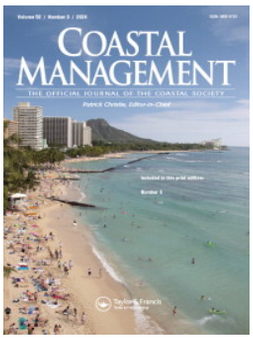

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RESEARCH ARTICLE

Enhancing Climate Resiliency Through Improving Ecosystem Services in Shoreline Municipalities – Lessons from Canada

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ABSTRACT

The accelerated impacts of climate change in waterfront areas and the proven inefficacy of the aging hardened shoreline infrastructure have driven shoreline management practices to evolve toward the enhancement of ecosystem services at the land-water interface. Gaining momentum as an adaptive approach in regenerative projects, living shorelines are comprised of natural ecosystem components used in combination or in place of traditional hard engineering methods to provide coastal protective services and erosion mitigation. The success of living shorelines in protecting shoreline property and ecosystem integrity varies based on the biogeomorphology and hydrology of the region and is also heavily reliant on social acceptance of the chosen approach and best practice for implementation. The relatively lower lifecycle cost and associated co-benefits of living shorelines have well positioned them as a promising alternative approach in theory. There are, however, gaps in regional long-term datasets and evidence-based guidelines. This research provides an overview of the underlying geopolitical readiness for integrating nature-based solutions in climate adaptation strategies within shoreline municipalities based on a comprehensive literature review complimented by expert interviews. The synthesized data can inform decisions for minimizing the destructive effects of traditional shoreline erosion prevention approaches and encourage successful implementation of solutions that offer ecological, health, social, and economic benefits.

KEYWORDS

Climate change adaptation; living shorelines; nature-based solutions; watershed management

Introduction

The accelerated rate of global warming in recent years has led to melting polar ice and glaciers, thermal expansion of the oceans, and consequently the rising of sea levels (IPCC (Intergovernmental Panel on Climate Change) 2014; Shepherd et al. 2018; Rignot et al. 2019; Frederikse et al. 2020; IPCC (Intergovernmental Panel on Climate Change) 2021; NASA 2023). This is exposing coastlines to greater erosion and flooding pressures, has resulted in changes in precipitation patterns, and in general, increased frequency and intensity of extreme weather events (Grover 2014).

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Lake ecosystems in particular, are vulnerable to alteration of environmental quality and water renewal rates (Vincent 2009). The onset of changes in the physical, chemical, and biological attributes of lakes affects their ability to maintain well-functioning communities of aquatic plants, animals, and microbes, and their capacity to provide ecosystem services such as safe drinking water and inland fisheries (Vincent 2009).

Additionally, land-cover changes and land-use activities in watershed areas directly impact the resilience of shoreline ecosystems (Lemmen et al. 2016). The term shoreline is used here to refer to the area where a large body of water (fresh or salt) meets the land. Within the scientific literature, the word "coast" is often used in the context of marine shoreline, and much of the research and practices surrounding shoreline protection use the term “coastal areas” in reference to area surrounding any major body of water including lakes. According to the Global Terrestrial Observing System (GTOS), coastal areas are regional mosaics of habitats including intertidal zones (mangroves, marshes, mudflats, rocky shores, sandy beaches), semi-enclosed bodies of water (estuaries, sounds, bays, fjords, gulfs, seas), benthic environments (coral reefs, seagrass beds, kelp forests, hard and soft bottoms), and the open waters of the coastal ocean to the seaward limits of the exclusive economic zone (Christian 2005). These areas are typically of great interest for the establishment of residential and recreational properties, and therefore are significantly impacted by development and human activities.

Along with land development, shorelines have been increasingly under pressure due to long-term industrial and agricultural uses that drive the economy of many regions but result in loss of historical wetlands and degraded habitat in the area (Hartig and Bennion 2017). Further injuries take the form of increases in greenhouse gases in the atmosphere affecting the structure, functioning, and stability of lake ecosystems throughout the world (Vincent 2009). Shoreline erosion is a natural process that removes shoreline material, causing the waterline to retreat inland. Shoreline municipalities can experience this change in the form of various infrastructure damages including damages to coastal protection infrastructure. Climate change exacerbates erosion and impacts the chemical composition of freshwater resources (Vincent 2009), all requiring upgrades to water infrastructure.

Climate change adaptation is a human intervention and the “adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities” (IPCC 2001). Adaptation as a strategy involves making changes in decisions, activities, and thought that includes technology transfer, adjusting planning and investment practices, and regulatory reform. For nearshore climate change adaptation, five major strategies include: (1) avoid (or prevention), (2) retreat (or relocation), (3) accommodate, (4) protect, and (5) procedural approaches that mainly focus on policies and regulations (van Proosdij et al. 2016). Poorly planned engineering solutions for adaptation could work against nature by constraining regular ecological cycles, which may lead to mal-adaptation and increased social and ecological vulnerability (BirdLife International 2009; CBD (Convention on Biological Diversity) 2009; Adger et al. 2013; Eriksen, Nightingale, and Eakin 2015; Barnett and O’Neill 2010; Sovacool and Linnér 2016).

Shorelines management and climate adaptation

A common adaptation practice initiated in the twentieth century is hardening shorelines for stabilizing the land-water interface and protecting humans from flooding and erosion (Hartig and Bennion 2017) while providing access to waterbodies for leisure and mobility. These pracetices are, however, not adaptable to climate conditions, therefore, are becoming less effective with changes in precipitation regime that accompanies climate change and impacts the erosion rates (O'Donnell 2017; Pace and Morgan 2017; Hartig and Bennion 2017; Rahman et al. 2021). In many cases, if the loss is insured, what is paid out in insurance goes toward rebuilding similar shoreline armoring infrastructure that shortly becomes similarly vulnerable to storms and flooding, is environmentally and financially costly to maintain, has detrimental impacts on its neighboring environmental when demolished, and continues to degrade its surrounding ecosystem, making them prone to more hazards (World Bank 2016). The anthropogenic hardening of shorelines not only destroys natural features and biological communities, but it also alters the transport of sediment. This disrupts the balance of accretion and erosion of materials carried along the shoreline by wave action and long-shore currents which in turn can intensify the effects of erosion, causing ecological and economic impacts (Hartig and Bennion 2017).

