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PERSPECTIVE

Visualizations as a tool to increase community engagement in climate change adaptation decision-making

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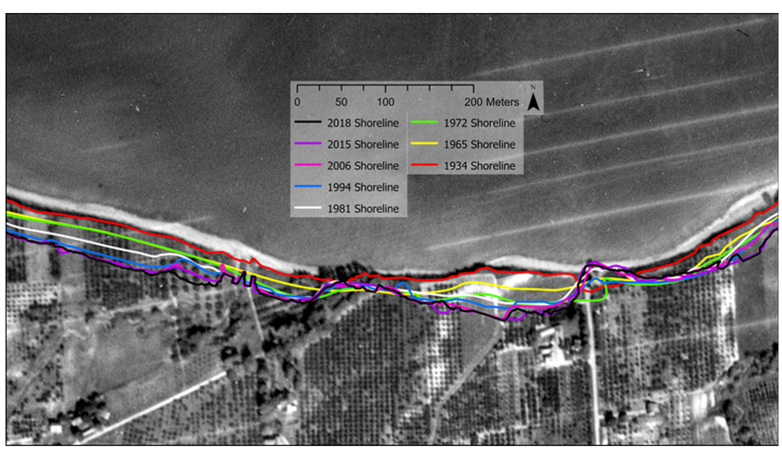
Abstract

Many barriers to behavioural change exist when it comes to climate change action. A key element to overcoming some of these barriers is effective communication of complex scientific information. The use of visualizations, such as photographs or interactive maps, can increase knowledge dissemination, helping community members understand climatic and environmental changes. These techniques have been utilized in many disciplines but have not been widely embraced by climate change scholars. This paper discusses the utility of climate change data visualization as a tool for climate change knowledge mobilization. This paper draws on the case studying drivers of coastline change of Lake Ontario in the Town of Lincoln, Ontario, Canada. Historical aerial photographs were used to measure the rate of coastline change and visualize vulnerable sections of the coast. To better visualize the changes that occurred over time from a resident viewpoint, selected land-based historical photographs were replicated by taking new photographs at the same locations. These visualization tools can be useful to support the community in developing strategies to adapt to climate change by increasing understanding of the changes and knowledge through social learning. These tools can be generalized to other case studies dealing with community engagement in coastal adaptation efforts.



(Graphical abstract image: base layer—Ontario Ministry of Natural Resources Canada, with permission.)

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Introduction

Concepts regarding climate change are difficult to communicate. One of the key challenges has been the lack of knowledge mobilization related to these concepts. This has led, in part, to individual psychosocial barriers of climate change and climate change action, such as mistrust, denial, uncertainty, and scepticism (Kollmuss and Agyeman 2002; Lorenzoni et al. 2007; Vasseur and Pickering 2015). Without increased knowledge, these barriers may be difficult to overcome. Unfortunately, scientific information is still generally out of reach for citizens due to the jargon used, often leaving the reader uninterested or disengaged (Ohio State University 2020). Gaps between adaptation research and knowledge users, including the absence of knowledge transfer and lack of participatory methods, must be addressed to face the challenges climate change present (Dhar and Khirfan 2017). Vasseur and Pickering (2015) identified an urgent need for applied research around "optimal messaging/communication strategies to fully engage Canadians in taking the necessary action to address this wicked and existential challenge" (p. 54).

Long-term planning and decision-making to adapt to climate change is a challenge. For people to change their behavioural attitudes and translate those into action, a critical understanding of what climate change is and how it will impact communities at a local level must occur (Vasseur and Pickering 2015). At the community level, climate change action is generally very limited, even though many municipalities have developed adaptation plans (Vasseur et al., unpublished data; Fraser et al. 2017). Although financial incentives, such as lower premiums on property insurance for individual adaptive efforts, have sometimes been promoted, they remain limited in their success (Seifert-Dähnn 2018). This paper proposes the use of visualizations as one effective element required to engage communities.

