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Using an inverted funnel analogy to develop a theory of change supporting resilient ecosystem-based adaptation in the Great Lakes Basin: a case study of Lincoln, Ontario, Canada

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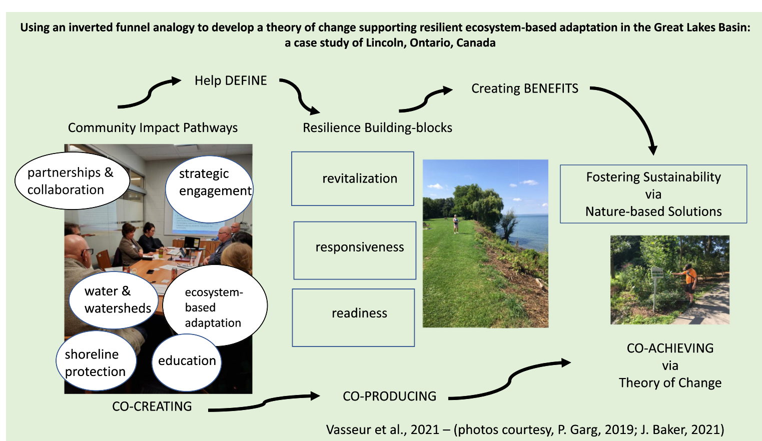
Abstract

Communities in coastal areas of Canada, including the Great Lakes, face a number of challenges, including increased water level variability and extreme weather events, causing flooding and localized erosion. To effectively respond to these coastal risks requires structured, deliberative approaches with the aim of fostering resilience and contributing to sustainability. A collaborative engagement process was used to explore community challenges. This included a project launch, key informant interviews, meetings, focus groups (agriculture, tourism, youth), and on-line methods (shoreline residents). Participatory social network analysis and theory of change were used for overall sense-making. As a result, community members identified six impact pathways moving forward with climate action: partnerships and collaboration; strategic engagement; water and watersheds; ecosystem-based adaptation; shoreline protection; and education. These themes are consistent with current theory on sustainability and theory of change development.



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Introduction

Riverine and coastal communities along the St Lawrence River and the Great Lakes have been exposed to frequent flooding and erosion over the centuries (Bartolai et al. 2015; Hudon1997; Maghrebi et al. 2015). This region represents at the same time an important economic and socio-cultural system where large populations are located along its coast (Bartolai et al. 2015; Carter and Steinschneider 2018; Gronewold et al. 2013; Maghrebi et al. 2015). Future climate scenarios project important changes including increased variability on lake water levels, increased frequency of extreme weather events, and gradual disappearance of ice in most of the St Lawrence and Great Lakes Basin, which may amplify a number of hydrometeorological hazards (WMO 2015; Bartolai et al. 2015).

Over the past years, water levels in the Great Lakes Basin have been setting historical high records across the Basin (GLAM 2018). These record levels have led to the exposure of coastal communities to increased flooding and erosion. For example, in Lake Ontario, the springs of 2017 and 2019 had significant shoreline flooding events (EC/NOAA 2020). With increased variability in water level, partly due to climate change, coastal habitat can be lost due to erosion (Theuerkauf and Braun 2021). New hydrometeorological conditions and flow regimes require longer term planning approaches. As a result, agencies, such as the International Joint Commission, have recognized the need to develop performance indicators and geographical coping zones for assessing this risk, which includes consideration of socio-economic impacts (GLAM 2018).

These changes have brought considerable environmental, physical, social, and psychological challenges for coastal municipalities and their residents. These challenges differ geographically. Several communities are exposed to risks due to coastal development where land degradation may lead to further damage and gradual displacement of the population and therefore loss of both municipal revenue and natural capital (Angel and Kunkel 2010). Other communities may face pressures from the demands of different economic sectors such as agriculture, tourism, and urban development, leading to increased risk, especially during extreme weather events (EPA 2019; Bush et al. 2014). While large cities have populations with a relatively wide range of ages (although still older than in the 1960's), rural and remote smaller communities within the Great Lakes Basin, such as the Niagara Region, are composed of an aging population (Méthot et al. 2015; Niagara Region 2022a, 2022b).

In the Niagara Region, climate change impacts are consistent with national projections (Bush and Lemmen 2019). They include an increase in annual average temperature, days with temperatures over 30 °C, heat waves of three or more consecutive days, length of the growing season, with May and September significantly warmer, average number of frost-free days with 10 more per year compared to 1970, rainfall with less snow in winter, and frequency of heavy rain events, especially in spring (Penney 2012; Gronewold and Rood 2019). These broader impacts are particularly relevant for the Region's public and private infrastructure, health care, as well as sectors such as agriculture, tourism, and other businesses. For instance, in the agricultural sector, vineyard production, especially for the signature icewine, may be impacted by reduced revenues (Garg 2020; Hewer and Gough 2020).

