations, entitled "*Working together with water,*" resulted in the Delta Act, the associated Delta Programme and Delta Fund, to protect the country against flooding (both riverine and coastal) and make it climate-proof.[43]

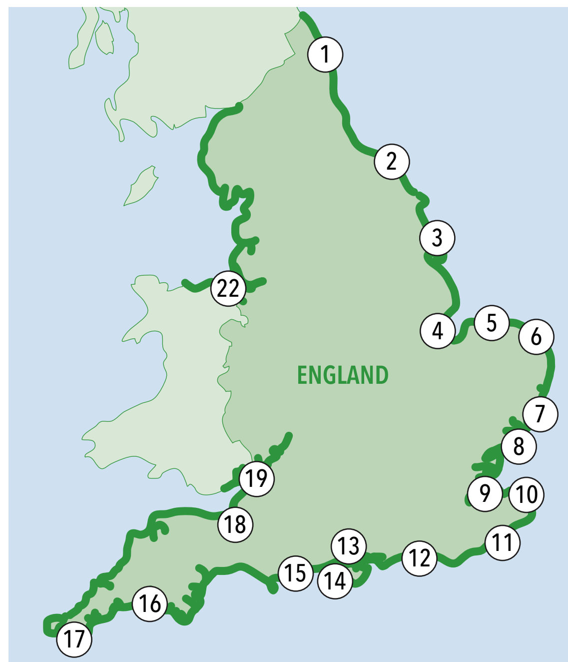
At the core of coastal protection under the Delta Programme is the concept of working with natural sediment processes. Managing the sediment budget of the sandy coast is one of the main strategies for coastal protection. This is coupled with dike defenses further inland[44]. Sand nourishment has been practiced since 1990 to maintain dunes and beaches in their 1990 position, referred to as the Coastal Foundation Zone. A total of about 12 million m^3 is nourished every year and the effects last around 5 years.[45]

In 2011, the Sand Motor (Zandmotor) pilot project was implemented along the Delfland coast to provide a longer-lasting source of sand, deposited in a single operation. It involved 21.5 million cubic metres of sand being extracted ten kilometres offshore and deposited along the coast, to form a hook-shaped peninsula of 128 ha, including a dune lake and a lagoon.[46] Monitoring over the last ten years indicates the Sand Motor contributes to long-term coastal protection broadly as anticipated and with a lifespan that is longer than expected.[47]

Young dune and kitesurfers, Zandmotor, The Netherlands

2.2.2 England – Shoreline Management Planning

Strategic planning of coastal protection is carried out in England within the framework of Shoreline Management Plans (SMPs). The boundaries of SMPs divide the shoreline into a number of cells that reflect the coastal sediment processes occurring along the coast. In England, there have been two rounds of planning to date, and 22 SMPs are currently in place.[48] These plans were developed by "Coastal Groups", led by local councils and/or the Environment Agency. The SMPs set a strategic policy direction for coastal management and identify the most sustainable approaches to managing risks to the coastline in the short-term (0 to 20 years), medium term (20 to 50 years) and long term (50 to 100 years). Four broad policy options are available for SMPs:[49]



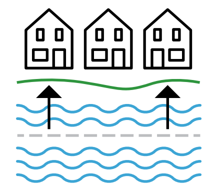
SMPs in England

- **Hold the Line:** an aspiration to build or maintain artificial defences so that the current position of the shoreline remains as it is. This can involve maintaining or changing the standard of protection.
- **Advance the Line (ATL):** by building new defences on the seaward side of the original defences. This is rarely used.
- **Managed Realignment (MR):** by allowing the shoreline to move backwards or forwards naturally but managing the process to direct it in certain areas.
- **No Active Intervention (NAI):** where there is no planned investment in coastal defences or operations, regardless of whether an artificial defence has existed previously.

The National Coastal Erosion Risk Map is a portal that enables citizens to view the policies in place around the coastline.[50]

Traditionally, coastal protection measures in England were focused on defending the coast using hard engineering measures – in 2009 it was estimated that around half of England's coast was protected by hard defences.[51] However, over the last 30 years, managed realignment and approaches that work with natural processes have gained increasing traction. Managed realignment may involve the deliberate breaching of hard defences, or not renewing defences when they reach the end of their expected life, to allow the coastline to move inland. The first official managed realignment project was carried out in the UK in 1991 on Northey Island in the upper reaches of the Blackwater Estuary in Essex[52] and since then, 75 other realignment schemes have been completed.[53]

75
realignment
projects



in the UK
since 1991

There is strong information exchange with the Netherlands, and the recent Bacton to Walcott Sandscaping Scheme, Norfolk, implemented in 2019,[54] closely mirrors the Dutch 'Zandmotor' project. The project entailed placing 1.8 million cubic metres of sand on the foreshore in front of Bacton Gas terminal and nearby villages that were at risk of both coastal erosion and sea flooding.

2.2.3 Japan – The Challenge of Tackling Catastrophic and Ongoing Coastal Risks

Japan is prone to coastal natural disasters, including typhoon-induced flooding and high waves, and tsunamis or tidal waves. While these natural disasters cause enormous damage over a short period of time, the most serious damage to coastal areas has arguably been by ongoing coastal erosion over a long period of time.[55]

Japan's coastline was significantly hardened as part of post-war development in the 1950s. In response to the 2011 earthquake and tsunami, Japan's hard protection was reinforced. Further reinforcement and raising of defences have recently been undertaken in response to sea level rise projections. For example, a system of flood gates and 54 km of seawalls, built up to +7 m above mean water level, protect Tokyo against storm surge, high tides and tsunamis.[56] While these measures protect urban areas against natural disaster, they do not address ongoing coastal erosion.

Tetrapods

Beach erosion in Japan has accelerated since the 1970s, largely due to artificial land alterations. Sediment supply along the coastline has been disturbed by the construction of port breakwaters, offshore barriers and hard protection, while port and dam developments have reduced sediment supply from rivers. With reduced sediment input, beach erosion has occurred at a faster rate.[57] Hard protection measures, such as "tetrapods", have been used to stabilise beaches, but do not address the issue of sediment supply.[58] Climate change is likely to significantly worsen beach erosion,[59] highlighting the ongoing importance of considering natural processes in the design of coastal protection.

2.2.4 United States of America – Towards Living Shorelines

Coastal hazards threaten approximately $1 trillion in real estate along U.S. coasts.[60] The National Coastal Zone Management Program is a voluntary partnership between the federal government, and coastal and Great Lakes states and territories. Authorized by the Coastal Zone Management Act of 1972, the program provides the basis for protecting, restoring, and responsibly developing coastal communities.[61]

Protecting the coast in the United States has historically been achieved primarily using grey infrastructure and sediment-based protection measures. In 1956, the U.S. Army Corps of Engineers was authorized to carry out beach nourishment for shoreline protection and has since participated in beach nourishment projects on approximately 350 miles of shoreline, mostly on the Atlantic and Gulf coasts of the United States. However, the impacts of these projects are temporary and repeated nourishment is required.

Immediately after planting

After growing season

Example Living Shoreline Project

According to the U.S. Climate Resilience Toolkit, there is growing recognition of the adverse impacts of grey infrastructure protection measures on natural coastal processes.[62] This, together with high installation and maintenance costs, has led many states to shift their focus from hard protection to the creation of so-called "living shorelines." A recent survey of regulatory responses to sea level rise and shoreline protection in U.S. coastal states, found that 21 of the 22 states surveyed have endorsed living shorelines or other "soft" coastal resiliency approaches in statute, regulation, state policy or guidance. In addition, many states have introduced much tighter permitting controls on hard coastal protection, and certain states and local governments have even banned new hard defences (e.g. the 2003 ban in North Carolina and the Town of Nantucket, Massachusetts).[63]

The National Oceanic and Atmospheric Administration (NOAA) actively encourages the use of living shorelines over hard protection where appropriate, particularly along sheltered coasts (i.e., coasts not exposed to open ocean wave energy). In 2015, NOAA issued national guidelines for considering the application of living shorelines[64] and continues to provide an expanding library of resources for practitioners, emphasising the multiple benefits of such approaches.[65]

2.2.5 Australia – Emergence of Nature-Based Approaches to Coastal Protection

Australia has strong historic ties to the UK and has introduced a strategic framework for coastal management based on Coastal Sediment Compartments, similar to the UK's Shoreline Management Plan (SMP) approach. A nested framework of primary, secondary and tertiary compartments has been identified to facilitate management over different scales of space and time (Figure 4).[66] Within this framework, there are differing approaches to coastal management between states and territories in Australia. New South Wales has been particularly proactive in developing strategic Coastal Management Programs (CMPs).

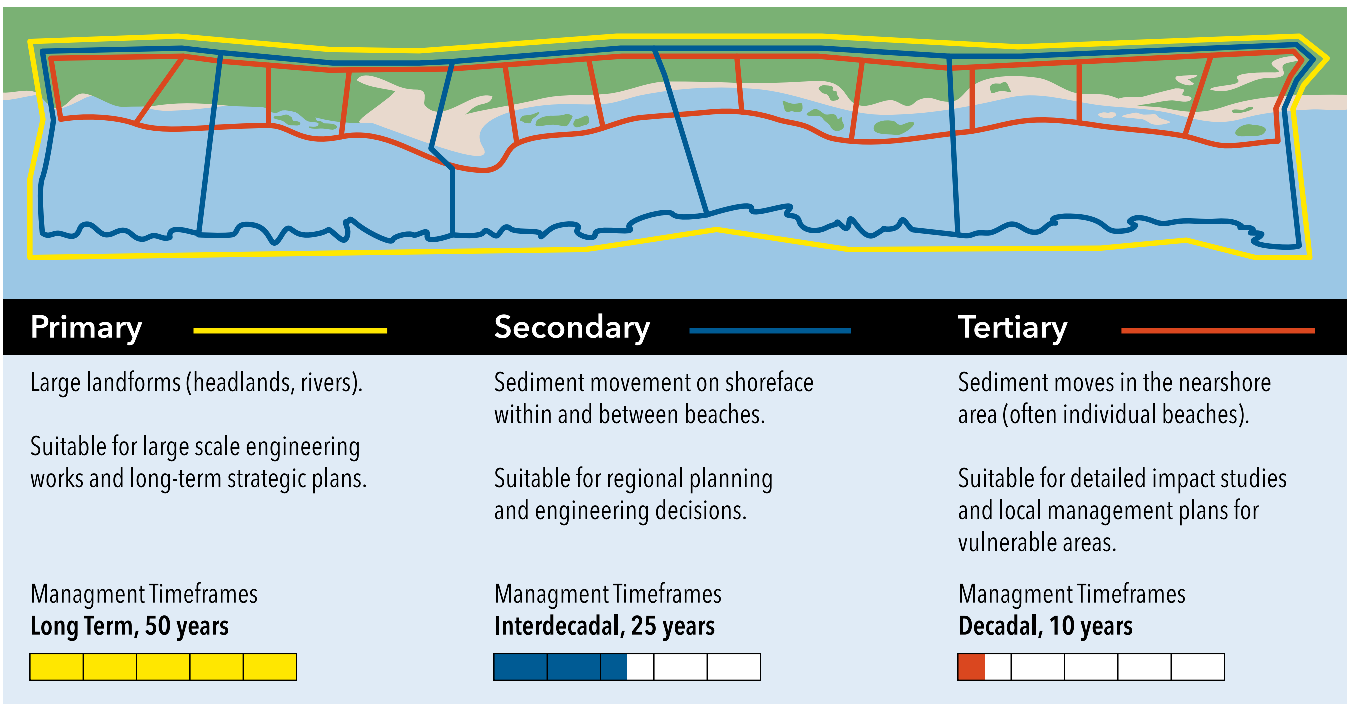


Figure 4: Primary, secondary and tertiary compartments used to manage Australia's coastline. (Source: Thom, 2014[67]).

The CoastAdapt portal, provided by the National Climate Change Adaptation Research Facility and funded by the Australia Government, is a key public resource of information on coastal adaptation to climate change.[68] The CoastAdapt Shoreline Explorer portal enables the public to readily view data for the 359 secondary sediment compartments identified around the Australian coast, including natural characteristics and sensitivity to climate change.[69]

In terms of coastal protection measures, the publication "Climate Change Adaptation

Guidelines in Coastal Management and Planning", prepared in 2012 by Engineers Australia, described engineering solutions, including shoreline protection, offshore protection and estuarine and entrance management measures, with nature-based solutions being described under emerging technology and novel solutions.[70] There is currently no national guideline on implementing nature-based coastal defence in place of traditional structures for protection in Australia. Since 2016, Living Shoreline projects have been piloted, but efforts have largely been led by NGOs such as Ocean Watch and Estuary Care Foundation. Improved knowledge at the local government level, and industry accreditation and guidelines for approaches have been identified as necessary to increase uptake of nature-based solutions.[71]

Chapter

3

Coastal Protection in Canada

Repairing sea wall in Stanley Park, May 2018

This chapter presents an overview of different types of coastal protection measures, their associated advantages and disadvantages, and examples of their application in Canada.

3.1 Classification of Measures

Canada does not yet have a strategic planning framework or standard classification of approaches for coastal risk management.

A "Protect, Accommodate, Retreat and Avoid" (PARA) framework has been proposed for the Canadian context (Figure 5).[72] This classification reflects four of the six types of coastal management responses identified by the IPCC in 2019 (illustrated previously in Figure 3). The IPCC also identified ecosystem-based measures as an emerging approach in coastal management (see Section 2.1). However, nature-based solutions can play a role in both coastal protection and retreat, as reflected in the modified PARA framework presented in in Figure 5.

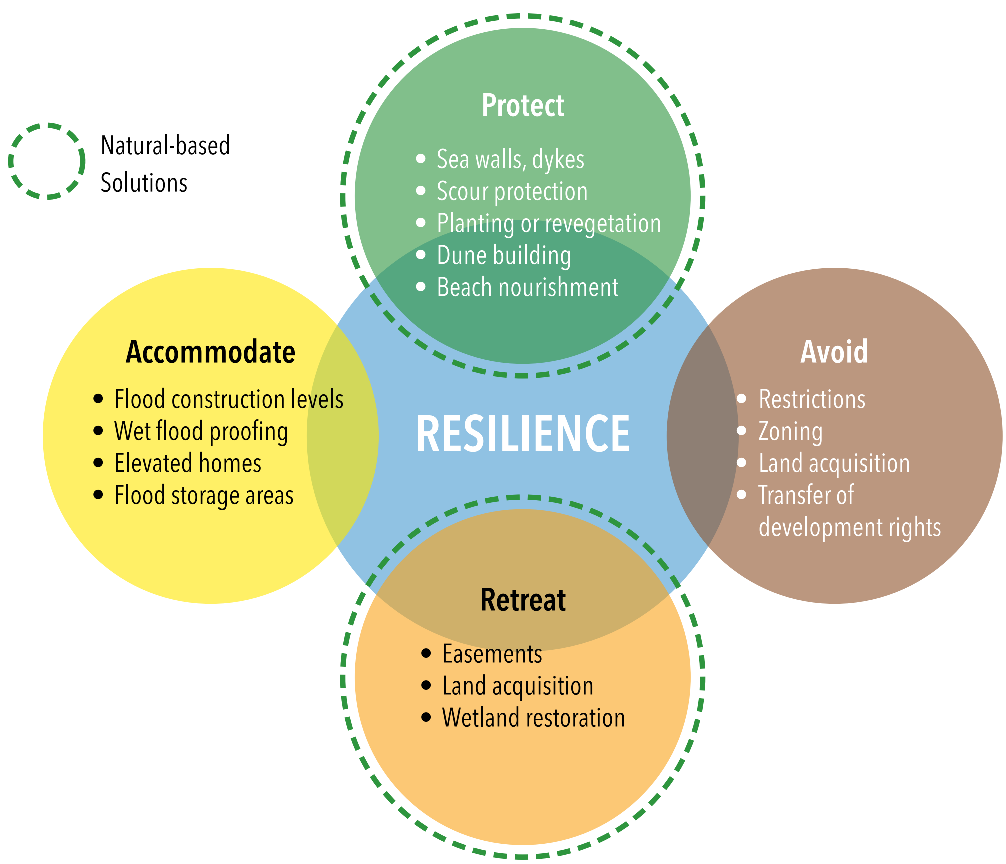


Figure 5: Protect, Accommodate, Retreat and Avoid (PARA) framework (proposed by Doberstein et al., 2019), amended to reflect the role of nature-based solutions in coastal protection and retreat.