Since 2009, the International Union for Conservation of Nature (IUCN) has promoted the adoption of Ecosystem-based Adaptation (EbA) as an operational tool for climate change adaptation (Andrade et al. 2011). EbA is a concept for increasing resilience to climate change using both natural and managed ecosystems as a cost-effective alternative or to complement traditional engineering approaches by leveraging elements of biodiversity and ecosystem services (Nalau 2018). EbA is not a new concept and borrows much of its principles from common ecosystem approaches practiced in the late 1970s and early 1980s. An ecosystem approach is a socio-ecological style of resource conservation that accounts for interrelationships among land, air, water, and all living things, including humans (Alsip et al. 2021). This approach involves all user or stakeholder groups in comprehensive management and collaborative governance (Alsip et al. 2021). The essence of an ecosystem approach is that it relates people to ecosystems that contain them, rather than distinct from the environments with which they interact (Hartig and Vallentyne 1989). Successful restoration and redevelopment programs must not only pursue technical, legal, and economic advances, but bring changes in underlying cultural values and societal conditions that sustain ecosystem integrity and the quality of life of humans (Hartig and Vallentyne 1989). We also see reflected in literature a growing trend involving a shift away from the restoration of an ecosystem and toward the restoration of ecosystem services (Palmer, Filoso, and Fanelli 2014). However, if ecosystem services are not fully captured in commercial markets or adequately quantified in terms comparable with economic services and manufactured capital, they are given too little weight in policy decisions (Costanza et al. 1997).

Nature-based Solutions (NbS) is an umbrella term that encompasses the objectives of EbA and aims to strategically conserve or restore nature to support conventionally built infrastructure systems for reducing disaster risk and producing more climate resilience. NbS is a policy-initiated concept that highlights interdisciplinary and

transdisciplinary collaborations based on pluralism rather than unification (Hanson, Wickenberg, and Alkan Olsson 2020). Living shorelines are in effect a problem-specific application of NbS that apply Natural and Nature-based Features (NNBF) as a "blue-green infrastructure" in harmony with traditionally engineered infrastructure to address the primary concern of shoreline erosion within an overarching shoreline management plan. A shoreline management plan addresses actual and potential shoreline erosion in relation to planned or existing development activities on the shore. The plan is to ensure (a) overall land use practices and general environmental policies are followed, (b) activities do not contribute to or aggravate erosion, (c) development activities are not occurring within sensitive ecodistricts, and (d) erosion control techniques are cost-effective and socially acceptable (Mangor et al. 2017).

Living shorelines: restoration in principle, resilience in practice

Living shorelines are coastal structures comprised of organic and natural materials, typically established to minimally interfere the coastal, estuarine, or geomorphological processes (Manis et al. 2015; Latta and Boyer 2012). When used at appropriate sites, living shorelines allow for continued coastal processes and ecosystem connections (Hartig and Bennion 2017) while stabilizing the land-water interface. The purpose is to increase the resilience of waterfront properties by enhancing ecosystem services in the area (Gittman et al. 2015; Manis et al. 2015; Pilkey et al. 2012; Currin, Chappell, and Deaton 2009). Regardless of the type of water body, these self-adapting natural or semi-natural infrastructure solutions help with erosion risk reduction, wave attenuation, and biodiversity restoration in addition to generating multiple indirect co-benefits for the communities near waterfront, including carbon sequestration and recreational value.

Living shorelines can support diversity of native flora and fauna, by creating or restoring a strip of coastal habitat such as dune, salt marsh, and submerged aquatic vegetation such as eel grass beds (Sutton-Grier, Wowk, and Bamford 2015; Wolanski, Brinson, and Perillo 2009; Currin, Chappell, and Deaton 2009; Silliman and Bortolus 2003). Such zones can trap marine plastics (Sanchez-Vidal et al. 2021), filter sediment and other pollutants such as pathogens, metals, or pesticides, absorb nutrients from runoff and septic systems (Jurries 2003), provide temperature regulation through canopy and shade (Wynn, Mostaghimi, and Alphin 2004), support the food web for wildlife, reduce carbon dioxide concentration in the air and the ocean water (Fitzsimons et al. 2020), and protect asset and property values.

Although the composition or construction of living shorelines have not been standardized globally (Gianou 2014; Paterson, Loomis, and Young 2014), these solutions use natural elements (such as biodegradable mats, stones, fill) and, if appropriate, manmade structural materials in such way that it does not disrupt the land-water continuum (Manis et al. 2015). Often, design considerations lead to a need for a mix of natural and hardened structures (hybrid living shorelines) in which case negative environmental impacts similar to those associated with engineered structures can incur (Gianou 2014). Commonly cited living shoreline practices in literature include non-structural approaches such as wetland, riparian corridors, dune plantings, seagrasses, beach nourishment, slope or bank grading, marsh restoration, and vegetated buffer

strip as well as hybrid approaches such as shellfish and oyster reefs (reef balls), branch packing, brush mattresses, marsh toe revetment, marsh sills or riprap sills, breakwaters, and fiber logs/coconut coir (O'Donnell 2017).

The efficacy of living shorelines has been recorded, though infrequently in many regions across the world for more than 200 years. In Atlantic regions of Canada, restoration of valued ecosystems such as tidal wetlands have been successfully achieved in projects unrelated to climate resiliency (Eyquem 2021; Sherren et al. 2019; Bowron et al. 2012; van Proosdij et al. 2016). The success of some case studies such as living dike projects in Atlantic Canada highlighted the importance of the community consultation process (Sherren et al. 2019). This emphasizes the importance of community engagement as a qualifying principle of a Nature-based Solution (Dhanya, Ramananda, and Dhyani 2022).