Some communities and conservation authorities have become early adopters in moving forward with climate action to address these hydrometeorological challenges (Henstra and Thistlethwaite 2017), with varying degrees of success (Feltmate and Moudrak 2021). For example, in identifying vulnerable coastal areas for priority management action, hazard zones for erosion have been identified for protection activities along the Lake Huron shoreline (MVCA 2020). The International Joint Commission has developed Coastal Performance Indicators to fulfill a similar protection and monitoring function (GLAM 2018). The Great Lakes and St. Lawrence Cities Initiative has established an Advisory Council on Coastal Resilience to develop a series of recommendations on how to adapt to climate change (files.constantcontact.com/267a5a2d401/8c56291a-c088-49b8-9718-7f315f8c3ebd.pdf). Along coastlines, it is common to see residents on the front line as their private property becomes impacted (FOCA 2016). However, the property ownership question is much more complex, with other competing interests such as private, public, agricultural, business, and land developers. Solutions are often developed without consultation with adjacent landowners or regulators under the belief that shoreline ownership is an individual's prerogative. Changing levels of risk in these overlapping coping zones have created a palpable conflict in values between private property ownership, increasingly faced with difficult adaptation and hazard mitigation choices, and more concerted public responses, such as open space parks planning.

The research described in this paper forms part of a larger study on how Great Lakes and St. Lawrence Basin coastal communities are responding to the challenges posed by climate change and whether they incorporate and then implement, or not, adaptation strategies as part of their plan. This article summarizes the results of a case study involving one Lake Ontario community, the Town of Lincoln. The project is based on two main concepts: community resilience and ecosystem-based adaptation to climate change. Ecosystem-based adaptation is often considered a Nature-based Solution (NbS) as it is based on the ecosystem approach of the Convention on Biological Diversity and uses in large part the natural environment as part of the strategy to reduce impacts of climate change (CBD 2019; IUCN 2020; Vasseur 2021). NbS can go further in enhancing resilience and consider any actions that address challenges that societies are facing by protecting, sustainably managing, and restoring natural or modified ecosystems (Cohen-Shacham et al. 2019; IUCN 2020). In the case of ecosystem-based adaptation, coastal solutions include soft or green infrastructure such as enhancement of vegetation diversity along a shoreline, planting windbreaks, placing sediment in the nearshore (beach nourishment), or managed realignment but sometimes with grey infrastructure if required. In agriculture, it may include adding natural windbreaks or hedgerows or cover crops. NbS are potential ways for many communities to ensure sustainability of some of their economic activities such as agriculture and tourism (Monahan et al. 2020; Ilieva and Amend 2019). Nature's contribution to adaptation has become a focus in the social-ecological transformation literature (Colloff et al. 2019).

Concurrent with ecosystem-based adaptation, resilience-based approaches have become popular since the late 2000s (Flood and Schechtman 2014). Resilience is a widely discussed term, with multiple definitions depending on the discipline, including engineering, ecological, social, community, psychological, and social-ecological resilience (see the following literature reviews: Bahadur et al. 2010; Reid and Botterill 2013; Brown et al. 2021; Walker 2020). Reid and Botterill (2013) warn that careful thought is needed on how resilience is used in policy debates, providing several examples in Australia of how policy and plans would change based on the use of different definitions of resilience. Gunderson (2010) and Aldrich (2012) have highlighted the relevance of considering ecological and human communities as part of resilience research in the face of natural disasters. How best to create useful metrics for resilience has been an ongoing debate in the scientific and policy literature.

Recent attempts at measuring resilience describe a desirable end state for individuals, organizations, and communities (Summers et al. 2018). For instance, in a post-disaster context, personal and familial socio-psychological well being, organizational and institutional and infrastructural restoration, economic and commercial resumption of services and productivity, and operational regularity of public safety and government are all important (Aldrich 2012). In this sense, measuring resilience along these dimensions before disaster occurs may be key. Along these lines, Berkes and Ross (2013) call for an integrated approach in considering overall social resilience. For example, community infrastructure can be assessed and managed via explicit asset-based community development. Also, knowledge, skills, and learning can be enhanced through explicit acknowledgement of the cross-cutting nature of climate adaptation and resilience planning. In summary, determining community resilience can be informed by measuring specific practices across three overall dimensions: readiness (*for action*), responsiveness (*to events and circumstances*), and revitalization (*transformation of structures and processes*), while at the same time considering the influence of social cohesion (Rodin 2014). To do so, a community-based adaptation approach is based on the participation of people in the community to design strategies that contribute to managing risk, community development, as well as other climate change adaptation actions. It is important to note that ecosystem-based adaptation can effectively be combined with community-based adaptation as some of their premises such as community participation and engagement are common to both (Vasseur 2021).

Further, co-creation of usable knowledge between researchers and community members – an actor-centred approach – is an important step for overcoming barriers to climate action, and especially adaptation (Cohen et al. 2006; Moser and Ekstrom 2010; Eisenack et al. 2014, Plante et al. 2016, Vasseur et al. 2018; Vasseur 2021). One particular starting point in crafting effective knowledge co-creation opportunities is by examining the role social capital and social networks play in supporting effective environmental governance (Cohen et al. 2012). These networks, which include actor/organization ties, can be identified and mapped via participatory processes. From there, a relevant theory of change can be developed which incorporates perspectives on hazards, risk management, community resilience, and nature's contribution to adaptation. In this paper, the distinction is made between the terms co-production (how knowledge is produced) and co-construction (how solutions are crafted).