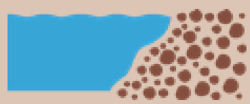
The 2021 "International Guidelines on Natural and Nature-Based Features for Flood Risk Management" affirm that nature-based solutions can contribute to protection against coastal flooding and erosion by:[73]

- Attenuating the energy and height of incoming waves
- Attenuating storm surge water levels along the shoreline
- Providing storage of floodwater in the upper tidal reaches of estuaries
- Reducing erosion of sediments and soils
- Attracting and stabilizing sediments
- Attracting and sustaining flora and fauna, which can stabilize structures such as dikes

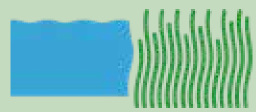
In this report, coastal protection measures are organized into two main categories:

Grey Infrastructure
Hard, engineered coastal protection measures

a.



b.



Nature-Based Solutions
Measures that depend on, or mimic, natural systems to manage flood and erosion risk,[74] and may be a) predominantly sediment-based or b) predominantly vegetation-based

Importantly, nature-based solutions deliver a suite of environmental and other societal co-benefits alongside improved flood and erosion management.[75] These measures may also be referred to as approaches based on "natural infrastructure" or "natural assets". Bioengineering solutions that involve a combination of engineered infrastructure and vegetation are also discussed under vegetation-based protection measures.

3.2 Description of Coastal Protection Measures, Advantages and Disadvantages

Table 4 provides an overview of coastal protection measures that may be utilized in Canada, as well as generic advantages and disadvantages associated with their practical implementation, as informed by literature review and input from coastal specialists. Grey infrastructure measures are shaded in grey, nature-based solutions that are predominantly sediment-based are shaded in gold, and nature-based solutions that are predominantly vegetation-based are shaded in green.

In addition to the measures presented in Table 4, research to develop guidance for nature-based solutions is also ongoing in Canada. For example, anchored driftwood (termed "large woody debris") is a technique that has been used in coastal British Columbia as a method to help stabilize beaches, possibly since the mid-1900s. Research suggests that this could be a viable alternative to grey infrastructure in some coastal situations, although its usage for coastal protection is considered experimental at present due to the limited design guidance available.[76]

Table 4: Coastal Protection Measures: Description, Objectives, Advantages and Disadvantages

GREY INFRASTRUCTURE PROTECTION MEASURES

Seawalls

Seawall, Stanley Park, Vancouver, British Columbia

Description and Function	Objective(s)	Main Advantage(s)	Main Disadvantage(s)
Onshore impermeable freestanding structures, often made of concrete or masonry, built parallel to the shoreline in order to intercept wave energy and reinforce part of the beach profile. Steel products (gabions, sheetpile) deteriorate quickly in saline waters and are not recommended in new design.	Protect assets and infrastructure immediately behind the seawalls from flooding and erosion.	Provide a high degree of localised protection against flooding and erosion inland along high-energy coasts. Smaller structural footprint compared to other hard coastal protection structures. Can be used for built-up areas that have limited land available.	Breaching of seawalls may be catastrophic with high potential to cause loss of life and property damage. When used in erodible coastal areas, increased erosion is likely to occur in front and down drift of the structure. May obstruct natural inland migration of coastal systems driven by sea level rise, resulting in "coastal squeeze" of intertidal habitats. Expensive approach with high life-cycle costs, including design, construction and maintenance. Susceptible to geotechnical failures and erosion. If drainage behind the seawall is not adequate, it can cause the seawall to buckle, move, or collapse. Sea level rise may mean that seawalls have to be frequently raised higher to provide the desired protection. May reduce attractiveness and access to the coastal area.

Detached / Nearshore Breakwaters

Detached breakwater, Cowes, UK

Description and Function	Objective(s)	Main Advantage(s)	Main Disadvantage(s)
Offshore structures, usually made from concrete or rock, built parallel to the shoreline to dissipate wave energy in the lee of the structure.	Reduce rate of beach erosion.	Effective at protecting the shoreline of high-energy coasts. Can extend lifespan of beach nourishment projects and create wave environments suitable for wetland creation projects. Often associated with recreational activities with associated social and economic benefits.	Expensive approach with high life-cycle costs, including design, construction and maintenance. May require beach nourishment for erosion control where sediment is limited. Trapping of sediment between the shore and the breakwater disrupts longshore drift and may increase coastal erosion down drift. Susceptible to geotechnical failures and nearshore erosion.

Attached Breakwaters / Headlands

Souris Harbor, Prince Edward Island

Description and Function	Objective(s)	Main Advantage(s)	Main Disadvantage(s)
Shore-connected structures extending outward from the shore, built to dissipate/reflect wave energy.	Reduce rate of beach erosion.	Effective at protecting the shoreline of high-energy coasts. Can extend lifespan of beach nourishment projects. Intercept and retain sediments transported alongshore. Useful substitutes for traditional groynes. Improvement of marine life in certain areas.	An expensive form of coastal protection due to high costs of the design, construction and maintenance. Trapping of sediment between the shore and the breakwater disrupts longshore drift and may increase coastal erosion down drift. Sea level rise may result in increased lee side erosion.

Submerged Breakwaters / Reefs

Artifical reefs, Stratford, Connecticut, US. Photo source: Scott Kruitbosch/RTPI

Description and Function	Objective(s)	Main Advantage(s)	Main Disadvantage(s)
Offshore structures with crest below the water surface, built parallel to the shoreline to dissipate wave energy before it reaches the shore.	Attenuate waves. Reduce rate of beach erosion.	Can be effectively combined with other protection measures. For example, to extend the lifespan of beach nourishment projects or contribute to shoreline stabilization. Improvement of marine life in certain areas. Increase economic and social benefits of coastal recreational activities.	Limited potential to reduce flooding in areas with large tidal ranges (above 4m), as is the case in many areas of Canada that are exposed to flood risk. Potential for artificial reef structures to become habitat for invasive species. Trapping of sediment between the shore and the breakwater disrupts longshore drift and may increase coastal erosion down drift. As sea levels rise, the effectiveness of submerged breakwaters may be reduced. May pose a navigation risk at high tide or during storm surge.

Permeable Revetments

Description and Function	Objective(s)	Main Advantage(s)	Main Disadvantage(s)
Onshore structures to dissipate wave energy and reduce erosive power of waves. The design of the revetment and materials selection will depend upon wave energy, with large armour rock or concrete armour units best-suited for the most exposed coasts.	Reduce rate of coastal erosion.	Protect coasts subject to severe and ongoing erosion.	Large structural footprint may increase the cost of structures. Reduced sediment supply for longshore drift may increase coastal erosion down drift. May obstruct natural inland migration of coastal systems driven by sea level rise, resulting in "coastal squeeze" of intertidal habitats. Can require frequent maintenance as a result of settlement, scour and destabilization of the revetment slope. May reduce attractiveness of the beach.

Impermeable Revetments / Retaining Walls

North Beach retaining wall, Swanage, UK

Description and Function	Objective(s)	Main Advantage(s)	Main Disadvantage(s)
Onshore continuous sloping or vertical structures that act as a barrier against wave action and erosion. Steel products (gabions, sheetpile) deteriorate quickly in saline waters and are not recommended in new design.	Stabilize slope of adjacent land. Reduce rate of coastal erosion.	Provide a fixed line of defense for high value assets exposed to wave-induced erosion.	Obstructs sediment processes and should not be used in beach-dune sand systems. When used on erodible coastal areas, increases erosion in front and down drift of the structure. Reduced sediment supply for longshore drift may increase coastal erosion down drift.

Groynes

Groynes at low tide

Description and Function	Objective(s)	Main Advantage(s)	Main Disadvantage(s)
Structures usually made from rock or timber, built perpendicular to the shoreline and over the beach to reduce longshore drift and trap sediments.	Reduce beach erosion updrift of structure.	Intercepts and retains sediment to maintain the beach environment at the site of implementation. Can help extend lifespan of beach nourishment or island restoration projects.	Trapping of sediment between the shore and the groynes disrupts longshore drift and may increase coastal erosion down drift. Sea level rise may result in increased lee side erosion. May restrict access to and along the beach.

Storm Surge Barriers / Tidal Barriers

Photo 111764898 © Ruud Morijn | Dreamstime.com

Storm surge barrier, Netherlands

Description and Function	Objective(s)	Main Advantage(s)	Main Disadvantage(s)
Movable gates constructed near the entrance of river estuaries and tidal inlets to prevent flooding during storm surge events. Small-scale barriers or sluices, frequently termed "aboiteaux", allow inland runoff to drain from lands behind the structure during low tide and prevent seawater from coming in during high tide.	Reduce storm surge flooding and seawater intrusion into estuaries.	Allow maritime traffic and natural movements of water. Prevent seawater from flowing inland during high tide.	Expensive approach with high life-cycle costs, including design, construction and maintenance. Require frequent maintenance to be effective. Disturb natural exchange of flow and sediments in estuaries and intertidal habitats. Increase erosion of shoals and sedimentation of inlet channels.

Sea Dikes / Embankments / Levees

Wadden Sea at Schiermonnikoog, Netherlands

Onshore, often earth-filled structures, constructed parallel to low-lying coastlines in order to separate the shoreline from hinterland.	Protect low-lying coastal areas against flooding.	Effective at protecting a shoreline of low-moderate coasts. When armored with rock, can resist wave action.	Breaching of dikes may be catastrophic with high potential for loss of life and property damage. Often require a one-way culvert, or aboiteau, to allow the lowlands to drain during low tide and to prevent seawater from coming in during high tide. Require frequent maintenance and incremental raising in response to sea level rise to maintain level of protection. An expensive form of coastal protection due to high costs of design, construction and maintenance. Disturb natural exchange of flow and sediments between the sea and intertidal habitats. May obstruct natural inland migration of coastal systems in response to the sea level rise.

NATURE-BASED SOLUTIONS - PREDOMINANTLY SEDIMENT-BASED PROTECTION MEASURES

Dynamic Revetment / Cobble Berm

Dynamic revetment at Point Grey cliffs. (Photo credit: Enda Murphy)

Description and Function	Objective(s)	Main Advantage(s)	Main Disadvantage(s)
Use of gravel or cobble-sized rocks to mimic a natural cobble storm beach, typically at or above the high tide mark.	Dissipate wave energy. Reduce rate of coastal erosion.	Mimics natural beach appearance and function. Can improve fish habitat and may be combined with large woody debris.	Under severe storm conditions, excessive loss of material or failure can occur. Periodic maintenance is likely to be required, and potentially addition of material over time or after severe storm events. Post-construction monitoring is recommended to guide this. Available design guidance is currently limited. Sediment supply to downdrift shorelines can be restricted.

Submerged Sills / Perched Beach

Photos from Center for Coastal Resources Management (ccrm.vims.edu/livingshorelines/photo_gallery.html), Virginia Institute of Marine Science.

Description and Function	Objective(s)	Main Advantage(s)	Main Disadvantage(s)
Nearshore semi-continuous structures usually made from rock to dissipate wave action and delay offshore movement of sediment, enhancing the beach behind the structure.	Reduce beach erosion.	Can enhance ecological value of the beach by encouraging sediment deposition and vegetation growth. Can improve attractiveness of the beach.	Not suitable for high energy coasts. Certain perched beach material may reduce accessibility between the backshore and the sea. Reduced sediment supply for longshore drift may increase coastal erosion down drift. May obstruct natural inland migration of coastal systems in response to the sea level rise, resulting in "coastal squeeze" of intertidal habitats.

Beach Nourishment


Photo 81796723 © Serenethos | Dreamstime.com
Fort Lauderdale, Florida, U.S.A.

Description and Function	Objective(s)	Main Advantage(s)	Main Disadvantage(s)
A repetitive placement of sediment along the shoreline to reduce the erosive power of waves.	Reduce beach erosion and storm surge flooding.	Can provide cost-effective disposal option for sediment dredged for other purposes. Provides additional sediment for longshore drift, contributing to maintenance of beaches down drift. Can enhance ecological, recreational and tourism value of the beach and areas down drift.	Unpredictable lifetime. May require continual re-nourishment, although "mega-nourishment" approaches with longer lifespans have been successful to date. May need to be used in combination with hard-engineered measures, such as groynes and breakwaters, if it is desired that the sand remains in place.

Island Restoration or Enhancement


Sandy Island, British Columbia

Use of sediment to construct or, in most cases, restore existing islands that have been degraded. Includes barrier islands, deltaic islands and in-bay islands.	Reduce storm surge flooding along nearby coastline. Reduce wave action and coastal erosion along nearby coastline.	Can provide cost-effective disposal option for sediment dredged for other purposes. Provides additional sediment supply that may benefit nearby beaches. Can provide additional habitat and recreational opportunities.	Requires site characteristics and physical processes that support island formation. May require continual re-nourishment, although "mega-nourishment" approaches with longer lifespans have been successful to date. May need to be used in combination with hard-engineered measures if it is desired that the sediment remains in place.

NATURE-BASED SOLUTIONS - PREDOMINANTLY VEGETATION-BASED PROTECTION MEASURES

Dune Restoration or Stabilization

Sand dune restoration, Prince Edward Island

Description and Function	Objective(s)	Main Advantage(s)	Main Disadvantage(s)
Planting of native, salt-tolerant species and setting up protective systems to trap sand and enhance dune build up.	Reduce dune erosion and protect inland areas from storm surge flooding.	Provides habitat for aquatic species and improve water quality. Protects inland areas and habitat from erosion and storm surge flooding.	Stabilization may reduce sediment supply for longshore drift and may increase coastal erosion down drift. May obstruct natural inland migration of coastal systems in response to the sea level rise.

Cliff Stabilization / Revegetation

Cliff stabilisation, Newquay, UK

Description and Function	Objective(s)	Main Advantage(s)	Main Disadvantage(s)
Managing existing vegetation and/or planting new fast-growing and deep-rooted vegetation to create protective "skin" that would reduce cliff instability and erosion.	Limit the rate of cliff erosion.	Reduces risks of landslide, collapse, falling of rocks. Promotes preservation of natural cliff habitats.	Requires detailed geotechnical studies to determine the causes of cliff instability. Stabilization of naturally eroding cliffs may reduce sediment supply for longshore drift and increase coastal erosion down drift.