Nonetheless, the evidence supporting the efficacy of living shorelines as a climate adaptation strategy is vastly underrepresented in literature. Better estimates of maintenance costs and the additional ecosystem services and co-benefits (or lack thereof for hard infrastructure) are required for evaluating the overall costs and benefits of living shoreline restoration projects (Narayan et al. 2016). Moreover, establishing dense root systems enhances biological cycling of nutrients (Räty et al. 2010; Kieta et al. 2018), increases soil strength through mechanical enforcement, and is therefore an essential consideration in assessing a living shoreline efficacy (Wynn, Mostaghimi, and Alphin 2004; Räty et al. 2010; Roberts, Stutter, and Haygarth 2012; Sigren, Figlus, and Armitage 2014; Kieta et al. 2018; Ellis, Lohnes, and Lundholm 2022). The lack of quantitative data for physical and geomorphological parameters of examples in literature makes it difficult to translate the success of a case study in one region to another.

Legislative landscape and jurisdictional responsibility for shoreline management in Canada

Canadian coastal zone management is influenced by shared jurisdiction between all orders of government pertaining to both freshwater and marine shorelines (Harrison and Parkes 1983; East Coast Environmental Law 2018). Historically, the concentration of shoreline management efforts in Canada prior to 1980s was focused on the scientific aspects of the coast and only began to devise mechanisms for addressing challenges associated with the polycentric nature of the Canadian confederation in the early 1980s (Harrison and Parkes 1983). By the early 1900s, the efforts resulted in various legislations stating the need for management at the watershed scale which resulted in the introduction of Watershed Management in Canada, primarily focused on flood, drought, and water quality (CCME (Canadian Council of Ministers of the Environment) 2016). The impacts of erosion and stormwater began to be incorporated in 1970s and the list of concerns grew to include matters such as aquatic habitat, riparian systems, and natural infrastructure (wetlands, woodlots, wildlife habitat, etc.) throughout 1990s (CCME (Canadian Council of Ministers of the Environment) 2016). Having slowly evolved over the last 40 years, shoreland governance approaches within Canadian municipalities are typically a combination of jurisdictional authority (top-down approach) and grassroot efforts (bottom-up approach) (CCME (Canadian Council of Ministers of the Environment) 2016).

The Constitution Act, 1867 provides the framework for the division of powers between federal and provincial governments but leaves environmental responsibilities such as shoreline protection shared between the two (East Coast Environmental Law 2018). Aboriginal and treaty rights may also include title to coastal lands as well as specific rights to coastal resources such as fisheries and trades (East Coast Environmental Law 2018). Generally, provinces have constitutional jurisdiction over numerous environmental issues as well as municipal institutions in the province (section 92(8)) under which authority they may delegate the power to municipalities to regulate matters such as zoning and development (Becklumb 2020). While provinces have jurisdiction over most wildlife within their borders, principal exceptions for matters such as migratory birds and aquatic species falls under federal jurisdiction under the constitution (Becklumb 2020). As such, regulations related to shoreline protection is a combination of municipal by-laws and provincial and federal legislations (East Coast Environmental Law 2018; West Coast Environmental Law 2020). This means that although the federal government partially controls coastal waters[1] and has authority over certain coastal activities,[2] municipalities have primary jurisdiction over land with limited power to control the extent of coastal developments (East Coast Environmental Law 2018). Municipal governments are also responsible for monitoring and evaluating the stormwater infrastructure as it relates to potential flooding from storm events and identify strategic components and areas to be sustained prior to a catastrophic system failure (Garnett and Adams 2018).

Specifically for shorelines, all alteration work requires permission from one or more governmental agencies depending on the jurisdiction. These permit agencies are often denoted as local authorities meaning municipal and provincial only, as long as there is "no in-water" work or the work performed is not below the high watermark which can impact fish habitat during sprawling or nursery season. It is generally an advisement but not an enforceable regulation to use native vegetation. These advisements generally include high level matters such as use of materials that are not easily suspended or moved by wave action or ice, or use of loose soil that is not supporting runoffs contributing to aquatic habitat degradation (Rideau Valley Conservation Authorit). While the municipal authority is not constitutionally based, the authority to pass by-laws that protects the general welfare and health of the residents combined with municipal planning strategies provides municipalities with tools to prevent destructive development on a fragile shoreline areas and devise ecosystem protection, climate adaptation, and hazard management strategies, especially where there are gaps in federal and provincial activity (East Coast Environmental Law 2018).

The need to mainstream adaptation strategies that are ecosystem-driven is widely advocated within scientific literature for municipal planning. There is, however, very little guidance on the implementation of systemic and successful implementation of nature-based shoreline protection globally (Wamsler and Pauleit 2016). This study reviews global frameworks, principles, and strategies applicable for mainstreaming nature-based climate change adaptation for shoreline protection in Canada. Additionally, this research summarizes a set of practical pathways and strategies obtained from systematic interviews with subject experts and presents recommendations for overcoming barriers to the use of living shorelines for climate change adaptation.

Materials and methods

Data collection

This investigation is a qualitative study based on both primary and secondary research. The secondary research was done based on principles of systemic literature review as identified by Page et al. (2021) for collecting, screening, and synthesizing the knowledge within the English-language body of literature published between 1992 to 2022 for nature-based strategies adopted in coastal communities bordering Pacific, Atlantic, and Arctic oceans as well as the North American Great Lakes. Emphasis was put on shoreline stabilization, coastal restoration, and flooding and erosion control. The secondary research reviewed and analyzed academic papers, policy and governmental documents, and reports published by organizations involved in design and implementation of relevant natural and nature-based projects. Seventy-five percent of resources included are peer-reviewed scientific and academic articles, fifteen percent are government documents, public records, and legislative texts, and ten percent are grey literature. Academic journals were searched using several permutations of key terms "living shorelines," "nature-based adaptation" "Eco-DRR," "blue-green infrastructure," and other similar phrases separated by Boolean "OR" operator. After an initial search, this protocol was amended to exclude terminologies such as "aqua-culture" that skewed the search results using "NOT" operator. A publication was determined to be relevant if it discussed innovative shoreline protection measures, implementation of living shorelines, and governance mechanisms involved in planning of these projects. The primary databases for this secondary research were "GeoBase", "Google Scholar", "Science Direct", "ProQuest (Natural Sciences Database)", "JStor", and "Engineering Village". Subsequent databases (such as Green Infrastructure Effectiveness Database by NOAA) were found later in the research process and used to complement the analysis and the responses provided by the expert interviewees. Relative thesis publications in Canada were also accessed through Library and Archives Canada (LAC) in addition to abovementioned databases in an effort to build upon the previous work.