To further understand ways to enhance climate change adaptation uptake in communities, a multi-case study funded by Marine Environmental Observation Prediction and Response (MEOPAR) (Principal investigator (PI): Plante, co-PIs: Cloutier, Dubé, Vasseur, and Weissenberger) aims to examine how six coastal communities of Quebec and Ontario, Canada, seek to determine the elements required to effectively move from climate change inaction to action. Community participation is essential to enhance resilience and ensure that adaptation plans are effectively implemented. To increase public engagement, it is essential to first gauge their level of knowledge. Then, through education and knowledge mobilization (workshops, townhalls, newspaper articles), social learning can improve the capacity of the community members to be more engaged in the decision-making process. It is expected that with increased engagement, strategies and solutions can be coproduced within the community in a way that is more appropriate and socially accepted considering its socio-cultural context (Plante et al. 2016). This leads to greater ownership by the community of their project vision and outcomes.

In Ontario, one of the components of the project is the use of visualization tools to communicate the physical changes of the coastline of the Town of Lincoln, located on the southern shore of Lake Ontario. The visualizations will be integrated into the larger project during the latter stages of coproduction of climate change adaptation strategies. This visualization technique can also be applied in other locations globally, most likely with some modifications to reflect the local context. In this article, we want to highlight the use of accessible visualization tools for science communication that may lead to increased knowledge mobilization and community engagement, ultimately leading to climate change adaptation action.

Study site—Town of Lincoln, Ontario

The Town of Lincoln is located within the Niagara Region, bordered by Lake Ontario to the north. Lincoln was selected as one of the communities for the larger MEOPAR project. Covering 163 km^2, the land use is largely agricultural with several small urban centres. Its topography varies, with elevations ranging from 58 to 68 m above sea level (masl) close to the lake and 150 to 175 masl farther inland due to the presence of the Niagara Escarpment (Gao 2011). As a municipality along Lake Ontario, Lincoln is subject to many issues faced by coastal communities including the erosion of the coastline. Increased residential and road network development in the past decades are likely driving some of this coastline change (Jahangirzadeh et al. 2012; Vasseur et al. 2017). With a recent increased frequency in storms (including heavy rainfall in spring, summer, and fall and freezing rain in the winter) as well as stronger winds, the Town has been faced with new challenges that were not previously anticipated. In the springs of 2017 and 2019, the Lake Ontario water levels significantly increased leading to flooding and voluntary evacuations in parts of the town. Damage caused to road infrastructure has been costly for the town and its residents, increasing the urgency to develop adaptation strategies.

Using visualization tools in research

Visual research is commonly applied in certain disciplines, such as public health and psychology, as it draws on our sense of sight to interpret the world and surrounding phenomena (Pole 2004). Photographs have been integrated into many types of studies, mental health for example, to better visualize changes that are occurring and what people experience in their daily lives (Cooke et al. 2016; Phipps et al. 2017). An important aspect of knowledge mobilization in the health care literature has been to ensure the activities of coproduced knowledge are made visible (Cooke et al. 2016). Likewise, repeat photography has been used as a tool to identify and quantify changes of landscapes and ecosystems for decades (Frankl et al. 2011; Clark et al. 2016). Visualisations can take on many different forms, from photograph comparisons of how the Great Barrier Reef has changed over time (Clark et al. 2016) to the creation of actionable tools with implications for policy and practice (Cooke et al. 2016).

Spatial data are important components of many studies and it is often the visual components of a study that help with the dissemination and mobilization of research findings (Kong et al. 2014). Neset et al. (2016) report that the use of geographic visualization tools not only helps the community better understand their options for adaptive action but also opens the gate for discussion and collaboration. A study in Scotland has found that community engagement is enhanced with the use of quantitative scenarios in combination with an interactive visualization tool (Wang et al. 2016). Visualizations can be an effective method of science communication to help communities better understand local impacts of climate change (Shaw et al. 2009; Neset et al. 2016). Therefore, using a combination of visualization tools to engage community members and aid in the communication of complex concepts could lead to more participation in the decision-making or adaptation processes (Cooke et al. 2016; Kropáček 2019).