Salt Marsh / Coastal Wetland Restoration

Saltwater coastal marsh, near Waterside, New Brunswick

Description and Function	Objective(s)	Main Advantage(s)	Main Disadvantage(s)
Reestablishment of salt marshes and coastal wetlands through revegetation with native, non-invasive plant species to dissipate wave energy.	Reduce coastal erosion. Protect inland areas from storm surge flooding. Increase stormwater infiltration.	Even small, narrow wetlands provide wave attenuation. Provides essential fish habitat, improved water quality and stores carbon. If space allows, can naturally migrate landwards in response to sea level rise, avoiding coastal squeeze. Can self-recover from moderate damage from storm surge events.	Requires site characteristics and physical processes that support vegetation growth. May need to be used in combination with other solutions to create a suitable wave energy environment. Requires space, sediment and erosion protection until vegetation establishes in higher energy areas.

Submerged Aquatic Vegetation

Eelgrass

Restoration or expansion of seagrass beds, for example eelgrass beds, in particular those that have been degraded by human activity.	Absorb wave energy and slow water flow. Reduce coastal erosion and stabilize sediments.	Suited to small-scale projects. Provides habitat and water quality improvements, and store "blue" carbon. May be an important resource to Indigenous communities.	Requires site characteristics and physical processes that support natural vegetation growth. Not suitable in high wave-energy environments. Rarely used in isolation.

Bioengineering - Coir Rolls

Coir roll

Description and Function	Objective(s)	Main Advantage(s)	Main Disadvantage(s)
A combination of deep-rooted plants and erosion control products made of natural, biodegradable materials, such as coir rolls to help stabilize soil and buffer the shoreline against waves, tides and currents.	Reduce coastal erosion and storm surge flooding.	Coir rolls absorb more wave energy than seawalls, rock revetments, or other hard shoreline stabilization structures. Help to preserve the natural character and provide additional coastal habitat.	Synthetic and wire mesh that remains after the rolls are degraded has the potential to entangle wildlife, disrupt navigation and harm recreational beach users. Reduced sediment supply for longshore drift may increase coastal erosion down drift. May obstruct natural inland migration of coastal systems driven by sea level rise, resulting in "coastal squeeze" of intertidal habitats.

Bioengineering - Natural Fibre Blankets

Erosion control mesh, San Francisco, U.S.A.

A combination of deep-rooted plants and erosion-control products that are made of natural, biodegradable materials to help stabilize soil and buffer the shoreline against waves, tides and currents.	Reduce coastal erosion.	Natural fibre blankets absorb more wave energy than seawalls, rock revetments, or other hard shoreline stabilization structures. Help preserve the natural character and habitat value of the coastal environment.	Non-suitable for high-energy coasts. Reduced sediment supply for longshore drift may increase coastal erosion down drift. May obstruct natural inland migration of coastal systems driven by sea level rise, resulting in "coastal squeeze" of intertidal habitats.

3.3 Canadian Case Studies

3.3.1 Site-Specific Findings

Ten case studies have been prepared to illustrate the implementation and performance of different coastal protection measures. Table 5 introduces these case studies and Appendix A contains the case study details. Grey infrastructure measures are shaded in grey, nature-based solutions that are predominantly sediment-based are shaded in gold, and nature-based solutions that are predominantly vegetation-based are shaded in green.

Table 5: Overview of Canadian Coastal Protection Case Studies. Click 'case study' link to see additional case study details in Appendix A.

Protection Measure	Case Study Overview	What's the Risk?	Key Learning Points
Seawall Case Study 1 Google Map	**Northwest Arm Seawall Restoration at Sir Sandford Fleming Park.** Halifax Regional Municipality, NS.  Photo credit: M. Davies	**Hazard:** Flooding and failure of seawall. **Impact on:** Sir Sandford Fleming Park public park and trail, which provides unique natural scenery, heritage value and recreational opportunities.	Seawalls typically have high capital costs, and ongoing maintenance costs. Aesthetic appeal is a key consideration in areas of high social value.
Nearshore Breakwaters / Reefs Case Study 2 Google Map	**Protecting the Trans-Canada Highway (Highway 2) with Intertidal Reefs.** Town of Souris, PEI.  Photo credit: M. Davies	**Hazard:** Flooding and coastal erosion. **Impact on:** Highway 2 at Souris Beach. The road is a vital link to the Town of Souris and the Inter-Provincial ferry to the Magdalene Islands. The beach is a local tourist and recreational attraction.	Grey infrastructure can be designed to work with natural processes and enhanced to mimic natural habitats. Monitoring has demonstrated the reefs have performed as designed, enhancing the beach and dunes.

Protection Measure	Case Study Overview	What's the Risk?	Key Learning Points
Permeable Revetments Case Study 3 Google Map	**Rebuilding the Armour Stone Revetment along Cow Bay Causeway.** Cole Harbour, NS  Photo credit: M. Davies	**Hazard:** Flooding and failure of causeway. **Impact on:** 350 metres of Cow Bay Road along the causeway. Frequent repairs were needed to repair damage prior to the works.	Grey infrastructure may be cost-effective in protecting infrastructure for a defined time period (30 years in this case).
Sea Dikes Case Study 4 Google Map	**East Fraser Lands Integrated Coastal Flood Management.** Vancouver, BC  Photo credit: Space2place Design Inc	**Hazards:** Flooding. **Impact on:** New, sustainable community under development, including housing, services, and greenspace.	Flood protection can be combined with redevelopment. Includes use of "superdikes" –earthfill dikes coupled with raising of adjacent land. Need for future dike raising is anticipated - development is in the coastal floodplain.
Beach Nourishment (Replenishment) Case Study 5 Google Map	**Protection and Rehabilitation of the Anse du Sud.** Ville de Percé, QC  Photo credit: AECOM	**Hazards:** Coastal erosion and flooding. **Impact on:** Tourism assets, commercial properties, seasonal residences, infrastructure (sewer, road, outfall, wharf, promenade).	Coastal protection can be combined urban rehabilitation. Cost-benefit analysis is a key tool to evaluate alternatives against "non-intervention". Tourism can be a key economic benefit (value est. at $68 million over 50 years.)

Protection Measure	Case Study Overview	What's the Risk?	Key Learning Points
Beach Nourishment Case Study 6 Google Map	**Erosion Protection for Portage Park Midden.** View Royal, BC  Photo credit: R. Atkins	**Hazards:** Coastal erosion during storms. **Impact on:** First Nations midden of cultural and archaeological interest, estimated to be between 6,000 and 9,000 years old.	Coastal protection may be required for cultural and archaeological sites along the coast. Monitoring 2007 to 2019 indicates beach nourishment has performed well.
Dune Stabilization / Restoration Case Study 7 Google Map	**Stabilisation and Restoration of Le Goulet Dunes.** Le Goulet, NB  Photo credit: L. Richardson	**Hazards:** Coastal erosion and flooding due to dune overtopping or breaching. **Impact on:** Beach and dune habitat, residences behind the dunes are at risk.	Securing an appropriate supply of sand is essential to dune restoration and beach nourishment. Local communities should be actively involved in selection of protection measures.
Salt Marshes / Coastal Wetland Restoration Case Study 8 Google Map	**New Brighton Park Shoreline Habitat Restoration Project.** Vancouver, BC  Vancouver Fraser Port Authority	**Hazards:** Coastal flooding and stormwater/sewer system overflow, erosion due to marine traffic. **Impact on:** New Brighton Park public greenspace - included degraded coastal wetlands.	Habitat lost during historic fill and stabilization can be restored. Example of a Green Shores for Shoreline Development "Gold" project (see Box 4). Until the salt marsh is established, monitoring is essential to inform post-construction management.

Protection Measure	Case Study Overview	What's the Risk?	Key Learning Points
Combined Measures Case Study 9 Google Map	**Combining Grey Infrastructure and Nature-Based Protection at Alma.** Fundy National Park, NB  Photo credit: CBCL Limited	**Hazards:** Coastal erosion and flooding, in particular storm damage. **Impact on:** Highway 114 providing access to Fundy National Park from Alma. Parks Canada facilities.	Nature-based solutions can be used effectively alongside grey infrastructure. Incorporation of beach nourishment and habitat enhancement was more cost effective than armouring the entire shoreline and provided multiple benefits.
Combined Measures Case Study 10 Google Map	**Deltaport East Causeway Third Berth Habitat Remediation Project.** City of Delta, BC  Photo credit: T. Andrews	**Hazards:** Storm waves and lack of sediment supply. **Impact on:** Habitat compensation project (saltmarshes and beaches) along Deltaport East Causeway that was not performing as planned.	Nature-based solutions can be used to enhance grey infrastructure. Habitat creation / restoration must work with natural processes. Grey infrastructure may be used to artificially create conditions to support habitat creation where natural processes have been modified.

3.3.2 General Findings

In researching these case studies, some common findings became evident:

- The objectives of coastal protection vary widely between different sites and are specific to local settings, vulnerabilities, and community values.
- Implementation of projects requires several stages of assessment, design and construction, over multiple years, with maintenance commitments being made over the design-life of built infrastructure (if used).
- It is difficult to document the full, realized costs of a coastal protection project from start to finish due to the multiple stages involved. Different people and / or organizations (in particular, different technical consultancies) are frequently involved in different stages.
- Significant project or site-specific technical knowledge is held within private companies and detailed information is not always publicly accessible.
- Performance monitoring is lacking for many projects or is undertaken on an ad-hoc

basis where it is not required as part of the permitting process. It is therefore difficult to assess if projects have performed and delivered benefits as expected.

- There are few examples of nature-based solutions being used for coastal protection in Canada.

These findings guided further research presented in Section 4 of this report, relating to scaling-up the use of nature-based solutions.

3.3.3 Options Appraisal and Combining Coastal Management Measures

Every coastal community has a unique set of flooding and erosion challenges. The selection of appropriate coastal management approaches requires an understanding of existing and future coastal processes, coastal ecosystems, community values, and risks. These elements inform identification of potential options and the process of options appraisal.

Options appraisal is the comparison of different options against set criteria to help decision-makers select an approach that delivers the most desirable overall outcome. In the context of coastal management, options appraisal typically compares a suite of options against the "do nothing" option, which acts as a baseline for comparison.

Option appraisal must consider natural processes along the coast. Reduction of flooding and erosion at one site, if not carefully designed, can cause instability further along the coast and degradation of coastal ecosystems on which communities depend. Canada does not yet have a strategic planning framework or standard classification of approaches for coastal risk management. However, local governments and other organizations can work together to ensure that influences on coastal processes beyond their individual boundaries are appropriately addressed, as illustrated in the City of Surrey's Coastal Flood Adaptation Strategy in British Columbia (Box 2).

Options appraisal may identify that coastal protection is not the preferred strategy for some sections of coast. Alternative strategies to accommodate, retreat from or avoid flood or erosion risks, as identified in the PARA framework,[77] may provide more desirable outcomes, or be combined with coastal protection measures.

Options appraisal often identifies that a combination of complementary measures is appropriate to protect coastal communities. Grey infrastructure and nature-based solutions are not exclusive alternatives and may be used together within the same community (see Box 2).

The City of Surrey example also demonstrates how funding criteria can be instrumental in encouraging communities to consider innovative and collaborative solutions that deliver long-term benefits. The federal Disaster Mitigation and Adaptation Fund (DMAF) was set up in 2018, with additional funding announced in 2021. Funding is provided for structural and natural infrastructure projects to increase the resilience of communities that are impacted by natural disasters triggered by climate change.[78]

Box 2

Developing Coastal Flood Adaptation Strategy and Approaches for the City of Surrey, BC

Nicomekl River, Surrey, BC

The City of Surrey is part of the Metro Vancouver area, located between the Fraser River and the U.S. border. Approximately twenty percent of Surrey's land is coastal floodplain. By 2100, projections indicate that sea level rise and more frequent and extreme rainfall events could affect 125,000 residents who live in areas at high risk of coastal flooding. To prepare for this challenge, the city developed a Coastal Flood Adaptation Strategy (CFAS) between 2016 and 2019. The strategy identifies long-term management directions for different sections of the coast, together with 46 actions that can be taken over the short, medium and long-term.[79]

In 2019, the city secured a $76.6 million grant under the federal Disaster Mitigation and Adaptation Fund (DMAF). The grant is being used by the City of Surrey, in partnership with the City of Delta and the Semiahmoo First Nation, to implement a combination of ecosystem-based protection measures alongside hard protection and engineering measures, as detailed below:[80]

Nature-based solutions:
- Establishing a riverfront park on the Nicomekl River with natural flood-attenuating features
- Building two new "living dikes" as foreshore enhancements along Boundary Bay
- Nature-based solutions to protect Mud Bay Park ecosystems from coastal squeeze

Grey infrastructure measures:
- Upgrading over 10 kilometres of dikes
- Replacing the aging Nicomekl and Serpentine sea dams
- Upgrading three pump stations
- Replacing bridges over the Nicomekl, Serpentine and Campbell Rivers
- Installing 1.5 new kilometres of storm sewers

City staff shared the following insights into how DMAF criteria shaped the selection of approaches:

"The $20 million qualifying minimum for projects supported through DMAF stretched us to think about bundled approaches and making new partnerships. For example, critical railway upgrades were integrated with flood control upgrades, and in the Foreshore Enhancements Project, we partnered with the City of Delta to evaluate alternative approaches to managing coastal flooding along the shared Boundary Bay. Nature-based solutions were eligible for funding and encouraged us to advance new initiatives. DMAF also supported "long-term thinking" considering avoided damages over the infrastructure lifespan, which solidified the business case for prompt action on adaptation and flood risk reduction."

Source: Tjasa Demsar and Matt Osler, City of Surrey, BC

Chapter 4

Scaling-Up Use of Coastal Protection Measures that Work with Nature

Restoring beach dune vegetation in Prince Edward Island

Nature-based solutions could play a greater role in managing coastal flood and erosion risk in Canada, while delivering multiple benefits. In this report, both sediment-based and vegetation-based adaptation measures are considered as nature-based solutions. These measures depend on, or mimic, natural system processes to manage flood and erosion risk, while delivering a suite of additional co-benefits.[81]

Coastal nature-based solutions can deliver flooding and erosion management benefits by:[82]

- Attenuating the energy and height of incoming waves
- Attenuating storm surge water levels along the shoreline
- Providing storage of floodwater in the upper tidal reaches of estuaries
- Reducing erosion of sediments and soils
- Attracting and stabilize sediments
- Attracting and sustaining flora and fauna, which can stabilize structures such as dikes

In addition to these benefits, coastal nature-based solutions also provide a wide range of ecosystem goods and services, including:

- provision of food (e.g. fish and shellfish)
- climate regulation (through carbon sequestration and storage)
- air quality regulation
- water quality regulation
- provision of habitat promoting biodiversity
- assets for recreational activity
- provision of aesthetic values
- inspiration for culture, art and design

Despite their multiple benefits, research completed in 2021 indicates that nature-based solutions remain underutilized.[83] Two of the factors limiting their wider implementation are:[84]

- Undervaluation of the benefits of nature-based solutions in options appraisal and decision-making.
- A lack of data demonstrating the performance of nature-based solutions over time in Canada.

This chapter discusses how these barriers could be overcome, drawing on the findings of two workshops held online in June 2021. The workshops were attended by over 35 subject matter experts from across Canada and insights were gathered using online surveys and small group discussion (see Appendix B).