The primary research was designed to analyze experiences, principles, and opinions of experts in the field. In order to ensure that a representative range of the most relevant expertise for the issue was covered, the experts were chosen to represent academics and researchers (36%), planners (14%), regulators (14%), and practitioners (36%) working in related public and private institutions. Experts were selected to represent different regions within North America and OECD member states leading shoreline ecosystem restoration for the purpose of climate adaptation. Nonetheless, 90% of the responses included represent North America only. Figure 1 illustrates the geographical distribution of the interviewees. The responses deemed irrelevant to the policy landscape were used to inform and guide the questions asked from experts but were not included in the analysis of this research.

Following the suggestion by Vasileiou et al. (2018) on the optimum number of expert interviewees, the goal was set to interview minimum 10 and maximum 15 experts for the purpose of this research. The results represent the responses collected from 14 interviewees formally contacted through direct email or LinkedIn; one expert was directly approached immediately after their public presentation. The interviews were conducted in person, virtually *via* Zoom, and a limited number over the phone; with follow-up questions communicated *via* email correspondence. Experiences of experts were interpreted in recognition

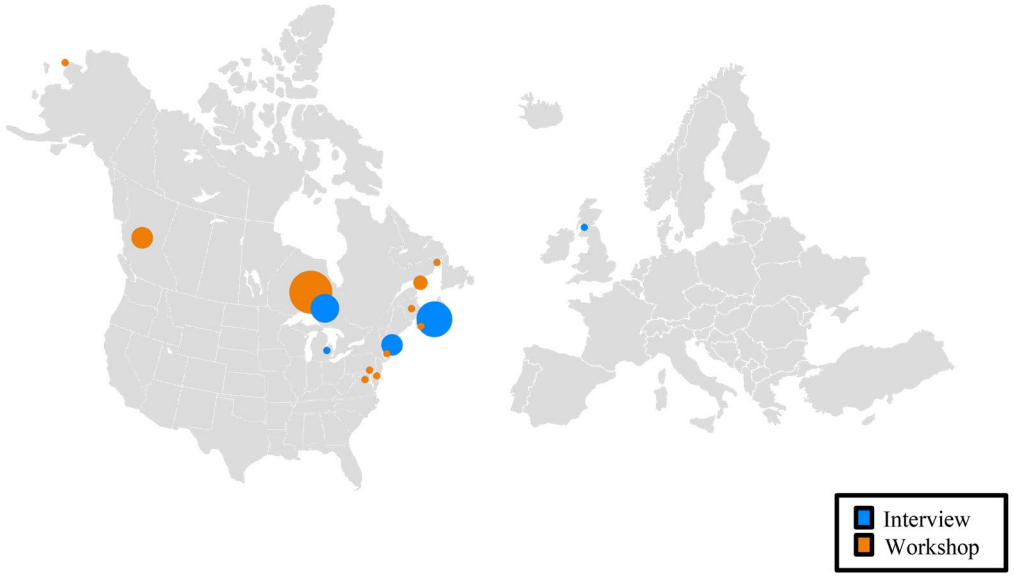

Figure 1. Geographical distribution of expert interviews and case studies.

of their diverse backgrounds and operational contexts. Interviewees were informed about the scope and subject of the project prior to the interview and received a set of questions as an interview guide in advance. The interviews were conducted semi-structured and informal, lasting for one hour on average. Interviewees were asked for consent to have the conversation recorded for the purpose of transcribing. Most interviewees agreed on the condition of anonymity and guaranteed confidentiality.

A set of workshops were attended to complement these interviews and better inform the literature search with respect to identified barriers. These workshops showcased the process and outcomes of implementing living shoreline solutions in North America. Those that had clearly stated barriers were selected to be used as evidence for expanding on challenges identified throughout the interviews. Figure 1 illustrates the geographical distribution of practitioners whose workshops were found relevant to the scope of this research.

Method of analysis

The qualitative data were collected in this research in form of notes from participatory observations and interview transcripts using Descript version 39.1.1. The thematic analysis and synthesizing of the notes and interview transcripts were performed using NVivo software version 20.6.2 on MacOS. All interviews were initially coded (indexed) using words and phrases that were (a) repeated in several places and in several interviews, (b) previously encountered in literature review, (c) resembled a concept presented in case studies collected during a workshop or conference on the topic, (d) explicitly stated as important by the interviewee, or (e) never encountered in the background research and therefore were surprising. These codes were recorded in a table and clustered into four following categories (themes) after multiple iterations that explored the connections between labels: (1) barriers in governance, (2) socio-scientific barriers, (3) technical barriers, and (4) socio-economic barriers.

Results

Opportunities

The practitioner views differ on the opportunities that can be leveraged for accelerating living shoreline adaptation. The core of the conversations taking place during the interviews conducted in this study revolved around habitat stewardship. This observation re-iterates the theory Rahman et al. articulated in a 2021 article that many practitioners and governmental authorities recognize habitat restoration policies as an opportunity that can compensate for the lack of institutional adaptation policies. In many cases, living shorelines *"are promoted for all the ecosystem service they can provide, which is important"*. Yet, in the context of adaptation, an anonymous interviewee highlighted that *"whatever the solution is, must answer the primary concern of the communities. The key message [must] be that the nature-based solution will address the primary concern, which is coastal erosion… because if it does not or if the communities do not perceive that a nature-based solution can do that, then they will probably prefer a seawall solution that they know would work. that means that, the public engagement is critical to get that message across"*.