Visualizations have started bridging the gap between adaptation research and citizen engagement processes across Canada. A study conducted on the west coast of Canada illustrates how visualizations can be used to help in the decision-making process of adaptation planning for sea-level rise by building awareness and capacity during community engagement steps (Barron et al. 2012). On the east coast of Canada, a risk assessment identified over 1,000 pieces of coastal infrastructure vulnerable to erosion on Prince Edward Island (Fenech et al. 2017). To ensure these important findings were shared widely, a visualization tool was developed to create space for citizen engagement and consultation. A Great Lakes study revealed that using a mix of visualization techniques in public engagement processes creates a deeper understanding of climate variability and the trade-offs involved in community-based resilience planning (Buckman et al. 2019).

Spatial data are an important component in many studies as they provide researchers easily accessible information (Li et al. 2018). Coastline change empirical studies are commonly conducted within coastal hazard and management scholarship (Gopalakrishnan et al. 2016; Grilli et al. 2017; Bevacqua et al. 2018). These geographic information systems (GIS) maps may have limitations when presented to the public. Researchers are increasingly integrating historical aerial photographs in GIS as a standard tool for data processing and analysis of coastal change (O'Brien et al. 2004; Bevacqua et al. 2018). Including these visualizations, which are mostly published in journals, into the decision-making process and therefore becoming more accessible to the general public, can increase knowledge within the target community. This may improve community engagement in the climate change adaptation discussion and decision-making process.

Methodological approach to visualize coastal changes

This project analyzed and visualized the physical changes of the Lincoln coastline over an 84-year period to ultimately produce an accessible science communication tool to share the results with decision-makers and residents of Lincoln. Using historical aerial photographs of the Niagara Region, acquired from the Maps, Data, and GIS Brock University Library, the erosion (loss of coastline) and accretion (addition of land) rates of the Lincoln coastline were calculated as rate of change statistics in a GIS. The coastlines from nine aerial photographs between 1934 and 2018 were drawn (vectorized) to visualize how different sections of the coastline have changed over the 84-year period (**Fig. 1**). The sections of the coastline have been previously split into reaches in a Lake Ontario Shoreline Management Plan Update, based on a series of factors including shoreline stratigraphy,