In addition, researchers have identified the need to build capacity to deliver nature-based solutions in Canada, including understanding of benefits among decision-makers, institutional capacity to oversee and implement nature-based solutions, and technical, multi-disciplinary design, construction and maintenance expertise.[85,86] This chapter identifies opportunities to build capacity by drawing on the private sector.

4.1 Including the Benefits of Nature-Based Solutions in Options Appraisal

The benefits of nature-based solutions are currently not adequately addressed in options appraisal approaches in Canada.

The first of the two workshops: "Upgrading Options Appraisal to include Ecosystem Good and Services" was held on June 17, 2021. This section summarizes workshop findings – further details are contained in Appendix B.

4.1.1 Options Appraisal Approaches and Tools Used in Canada

Many different tools are used to appraise coastal management options in Canada. There is currently no standardised approach and no strategic planning framework, similar to that used for Shoreline Management Planning (SMP) in England (see Chapter 2.2.2.) Commonly used approaches include:

- Multi-criteria analysis (qualitative assessment)
- Evaluation against performance objectives
- Cost-Benefit Analysis (quantitative assessment of tangible and intangible benefits/costs)
- Environmental Impact Assessment (consideration of alternatives)

Generic approaches are typically tailored by users to their specific project, often delivered by local governments. Structured decision-making is an additional identified approach that may be useful in integrating benefits of nature-based solutions. This method involves identifying locally relevant values, defining objectives and measures (which could include ecosystem goods and service levels), and comparing alternatives against these measures. The approach can also be used to evaluate trade-offs between options in a transparent manner, and in identifying a suite of complementary options to achieve the defined objectives.

Other specific protocols used to appraise coastal management options include:

- Application of Infrastructure Canada's Climate Lens (Greenhouse Gas Mitigation Assessment and Climate Change Resilience Assessment)[87]
- Evaluation against Disaster Mitigation and Adaptation Fund application criteria[88]
- Legally required Environment Impact Assessment procedures (vary by province and territory)

4.1.2. Accounting for the Benefits of Nature-Based Solutions in Options Appraisal

Nature-based solutions can deliver multiple benefits that are not provided by hard "grey" protection measures.[89] These benefits are commonly referred to as "ecosystem goods and services" that ultimately benefit people. These goods and services often do not have a direct market value and are therefore more challenging to integrate into options appraisal in financial terms.

Workshop findings indicate that ecosystem goods and services are not routinely considered in appraisal of coastal management options in Canada. When ecosystem goods and services are considered, qualitative and semi-quantitative methods, such as ranking and scoring, are commonly used, as well as economic valuation. One specialist commented that, in their experience, ecosystem goods and services were included in an "ad-hoc, non-structured way that would benefit from standardization."

Flood and erosion control benefits of coastal protection are typically quantified by calculating the cost of damages avoided over time.[90] [91] Other goods and services, such as air and water quality, carbon sequestration and storage, and fishery production are also perceived to be readily quantifiable. Semi-quantitative or qualitative approaches may be suitable to reflect ecosystem services perceived to be less readily quantifiable, such as recreation or aesthetics. Both quantitative and qualitative approaches may be used to assess changes in biodiversity and habitats. Specific methods used by specialists to appraise costs and benefits associated with selected ecosystem goods and services, are summarized in Table 6, alongside the lessons learned that were shared.

Table 6: Methods, indicators and lessons learnt in assessing costs and benefits of nature-based solutions, in terms of ecosystem goods and services

Impact	Methods, indicators and values used	Lessons Learnt
Water quality	• Modeling using bespoke software (InVEST) • Predicted change in key water quality indicators (referencing established standards) • Predicted change in treatment costs • Visual indicators of water quality (turbidity, algal blooms) may be obtained using airborne sensors	• Standard protocols are well established • Difficult to address variability over time and space
Carbon sequestration and storage	• Modeling using bespoke software (InVEST) • Predicted change in vegetation and soils, and impact on carbon flux and storage • Calculation of embedded carbon in hard protection measures • Social value of carbon	• No standardized method • Important to base calculations on local data • Need to account for time lag in carbon sequestration
Biodiversity and habitats	• Modeling using bespoke software (InVEST, iTree) • Predicted change in land use area of different habitats (using GIS) • Predicted change in species diversity / species at risk / invasive species • Use of Traditional Ecological Knowledge / participative mapping to obtain baseline	• Drones are useful to obtain high-resolution mapping • Difficult to adequately reflect the value of habitat connectivity • Different tools may be appropriate to different habitats
Aesthetics	• Participatory mapping • Analysis of social media activity (Instagram, Flickr) • Indirect valuation (for example using the difference paid for a room with a seaview) • Public consultation on visuals of option alternatives	• Difficult to quantify and avoid bias • Perceptions of aesthetics vary widely between people based on individual background and circumstance • Difficult to account for change over time
Recreation	• Change in area/length of recreational facilities • Indirect measurements – number of visitors, frequency of site use, travel-cost, local tourism revenues • Averted health care costs (including mental health) for recreational activities linked to improved health	• Opportunity to capture diverse perspectives • Often considered qualitatively, which may undervalue benefits

4.1.3 Canadian Options Appraisal Case Studies

This section describes how benefits of nature-based solutions have been included in options appraisal for selected case studies in Canada.

Cost-benefit analysis of adaptation options for five regions in Quebec

In 2016, Ouranos undertook cost-benefit analysis of adaptation options for five regions of the coastline in Quebec, considering both hard and sediment-based protection measures, as well as options without coastal structures (for example, planned retreat and flood proofing).[92] The positive and negative impacts included in the cost-benefit analysis are shown in Table 7, and go beyond flood and erosion damages avoided. However, the range of positive impacts considered did not reflect the full range of potential benefits that may be gained from ecosystem-based protection measures.

Table 7: Anticipated impacts included in cost-benefit analysis of adaptation options for five regions of the coastline in Quebec (source: Circé et al. 2016)[93]

Type of Impact	Negative Impacts	Positive Impacts
Related to erosion	• Loss of land • Complete or partial loss of residential or commercial buildings • Loss or damage to public infrastructure	
Related to flooding	• Damages to land • Damages to residential or commercial buildings • Damages to public infrastructure • Emergency evacuation • Debris clean-up • Traffic congestion or detour	
Economic	• Reduced land value • Loss of goods and commercial revenues • Loss of tourism revenues	• Gain in tourism revenues
Environmental	• Loss of natural habitats • Loss of fishing spawning grounds	• Improvement in fish spawning grounds
Social	• Loss of sea view • Loss of sea access • Decline in the coast's recreational use • Reduced quality of life (anxiety, insecurity, etc.) • Deterioration in the landscape • Deterioration in historical and cultural heritage	• Improvement in the coast's recreational use • Improvement in quality of life (security) • Improvement in the landscape

Platform for cost-benefit analysis of erosion and submersion (PANACÉES)

Building on this experience, a platform for cost-benefit analysis of erosion and submersion was developed (named "Plateforme pour l'analyse avantages-coûts en érosion et submersion"or PANACÉES). [94] This platform incorporates ecosystem-based protection measures, alongside hard and sediment-based protection measures. However, the analysis calculates benefits in terms of avoided damages and does not currently account for the improved ecosystem goods and services that may be delivered through ecosystem-based protection measures.

Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST)

Increasingly, modeling tools are being applied to evaluate changes in ecosystem goods and services associated with coastal management options. The "Integrated Valuation of Ecosystem Services and Tradeoffs" (InVEST) suite of open-source tools, developed by the Natural Capital Project, helps users explore how changes in ecosystems are likely to lead to changes in benefits that flow to people. [95]. Several modules are available, including modules that address coastal protection, habitat quality and coastal blue carbon.[96]

Coastal Protection and Benefit Tool

In 2021, a "Coastal Protection and Benefit Tool", was developed by a multi-disciplinary team led by the Municipal Natural Asset Initiative (MNAI), building on the InVEST coastal protection package.[97] The tool was designed to be a high-level screening tool and was applied to two pilot case studies, the Town of Gibsons in British Columbia,[98] and Pointe du Chene in New Brunswick.[99] A shortlist of options was identified in each case using multi-criteria analysis based on stakeholder consultation. The options shortlisted included eelgrass protection, shoreline planting, beach nourishment and dune improvement.[100] The Coastal Protection and Benefit Tool enabled the economic value of flooding and erosion control benefits associated with these nature-based solutions to be calculated, but their multiple co-benefits were not quantified.[101]

Disaster Mitigation and Adaptation Fund application process (2021)

As previously mentioned, the Disaster Mitigation and Adaptation Fund provides funding for structural and natural infrastructure projects to increase the resilience of communities that are impacted by natural disasters triggered by climate change. According to the application process, economic benefits are calculated as a Return on Investment (ROI), based on a ratio between avoided damages and the cost of the project. Anticipated project co-benefits, including environmental value and greenhouse gas reduction, are to be described under a separate merit criterion and do not currently factor into the ROI calculation.[102]

4.1.4 Standardized Valuation of Ecosystem Goods and Services: Example of Partnership Funding for Flood and Coastal Erosion Risk Management Projects in England

The following section summarizes an example of nationally standardized options appraisal for coastal risk management that was presented at the workshop. Funding for Flood and Coastal Erosion Risk Management (FCERM) projects undertaken in England is allocated based on standardized protocols set out by the national government.[103] Partnership funding is allocated to projects undertaken by risk management authorities and according to specific Outcome Measures (Table 8). A bespoke spreadsheet is provided for risk management authorities to calculate economic values under each of these Outcome Measures.[104]

Table 8: Outcome Measures Used to Allocate Partnership Funding in England

Outcome Measure		Description
OM1 - Economic benefits	OM1A	Overall economic benefits (based on the present value costs and benefits)
	OM1B	People-related FCERM benefits: include risk to life, stress and health benefits, mental health impacts, vehicle damages avoided and residential property evacuation costs avoided
OM2 - Households at risk from flooding	OM2A	Households at risk today that are better protected against flooding by this investment
	OM2B	Additional households at risk up to 2040 that are better protected against flooding by this investment
OM3		Households better protected from coastal erosion
OM4 - Environmental improvements	OM4A	Habitats created or improved
	OM4B	River habitats and natural processes restored and enhanced

Eligible economic benefits/costs considered within Outcome Measure OM1 specifically include natural capital benefits that may be derived from nature-based solutions (Box 3)

Box 3

Eligible Flood and Coastal Erosion Management benefits considered in OM1

- Residential properties Commercial properties
- Transport (road, rail, air, ports)
- Utilities (water, gas, electricity, waste)
- Health*
- Temporary accommodation
- Emergency services
- Flood risk asset repair
- Agriculture
- Recreation and leisure facilities
- **Environment****
- Built heritage
- Education
- Tourism
- Recovery, repair and clean-up impacts

* - including social and psychological impacts of flooding and public health - including damage to hospitals and health centres - and fatalities - including distress

** - all natural capital, including wildlife and heritage

Guidance in valuing environmental outcomes under Outcome Measure OM4 is provided in supplementary guidance.[105] Under Outcome Measure OM4A, payments are available for either creating new habitat or for improving the condition of an existing habitat. The different habitats considered are:

- intertidal wetlands
- woodlands
- wet woodlands
- wetlands and wet grasslands
- grassland
- heathland
- pond and lakes
- arable land

Under Outcome Measure OM4B, payments are determined based on the length of watercourse created or enhanced. Payments are defined under one of the following three categories:

- comprehensive restoration of natural processes, habitats and removal of physical modifications
- partial restoration of natural processes, habitats and partial removal of physical modifications
- a single major physical or habitat enhancement

Valuing environmental outcomes under both measures OM4A and OM4B must be based on the generic transfer values that are already built into the partnership funding spreadsheet provided. The guidance states this is to ensure consistency across the FCERM program and to improve efficiency by reducing the need for bespoke studies.[106] The values provided for habitats are intended to account for the following ecosystem services:

- provision of clean water
- provision of food (foraging only)
- provision of fuel/timber/resources
- climate regulation (through carbon sequestration)
- air quality regulation
- water quality regulation
- assets for recreational activity
- provision of aesthetic values
- inspiration for culture, art and design
- provision of habitat promoting biodiversity

For river enhancements, the values are taken from a previous National Water Benefits Survey (NWEBS) which gathered national data on people's "Willingness-to-Pay" for river ecosystem services.[107]

Under each Outcome Measure, the net present value of benefits is calculated (in the spreadsheet) by applying standardized discount rates across the appraisal period, which is typically 100 years.

This example illustrates how a proportionate approach can be adopted to calculate an economic value of ecosystem goods and services in a manner that is nationally consistent. While the values calculated are less representative of regional or site-specific conditions, the method makes it easy to include a value that is considered robust enough for funding allocation purposes.

4.1.5 Opportunities for Standardization

As part of the June 17, 2021 workshop, participants were asked if inclusion of ecological goods and services in options appraisal should be mandatory for all Canadian infrastructure projects, including coastal protection. Most participants replied "yes", and no participants replied "no". The point was made that, for inclusion of ecological goods and services to be taken seriously, standards and protocols must be universal.

It was stressed that federal and provincial governments would need to collaborate on work towards standardization. While it is useful to have protocols at the federal level, there is a need to reflect important regional differences across Canada. One suggestion was that minimum requirements could be set at the Federal level, under which different regions could have standards and criteria that are context specific.

Further opportunities for standardization that can be implemented at a local scale include certification schemes for coastal protection measures that work with nature. There are already several programs in North America that actively promote the implementation of nature-based solutions in developed areas. These programs include NOAA's Living Shorelines program in the United States, [108] (see Section 2.2.4.) the Shore Friendly Grant Program in Puget Sound, Washington State,[109] and, in Canada, the Stewardship Centre for British Columbia's, Green Shores® program (see Box 4).[110]

Box 4

Green Shores® Standards

Green Shores for Shoreline Development "Gold" project: New Brighton Park shoreline restoration, Vancouver, BC. (Photo credit: Vancouver Fraser Port Authority)

Green Shores is a voluntary incentive-based program launched by the Stewardship Centre for British Columbia, in 2010. It is similar to green building rating programs such as Built Green™ and LEED™ and consists of two credit and ratings systems: 1) **Green Shores for Shoreline Development** (for commercial, multi-family residential, subdivision, park and institutional waterfront development)[111] and 2) **Green Shores for Homes** (for residential properties).[112]

The Green Shores program encourages methods of shoreline development (both for marine and lake environments) that protect the land from flooding and erosion, increase the ability to access shorelines for recreation, and protect and restore natural habitats. The program supports and provides **capacity building tools**, and **best practice standards** for planning professionals, design and construction professionals, local government staff, and property owners.

Green Shores works with multi-disciplinary teams to apply Green Shores standards to shoreline projects and fosters education and planning frameworks to a target audience of shoreline professionals, waterfront property owners/managers, governments and policymakers. Green Shores was initially developed in the context of British Columbia coastal areas, but the approach is applicable to coastal and lake systems across Canada. Green Shores is currently active in British Columbia and Washington State and is working with stakeholders to bring Green Shores to Nova Scotia and Prince Edward Island.

4.2 Improving Performance Monitoring to Demonstrate Benefits of Nature-based Solutions

There is currently a lack of confidence in nature-based solutions in Canada. The lack of data demonstrating the performance of nature-based solutions discourages implementation of these types of measures, which in turn means there continues to be a lack of data demonstrating in Canada – the problem is cyclical.