Theory of change, at its most basic, is a structured model of how planned interventions are meant to work (Mayne 2015). It is used in planning and evaluation studies (Lam 2020), and more recently in sustainability science (Oberlack et al. 2019) to map project resources and activities to specific outputs and ultimate overall benefits. A theory of change approach is useful in understanding how a community transitions from adaptation and resilience planning to specific activities, concrete actions, and measurable changes in building adaptive capacity and resilience. This study used a variety of lenses to make sense of local challenges in the Town of Lincoln case study. These lenses include assessing community assets, community resilience, social capital, co-creating knowledge with actors, and developing a practice-relevant theory of change.

In this paper, one of the key research questions was related to how communities move from climate change and resilience planning to concrete climate action while exploring understanding of nature's contribution to adaptation (Colloff et al. 2019). We wanted to contribute an understanding to the question of how climate change adaptation and resilience planning is contextualized, structured, mapped, and then implemented to enable sustained and lasting change within affected communities.

Methodology

Study area

With a population of 23 787, the Town of Lincoln (hereafter, the Town or Lincoln) (**Fig. 1**) is situated on the western end of Lake Ontario. Lincoln is one of 12 municipalities forming the Niagara Region (Niagara Region 2022a, 2022b). It has a relatively diverse economy, currently focusing on the following sectors: agriculture, food and beverage, tourism, and manufacturing. In terms of natural capital, the Town is part of the Ontario Greenbelt with its 7 469 ha of natural and agricultural area, and the Niagara Escarpment along its southern border (4 402 ha). The Town also includes approximately 20 km of Lake Ontario shoreline. This coastline is comprised of agricultural, business, private residence, and municipal park land uses. Over the past several years, particularly in 2017 and 2019, the Town has had to respond to coastal and inland flooding as a result of a combination of spring

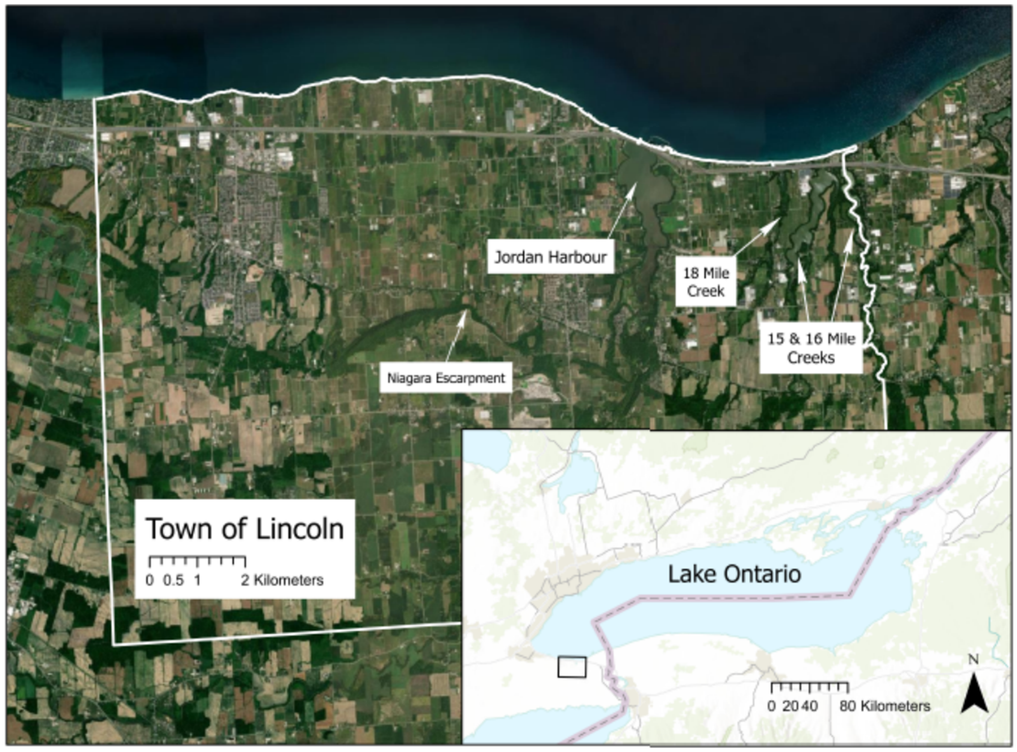

Fig. 1. Location of Study Area. Source: Esri Canada, For topographic Web Map, URL arcgis.com/home/item.html?id=98652eb8458a464fa95feb9bd812b29a, projection would be WGS 1984 Web Mercator, and Earthstar Geographics, Esri, for World Imagery Web Map, URL services.arcgisonline.com/ArcGIS/rest/services/World_Imagery/MapServer, projection WGS 1984 Web Mercator.

meteorological conditions and comparatively high Lake water levels. Damage in the spring of 2017 was estimated at $613,000. More recently, damage from 2019 flooding was estimated to be $1.1 million (Town of Lincoln 2019, personal communication). These estimates do not include damage from reduced agricultural production.