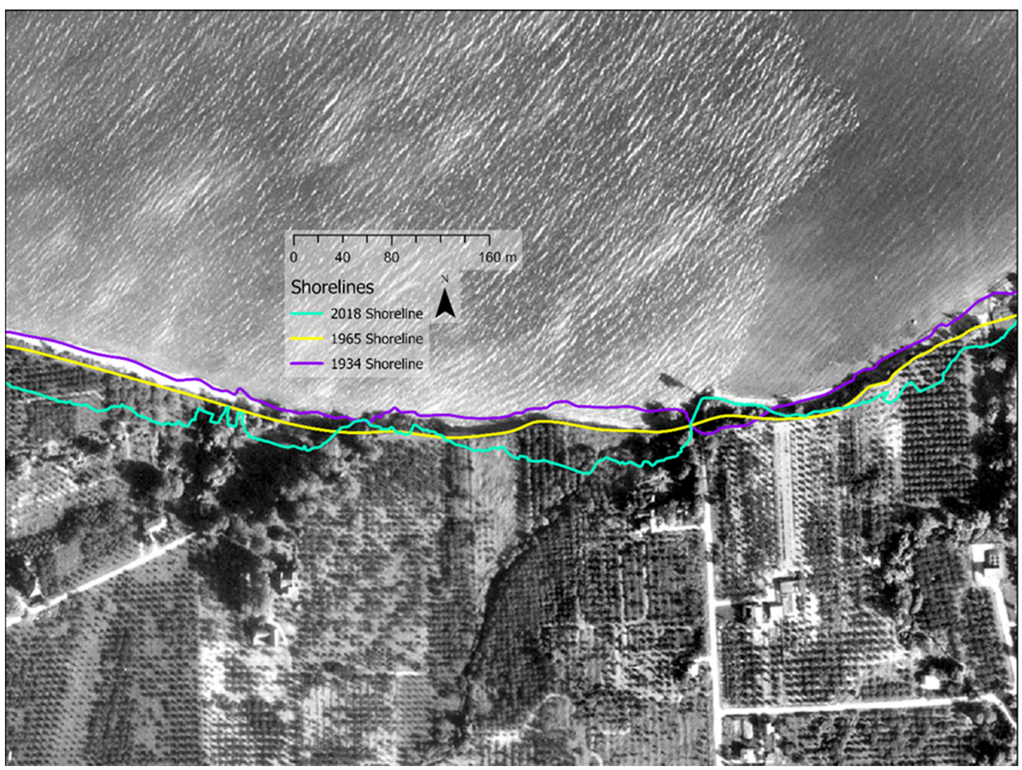

Fig. 1. Digitizing the Lincoln coastlines in a geographic information system. Aerial photograph base from 1965 with coastlines drawn for 1934 (purple), 1965 (yellow), and 2018 (green). Aerial photograph source: Map, Data & GIS Brock University Library. Produced by the authors under Licence with the Ontario Ministry of Natural Resources and Forestry © Queen's Printer for Ontario, 2020.

orientation, wave exposure, and bluff height (Baird and Associates Coastal Engineers Ltd. 2009). For this study, the coastline was defined as the geomorphic influence of the water body, using a combination of vegetation line and top of bank shoreline proxies, depending on the section of shoreline being examined (Alves 2007; Zarillo et al. 2008; Webster 2012). Once each image was vectorized, the rate of erosion or accretion of the coastline was calculated (**Fig. 2**), following the method outlined by the United States Geological Survey Digital Shoreline Analysis System user guide (Thieler et al. 2017). This GIS analysis has been used in recent studies (Thieler et al. 2017; Thinh and Hens 2017; De Serio et al. 2018) and the results can be used to highlight areas of the coastline that are more vulnerable to change.

The next phase of the methodological approach was an evaluation of select climatic and nonclimatic drivers of change in the form of a descriptive narrative. Focussing only on climatic drivers can mislead planners and developers. It is imperative to acknowledge that multiple, interacting drivers of vulnerability exist (Bennett et al. 2016). The drivers investigated for the Town of Lincoln are summarized in **Table 1**. The most vulnerable reaches identified in the coastline change analysis were examined for all drivers listed in **Table 1**. An aerial photograph review was conducted to identify observable changes over the years. These observations contributed to the narrative on how these parameters may have driven coastline change.

To supplement the coastline change analysis, a land-based photograph comparison of the Lincoln coastline was also conducted. First, a call for photographs was sent to the citizens of the town to acquire