The second of the two workshops: "Performance Monitoring of Natural Infrastructure Solutions" was held on June 29, 2021 to discuss how performance monitoring could be improved in Canada. This section summarizes the workshop findings – further details are contained in Appendix B.

4.2.1 Monitoring Approaches Used in Canada

There are currently no performance monitoring standards for nature-based solutions or other coastal protection measures in Canada. Approaches used in Canada, as identified by participants, included:

- Application of the Quebec government's results-based management framework.[113]
- Measurement against climate adaptation plan success criteria.
- A modification of the Global Programme of Action Coalition for the Gulf of Maine (GPAC) protocol developed to evaluate the performance of tidal restorations at local and regional scales.[114]
- Standard protocols for certain technical elements, including measuring vegetation establishment and water quality.
- Repeat topographic survey (including airborne LiDAR and terrestrial LiDAR).
- Repeat aerial imagery or photography using established viewpoints.
- Internally developed and project-specific protocols.

The critical need to collect baseline data that reflects natural and seasonal variation was highlighted, in order to evaluate project performance within the context of natural change. The opportunity to work more closely with First Nation members was also identified - one group is developing a "shared values protocol" that can be used to subsequently monitor nature-based solutions. One participant noted that, since none of their projects have received funding for monitoring to date, monitoring has been undertaken in a reactive manner, as part of deficiency management and warranty review.

There was strong support among workshop participants for an improved, more consistent approach to monitoring of nature-based solutions that deliver coastal protection. There is a perceived weakness in the current ability to monitor social outcomes in comparison with physical and biological outcomes.

4.2.2 Consideration of Minimum Coastal Monitoring Standards

There was overall support among workshop participants for a minimal coastal protection monitoring standard. However, participants indicated that additional elements could support improved monitoring, including:

- Regulatory requirements.
- Inclusion of long-term funding for monitoring in the project budget from the outset.
- Technical guidance.

There was also concern that, while setting minimum requirements can help establish consistency, this may discourage monitoring beyond these minimum requirements.

Workshop participants were asked to work in small groups to identify elements that should be covered by a minimum coastal protection monitoring standard. There was no consensus between the groups. However, there was more support for the inclusion of monitoring of hydraulic and sediment regimes, biodiversity and habitats and carbon sequestration and storage, as part of a minimum standard, than for inclusion of the other outcomes considered (Table 9).

Table 9: Considerations for the development of a minimum standard for coastal protection monitoring in relation to different physical, biological and social outcomes

Outcome	Considerations in development of a minimum standard
Hydraulic regime (flood protection)	• A key principle should be to maintain or restore coastal processes. • Important to flooding and biodiversity. • Monitoring may be required as a trigger for parametric insurance. • Variety of variables to consider – water levels, wave heights, extreme conditions during storms.
Sediment regime (erosion protection)	• A key principle should be to maintain or restore coastal processes. • Sediment processes underpin coastal resilience. • Monitoring may be required as a trigger for parametric insurance. • Could include qualitative geomorphological assessment and sediment characterization as a minimum.
Biodiversity and habitats	• Minimum requirements may depend on permitting/regulation, particularly for fish habitat compensation projects. • Habitat function and diversity is important. • Vegetation and presence of native plants could be a minimum.
Carbon sequestration and storage	• Growing importance for climate mitigation and to support carbon markets / attract private investment • Not a direct benefit to the project site but some workshop participant groups considered it should be a minimum requirement. • Measure change in vegetation cover and carbon density in soils. • More guidance needed in this emerging area.
Water quality	• Standards are already well established. • Subject to regulation. • May not be within the control of the project. • Variety of variables to consider – dissolved oxygen, pH, suspended solids and Biological Oxygen Demand.
Fisheries	• Could be covered by minimum monitoring standards relating to other variables, such as habitat, water quality and sediment regime. • Not considered a minimum requirement for all projects.
Aesthetics	• Valuable from a public buy-in perspective. • Not considered a minimum requirement for all projects.
Recreation	• Valuable from a public buy-in perspective. • Not considered a minimum requirement for all projects.

Workshop group discussions consistently highlighted that "one size does not fit all" in terms of performance monitoring. The technical requirements of performance monitoring are inherently tied to the setting of project objectives, which vary between projects. It was suggested that minimum standards could remain generic or provide an overall framework, with the details of required monitoring defined based on project-specific performance goals. A suggested alternative was to tailor standards to different magnitudes of project scope, so that minimum monitoring requirements remain proportional to the project implemented. Standards could also be developed to reflect the significant regional differences along Canada's East and West coastlines.

The need to engage with Indigenous people in the development of monitoring standards, drawing on Traditional Ecological Knowledge and addressing shared values, was another common theme highlighted in discussions. Several groups suggested that engagement with Indigenous people in developing and/or implementing performance monitoring should be part of a minimum standard.

4.2.3 Innovation in Performance Monitoring

Important opportunities for innovation were identified by workshop participants and can broadly be divided into technological advances and the potential to harness citizen science.

Technological advances

Unmanned aerial vehicles (drones) with remote sensing capability offer a promising tool for monitoring shoreline protection measures and physical/ecological changes. The technology is flexible, easy to implement, and cost-effective. Repeat datasets can be collected to quantify performance variables at a point in time, and to show the trend in performance over time. Examples identified by workshop participants included:

- Use of terrestrial LiDAR to obtain high-resolution topography along the coastline.
- Use of aerial imagery and topography captured by drones to characterise variables including changes in coastal landforms, visible indicators of water quality, vegetation cover, and aesthetics.
- Use of Google Earth Engine and freely available satellite imagery for monitoring of vegetation, water cover, and land cover change.
- Use of higher-resolution, commercially available earth observation data for quantitative monitoring of change.
- Use of machine learning and Artificial Intelligence to analyse large datasets and imagery.

Harnessing Citizen Science

Several participants highlighted the opportunity to involve local community groups, including Indigenous people, in monitoring of coastal protection measures. Cited examples include enabling citizens to upload their photographs to a common database, (for example, Parks Canada's "Coastie Initiative"[115]) and training and lending equipment to groups to undertake water quality monitoring. Engaging local community groups in monitoring can have further raise awareness of the benefits of nature-based solutions projects and create a sense of local ownership.

Data generated by cellular phones and social media may be used to inform coastal protection monitoring. This may be particularly useful for monitoring that involves people-centred outputs. For example, it may be possible to analyse public opinions about certain locations based on social media posts, or to understand the use of a site, based on cellular phone records.[116]

4.3 Building Capacity to Deliver by Engaging the Private Sector

In an era of unprecedented public debt, engaging the private sector in financing coastal protection is becoming increasingly important. To this end, public-private partnerships (P3s), which rely on a collaboration between governments and private-sector companies to finance, build, and operate projects can be leveraged. The definition embraced by The Canadian Council for P3s is as follows:

> "A cooperative venture between the public and private sectors, built on the expertise of each partner, that best meets clearly defined public needs through the appropriate allocation of resources, risks and rewards."[117]

The following P3 models are common in Canada:

- **Operation & Maintenance Contract (O&M):** A private operator, under contract, operates a publicly-owned asset (e.g. water/wastewater treatment plant) for a specified term. Ownership of the asset remains with the public entity.
- **Build-Finance:** The private sector constructs an asset and finances the capital cost only, during the construction period.
- **Design-Build-Finance-Maintain (DBFM):** The private sector designs, builds, and finances an asset, and provides hard facility management or maintenance services under a long-term agreement.
- **Design-Build-Finance-Maintain-Operate (DBFMO):** The private sector designs, builds, finances and provides hard facility management or maintenance services under a long-term agreement. Operation of the asset is also included for projects such as bridges, roads and water treatment plants

- **Concession:** A private sector concessionaire undertakes investments and operates the facility for a fixed period of time, after which the ownership reverts to the public sector.[118]

The concepts of P3s necessitate the transfer of risk between partners. In the context of P3s that support the implementation of nature-based solutions (which are often viewed as riskier than traditional, grey infrastructure projects, due to construction complexities and uncertainties in outcomes), the ability to insure against construction risks and project outcomes is critical.

International examples, where P3s were utilized to implement nature-based solutions for coastal resilience may offer rich and valuable learning for Canada. Box 5 describes one such example: a standard indemnity insurance coverage solution used to support the implementation of an innovative sand dike to protect the Island of Texel in the Netherlands.

Box 5

Prins Hendrik Sand Dike Reinforcement: Insuring a nature-based solution, designed to protect against rising sea levels (Island of Texel, Netherlands)[119]

The island of Texel is situated on the western side of the Wadden Sea. The Wadden Sea is a UNESCO World Heritage Site and the world's largest tidal flat system.[120] There are several towns and villages on the island of Texel, which is protected from the surrounding sea by a series of dunes and dikes, including the three-kilometre Prins Hendrik Sand Dike which runs along the Wadden Sea. The island of Texel offers significant ecological and economic value, with beaches and nature reserves. It is a popular tourist destination, welcoming about 1 million visitors every year.

Project: In 2006, several sections of the Texel Wadden Sea dike required reinforcement. A dredging company presented an innovative nature-based solution to reinforce the Prins Hendrik Sand Dike. This involved placing 5 million cubic metres of sand and planting 2 million marram grasses in front of the existing traditional rock/concrete dike, protecting the dike from erosion and supporting natural habitat. Constructed in 2019, the Prins Hendrik Sand Dike reinforcement project was one of the biggest dike reinforcement operations in the Netherlands.

Project Proponents: Water Board Hollands Noorderkwartier (principal), Jan De Nul NV (contractor) and Swiss Re (insurer). Swiss Re supported the construction of the sand dike by providing a 'Construction All Risks' policy that protected against risks incurred during project construction.

Benefits of Insurance: Due to the sensitivities of the project, completion protections were required in order to obtain funding and secure project go ahead. A standard 'Construction All Risks' (CAR) policy was provided, which covered:

- material damages to the project, due to weather events, design and execution errors
- liability for damage to third parties, due to project works during and after construction
- property and assets of the principal - damages to the existing dike during the construction

The policy buyer was the dredging company who led the solution design and execution. However a CAR policy also insures all involved parties, which in this case included the municipality, water management agency, engineers, and contractors.

Source: Cherie Gray, Swiss Re, Public Sector Solutions

Another international example, where an insurance product enabled a public sector entity (Mexico's Quintana Roo state) to utilize a nature-based solution (coral reef) to enhance coastal resilience, is provided below (Box 6).

Specifically, parametric insurance, which was at the core of this solution, is an agreement under which an entity assuming risk (the "insurer") agrees to pay the indemnitee (the "insured") an agreed amount upon the occurrence of a specified event, such as an earthquake or hurricane of specified intensity. The event, or "parameter," is often indicated by an established and authoritative index for that type of event, such as the Richter scale for earthquake intensity or the Saffir-Simpson scale for hurricanes. For that reason, parametric coverage is also referred to as "index-based insurance." Parameters can be defined by other objective factors, such as the extent of physical damage, and are typically limited to certain time periods and geographic areas.[121]

Once the specified parameter is reached, or "triggered", a payment for a pre-determined claim amount is processed. Because this solution does not rely on any loss assessment of physical damages, the claim processing time for parametric insurance is significantly reduced.

Box 6

Parametric Insurance Solution Protects Mexico's Quintana Roo Coral Reef

The first parametric insurance to protect Mexico's Quintana Roo coral reef, the longest barrier reef in the western hemisphere, was introduced in 2017. The coral reef provides a protective function to the local communities, helping reduce the destructive impacts of storm surges and beach erosion. If the reef is damaged, it can no longer provide this function, which would threaten the region's key source of income - tourism.

To respond to this challenge, Swiss Re collaborated with The Nature Conservancy and Mexican regional governments to protect the local tourism industry, dependent on a healthy coral reef, with a parametric insurance cover. The claim payment was triggered if a Category 4 hurricane affected the area (this level of hurricane was assumed to be damaging to the coral reef). The payment enabled trained community members to launch restoration actions quickly and minimize coral damage following a severe storm.

When Hurricane Delta hit Quintana Roo in October 2020, it triggered a payout that enabled the stabilization of uprooted coral colonies, and the collection and replanting of broken coral fragments – all in the eight days immediately following the hurricane.

The high market interest in this insurance product has seen additional projects develop and more re/insurers enter this space.

Source: Cherie Gray, Swiss Re, Public Sector Solutions

Chapter
5

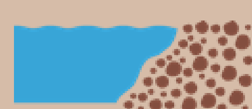
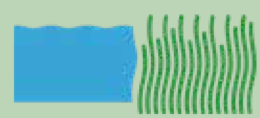
Conclusions and Next Steps

Huge waves break against the shoreline in Victoria, British Columbia

Canada's Eastern and Western coastal communities are exposed to flooding and erosion, that will become more frequent and intense as a result of climate change. **Canada can use nature-based solutions, alongside grey infrastructure, to protect coastal communities along the East and West coastlines in a changing climate.**

Multiple coastal protection measures can be used to protect Canadian communities (Table 10). Each of the measures has associated advantages and disadvantages, and different measures can be combined to fulfill multiple objectives within coastal communities.

Table 10: Overview of coastal protection measures utilized in Canada

Grey Infrastructure	Underutilized Nature-Based Solutions	
	Predominantly sediment-based	Predominantly vegetation-based
		
• Seawalls • Detached / Nearshore Breakwaters • Attached Breakwaters / Headlands • Submerged Breakwaters / Reefs • Permeable Revetments* • Impermeable Revetments* / Retaining Walls • Groynes • Storm Surge Barriers / Tidal Sluices • Sea Dikes / Embankments / Levees	• Dynamic Revetment* / Cobble Berm • Submerged Sills / Perched Beach • Beach Nourishment • Island Restoration or Enhancement	• Dune Restoration or Stabilization • Cliff Stabilization / Revegetation • Salt Marsh and Coastal Wetland Restoration • Submerged Aquatic Vegetation • Bioengineering - Coir Rolls • Bioengineering - Natural Fibre Blankets

* Revetments are sloped coastal treatments used to protect the coastline.