Methodological approach

Our research took a mixed-methods approach where researchers, local authorities and managers, and residents of the Town became engaged via various activities. To do so, we first obtained the research ethics approval for interviews and focus groups in November 2018. The research process consisted of an initial public project launch, development of a community profile, key informant interviews, and targeted focus groups. As part of the research design and over the course of the study, researchers developed a stakeholder database of 73 individuals. An additional 16 key organizations were identified.

In the project launch phase in late 2018, community members were invited to participate in a brainstorming exercise focused on what they saw as the vision for the process, what they would like to learn, and how success should be measured. Concurrently, a standardized community resilience profile was developed to assess overall community resilience. This was completed to gain a full appreciation of the municipality's resources and capabilities, as well as facilitate cross-case study comparison.

We then organized initial semi-structured interviews targeting representatives from local, regional, provincial and federal governments, conservation authorities, citizens, and non-government organizations to better understand (*i*) their current understanding of climate change impacts in Lincoln and Niagara Region, (*ii*) their perception of actions by various governments, (*iii*) their personal dealing with climate change impacts, if any, and (*iv*) who they felt were important to be involved in climate adaptation for the Town of Lincoln. This series of semi-structured interviews served as the baseline to gradually support the development of the social network. Nineteen (19) key informant interviews were held to explore the same questions as the project launch around the concepts of visioning, learning, and success. These interviews were supplemented by reviewing publicly available documents and other material, in addition to a total of nine information-gathering meetings and attendance at two councillor-led Ward meetings.

To increase public involvement and awareness of the project, the project team provided an on-line presence through the UNESCO Chair web site at Brock University to share information on relevant topics that were identified as part of the ongoing research (brocku.ca/unesco-chair/marine-environmental-observation-prediction-and-response-network-meopar-project/). To ensure greater transparency and overcome issues related to lack of understanding of scientific jargon and technical terms generally used in climate action, a series of regular blogs were posted on the website as well as published by all local newspapers (brocku.ca/unesco-chair/category/meopar-lincoln/). Regular meetings with the municipality and the municipal council helped maintain communication and information between partners for greater coordination.

Following the interviews, five specific focus groups for the Town were identified and one or two meetings were completed before restrictions were introduced due to the COVID-19 pandemic: agriculture (two meetings), tourism (one meeting), and youth (18–30 years old) (one meeting). The shoreline residents focus group was identified and two virtual (due to pandemic restrictions) focus group meetings were organized after the publication of a StoryMap (brocku.ca/unesco-chair/lincoln-story-map/). This visualization tool came from the analysis of the evolution of the coastline in Lincoln from 1934 to 2018 using aerial photos to engage the community in dialogue (De Cock-Caspell and Vasseur 2021; Caspell and Vasseur 2021). To supplement information to the agricultural and tourism focus groups, two analytical reviews were completed to define potential adaptation strategies for both sectors (Garg 2020 for agriculture; Gauthier et al. 2021, for shorebird/shoreline tourism). In the case of the business focus group, a combination of operational demands, community recommendations and pandemic-related restrictions did not allow for a business focus group component. At the end of the project, an on-line survey was conducted to solicit stakeholder opinions on the effectiveness in moving from resilience planning to concrete action.

Sense-making techniques

Integral to the methodological approach were tools which could assist in making sense of the richness of the data collected through progressive contextualization (Vayda 1983). Specifically, to effectively engage in the co-production of knowledge and ultimately, facilitate the co-construction of solutions, these tools were used to assist in assessing overall community resilience. Two specific sense-making techniques were selected to analyze and synthesize data: participatory social network analysis and theory of change development. Participatory social network analysis documented the relationship of various community actors and agencies. Theory of change development created a roadmap for integrating knowledge into specific solutions and adaptation actions, not only for municipalities and government agencies, but also civil society, private landowners, and other community members.

Participatory social network analysis

Although social network analysis (SNA) has roots in sociology, it has been used in many other disciplines such as physics, psychology, public health, and management (Wasserman and Galaskiewicz 1994; Liebowitz 2007; Borgatti et al. 2009). SNA is used to describe relationships or ties between people (Kadushin 2012). Recently, there has been an increased interest in using social network analysis to explore and investigate environmental governance. For example, Bodin and Crona (2009) examine how networks influence key social processes in natural resource governance. The use of social network analysis in environmental research and for governance purposes is increasing (see for example Cohen et al. 2012). It is especially useful when examining ways to engage society in climate adaptation and improve community resilience (Rodin 2014). Social network analysis was chosen for this project to uncover the actors involved in governance and better understand relationships within the community network.

Specific aspects of social capital identified by Lin et al. (2017) are social network density, bridges, weak ties, and structural holes. A computer program, Gephi (gephi.org/), was used to document and visualize the case study social network by using data collected via the above-noted engagement processes. It was used in an iterative way to build upon knowledge acquisition as the project unfolded. By understanding factors that affect the relationships, in either a positive or negative way, we could better understand the barriers for implementation, and these could be integrated into the theory of change, the approach that we used to analyze the process for moving from awareness to action.