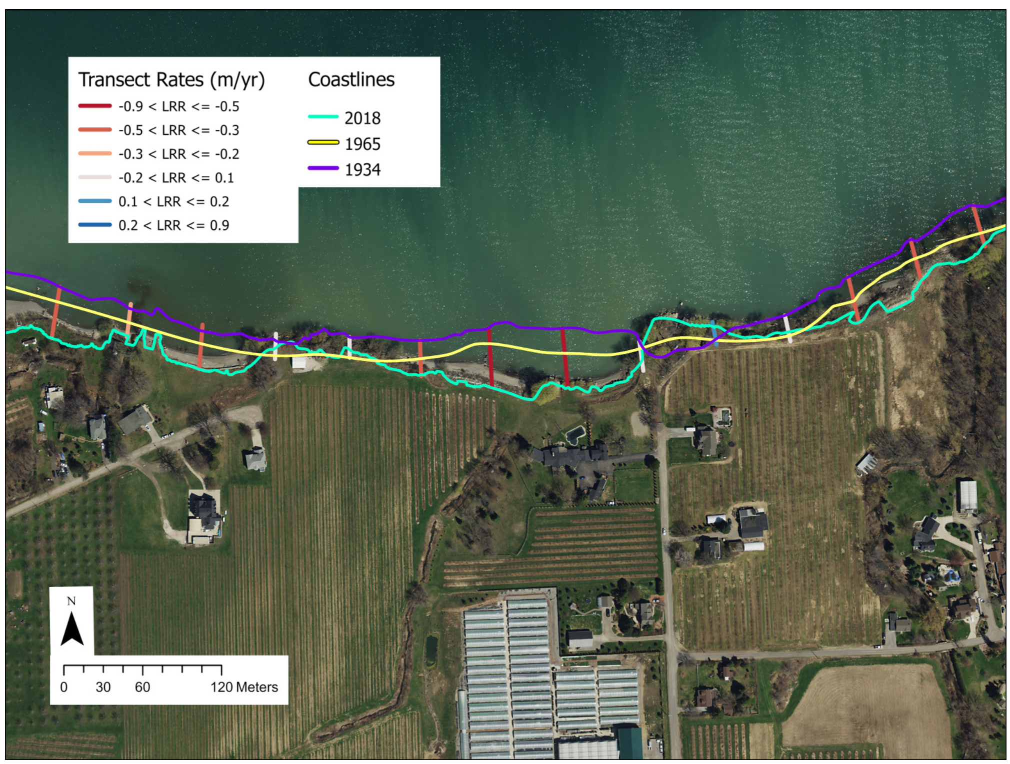

Fig. 2. Visualization of the change rates across a section of the Lincoln coastline. Aerial photograph base from 2015 with coastlines drawn for 1934 (purple), 1965 (yellow), and 2018 (green), and Digital Shoreline Analysis System analysis transect rates (transects set at 50 m intervals, erosion or accretion rates are in m/year). Aerial photograph source: Map, Data & GIS Brock University Library. Produced by the authors under Licence with the Ontario Ministry of Natural Resources and Forestry © Queen's Printer for Ontario, 2020.

Table 1. The climatic or physical and the nonclimatic or human-induced drivers selected to be most reflective of the changes of the Lincoln coastline and the rationale for their selection.

Driver	Rationale
Climatic or physical	
Heavy rainfall events	The Niagara Region has had numerous severe storm events in recent years which caused significant flooding and erosion to the coastline. Significant events were identified and used as examples of how heavy rainfall might have contributed to the erosion of the coastline.
Wind speed and direction	Observing the wind speed and direction during identified storm events might lead to insightful patterns in the area, as windstorms have been increasingly causing damage in the Niagara Region over the recent past.
Ice cover	Ice cover was selected as ice can lead to ice jam erosion or ice-jam-related flooding, leading to erosion.
Water levels	Elevated water levels may enhance wave attack and lead to increased coastal erosion and flooding. Investigating the historical water levels of Lake Ontario could correspond with or reveal patterns that coincide with the other parameters.
Nonclimatic or human-induced	
Land-use change	Land-use change from natural to agricultural, residential, or industrial can increase the amounts of impervious surfaces, increasing the likelihood of flooding and overall vulnerability. Investigating land-use changes may reveal time frames of significant change as different land uses can indicate relative differences in vulnerability.
Road network development	Road networks have been used to evaluate coastal vulnerability and risk, or local accessibility, defined as the presence of roads in terms of distance from the shore. Exploring how the road network has changed may help understand their contributions to erosion in specific areas.
Coastline protection action	Protection measures are commonly used along coastlines to protect against wave action, wind and storm surges. Differences in coastal change rates from one timeframe to another may be a result of coastline protection features, as they have been found to exacerbate erosion in some cases and create uneven retreat in others on the property or the vicinity.
Vegetation along banks	Vegetation, such as shrubs and trees with stronger and deeper root systems, are known to help stabilize the banks. Absence of such vegetation along the banks or shore may indicate increased vulnerability to erosion.

a collection of historical photographs of the coastline. Then for the selected historical photographs, the author (MDC) took photographs of the current conditions at the same locations to be able to compare the changes over time. The photographs can be used during focus group discussions to better understand how people experience these changes, as dialogue is an important part of social learning and a step toward defining avenues of solutions (Vasseur et al. 2018). Visuals are often effective in communicating complex data into simplified and digestible pieces. For example, a figure showing large sections of land loss can be more powerful than reporting a change rate value on its own.