Nature-based solutions are currently an underutilized option. These measures can provide multiple co-benefits in addition to reducing coastal flooding and erosion risk, including:

- provision of food (e.g. fish and shellfish)
- climate regulation (through carbon sequestration and storage)
- air quality regulation
- water quality regulation
- provision of habitat promoting biodiversity
- assets for recreational activity
- provision of aesthetic values
- inspiration for culture, art and design

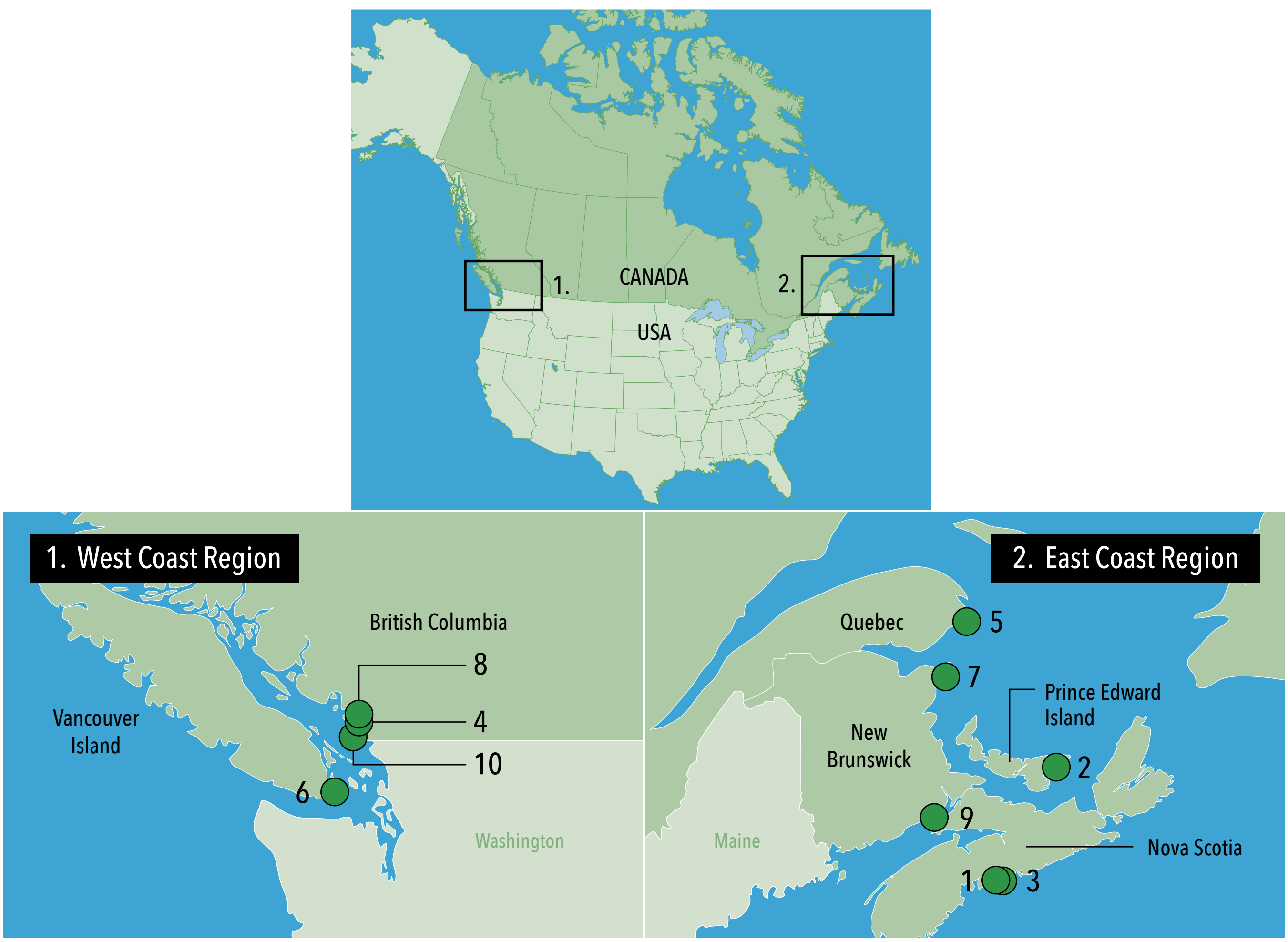
Three courses of action are recommended to scale-up the use of nature-based solutions for coastal protection in Canada:

1. **Develop national standards to support consistent evaluation of the benefits of nature-based solutions when comparing infrastructure options, including for coastal protection.** This should include minimum requirements, regional-specific standards, engagement with Indigenous people and recommended methodologies for reflecting the financial value of benefits provided by nature-based solutions.
2. **Develop national monitoring standards for coastal protection measures, focused on nature-based solutions.** This should include consideration of minimum monitoring requirements, as well as how monitoring should be tailored to document performance against project-specific objectives. Funding for long-term monitoring and engagement with Indigenous people could be considered as minimum monitoring requirements.
3. **Build capacity to finance and deliver nature-based solutions by engaging the private sector.** Public-private partnerships can potentially assist in financing, delivering, monitoring, and maintaining nature-based solutions. The insurance industry can also assist in managing construction risks and offering innovative insurance products that provide funds to restore natural features protecting the coastline, should they be damaged during extreme events.

The outcomes of these actions will help governments and other organizations make better management decisions regarding coastal flooding and erosion along Canada's East and West coastlines. They will also help position Canada as a global leader in the implementation of nature-based solutions, delivering multiple benefits to coastal communities and far beyond.

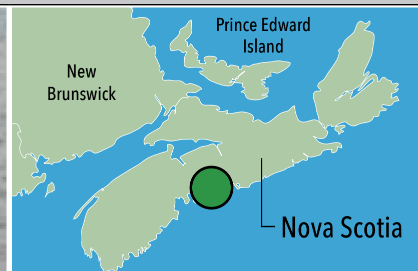
Appendix A: Practical Examples of Coastal Protection Measures Utilized in Canada

This appendix provides additional details in relation to the 10 case studies presented in Table 5 of the report (section 3.3). The location of the case studies is illustrated below:

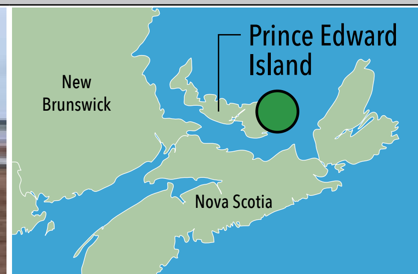


We offer thanks to all the stakeholders who provided support during the development of the case studies presented.

Case Study	Title	Acknowledgements
1	**Northwest Arm Seawall Restoration at Sir Sandford Fleming Park.** Halifax Regional Municipality, NS	Shannon Miedema, Halifax Regional Municipality Shilo Gempton, Halifax Regional Municipality Michael Davies, Coldwater Consulting Ltd.
2	**Protecting the Trans-Canada Highway (Highway 2) with Intertidal Reefs.** Town of Souris, PEI.	Michael Davies, Coldwater Consulting Ltd.
3	**Rebuilding the Armour Stone Revetment along Cow Bay Causeway.** Cole Harbour, NS	Shannon Miedema, Halifax Regional Municipality Shilo Gempton, Halifax Regional Municipality Michael Davies, Coldwater Consulting Ltd.
4	**East Fraser Lands Integrated Coastal Flood Management.** Vancouver, BC	Angela Danyluk, City of Vancouver Jeannie Lee, City of Vancouver Amir Taleghani, City of Vancouver (formerly Kerr Wood Leidal Associates Ltd) Robin Hawker, Integral Group (formerly Kerr Wood Leidal Associates Ltd) Eric Morris, Kerr Wood Leidal Associates Ltd
5	**Protection and Rehabilitation of the Anse du Sud.** Ville de Percé, QC	Lisa-Marie Gagnon, Ville de Percé Ursule Boyer-Villemaire, Ouranos Régis Xhardé, Tetra Tech Jean-François Rolland, AECOM
6	**Erosion Protection for Portage Park Midden.** View Royal, BC	Rowland Atkins, Self-employed (formerly Golder) Phil Osborne, Golder
7	**Stabilisation and Restoration of Le Goulet Dunes.** Le Goulet, NB	Robert Capozi, Government of New Brunswick Reid McLean, Government of New Brunswick Lewnanny Richardson, Nature NB Cindie Hebert, University of Moncton
8	**New Brighton Park Shoreline Habitat Restoration Project.** Vancouver, BC	Charlotte Olson, Vancouver Fraser Port Authority DG Blair, Stewardship Centre of British Columbia Kelly Loch, Stewardship Centre of British Columbia
9	**Combining Grey Infrastructure and Nature-Based Protection at Alma.** Fundy National Park, NB	Debra Hickey, Parks Canada Danker Kolijn, DHI (formerly CBCL Limited). Jason Bernier, CBCL Limited.
10	**Deltaport East Causeway Habitat Remediation Project.** City of Delta, BC	Trevor Andrews, Vancouver Fraser Port Authority Phil Osborne, Golder

Case Study 1: Seawall	**Northwest Arm Seawall Restoration at Sir Sandford Fleming Park** Halifax Regional Municipality, NS
	 East Coast Google Map Link Overtopping of the seawall at The Dingle in 2010, prior to restoration works. (Photo credit: M. Davies)
Timeline:	Investigation and Design: 2010-2011 Implementation: Completed in four phases 2011 to 2017 at a cost of $2,523,000.
Coastal flooding and erosion:	Flooding and wave action degrading existing coastal protection. In 2010, the 800m drystone seawall was in a poor state of repair, due to wave overtopping, poor drainage and inappropriate backfill.
Coastal vulnerabilities:	Sir Sandford Fleming Park, known as The Dingle, is located along the western shore of the Northwest Arm, part of the wider Halifax waterfront. The walking paths and parkland are very popular. The existing seawalls were drystone walls made of quarried stone and a defining aesthetic component of the area.
Project objectives:	Main goals of the restoration works were to: • Minimize the frequency and severity of overtopping events; • Preserve and enhance access and usage of the seawall paths and surrounding lands, and; • Preserve and enhance the aesthetic appeal of the shoreline.
Selection of coastal protection measure(s):	• Three alternatives were considered: 1) Dry stone masonry seawall, 2) Precast concrete block seawall, 3) Seawall with sand beach. • Evaluation of alternatives involved scoring options according to five weighted criteria: Aesthetics (30%), Durability (20%), Engineering performance (20%), Constructability (20%) and Cost (10%). • Computer modelling was used to compare the performance of alternatives over time, considering sea level rise. Estimations of life-cycle costs over the 50-year design life of the structure (including repair works to the path) were used to optimize the design. • Selected design was a quarried granite block wall, 665m long and raised to account for sea level rise, together with an asphalt trail.
Performance:	The project was delivered under budget. No post-construction monitoring information was available.
Further information:	Halifax Regional Council. 2016. "Tender No. 16-253 Northwest Arm Seawall Phase 4, Sir Sandford Fleming Park – West Region." Accessed at: https://www.halifax.ca/sites/default/files/documents/city-hall/regional-council/161213rc1411.pdf

Case Study 2: Detached / Nearshore Breakwater	**Protecting the Trans-Canada Highway (Highway 2) with Intertidal Reefs** Town of Souris, PEI



East Coast
Google Map Link

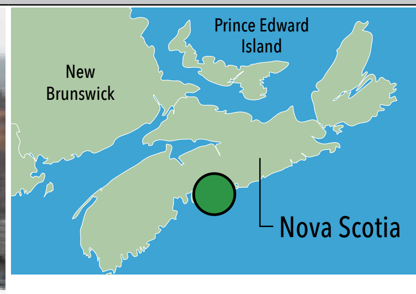
Inter-tidal reefs at low tide, August 2018 showing sediment accumulation in lee. (Photo credit: M. Davies)

Timeline:	Investigation and Design: 2011-2012 Implementation: 2012-2018, including construction of the intertidal reefs in early 2018 at a cost of $115,000.
Coastal flooding and erosion:	Rising relative sea-level, reduced ice cover and changing storm patterns were increasing the potential for flooding and erosion along Highway 2. A combination of storm surge, tides and wind waves from storms in 2016 eroded much of the small dune system along the beach, bringing flood waters to the edge of the highway.
Coastal vulnerabilities:	Highway 2 at Souris Beach. The road is a vital link to the Town of Souris and the Inter-Provincial ferry to the Magdalene Islands. The beach is also a local tourist and recreational attraction.
Project objectives:	Key objectives of the inter-tidal reefs were to: • Reduce wave action and the effects of storm waves on the beach area and highway infrastructure; • Encourage growth of Souris Beach by creating an area of calmer water to encourage sand moving naturally along the shore to be deposited. Use of locally-sourced PEI sandstone for the reefs aimed to provide natural substrate for coastal flora and inter-tidal pool habitat. The project served as a demonstration project of the use of intertidal reefs - a example of 'building with nature'.
Selection of coastal protection measure(s):	The US Army Corps of Engineers "GENESIS" model (GENEralized Model for SImulating Shoreline Change) was used to predict the impact of the intertidal reef design. Modelling indicated the design would result in minimal downdrift erosion while offering coastal protection at the site. The reefs were combined with construction of a timber seawall parallel to Highway 2 and dune restoration work.
Performance:	Post-construction monitoring is being conducted, including drone surveys. There has been an increase in the dry beach area that has, in turn, led to growth and vegetation of the landward dunes. It would be possible to adapt the reefs on-site, but no adjustments have been necessary to date. From a tourism/recreation perspective, the changes to the beach have met with positive feedback from beachgoers and the Souris community.
Further information:	Davies, M.H. and B.F. Thompson. 2019. "Protecting the Trans-Canada Highway at Souris with Inter-tidal Reefs." Paper prepared for Transport Association of Canada Joint Conference, Halifax, NS. Accessed at: https://www.tac-atc.ca/sites/default/files/conf_papers/daviesm_-_protecting_the_trans-canada_highway_at_souris_with_inter-tidal_reefs_-_v1.pdf

Case Study 3: Permanent Revetment

Rebuilding the Armour Stone Revetment along Cow Bay Causeway

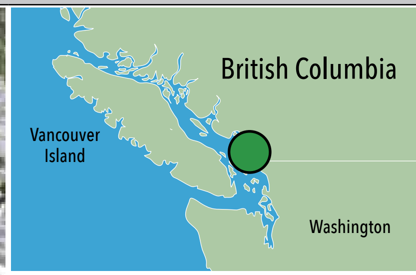
Cole Harbour, NS



East Coast
Google Map Link

Cow Bay Causeway experiencing a storm in 2010.
(Photo credit: M. Davies)

Timeline:	Investigations and Design: 2009-2010 Implementation: Phase 1 in 2012 and Phase 2 in 2013, at a cost of $1,209,500.
Coastal flooding and erosion:	Rising relative sea-level and increased storm intensity, causing overtopping and wave damage to the causeway – for example during Hurricane Juan in 2003, post-tropical storm Noel in 2007, and a storm in January 2010.
Coastal vulnerabilities:	The Cow Bay Causeway is a 350 m stretch of Cow Bay Road, built over a beach of cobbles and boulders. The causeway was not high enough in some areas to prevent waves from overtopping. Most of the existing armour stone was not sized to resist the force of waves during a major storm and voids between the stones allowed small stones and seaweed to wash through onto the road. The causeway required repairs every three to five years.
Project objectives:	The key objective was to repair and upgrade the causeway, to withstand higher water levels and greater wave action during storms. Measures were identified to minimize the impact of the works on the environment, in particular fish and fish habitat.
Selection of coastal protection measure(s):	• Four alternatives were considered: 1.) Erosion-proofing the causeway; 2) Erosion-proofing, plus elevating the roadway to reduce risk of overtopping; 3) Rebuilding the revetment in its entirety (including impermeable technologies); or 4) Rebuilding the revetment as (3) in prioritized phases. • Analysis of life-cycle costs and risk assessment indicated that re-building the revetment, in two phases, to withstand higher water levels and bigger waves was the most cost-effective approach for the next 30 years. • In the longer-term, the causeway may need to be abandoned and the road routed further inland.
Performance:	No post-construction monitoring information was available. HRM staff have reported that the causeway is holding well with some erosion on the eastern edge. The causeway requires less maintenance in comparison to the past.
Further information:	Rapaport, E. and D. Hubley. 2017. "Case Study 2: Defensive adaptation in Cow Bay (Halifax, Nova Scotia)". In: Climate risks and adaptation practices for the Canadian transportation sector: Chapter 8 Atlantic Canada. Government of Canada pp.234-235. Accessed at: https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/earthsciences/pdf/assess/2016/Chapter-8e.pdf