Theory of change

Oberlack et al. (2019) argue that theories of change are useful for sustainability science in understanding how change happens. Creating a clear mapping of a desired end state or long-term outcome, from its antecedent attributes i.e., activities, outputs, and immediate and intermediate outcomes can build scaffolding for understanding the change process, through creation of impact or change pathways (Mayne 2015; Lam 2020). Benefits are the "*measurable improvement resulting from an outcome perceived as an advantage by one or more stakeholders … which contribute towards one or more organizational objective(s)*" (UKTSO 2011: 283). Theories of change are used extensively both in the international community and the Canadian regulatory environment to monitor program change and inform overall program success (e.g., Brooks et al. 2011; EC 2010; ECCC 2017). For instance, one of these theory of change exercises was used to guide the development of a logic model, whose overall long-term strategic outcomes were: "*Reduced vulnerability of individuals, communities, regions and economic sectors to the impacts of climate change and increased capacity of individuals, communities and economic sectors to adapt to climate change*" (ECCC 2017, 43). Such integrated overall long term strategic outcomes highlight the need for navigation of adaptive challenges that are at concurrently difficult, complicated, and complex (Bourgon 2011; Bourgon 2017).

Results

A community profile was developed (brocku.ca/unesco-chair/resources/). It was useful for the Town staff and research team in that it created a comprehensive social-ecological summary that highlighted the diverse natural capital within the community, as well as detailed current social capital and economic diversity of the Town and its broader place within the Niagara Region and Great Lakes Basin. Briefly, the profile highlighted a rich natural environment, which includes the Niagara Escarpment, provincially designated Green Belt, additional provincial parks, and conservation areas. The population of Lincoln is steadily increasing, influenced by its proximity to Hamilton and Toronto. As the Town remains a rural setting, it aims to become a Centre of Excellence for Agriculture. The unemployment rate (prior to the pandemic) was lower than the provincial average and household income slightly higher than the provincial average. The Town has developed several strategies regarding housing and tourism, among others.

Lincoln is aware of some of the major hazards that can increase its vulnerability, such as snowstorms, hailstorms, droughts, and flooding. The population at risk is located mainly along the Lake Ontario shoreline and the various creeks that flow from the Niagara Escarpment toward the Lake and well as transportation due to its location both above and below the Niagara Escarpment. Water vulnerability is relatively high in some areas of the Town where agriculture is also important. This richness formed the basis of the social network analysis and theory of change presented below. In addition, for the theory of change, various focus group discussions (see **Supplementary Material, Table S2**) identified several, specific issues. The agriculture focus group identified experiences with extreme weather events and increased patterns of uncertainty; they identified priorities such as access to reliable water, technical guidance for landowners, and green infrastructure standards. In the case of the tourism discussion, fluctuating water levels, habitat loss, and declining wildlife population have experienced impacts. Their priorities were identified as linking conservation with tourism, wetland protection, and ecosystem restoration. For the youth focus group, lived experiences were related to flooding and extreme weather events, and their priorities were access to public transportation, more relevant climate data, and making adaptation more affordable. The virtual shoreline focus group reflected on the findings of the project StoryMap. Those participants suggested a number of potential options for increasing shoreline resilience, which included standardized coastal risk assessment tools and solutions, increased use of green infrastructure as a protection mechanism and tax relief/subsidies to lessen the financial impact of risk reduction. This group also identified the need to involve elected officials at all levels in searching for sustainable solutions.

Participatory social network analysis

The social network identified 100 nodes (actors/organizations) and 335 edges (interactions/relationships). The nodes reflected one of eight groups: residents, town management, elected officials, region management, other levels of management (federal, provincial), non-government organizations, research groups, and other. The edges were then assigned values as to whether node interactions/relationships were strong (greater than 5 connecting edges), targeted (3–5) or weak (1–2). Nodes with no connecting edges were identified as isolates, and their lack of an edge characterized as a structural hole in the network. In addition, the question of which nodes played a leadership role in sustainability was addressed during key informant interviews and focus groups, and those edges were noted as such in the SNA (see **Fig. S1**).

First, our analysis revealed a generally centralized network focused on Town management. Edges radiated out from there to other actors and actor groups. There was also an important, strong dyadic leadership relationship between the Town's chief administrative officer and the elected mayor, and from there from the mayor to other Town elected officials. Further, leadership nodes were identified as important for sustainability and climate action. These were positional in nature, that is, municipal actors who played a role as bridges and boundary-spanners to regional and other key partners (peer-to-peer on specific issues). Such shared leadership responsibilities with others included the functional areas of emergency management, climate change adaptation planning, water and wastewater management, economic development, public health, and strategic communications. In addition, in terms of network density, as one might expect, town staff and councillors formed strong connections to fulfill the Town's corporate strategic mandate. These internal working relationships between elected officials and Town managers promoted coordination and sharing of risk-based information to inform decision-making. Elected officials, in turn, were able to reach their constituencies, primarily through ward meetings.

Second, in terms of weak ties (connectivity by no formal decision-making authority within the network but nevertheless influential), it was observed that a number of community clusters informally interacted on specific climate issues, such as exchanging information on options for dealing with shoreline risk and shoreline change. As mentioned, Town staff provided links to other levels of government, particularly federal, to leverage funds for adaptation and resilience. Some connection between local government and broader collaborative networks in the Great Lakes, such as the Western Great Lakes Collaborative, were also detected in the SNA. An important weak tie in the network involved the positioning of the Town's climate change coordinator in focus group activities that the project organized. The coordinator was able to use their position in the network to gain an understanding of community issues in advance of developing a draft climate change adaptation plan, for senior Town management and elected official endorsement. This allowed for access to information, concerns, and possible solutions that otherwise would not have been considered and incorporated into municipal resilience and sustainability policy.