Select photograph comparisons and the aerial photograph GIS analysis maps were integrated (Fig. 3) into an online interactive map shared with the community. The ESRI StoryMap was created to reveal how the coastline has changed using maps, time lapses, and photographs. It is important that online web application or interactive maps present the data in such a way that is clear and engaging, without compromising scientific defensibility (Wang et al. 2016; Herring et al. 2017). By clicking on the interactive map and embedded photographs, people can visualize how the coast has evolved over time and increase social learning. This can be beneficial during the next stages of the project, when the

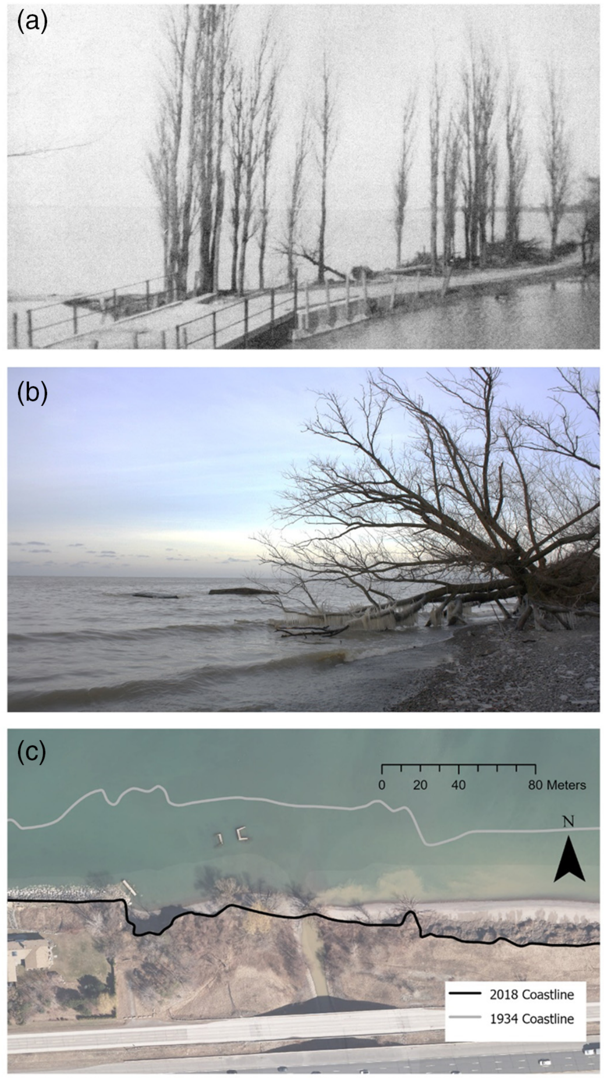

Fig. 3. Remnants of the Lakeshore Road bridge at 18-Mile Creek. (a) Historical photograph showing the bridge passing over 18-Mile Creek outlet, circa 1930; photo source: Friends of Lincoln Archives, with permission. (b) Remnants of the Lakeshore Road bridge over 18-Mile Creek outlet, 2019; photo source: DeCock-Caspell, 2019, with permission. (c) Aerial photograph from 2018 showing the remnants of the old bridge in relation to the 18-Mile Creek outlet; photo source: Map, Data & GIS Brock University Library.

community would co-produce possible climate change adaptation strategies to increase coastal resilience. The StoryMap can also be useful for the Town, which has started a process of climate change adaptation planning for a proposed residential development project along the shore.