Moreover, there are programs that are increasingly promoting green recovery and green development in terms that promote higher property valuation, higher return on investments, or opportunities for lower insurance rate or tax breaks. Examples mentioned throughout the interviews include the Living Shorelines Projects by National Oceanic and Atmospheric Administration (NOAA) in the United States providing evidence, technical support, and financial incentives to encourage installation of living shorelines for improved habitat and its ecosystem value at the land-water interface. The Coastal Barrier Resources Act (CBRA) administered by the U.S. Fish and Wildlife Service is also a notable example in this category for encouraging preserved natural landscape by decentivizing development-induced erosion. Similarly in Canada, Ontario's Conservation Land Tax Incentive Program administered by Ministry of Natural Resources and Forestry provides incentives through property tax exemption on eligible conservation lands in return for landowner agreement not to undertake activities that will have a negative impact on the natural value of those lands. While fundamentally important, the *"full cost accounting has to be incorporated"* in conversations of this sort as opposed to traditional accounting methods still used for many other green development projects (such as renewable energy solutions). This includes the downstream effects, the financial and climate cost of building and maintaining conventional solutions or quantifying the resiliency benefits which requires a different cost modeling paradigm than simply calculating a payback period (various anonymous interviewees). Depending on the kind of the payment or credit systems, some may choose to incorporate the solutions for the money rather than having an intrinsic motivation to do it, in which case *"… as soon as the money goes away, they stop doing it"* (anonymous interviewee). This ties into the generally identified *"reluctance to monitor and maintain the property if it is done with private money"* (anonymous interviewee). The sporadic maintenance and monitoring can consequently result in inefficacy of the solution for its primary function (various anonymous interviewees).

Socio-economic barriers

92% of the interviewees highlighted that socioeconomic barriers impact successful implementation of living shorelines to various degrees. However, only a small proportion of the total interview transcripts contained language emphasizing barriers in this category. This was translated to be rather an instant response which was identified to have different connotations upon further reflection on the topic by the interviewees. Issues such as fear of property investment loss or having to pay more for maintenance costs indefinitely highlighted the need for creating a culture of monitoring and maintenance, fostering local champions, uncovering shared resources and materials, sustaining long-term motivation, and ensuring multi-stakeholder engagement (Table 1).

To better understand the tendency in initial identification of cost as a barrier and due to the lack of accurate estimates about the cost amongst the interviewees, literature

Table 1. Key phrases used in thematic analysis of expert interviews.

Category	Barriers in Governance	Socio-scientific Barriers	Technical Barriers	Socio-economic Barriers
Key phrases used in indexing interview scripts	planning and management practices	false perceptions	lag time for the solutions to take effect	fear of loss or tradeoffs
	permits and regulatory procedures	communication barriers	location-specific and locally driven needs	persistence
	funding and budgetary restrictions	lack of transparency	risk of ecosystem disservices and unintended impacts	lack of culture of monitoring and maintenance
	politicized nature of the issue	lack of evidence-based science	non-native and invasive species management	need for local champions
		lack of expanded evidence	space requirements	shared mission support
		limited regional knowledge share tools and databases	scale of the projects	leveraging shared resources and materials
		limited comprehensive educational programs for property owners	weather conditions	long-term motivation
		lack of awareness among regulators	maladaptation	multi-stakeholder engagement
		limited accountability and sense of responsibility	uncertainty of the climate conditions	multi-property involvement
		low rate of public engagement during notice periods	need for recurring maintenance and intervention	trend-driven adoption
		lack of knowledge about destructive leisure activities	difficulty quantifying erosion	
		individual world view	implementation issues	
		stewardship ethics	limitations of laboratory experiments	
			need for protection of the solutions from wildlife	
% interviewees that raised at least one relevant key phrase	100	95	95	92
% relevant key phrase(s) appearing in interview scripts	36	35	17	12

was consulted. According to the USACE (United States Army Corps of Engineers) (2015), "living shorelines tend to cost less than hard shoreline infrastructure, for both installation and maintenance". According to information available from NOAA's Digital Coast platform (2015), installation fees for establishing living shorelines vary from less than $1,000 up to $5,000 per linear foot for most expensive living shoreline options while the costs reported for common structural solutions is upward of $2,000 per linear foot with lake retaining walls or seawalls nearing $10,000 per linear foot for complex projects. Maintenance fees are typically less than $100 to a maximum of $500 per linear foot annually for living shorelines while it is estimated to be over $500 per linear foot per year for traditional structures (NOAA (National Oceanic and Atmospheric Administration) 2015). Evaluations performed on Canadian West Coast properties such as the one published by Lamont et al. (2014) report consistent trends for cost-per-meter of shoreline with estimate accuracy range of ±50 per cent. The type of materials used in building living shorelines influence cost and can be limiting during implementation depending on local availability.

Much of the resistance to adopting soft engineering methods appear to be rooted in fear of investment loss for property owners and typically a general sense of unfamiliarity and lack of trust in the solutions. These issues resurfaced as many urban residents moved back to their waterfront properties upon nationally imposed lockdown measures during the global pandemic in 2021 and began to harden the shorelines as they observed erosion impacts (King 2021b). One of the most prominent driving factors for avoiding vegetated buffers or living shorelines particularly on a privately-owned property is either the cost or the time required for monitoring and maintenance. Many waterfront properties are only occupied seasonally which is a challenge for monitoring and maintenance. Even for those that are not, "*almost nobody wants to pay for monitoring*", an interviewee stated. Further, majority of grant programs are limited to installation and space creation. As such, monitoring and maintenance is often done through a community driven stewardship systems or monitoring programs spearheaded by volunteers.

Various experts also pointed out problems associated with following trends resulted from overcorrecting socio-economic issues, *"the worst thing we could do as nature-based solutions advocates is to propose nature-based solution in a place where it is simply not going to work"* an anonymous expert stated and further linked the potential catastrophic outcomes of the issue to lesser levels of community trust.

Technical barriers

Key phrases in technical barriers category constituted 17% of total indexed phrases within interview transcripts and appeared in 95% of the interviews (Table 1). These barriers represented ecological restrictions and technological limitations that can complicate living shoreline projects. Some examples of these technical challenges include the lag time for the solutions to take effect, location-specific and locally driven needs, risk of ecosystem disservices and unintended impacts, non-native and invasive species management, and space requirements. Further challenges include maladaptation, uncertainty of climate conditions, need for recurring maintenance and intervention, difficulty quantifying erosion, and the impacts of public waterfront access infrastructure (such as docks, boat ramps, etc.) on vegetated shorelines Moreover, although much of the

vegetation arrives on site semi-established, safeguarding the plantlets against natural ecosystem threats such as herbivores complicates some projects. The loss of materials used in developing living shorelines in cases where disaster occurs before full establishment of the root system poses challenges for property owners as well as contractors to invest in these solutions.