Third, a number of structural holes were identified in the network. This included regular engagement of First Nations, quasi-regional environmental regulatory agencies (e.g., the Niagara Escarpment Commission, Greenbelt Foundation), and provincial agencies tasked with shoreline protection and adaptation planning (e.g., Ministry of Natural Resources, Municipal Affairs and Housing). In addition, certain neighbourhoods within the Town did not appear in the network, particularly those residents living south of (i.e., above) the Escarpment.

Finally, five municipal actors were identified by others in the network as important leaders for climate change adaptation and resilience planning. These leaders were seen as able to identify climate challenges, work collaboratively in developing solutions, and make connections external to the organization for managing change. More detail is provided in **Fig. S1**. In addition, while not identified as leaders *per se*, some community members who participated in interviews and focus groups were able to perform additional leadership activities by virtue of their status as both community members or as members of other relevant specific interest organizations or both. This duality of purpose was an important asset in both increasing ties outside of the network for both knowledge sharing and being vested in the climate solutions recommended as part of the process.

Theory of change

To establish the baseline for the theory of change, the interviews with key informants were crucial as they provided answers related to what an overall vision might be for the project, what they would like to learn about, and how they would measure success (**Table S1**). The visions of these groups of key informants differ in most aspects, although there were commonalities between the launch and residents in terms of collaboration/cooperation (note that the people at the launch were a mix of residents and managers regarding the shoreline/waterfront topic). The idea of conversations for residents might have been linked to "connect the community" at the manager level. On the learning aspect, several questions were highly similar among the three groups, although managers tended to have more advanced questions. More detail is provided in the Supplementary Material section – **Tables S1** and **S2**. Thematic analysis of the data identified certain key themes or output impact pathways from which to derive higher level outcome levels and benefits. The six thematic outcome impact pathways were:

1. Partnerships and Collaboration – developing meaningful relationships between organizations;
2. Strategic Engagement – involving citizens and civil society in meaningful ways;
3. Water and Watersheds – protecting water resources and promoting sustainable use;

4. Ecosystem-Based Adaptation – considering nature-based solutions in infrastructure development;
5. Shoreline Protection – building resilience to shoreline change and climate risk;
6. Education and Research – providing information for informed adaptation action.

For each output theme, a series of higher-level co-production activities were identified, which could contribute to increase longer-term co-construction and integrated community outcomes. For instance, for ecosystem-based adaptation (impact pathway 4), vegetative buffers, wetland protection and green infrastructure development were envisioned as being stepping-stones to managing at-risk areas, restoring habitat and biodiversity, and improving overall resilience for residents. These co-constructed immediate outcomes, in turn, were classified according to their contribution to the three portfolios of resilience discussed previously – readiness, responsiveness, and revitalization. With these outcomes, change can be monitored and characterized as they lead to a safer and more prosperous community. Similarly, activities for education and research, up-to-date climate risk information, exploring best practices from other communities, and understanding lake level management protocols can be used to support these higher-level outcomes. The theory of change summarizes a structured process to inventory, manage, track, and evaluate adaptation and broader sustainability decisions.

Figure 2 presents a graphic logic model, derived from the project research. It can be best described as an *inverted funnel* model, whereby community ultimate long-term outcomes are expressed through the United Nations Sustainable Development Goals (SDGs; UN 2015). But first, working from the bottom of the model, co-production activities (*outputs*), enabled change impact pathways (*outcomes*), which created immediate outcomes. Co-creation activities that provided data in support of outputs and outcomes included analysis of interviews, focus group meeting summaries and meeting notes. These co-production outcomes (*benefits*) were measured in integrated community outcomes, in this case exemplified by the Town's corporate climate change adaptation and economic development plans, which further realized gains in three portfolios of community resilience, the *spout* of the inverted funnel. The three portfolios of resilience – readiness, responsiveness, and revitalization, served as conduits for a subsequent branching out into targeted achievement of the SDGs.

For example, standardized assessment protocols (*outputs*) enabled shoreline protection. Shoreline protection created technically sound solutions (*benefits*) which further realized community outcomes through mitigating the harmful consequences of extreme weather and emergency events. This helped to further realize resilience by enhancing both community readiness and revitalization. From here, the logic model facilitates achievement of the SDGs of good health and well-being (SDG 3), sustainable cities and communities (SDG 11); and climate action (SDG 13).

In another example, promoting wetlands (*output*) as part of an impact pathway for ecosystem-based adaptation could create benefits in terms of ecosystem restoration. These benefits were measured in the degrees of protection of natural resources and enhanced ecosystem services. In a resilience portfolio, this relates to community revitalization, in turn helps to achieve the SDGs of clean water and sanitation (SDG 6); sustainable cities and communities (SDG 11); climate actions (SDG 13); and life below water (SDG 14).