Connecting people to their environment

The visualization tools used in our research can provide the community with visual access into the physical history of the coastline. It can help them connect with their environment and understand how their coastline has already been affected (Barron et al. 2012; Fenech et al. 2017; Buckman et al. 2019). This tool also allows them to imagine how the coastline may continue to change in the face of changing climate and environment and why these changes may have occurred. The coastal region of Niagara is predicted to be exposed to increased annual precipitation and frequencies of heavy rainfall and high wind events (Penney 2012). These predictions are known to impact coastal areas and increase erosion (Chang et al. 2018). Visualization techniques can increase knowledge mobilization to the target community seeking to combat these predicted challenges.

Visualizations can help create space for social learning through enhanced and meaningful public engagement (Wittmayer and Schäpke 2014). Such tools have been used in the past, such as in the context of demonstrating the role of phosphorus in the eutrophication of the Experimental Lakes Area (Schindler 1974; Schindler et al. 2008) and have led to actions and changes in policies. Communication, awareness improvement, and social learning can be enhanced by sharing local knowledge among community members and researchers during discussion groups with citizens and the interaction with visualization tools (Neset et al. 2016). This may lead to increased social learning and willingness for public engagement to develop adaptive solutions. With an increased awareness of how the coastal zone has evolved over time and a better understanding of some of the drivers of these changes, communities may have more capacity to discuss possible adaptation strategies to climatic and environmental changes. This could alleviate some of the pressure on policy makers with greater collective buy-in from the community (Vink et al. 2013).

As members of the community interact and share the knowledge gained through a visualization tool, they may feel empowered in the climate change adaptation conversation (Vink et al. 2013). If coastline change can be communicated and visualized in a way that shows it is not a result of a natural processes alone, but also a social process in which human activity plays a part, a more sustainable lens can be used to develop long-term adaptation strategies (Loring 2020). This type of research may help overcome some of the barriers of adapting to climate change by reducing issues such as denial, thus leading to action. This is a critical step for the engagement required to build adaptive capacity and resilience in the Town of Lincoln and many other coastal communities.

Despite the potential of using visualization techniques for increasing engagement in the decision-making process, the methodological approach outlined in this article has its limitations. The utilization of publicly available data is one of the advantages of this methodology, making it replicable in many coastal regions. Areas where publicly available data are not as accessible may be limited in their ability to replicate some of these visualization techniques. Finding historical land-based photographs was a challenge, for example landowners may have only purchased the land within the last several years. However, there are other sources such as archival collections such as a museum or local library. Additional visualization techniques (such as future scenarios or transect drawings) could add more depth to the understanding of the complexity of resilience planning in a coastal community (Buckman et al. 2019). Although there is an increasing amount of studies that are using visualization techniques for knowledge mobilization, there has not yet been a substantial amount of research to quantify the success visualizations have compared with text communication alone (Hoeppe 2015) or whether the visualizations are suitable (Savelli and Joslyn 2013).

Initial responses from town staff suggest that the StoryMap is useful and worth sharing more widely with the community. The StoryMap was released to the public in October 2020 through our research webpage and town media outlets to give residents the opportunity to share their reactions to the research results via email or virtual meetings. The StoryMap can also track how many users have interacted with the webpage. Sharing this visualization tool will play a key role in social learning and may lead to increased public engagement in the next steps of the project when a focus group is formed to co-produce adaptation strategies along the shore. The initial discussion with the town staff showed that the visualization tool is needed for a more collaborative effort with the community to develop a coastline management framework to guide future development of the shore. As the Town of Lincoln is just one municipality along Lake Ontario, the success of such a framework may lead to the adoption of similar ones across the lake, which may lead to an overall larger-scale management plan of Lake Ontario and beyond.

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Author contributions

MD-C and LV conceived and designed the study. MD-C performed the experiments/collected the data. MD-C and LV analyzed and interpreted the data. LV contributed resources. MD-C and LV drafted or revised the manuscript.

Competing interests

The authors have declared that no competing interests exist.

Data availability statement

All relevant data are within the paper.

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