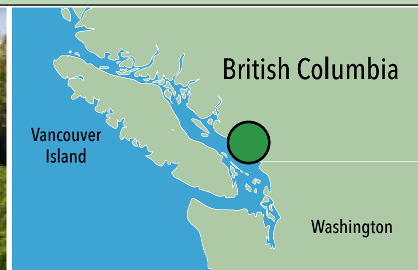
Case Study 4: **Sea Dikes**	**East Fraser Lands Integrated Coastal Flood Management** Vancouver, BC
	 West Coast Google Map Link Visualization of forthcoming development and waterfront park with integration of flood protection measures (solid red line represents dikes, dotted red line represents flood wall). (Graphic credit: Space2place Design Inc.)
Timeline:	Investigations and Design: Climate change adaptation strategy (2011), Coastal Flood Risk Assessment Phase 1 (2012-2014). Area 2 Planning and Design (2016-2020). Implementation: Area 2 ground improvement works, earthfill dike, and flood wall construction 2019-2020 at a cost of about $7 Million.
Coastal flooding and erosion:	Rising sea levels and flooding in the coastal floodplain along the estuary.
Coastal vulnerabilities:	Formerly a sawmill, the area is being developed into a new, sustainable community, including housing, services, and greenspace. Four existing buildings and 30+ proposed buildings are exposed to current and future flood hazards. Two of the existing buildings constructed pre-2014 have an older and lower flood construction level and are exposed to first floor property damage.
Project objectives:	Main objectives for flood protection were to: • Provide flood protection for a 500-year return period event allowing for 1 m of sea level rise (projected for Year 2100) and associated land subsidence (0.2 m). • Integrate flood protection into a pre-existing mixed-use community development plan including a major waterfront park. • Avoid impacts to Fraser River fish habitat, including a portion of the shoreline (mudflat/salt marsh with adjacent riparian trees) categorized as high quality habitat.
Selection of coastal protection measure(s):	• Alternatives considered were: 1) Reliance on new building floodproofing (construction above flood level), 2) Conventional shoreline diking and 3) Structural flood protection incorporated into development and waterfront park plans using a variety of techniques. • Alternative 3 was selected. Design includes use of "superdikes" –earthfill dikes coupled with raising of adjacent land to the dike crest height. • Future need for further dike raising is already anticipated within the design. • Setting back of flood protection left space for mudflat/salt marsh habitat. • Waterfront park offers multiple community benefits.
Performance:	No post-construction monitoring information was available.
Further information:	City of Vancouver. 2021. "East Fraser Lands (River District)." Accessed at: https://vancouver.ca/home-property-development/east-fraser-lands-river-district.aspx City of Vancouver. 2021. "East Fraser Lands (River District) Shoreline Resilience Upgrades" Accessed at: https://vancouver.ca/streets-transportation/east-fraser-lands-shoreline-resilience-upgrades.aspx

Case Study 5: Beach Nourishment (replenishment)	**Protection and Rehabilitation of the Anse de Sud** Ville de Percé, QC
	 East Coast Google Map Link View of completed works along Promenade e la Grave towards Roche Percé. (Photo credit: AECOM)
Timeline:	Investigations and Design: 2008 – 2018. Implementation: 2017 – 2019 at a cost of about $17.6 Million. Monitoring: To be carried out 2019 -2024.
Coastal flooding and erosion:	Loss of ice cover on the Gulf of St. Lawrence and changing storm patterns increasing ongoing coastal erosion and flooding. As a significant portion of storms occur during the winter, changes in shorefast ice and sea ice conditions impact the risk of storm-surge flooding and exacerbate coastal erosion.
Coastal vulnerabilities:	Industrial, commercial and business properties, including commercial properties, seasonal residences, buildings of high heritage value and a yacht club. Municipal infrastructure, including sewer, roads, outfalls, pumping station and a federal wharf. Overall, the total estimated value of economic losses, including damages to assets and a decline in tourist revenues, was estimated at $705 million over a 50-year timeframe under the non-intervention option.
Project objectives:	Key project objectives were to: • Stabilize the shoreline and reduce flood risk to a minimum. • Create a continuous waterfront trail system along the shoreline. • Provide opportunities for public/private investment, tourism and recreation. • Retain and enhance characteristics of the waterfront. An environmental impact assessment was conducted to identify measure to minimise impacts on the existing environment. Artificial reefs were constructed to compensate for the loss of existing lobster habitat.
Selection of coastal protection measure(s):	• Five alternatives were assessed using cost-benefit analysis: 1) Beach replenishment, 2) Beach replenishment with groynes, 3) Concrete seawall with deflector, 4) Rubblemound revetment, 5) Riprap protection. • Cost-benefit analysis identified that beach nourishment was the most beneficial option over the 50-year period considered. • The design included rehabilitation of the waterfront and boardwalk – benefit from tourism was estimated at $79.4 million over 50 years. • Partial replenishment is anticipated to be required every 10 years and monitoring will be carried out to assess maintenance needs.
Performance:	No post-construction monitoring information was available.
Further information:	Circé, M., et al. 2016. Cost-Benefit Analysis of Coastal Adaptation Options in Percé. Accessed at: https://www.ouranos.ca/wp-content/uploads/Report-CBA-Perce.pdf Tetra-Tech. 2019. "Protection et réhabilitation de l'Anse du Sud." Accessed at: https://afg.quebec/uploads/grandsprix2019/laureats/PrixVisionnaire_TetraTech_Perce.pdf

Case Study 6: Beach Nourishment	**Erosion Protection for Portage Park Midden** View Royal, BC
	 West Coast Google Map Link Site of First Nations middle at Portage Park 12 years after beach nourishment. (Photo credit: R. Atkins)
Timeline:	Investigations and Design: 2004 – 2006. Implementation: Works completed in 2006 and 2007 at a cost of about $96,000.
Coastal flooding and erosion:	Coastal erosion occurring during storms, due to wave action and elevated water levels. Hazard likely to increase with sea-level rise.
Coastal vulnerabilities:	A First Nations midden of cultural and archaeological interest is located in Portage Park. The midden was damaged during the winter storms of 2006/2007. The midden is estimated to be between 6,000 and 9,000 years old. The site includes both shell and skeletal remains.
Project objectives:	Key project objectives were to: • Provide protection against a 100-year combined probability storm wave and water level event, with a 25-year design life. • Maintain public access to the foreshore and beach. • Maintain beach habitat and cross-shore sediment processes.
Selection of coastal protection measure(s):	• Four alternatives were considered: 1) Log crib wall, 2) Seawall, 3) Riprap, and 4) Beach nourishment. • The alternatives were evaluated using a ranked analysis based on desirable outcomes (minimal disturbance of midden, maintain access and use of beach, maintain supply of material to beach, aesthetics and maintenance needs). • Estimates costs varied between $80,000 and $120,000, excluding archaeological works. • The beach nourishment option was the cheapest solution and highest ranked. • A temporary berm of material the same as proposed for the beach nourishment was placed over half the site in winter 2006 – the berm responded well to winter storms, whereas the unprotected area was eroded. • Beach nourishment was implemented in 2007 was designed to offer protection while improving fish habitat.
Performance:	Monitoring between 2007 and 2013 and ad-hoc review in 2019 indicates that the protection is performing well. The cultural site has been protected and no further erosion has been observed over the 12 years since placement. Access to the beach, and the beach habitat, has been maintained.
Further information:	Government of British Columbia. "Province funds protection for Portage Park midden." News Release. March 1, 2007. Accessed at: https://archive.news.gov.bc.ca/releases/news_releases_2005-2009/2007tsa0014-000193.htm

Case Study 7: Dune Stabilization / Restoration	**Stabilisation and Restoration of Le Goulet Dunes** Le Goulet, NB
	 East Coast Google Map Link Lobster traps used as part of dune stabilisation efforts in 2013. (Photo credit: L. Richardson)
Timeline:	Investigations and Design: Coastal Erosion and Flood Risk Assessment (2009-2011), Climate adaptation zoning recommendations (2012). Cost-Benefit Analysis (2016) Implementation: Yearly dune restoration efforts (2013-2019). Annual Monitoring: 2014-2020.
Coastal flooding and erosion:	Sea level rise, flooding during storms and ongoing erosion of the dunes and the beach in front of Le Goulet village. It has been supposed that sediment transport along the coast is likely modified by the quai at Shippagan Gully, updrift of the Le Goulet, causing sediment to be transported away from the shore and reducing supply to the eroding section of the dunes. Use of the dune by All Terrain Vehicles is making dune erosion worse.
Coastal vulnerabilities:	Beach and dune habitat are actively eroding in front Le Goulet village. Residences behind the dunes are at risk of flooding in case of dune overtopping or breaching.
Project objectives:	The key objective of the project is to protect and slow the ongoing erosion of the beach-dune system, which provides natural protection to the village of Le Goulet.
Selection of coastal protection measure(s):	• Dune protection is one of several adaptation measures that have been identified by working closely with representatives of the local community. • Sand retention structures comprised of lobster traps and recycled Christmas trees were placed on the dunes in 2013 and monitoring has been undertaken since to assess their performance. Attempts have also been made to plant Marram grass to stabilize the dunes. • Cost-benefit analysis considered two alternatives - 1) Dikes and 2) Beach nourishment. Beach nourishment was identified as the most beneficial alternative, even if a breach in the system occurred. • Beach nourishment requires an appropriate supply of sand. Dredged sediments from nearby small craft harbours were reportedly too silty to be appropriate for restoring dune habitat, where piping plover (a bird listed as Endangered in Canada) are present. • The climate adaptation plan for Le Goulet also includes several measures to accommodate flood risk within the village.
Performance:	Significant information is publicly available regarding the performance of the restoration measures. Although many of the sand retention structures and areas of dune nourishment were severely damaged by Hurricane Dorian in September 2019, they may be contributing to sediment accumulation and vegetation colonisation in certain areas.
Further information:	VALORĒS Coastal Zones Research Institute. 2021. "Centre Péninsule and Shippagan – Le Goulet." Project Adaptation PA (Péninsule acadien). Accessed at : https://adaptationpa.ca/en/secteur-centre-peninsule-et-shippagan/le-goulet

Case Study 8: Salt Marsh / Coastal Wetland Restoration	**New Brighton Park Shoreline Habitat Restoration Project** Vancouver, BC



New Brighton Park Tidal Wetland.
(Photo credit: Vancouver Fraser Port Authority)

West Coast
[Google Map Link]

Timeline:	Investigations and Design: 2015 – 2016 Implementation: 2016-2017 at a cost of around $2 Million. Annual monitoring (2018 onwards)
Coastal flooding and erosion:	Coastal flooding and flooding caused by stormwater/sewer system overflow. Much of New Brighton Park was built on construction fill that was created in the 1960s. Historic loss of natural features along the shoreline (such as mud flats and saltmarsh) led to increased impacts of wave-related erosion (due to increased marine traffic as well as natural erosion) along the eastern portion of the park.
Coastal vulnerabilities:	This prompted the initiation of shoreline stabilization works in 2006 and 2007 by the City of Vancouver.
Project objectives:	The project was selected to address the loss of valuable habitat in the Burrard Inlet and developed as part of the Vancouver Fraser Port Authority's Habitat Enhancement Program. Key project goals were to: • Enhance fish and wildlife habitat and • Increase public access to nature The project also aims to help to reduce coastal erosion and flooding and protect water quality by filtering runoff.
Selection of coastal protection measure(s):	• Measures were mainly designed to increase fish and wildlife habitat and public amenity value rather than for coastal protection. • Costs-benefit analysis of the project evaluated the net annualized benefits as about $0.7 million, and the corresponding benefit-cost ratio as about 2.5. • Estimated equivalent annualized benefits were evaluated at around $1,198,000 annually. This estimate includes benefits provided by habitat and cultural services, climate regulation and waste treatment services, nutrient cycling and disturbance regulation services.
Performance:	An annual monitoring protocol was established at the design stage. Monitoring to date indicates that the project is performing as anticipated, although some adaptive management has been required post-construction (fencing to exclude Canada geese and the public from establishing saltmarsh, supplemental vegetation planting, irrigation).
Further information:	Vancouver Fraser Port Authority. 2021. " New Brighton Park Shoreline Habitat Restoration Project." Accessed at: https://www.portvancouver.com/new-brighton-park-shoreline-habitat-restoration-project/

Case Study 9: Combined Measures	**Combining Grey Infrastructure and Nature-Based Protection at Alma** Fundy National Park, NB
	 East Coast Google Map Link View across the boardwalk and tidal wetlands to the east of the revetment. (Photo credit: CBCL Limited)
Timeline:	Investigations and Design: 2017 Implementation: Works undertaken 2017 - 2018 at a cost of around $3.5million.
Coastal flooding and erosion:	Coastal erosion and flooding, in particular storm damage, when high tide coincides with heavy wave and wind activity. A winter storm of December 30, 2016, and a second on January 11, 2017, in particular caused damage to the existing coastal protection.
Coastal vulnerabilities:	Federally-owned Highway 114, providing access to Fundy National Park from Alma. Parks Canada facilities and supporting infrastructure.
Project objectives:	Key project objectives were to: • Protect the road linkage and Parks Canada infrastructure. • Minimize cumulative storm damage mitigation costs. • Maintain the natural beauty of the site for continued visitor enjoyment at the Park entrance. • Maintain easy beach access. • Maintain or enhance habitats – including provincially-significant wetlands.
Selection of coastal protection measure(s):	• Three alternatives were considered: 1) Conventional protection using armour stone over the 1km of coastline, removing the beach and salt marsh. 2) Relocate the road and let nature reclaim the shoreline 3) Use of nature-based features and less grey infrastructure. • The third alternative incorporating nature-based features was found to be more cost effective than armouring the entire shoreline. • Design included; construction of a revetment along the highway embankment, beach nourishment and planting of grasses to the north-east of the revetment, and protection and enhancement of the existing salt marsh to the south-west of the revetment. • Beach access was improved by extending the existing boardwalk.
Performance:	Formal monitoring has not been undertaken after construction. However, in summer 2020, the revetment and saltmarsh appeared to be stable, and sediment has accumulated in the pocket beach formation to the east of the revetment.
Further information:	Parks Canada. 2017. "Alma Shoreline Protection-Fundy National Park: Parks Canada Basic Impact Analysis." Accessed at: https://buyandsell.gc.ca/cds/public/2017/11/15/45b96dfb90a055888fbeb476b7164fab/appendix_a_-_bia.pdf

Case Study 10: Combined Measures	Deltaport Third Birth - East Causeway Habitat Remediation Project City of Delta, BC
	 West Coast Google Map Link March Lagoon 9 and adjacent barrier beach August 2019. (Photo credit: T. Andrews)
Timeline:	Investigations and Design: 2016 Implementation: 2017, at a cost of around $2.4 Million. Operations and maintenance is undertaken on an ongoing basis. Monitoring: 2017 – 2021.
Coastal flooding and erosion:	Wave and wind exposure were limiting establishment of habitats along the causeway. The presence of the causeway itself has also modified natural sediment processes, meaning there is a lack of sediment supply to maintain the beaches along the causeway.
Coastal vulnerabilities:	The original habitat compensation project, implemented in 2010, included enhancement of the causeway with salt marsh lagoons, pocket marshes, and forage fish beach spawning habitat. Monitoring revealed the project was not performing as planned.
Project objectives:	• The primary goal of the remediation project was to modify the original measures to deliver coastal habitat benefits. This means maximizing the ecological function of the barrier beaches and pocket marshes along the causeway. • The habitat measures also reduce the exposure of the vertical sheet-pile walls protecting the Roberts Bank causeway to direct wave action.
Selection of coastal protection measure(s):	• Remedial measures were designed to work with modified natural processes. • Grey infrastructure was used to artificially create conditions to support habitat creation, using artificial headlands. • Artificial headlands provide sheltered conditions for barrier beach and salt marsh habitats and prevent beach added by beach nourishment being transported away (since no sand is being supplied to the site). • Beach design drew on “natural analogs” - local beaches subject to the same wave conditions.
Performance:	Monitoring indicates the barrier beaches have generally maintained their sediment and form. Salt marshes are still establishing. Drought and the presence of invasive species have impacted vegetation growth. Some erosion has occurred at the marsh toe.
Further information:	Black, S. 2018. “Deltaport East Causeway Intertidal Habitat Enhancement - Saltmarshes, Mother Nature and Coastal Engineering.” SER-Western Canada 2018 Conference. Accessed at: https://6zvjw1i9d632in9ii1izgap9-wpengine.netdna-ssl.com/westerncanada/files/2018/03/BlackScott_SERWC2018_ConferenceProceedings.pdf

Appendix B: Online Workshops – Overview and Outputs

This appendix provides an overview of the two workshops held in June 2021. Each of the workshops was attended by over 35 subject matter experts from across Canada. Attendees are recognized in the acknowledgements list at the beginning of this report.