Results of the final on-line stakeholder survey revealed a number of interesting observations. Twelve respondents represented community members (8), local managers (2), and non-government organizations (2). All of the key themes were validated in terms of importance, which lends support to the relevancy of the theory of change developed. The top three adaptation actions taken by respondents as a result of the project were personal lifestyle choices, working with others, and seeking out more

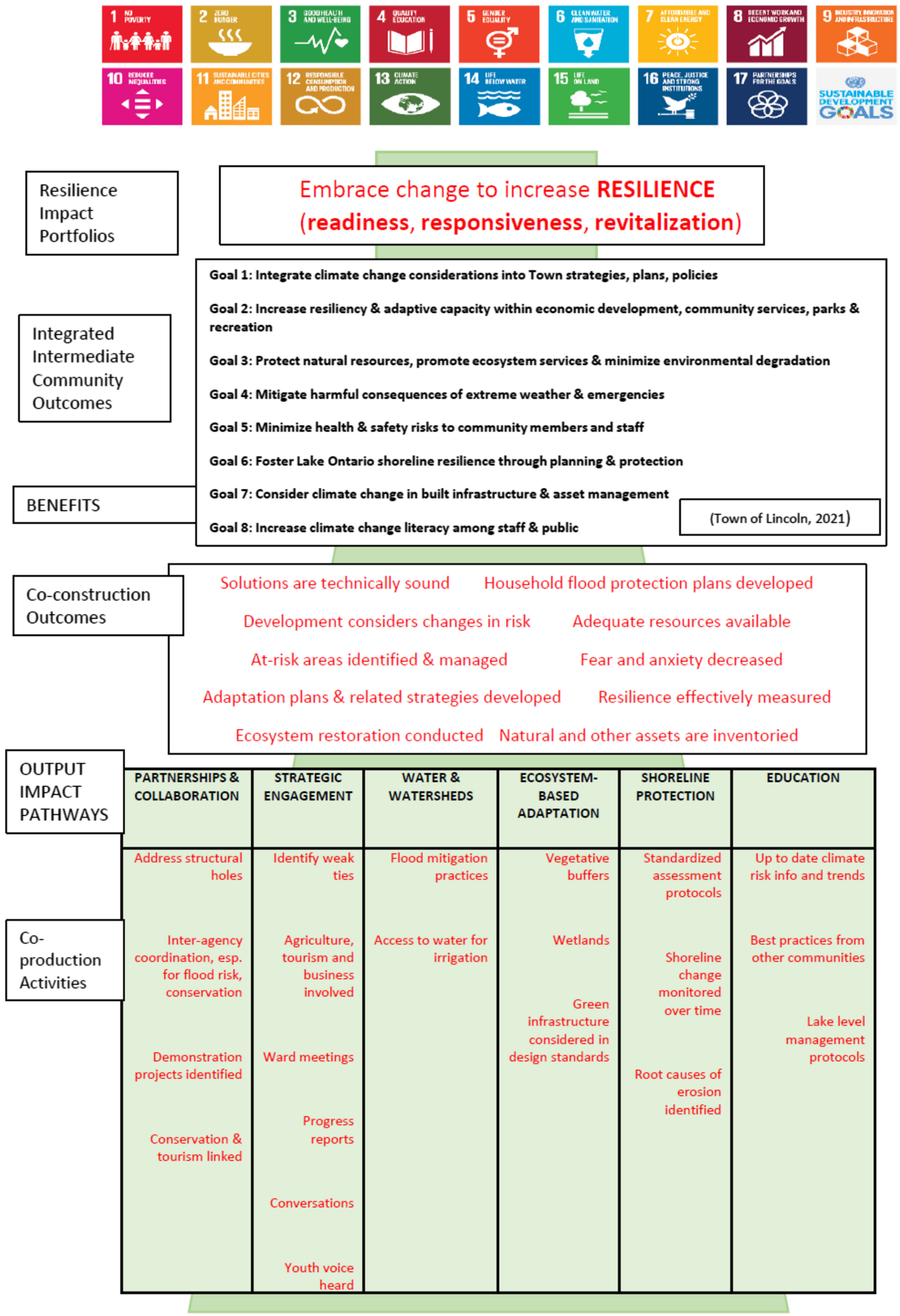

Fig. 2. Derived logic model.

information. Some examples included shoreline protection with native shrubbery, being more energy conscious, being proactive about waste reduction, and managed retreat. Some barriers identified were lack of political support/guidance from all levels of government, trusted metrics for adaptation, and lack of financial support for needed shoreline repair. In terms of the research process, the most useful activities identified were the StoryMap visualization of coastline change, focus groups, and articles in local media outlets. The top two outcomes chosen from the MEOPAR project were that it increased awareness about climate change adaptation, and it changed views and attitudes on the importance of climate change adaptation.

Discussion and conclusion

The case study described in this paper suggests a useful future direction for similar community climate action and related sustainability initiatives. In general, the Town can be considered to have a high degree of adaptive capacity, both operationally as well as strategically (Armitage 2005). Operationally, it has the technical resources and political engagement to manage resources within the community. Strategically, it has community dynamics and culture which supports consultation, engagement, and responsiveness to external challenges. Our results, through the theory of change, identified a positive path process that can be further implemented in the long term to continue monitoring changes. The use of a mixed-methods approach was effective in integrating data from various sources and aspects into this process.