The interviews reveaved a unique challenge faced in Canada and many parts of the United States for implementing Nature-based Solutions as the cold climate and freeze/thaw conditions for the larger portion of the year. While commonly known to begin in late fall through early spring, Freeze/thaw cycle timing can vary based on the region, with northern regions extending from early fall to late spring (Su et al. 2011; Liu et al. 2013; National Weather Service 2021; US Geological Survey 2021). Studies show that in cold climates, the majority of runoff occurs during snowmelt periods, when soil is frozen and vegetation has been flattened by snow and ice, creating conditions that hinder the ability of vegetated buffers to work as designed (Kieta et al. 2018). The freeze/thaw cycles can also lead to soil structure breakdown, further reducing infiltration capacity and increasing surface runoff (Kieta et al. 2018). Phosphorus and nitrogen loads can be particularly high during snowmelt periods due to the rapid runoff over frozen soils, which do not absorb these nutrients effectively (Su et al. 2011; Liu et al. 2013; Bennett, Peterson, and Gordon 2009). This poses design challenges for the local practitioners and underscore the need for tailored approaches to account for reduced vegetation effectiveness and soil compaction and maintain some effectiveness in managing runoff and preventing erosion and nutrient loading despite harsh conditions during freeze/thaw cycles and snowmelt events.

Socio-scientific barriers

A highly agreed upon set of issues as pointed out by the interviewed experts involved the quality, distribution, and mobility of knowledge and information, titled here as "socio-scientific" issues. These include false perceptions, communication barriers, lack of transparency, lack of evidence-based science, limited regional knowledge sharing tools and databases, limited educational programs for property owners, lack of awareness among regulators resulting in permit rejections, delays in approvals, limited accountability by property owners, and a lack of knowledge about destructive leisure activities (Table 1).

Much of the socio-scientific issues identified in this analysis are rooted in behavioral, cultural, and individual beliefs varying from personal esthetic preferences by the landowners to risk perceptions and relationship with the natural environment. Many of the experts believed that the scientific community (public or private) plays an important role in eliminating prominent issues such as lack of trust or the fear of unknown. Many issues however are interlinked with lack of sufficient policy and cannot be addressed as a standalone socio-scientific issue. For instance, by NbS principles, early consultation is key for responding to local needs. An expert indicated that *"sometimes we get projects come in that have done so much work on the design, the report, but had not done the early consultation and they had to go and back and redo everything"* which interferes with scheduling and urgency from a

personal perspective of private landowners, *"as soon as they notice the erosion, they want it [to be addressed] right away. They don't want to wait six months for you to research it or get an engineer to do a survey that may take a year. They want action right away"* (anonymous interviewee). Consuistent with this claim, it is commonly observed in literature that after a large storm event, more owners tend to act quickly and default to shoreline hardening solutions that provide immediate protection (Stafford 2020).

Many experts agree that *"engagement is expensive and time consuming"* and must be incorporated as part of the initial planning, as one expert indicates "*for success with volunteers, they have to be part of the process from the very beginning. You cannot recruit them afterwards and expect them to have buy-in. If they are not part of the planning, the problem solving, the design, you have just asked too much of people to come in on the edge*".

Another risk factor that can pose as a barrier if not addressed is the impacts of recreational activities such as boat wakes and the erratic and reoccurring waves generated by small vessels on the health of living shorelines. Boat wakes are distinguished from wind-induced waves by their characteristic appearance, which consists of a group of long waves followed by high frequency, large amplitude waves (Houser, Hapke, and Hamilton 2008; Houser 2010; Houser and Hill 2011; Herbert et al. 2018). The frequent wakes with high speed can increase sediment resuspension, heightened erosion, and damage to the vegetated structure (anonymous interviewee). The resulted increased turbidity can also interfere with structured soft approaches such as oyster reefs (Meyer, Townsend, and Thayer 1997; Newell et al. 2005; Erftemeijer and Lewis 2006; Gabel et al. 2012; Herbert et al. 2018). While this is a reccurring problem observed by a few of the practitioners interviewed in this study and the property owners they work with, many experts were unaware of the impacts or did not believe this was an important consideration. A review of small vessel licensing requirements across different jurisdictions revealed a gap in specific information or recommendations pertaining to safe near-shore speed for the purpose of vegetated shoreline protection.

Barriers in governance

In categorizing the responses, those that referenced planning and management practices, permits and regulatory procedures, funding and budgetary restrictions, and concerns around the politicized nature of the issue were grouped as "barriers in governance" (Table 1). All interviewees mentioned at least two of the items referenced in this category and believed them to be of high importance.

The main complaint among experts implementing public projects using living shoreline practices is the complex, inconsistent, fragmented, and inefficient system of legislation and the regulations created under this system. Compared to many international counterparts implementing nature-based shoreline stabilizing solutions, *"there seems to be a general lack of holistic understanding of system-based approaches in Canada"*, an anonymous expert indicated and elaborated that *"by largely devoting erosion risk responsibility to municipalities, solutions are very localized as opposed to taking into larger spatial and temporal scales"* even in the case of pilot sites which reduces the ability to establish regional evidence base. Many of the expert ecologists interviewed believed

that "*a good restoration has to be [performed] at large scale and not just a little bit in someone's backyard and a little bit in another's*". That said, many of the practitioners indicated they often avoid larger scale projects or ecologically complex solutions to circumvent the burden of permitting.

Generally, the complexity of the permit process depends heavily on the location of the project, the jurisdiction involved, and the space available for restoration activity. In cases of undersized lots or in presence of an insufficient setback area, to create the slope required for implementing a soft solution by design, it is necessary to extend the intervention into the water to regrade the slope which in some jurisdictions means permits from both federal and local authorities. This demands extensive application preparation time, extended review time with no guarantee of acceptance, and substantial financial resources many clients and landowners are unwilling to invest. In Canada, the financial disparity between permits from local authority and federal-provincial authorities is in orders above $10,000, according to the private sector practitioners interviewed. Additionally, "*it is extremely difficult for somebody new coming in [to this field] to overcome the permit barrier or even have their application reviewed, if they do not have a relationship with the permit office*" an anonymous expert said and elaborated that there is currently no specific incentive program for private sector practitioners to overcome these challenges. One expert believed that the challenge could be resolved with time as it did for "*traditional companies [that] had a lot of time to work with regulators to smooth out regulations to make them more efficient. They have learned to work with them*". That said, the regulations are "*reforming slowly. We are beginning to see climate a consideration in permitting, which is a new thing. It never was before*" an anonymous interviewee indicated.