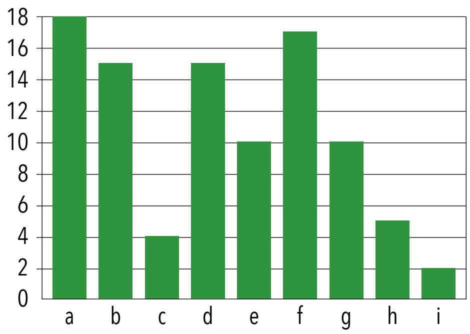
Online Workshop #1: Upgrading Options Appraisal to include Ecosystem Good and Services	
Date:	Thursday, June 17, 2021, 1-4pm EST
Goals:	• Identify options appraisal tools currently applied across Canada to plan and design coastal flood and erosion management infrastructure. • Capture subject matter expertise regarding how costs and benefits relating to Ecosystem Goods and Services are being / can be better addressed in options appraisal. • Inform guidance for options appraisal that specifically includes the co-benefits of nature-based solutions.
Content:	Pre-workshop questionnaire Polling activities Presentations: • Nature-Based Solutions for Coastal Flood and Erosion Risk Management (Enda Murphy, National Research Council of Canada). • Coastal Resilience: Natural Infrastructure and DMAF (Tjaša Demšar, City of Surrey). • Avoiding White Elephants - Making Good Decisions for Coastal Adaptation (inc. Case Study of Structured Decision Making in the City of Vancouver (Tamsin Lyle, Ebbwater Consulting Inc). • Addressing Ecosystem Goods and Services through UK Outcome Measures (Joanna Eyquem, Intact Centre on Climate Adaptation). Small-group, virtual whiteboard sessions: • Natural Infrastructure and Mainstream Options Appraisal Tools • Methods of incorporating Ecosystem Goods and Services in Canada Review and Structured Plenary Discussion • Technological developments • Economic context, roles and responsibilities

Outputs:

Key points raised in workshop discussions are summarized in Section 4.1 of the report.

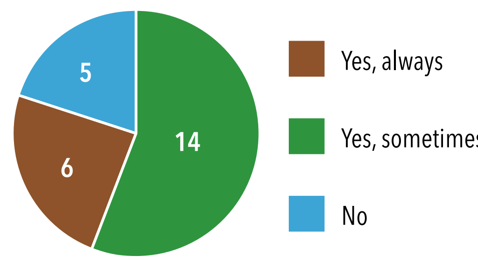
Pre-workshop online survey responses (25 respondents)
Responses to the pre-workshop online survey are summarized below:

Question: What mainstream approaches and tools have you / do you apply during options appraisal to compare different coastal resilience options?

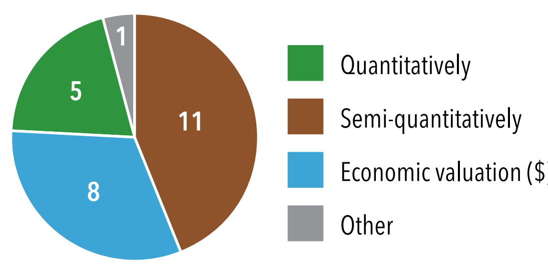


a) Multi-Criteria Analysis (qualitative)
b) Evaluation against Performance Objectives
c) Return on Investment (quantitative - focused on tangible financial gains/costs)
d) Cost/Benefit Analysis (quantitative - tangible and intangible benefits/costs)
e) Climate Lens GHG and Resilience Assessment
f) Environmental Impact Assessment (Consideration of alternatives)
g) Evaluation against Disaster Mitigation and Adaptation Fund application criteria
h) Evaluation against other funding application criteria
i) Internal organization-specific options appraisal procedure (please specify in the "other" box)

Question: Do you typically take into account, in some form, costs/benefits specific to natural infrastructure (i.e. ecosystem goods and services that are not delivered by "grey" infrastructure solutions), during options appraisal of coastal resilience measures?



Question: How do you most commonly take into account the costs/benefits of impacts on natural assets (ecosystem goods and services) as part of options appraisal relating to coastal resilience projects?

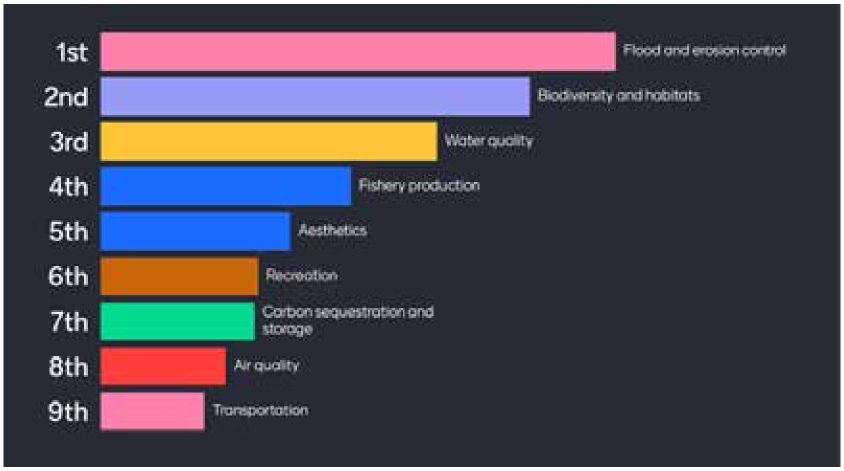


Outputs:

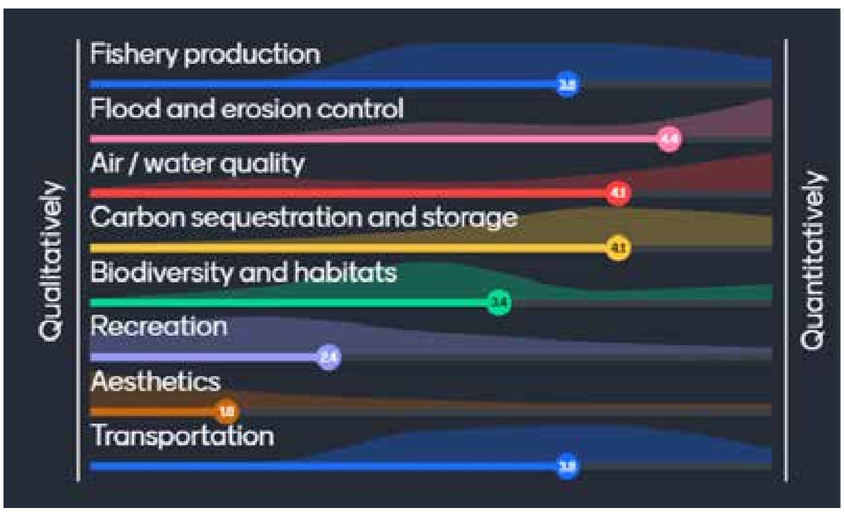
Online polling responses

Responses to online polls undertaken within the workshop are summarized below:

Question: Which are the most important ecosystem goods and services to consider for coastal resilience projects? (respondents were asked to rank the identified ecosystem goods and services). 17 responses.



Question: How do you think each good/service is best reflected in option appraisal? (1 = completely qualitatively, 5 = completely quantitatively). 19 responses.



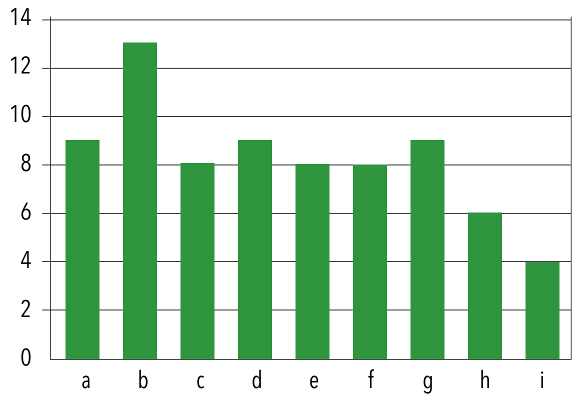
Online Workshop #2: Performance Monitoring of Natural Infrastructure Solutions	
Date:	Tuesday, June 29, 2021, 1-4pm EST
Goals:	• Identify monitoring approaches that are currently applied across Canada to assess the performance of coastal resilience measures against their objectives. • Capture subject matter expertise regarding how monitoring protocols are being / can be improved, particularly in relation to performance of nature-based solutions. • Inform guidance for performance monitoring for coastal resilience projects that specifically addresses the co-benefits of natural infrastructure and nature-based solutions.
Content:	Pre-workshop questionnaire Polling activities Presentations: • Key Challenges to Monitoring of Coastal NbS Projects in Canada (Phil Osbourne, Golder, and Danika van Proosdij, Saint Mary's University). • Habitat Enhancement Program –New Brighton Park Shoreline Habitat Restoration Project (Charlotte Olson, Vancouver Fraser Port Authority). • Performance Monitoring of Natural Infrastructure Solutions at Baird (Matthew Armstrong, Baird). Small-group, virtual whiteboard sessions: 1. Priorities for Coastal NbS Project Monitoring (Monitoring Design) 2. Priorities for Coastal NbS Project Monitoring (Monitoring Methods) Review and Structured Plenary Discussion • Towards a minimum standard for monitoring coastal infrastructure projects? • Immediate Recommendations and Long-Term Goals

Outputs:	Key points raised in workshop discussions are summarized in Section 4.2 of the report.

Key points raised in workshop discussions are summarized in Section 4.2 of the report.

Pre-workshop online survey responses (15 respondents)
Responses to the pre-workshop online survey are summarized below:

Question: What do you feel is required to improve monitoring of coastal NbS projects in Canada? (please tick all that apply)?



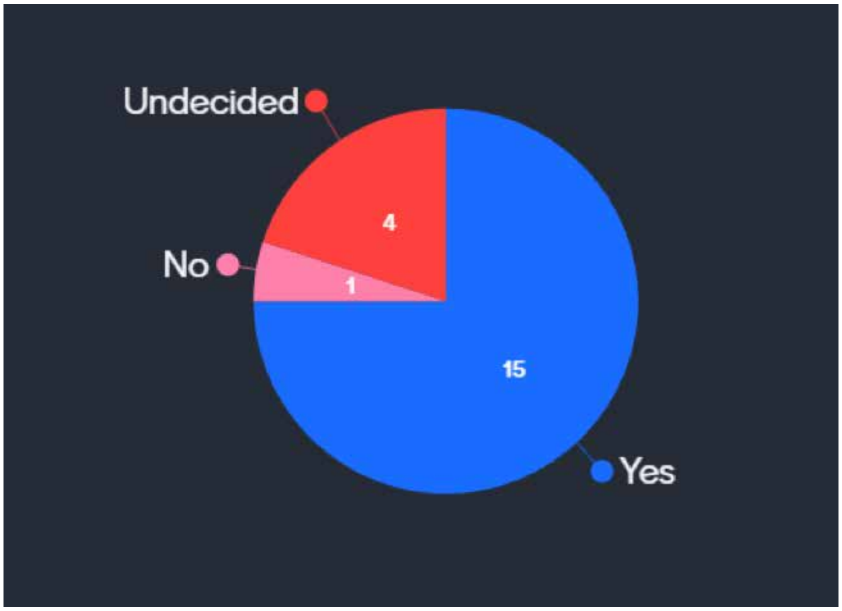
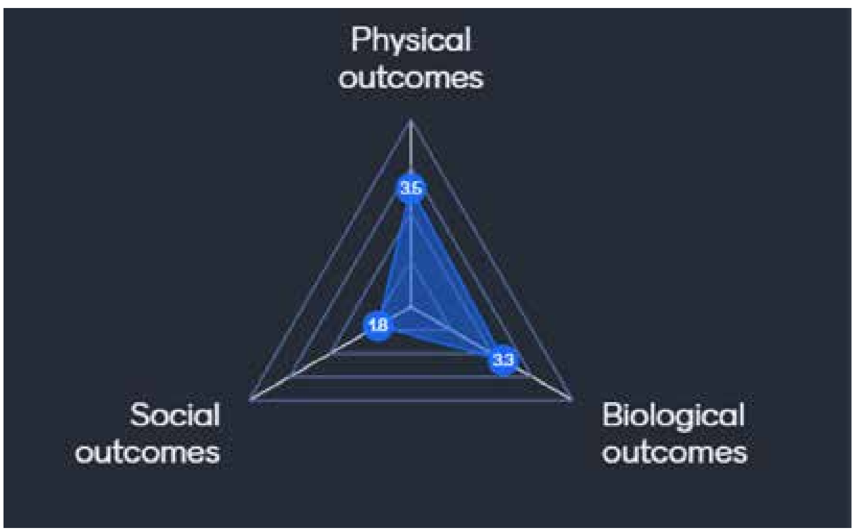
a) Regulatory requirements
b) Technical guidance
c) Centralized repository for monitoring results
d) Longer-term funding “baked in” from project outset
e) National monitoring protocols
f) Provincial monitoring protocols
g) Minimum monitoring protocols
h) National monitoring programme
i) Other

“Other” identified requirements included:

- A credit (like a scoring card) provided to reward good monitoring practices, which could be used in many ways (securing more funded projects, tax benefits,..).
- Protocol or standard approach to include Indigenous groups in monitoring.
- Support for municipalities and communities with trailing costs.
- Monitoring of NbS projects post-storm events.

Online polling responses
Responses to online polls undertaken within the workshop are summarized below:

Question: How do you feel about coastal monitoring in Canada today? 17 responses.

Outputs:	Question: Would you be supportive of a minimum coastal monitoring standard? 20 responses.  Question: How strong do you think we are at monitoring physical, biological and social outcomes. (respondents were asked to indicate their perception of strength in monitoring from 1 (weak) to 5 (strong) for each type of outcomes) 

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To find out more:

Joanna Eyquem PGeo. ENV SP. CWEM. CEnv.
Managing Director, Climate-Resilient Infrastructure
Intact Centre on Climate Adaptation
Faculty of Environment, University of Waterloo
514-268-0873 | joanna.eyquem@uwaterloo.ca
www.intactcentre.ca | Twitter @ICCA_Canada

UNIVERSITY OF WATERLOO

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