Structured community profiles are an important first-step for inventorying resilience-relevant assets. The information, once collected and collated, defines a baseline from which to view the current situation and identify future challenges (Scherzer et al. 2019). For the Town, this was found to be an important integrative tool to incorporate natural, cultural, social, and economic characteristics in one document. Quite often, each of these community aspects can tend to be treated in silos. The profile was also a useful way to start a conversation about building resilience to future climate risk. For instance, in terms of vulnerability, challenges related to high water levels, extreme rainfall, and flooding were only some of the hazards the community mentioned facing. In addition, mandated hazard, impacts and risk assessment (HIRA) exercises also can identify other relevant hazards such as water quality and human health emergencies (Webb 2016). These challenges in turn lend themselves to a broader discussion of sustainability, ecosystem-based approaches, and overall community resilience (Richardson 2010; Brown et al. 2021). This broader view was further validated by the various focus groups, which reflected the views of community members. For example, water supply and access for the agriculture sector; ecosystem connectivity and conservation for the tourism sector; active transportation for youth; and availability of technical guidance and advice on innovative coastal protection measures for private shoreline landowners.

The use of targeted, participatory social network analysis, in conjunction with other methods, such as focus groups and key informant interviews, helped to build a coherent theory of change. Deliberation around questions of climate impacts, learning outcomes and issues of priority led to the definition of key thematic adaptation entry points. From there, discussion of potential actions and success measurement as it relates to key areas of community resilience, could take place (c.f., Oberlack et al. 2019). Further, the analysis was able to identify general characteristics of the climate action network, such as overall density, the presence of bridging actors, the importance of weak ties, and potential structural holes that might impede collaborative action.

A consideration of network leadership opportunities was possible. In a previous study (Baird et al. 2014), organizational and individual leadership in the Niagara Region was identified as a barrier to climate change adaptation action. Results from the current study reveal that this may be incrementally changing. For instance, five nodes in the network were identified as leaders by others in the network. Some were positional by virtue of their roles in Town municipal government, such as mayor, chief administrative officer, and fire chief. Others were found to have connective roles, such as economic development officer, and environmental services manager. Certain organizations identified by Baird et al. (2014), such as the Niagara Region and the Niagara Peninsula Conservation Authority, were also mentioned as not taking an active leadership role. In this study, participants were able to identify specific actors within those organizations that are playing a key role in climate action activities (e.g., emergency management, public health, wastewater, and related services; parks and natural space management). This suggests that despite having no one point of contact in these organizations on climate action issues, distributed leadership within these organizations appeared to be developing slowly and "under the radar scope" (May 2017). Further, this study is consistent with others suggesting that dedicated climate change officers can be utilized to perform targeted enabling and connective leadership functions (Stiller and Meijerink 2016). In the Town, the climate change coordinator was able to extend the reach and influence of the municipal governance function via their participation in the various focus groups and other meetings.

It is acknowledged that a multitude of adaptation options are available to shoreline and riverine communities. These options lie on a continuum of action, from either defending the status quo or co-existing with observed changes or ultimately retreating from existing and emerging climate risk altogether (Sinay and Carter 2020). Use of nature-based adaptation is one of these options. Further, shoreline vulnerability to high water levels and flooding is just one of the hydrometeorological and other hazards communities face. Bounding community challenges through an explicit theory of change is one way to comprehensively select and manage adaptation options within broader community sustainable development (Oberlack et al. 2019). It also provides a mechanism, not only for local governments and agencies, but also impacted citizens, the broader community, and civil society to see their place in how knowledge and action are a shared responsibility. In this instance, a resilience lens was applied to frame the benefits of integrated climate action for sustainability, advocating a transparent and streamlined approach (Moudrak and Feltmate 2017).

In conclusion, through this research, we envisioned and tested a process, using both participatory social network analysis and theory of change development to define possible pathways for climate change adaptation that involved community members instead of only municipal authorities. This was accomplished despite the necessary restrictions on face-to-face interactions posed by the COVID-19 pandemic. As a result, both social and ecological considerations for climate action were co-created. This process addresses concerns raised by resilience scholars, such as Berkes (2007), in dealing with crisis and uncertainty as social acceptance of municipal actions may not always be high if residents are not aware or involved in some manner. Participatory processes and nature-based solutions are a must for communities, and it is now increasingly acknowledged by mayors such as with the Great Lakes and St. Lawrence Cities Initiative (e.g., through the Advisory Council for Coastal Resilience). With a structured theory of change in place, the next research step will involve testing the inverted funnel with participants. This will be completed to ensure that their views are represented in moving from community co-creation to co-production in the long-term. Through the theory of change, this process can be monitored and reported on regular bases.

Competing interests

The authors have declared that no competing interests exist.

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Author contributions

LV conceived and designed the study. LV, BM, MC, AM, PG, JB, and SG performed the experiments/collected the data. LV, BM, and JB analyzed and interpreted the data. LV contributed resources. LV, BM, MC, AM, PG, JB, and SG drafted or revised the manuscript.

Supplementary material

The following Supplementary Material is available with the article through the journal website at doi:10.1139/facets-2022-0121.

Supplementary Material 1

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