Overall, "*there should be equal consideration given to both types of proposed projects [(hard and soft engineering)] but it is often not the case at the permit office; hard engineering is pre-approved before we get there*" (anonymous interviewee). Some experts believe that often there is lobbying pressure to oppose the gain from deconstruction that prevents regulations to be equally imposed. Many believe in order to make visible progress "*we have to de-politicize nature stewardship*" (Naolo Charles, Thriving Natural Environment Workshop, ECCC, July 11, 2022). Others view planning as the root cause and believe the lack of a strategic shoreline management plan in some areas prevents "*strategic assessment of the areas we need to protect versus areas we can allow to recede*". Some experts presented examples of exceptions made that have negatively impacted the landscape and has allowed for developments in sensitive areas.

Another aspect is the challenge posed where conditions are not registered on title. In such cases where a new property owner lacks knowledge (or care) about the conditions attached to developments preceding their ownership (Upper Rideau Lake Association, Healthy Shorelines, Healthy Lakes, June 14, 2022). In many cases, "*developers divide a degrading shoreline property into smaller residents selling them to lower income young couples who do not know of the extent of the erosion and do not have the funds for implementing or maintaining the living shoreline, so they go ahead and harden it*" (anonymous interviewee).

It was unanimously agreed that it is difficult to access funding for implementing natural flood prevention solutions in many jurisdictions in Canada as they "*are not really recognized as infrastructure or assets by funding agencies*" or "*because there is*

not enough long-term and expanded experience in this part of the world", there is a hesitancy on funding. Those who were able to secure fundings indicated that funding is often specific and does not cover monitoring and evaluation. From a municipal standpoint, considerable budgetary pressures exist that results in hesitancy in utilizing soft engineering techniques in public infrastructure projects. This is further emphasized as the risk of malpractice or incorrect installation and consequently the costs of correction are still high among the local contractors who are not familiar with unconventional solutions. Being ahead of Canadian provinces in terms of the shoreline protection governance, the state of Massachusetts has mechanisms that ensures "funding comes from permit" and includes a mandatory monitoring period. Nonetheless, the monitoring is not standardized and varies with the source of funding.

While many experts found implementing public projects a good advocacy and educational tool for showcasing living shoreline projects, it is often a challenge to restrict public access to newly vegetated areas while they are in the process of establishment. Many experts have used educational signage and caution tapes in the past but have found it impossible to fully protect the area. Similarly, "*the lack of enforcement to protect the shorelines before the naturally vegetated shoreline is removed is a major barrier*" (Victor Castro, Ministry of the Environment, Conservation and Parks, Shoreline Buffer Workshop, June 14, 2022).

Limitations

Expert interviews are used to analyze the perspectives, less biased opinions, and empirical knowledge of the interviewees but are disadvantaged in obtaining complete and factual knowledge (Döringer 2020). Despite all efforts, some results may not represent all perspectives comprehensively. Additionally, due to the limited scope, this research may not represent the marginalized groups or communities most impacted by the solutions discussed.

Discussion

The literature on barriers for various the installation of nature-based solutions points out that the range of issues from those enabling destruction to those impeding restoration are rooted in legislative frameworks and complex permitting processes (O'Donnell 2017; Pace and Morgan 2017; Shumway et al. 2021; Rahman et al. 2021). Challenges are generally summarized as lack of institutional commitment, lack of broader context for shoreline management decisions, and lack of advocacy (RAE (Restore America's Estuaries) 2015). Peer-reviewed literature also indicates that progress toward application of adaptive coastal management approaches is hindered by reliance on linear models and non-flexible policy processes (Bilkovic et al. 2016). Nonetheless, there is opportunity for public perceptions to drive the necessary regulatory reform through public policies within a democratic governance system. As such, public acceptance of living shorelines as a tool for risk reduction is necessary before it can be widely adopted as an adaptation strategy (Anderson and Renaud 2021).

Within the legislative landscape, "Nature Climate Solutions" are becoming increasingly known and accepted. Nature Climate Solutions refer to a subcategory of green

infrastructure initiatives that are primarily focused on mitigation rather than adaptation (Griscom et al. 2017). This includes networks of natural and designed vegetation elements such as urban gardens, green pockets, and increased tree canopies, as well as green roofs, green walls, and rain garden technologies. Similarly, restoration efforts are primarily focused on meeting biodiversity targets and conservation objectives. While these objectives are different in principle, it is beneficial to capitalize on the net benefit outcomes by leveraging the tools available (i.e., policies and programs designed and widely accepted for restoration projects) and further nature-based solutions for adaptation purposes (Hartig and Vallentyne 1989; Shumway et al. 2021; Baker, Dupont, and Vasseur 2021).

Watersheds Canada (King 2021a) comprehensively studied the perceptions of three stakeholder groups (municipal planners, councilors, and lake and river association representatives) about the most pressing needs for Canadian freshwater shores. The study revealed a need for serious application of shoreland best-practices, increased education of all three stakeholder groups as well as the general public, and the creation of a collaborative network between the decision-makers of communities and organizations (King 2021a). In another initiative by the Commission for Environmental Cooperation (CEC), the barriers identified by Canadian, American, and Mexican experts included lack of data and authoritative design guidance, difficulty quantifying co-benefits and creating business cases, and uncertainty concerning efficacy and performance of NbS in extreme conditions, different environments, and changing climate conditions (CEC (Commission for Environmental Cooperation) 2021). Survey-based studies in various waterfront areas in the United States identified the most predictive driver for property owner's choice of shoreline protection solution was that of the neighboring property (Stafford 2020). Solutions using green infrastructure involve local social interactions across all phases of the project implementation compared to traditional hard infrastructure implementation for reducing risk which can impact the implementation timelines (Anderson and Renaud 2021). While consistent with these trends, the findings in this study suggest that the core of the problem can be viewed as a knowledge communication challenge among all actors and stakeholders. The literature shows that the presentation of scientific evidence alone can have little influence on public attitudes and behavior (Anderson and Renaud 2021). Instead, there is a need for creating a social system that incentivizes, rewards, reinforces, and integrates nature-inclusivity with the help of science and technology.

To summarize, the four clusters under which the comprehensive list of barriers in this study is structured (i.e., governance, socio-scientific, socio-economic, and technical) are greatly interlinked and include one or more aspects of the state of information amongst the stakeholders:

1. Regulators and legislative authorities seem to be generally unaware of regional efficacy of NbS, the challenges practitioners and public face with the permitting processes, and the impacts these restrictive processes have on the society at large. As such, despite the accelerating rate of climate change, limited progress has been realized.
2. There is considerable misinformation and erroneous perceptions amongst the public as well as policy makers about the state of the problem and the pathways to adopt NbS for erosion control and climate change adaptation; often resulting in avoidance of innovative solutions.

3. Shoreline protection is often deemed a matter of municipal concern for property owners and any federal intervention is often translated to unnecessary longer process times and more money. This poses a challenge for practitioners and can be due to (a) a lack of property owners' understanding of the legislative structure and (b) a lack of public exposure to the ideas involved in ecosystem-based approaches and the interconnectivity of different elements. Being transparent about the risks of implementing these solutions hastily can assist in addressing the property owners' perceived sense of urgency for immediate solutions and alleviate the pressures posed on practitioners.
4. There is still a sense of doubt among some professions such as engineers that nature-based solutions can satisfy their obligation to "hold public safety paramount". This is also evident from the lack of any language referencing EbA within advisory documentations outlining "principles of climate adaptation and mitigation for engineers" published by Engineers Canada. Ecologists, researchers, and landscaping professionals on the other hand believe there is evidence supporting the efficacy of living shorelines and are willing to incorporate in their monitoring any additional indicators requested by the engineers. There is a fundamental *"need to move away from over-engineered solutions as a guaranteed approach to safety"*. One strategy for addressing these concerns is the development of region-specific design guidelines as currently ongoing and spearheaded by the National Research Council of Canada.
5. A reason for the dispute over lack of evidence is the location-specific nature of the living shoreline solutions. Another can be that despite the term being used in the scientific and technical literature since early 2000s, "living shorelines" continue to be defined inconsistently. The term has been almost exclusively restricted to North America (Smith et al. 2020) while the practice has been widely adopted globally since 1981 termed soft engineering, nature-based solutions, or green infrastructure (Currin, Chappell, and Deaton 2009; Smith et al. 2020). This contributes to inconsistencies in communicating the science of the solution to regulators. It is therefore necessary to clarify the concept of living shorelines to acceleration adoption.
6. Once the term is uniformly defined, many existing mechanisms can be leveraged to incentivize the integration of living shorelines for privately owned lands. Some grassroot initiatives such as the Green Shores program initiated in British Columbia applies a credit system to encourage the uptake of living shoreline installation (Emmett, Blair, and Faghin 2017). Other incentive programs such as Nature Force introduce reduced costs of insurance (Massey 2022). There is, however, no consensus about the role of incentive programs in this study which suggests that responses to financial incentives are not consistent. Some believe increased education and engagement are more effective in the long term.

Concluding remarks and recommendations

Taking inspirations from the natural ecosystem and incorporating ecosystem integrity into solutions for addressing human-centric issues such as shoreline hazard mitigation has been proven highly effective over the last decades. Nonetheless, the approach is still perceived as novel and costly compared to traditional hard engineering measures, resulting

in regulatory and permitting processes to remain in favor of conventional methods. There are substantial records of lessons derived from projects implemented binationally to restore and maintain the integrity of the Great Lakes Basin Ecosystem that embody the comprehensive ecosystem approach required for a successful living shoreline implementation (Hartig et al. 1996; Hartig 2014). These lessons offer a tool and a framework for policy makers and practitioners to leverage existing mechanisms for incentivizing living shoreline as a promising solution for restoration of ecosystem services while refining the approach to address region-specific challenges. To build a long-term social and institutional commitment, there is a need for a clear and consistent communication and, more importantly, a strong engagement strategy among all stakeholders that focuses on co-creating, co-implementing, and co-monitoring the solutions. The following are five recommendations resulting from the consolidated findings in this research:

- In places where nature and natural structure are successfully incorporated, they are often the preferred solutions for climate change adaptation. As such, all orders of the government should promote soft shoreline engineering through updating the permitting processes.
- Public agencies can be role models for change; benefiting from existing public projects as demonstration sites while increasing large-scale pilot projects to positively influence public perception of natural infrastructure and attract partners, developers, and investors to leverage the social license.
- The focus should be on developing tools rather than rules, by treating the projects as means to increase interactions among individuals, government agencies, and the community of practice. This should result in risk reduction.
- Investment and financial support should include creating platforms wherein knowledge can be shared and accessed by practitioners and researchers nationally and internationally and provide the public with a database of regional solutions to build more trust among property owners.
- NGOs and independent practitioners play a fundamental role in educating public, promoting critical thinking, and addressing misperceptions in ways that are relatable and easily understandable for all, regardless of the level of scientific education; the efforts should be toward engaging multiple neighboring properties to enhance the technical and socio-economic benefits.
- An important avenue for future research involves better assessing the impacts of mainstreaming living shoreline projects on vulnerable populations. The efforts toward incorporating social license in the implementation of the latest case studies is notable yet visibly lacking early consulting and inclusion of the most vulnerable groups. An area with high impact is the educational curriculum which has already begun in many jurisdictions in Canada and can extend to include early education systemically to rehabilitate human relationship with nature.

Notes

1. from the ordinary low watermark seaward to 200 nautical miles (370.4 km).
2. navigation and shipping, small vessel, seacoast, and inland fisheries.

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Disclosure statement

The participants of this study did not give written consent for their data to be shared publicly, so due to the sensitive nature of the research supporting data is not available.

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