Applying Ecosystem-based Adaptation to Protect Biodiversity of Avian Species in Coastal Communities in the Greater Niagara Region

by

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A Major Research Paper Submitted in Partial Fulfilment of the
Requirements for the Degree of
Master of Sustainability
in
The Faculty of Social Sciences

Brock University
St Catharines, Ontario, Canada

November 2020

ABSTRACT

Communities located in the coastal zone are increasingly vulnerable to climate change. The effects of climate change may push coastal ecosystems to undergo irreversible changes. This is especially true for shorebirds as it results in the loss of biodiversity and resource-rich areas to rest, refuel and breed. To protect these species, it is critical to conduct more research related to nature-based solutions. Through a scoping review of scientific literature, this paper evaluated 85 articles and included a summary of various sustainable ecosystem-based adaptation strategies, including living shorelines and beach nourishment. These strategies were evaluated under the eight core principles of nature-based solutions in order to determine the efficiency of protecting shorebird biodiversity in the Greater Niagara Region. All adaptation strategies were examined through a social, economic and environmental lens and future improvements were suggested to increase the efficiency of these strategies. This research also highlights its contribution to sustainability science.

Keywords: shorebirds, ecosystem-based adaptation, nature-based solutions, climate change, coastal, shorelines, biodiversity

ACKNOWLEDGMENT

My experience while completing my master's degree has been an amazing opportunity for me to grow as an individual, in the research field, and for my future career path. I would like to thank many individuals who have helped me start this journey as well as complete it to my upmost potential. Without your support I may never have believed I could complete such a tremendous task. During the time of my life that I was applying to graduate school, I was facing many challenges in my personal life and without the support of my peers, this is something I may not have pursued. To my supervisor, Dr. Liette Vasseur, I would like to thank you for your drive, passion and leadership. We share many qualities that I believe made us a great match. You always knew how to make me feel like I was on track and reassure me when I was doubting something. Thank you for pushing me to my fullest potential and helping me to be the best student that I could be. I would like to thank my second reader, Dr. Bradley May, as you played a crucial role in making this paper truly come to life. You were always willing to share many great resources and helped me further both my passion and knowledge on coastal protection. You both have made this experience one I will not forget. To my fellow sustainability cohorts and to the staff at the ESRC, I would like to thank you for being such an amazing and accepting group of people. You all come to this group with your own talents and expertise and you have all taught me so much during this time. Finally, to all my friends and family, you have been there since day one, through both the greatest times in my life and the worst. Without you I sincerely would not be here today. Having a support system that you can truly rely on is often hard to find and I will forever be grateful for your endless support.

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GLOSSARY

Adaptation - Adaptation involves adjustment, decision making and transformation in communities that improve the capacity of people and organisms to respond to climate change. Understanding species specific adaptive capacity is important for determining the potential long-term impacts and population viability when facing future climate change scenarios. In the context of climate-change planning, the term adaptation refers to human activities intended to minimize the adverse effects of climate change on the natural environment (Mawdsley, O'Malley, & Ojima, 2009; Saalfeld & Lanctot, 2017; Boesch, 2006).

Adaptive capacity – Adaptive capacity is the ability of a system or organism to prepare for stressors or changes in advance and adjust or respond accordingly. Adaptive capacity improves the opportunity of organisms to manage varying ranges and magnitudes of climate impacts, while allowing for flexibility to adapt to such changes (Engle, 2011).

Avitourism - Avitourism (or bird watching) is a growing niche sector of the broader nature-based tourism industry with avitourists travelling great distances to see bird species they may not have seen before, or have the opportunity to see regularly near their place of residence (Steven et al., 2015).

Beach nourishment – Beach nourishment is the process of adding sand onto eroding beaches. Sand is dredged from offshore and pumped onto eroding beaches and helps to restore beaches while also protecting shoreline structures from erosion and storm forces (Mycoo & Chadwick, 2012; Snoussi et al., 2009).

Biodiversity - Biodiversity is the variability of life, which can be measured by the totality of genes, species, and ecosystems in a region or by the structure and function of a community. Biodiversity consists of all levels of the biological temporal and spatial scale. Biodiversity can also be measured by the number and variety of natural communities that exist side by side in a given area. A high degree of biodiversity is often considered as an indication of a healthy sustainable community or ecosystem. When used properly biodiversity concepts can provide a useful framework for conservation efforts (Gaston, 2000; Savard et al., 2000).

Climate change - According to the Intergovernmental Panel on Climate Change (IPCC), climate change can be described as a change in mean and/or the variability of the climate, and persists for an extended period, typically decades or longer. While climate change may be due to natural environmental processes, most changes in modern times come from external processes such as persistent anthropogenic activities, including burning of fossil fuels. This is a problem that is occurring at all scales and requires immediate attention in order to address the impacts related to climate change (IPCC, 2014).

Coastline - Coastline is the geomorphology of a water body using a combination of characteristics such as the vegetation line and elevation (Raju et al., 2010).

Ecosystem-based Adaptation (EbA) - Ecosystem-based adaptation uses biodiversity and ecosystem services as part of an overall adaptation strategy to help people adapt to the adverse effects of climate change. The purpose is to address the impacts of climate change through adaptation measures and to increase resilience in these communities (Cohen-Shachum et al., 2019; Carro et al., 2018).

Ecotourism - Ecotourism is a form of nature-based tourism that places first-hand emphasis on learning, sustainability, conservation, ethical planning, development and management. Ecotourism involves the participants to travel to different locations in order to experience nature while being able to learn and enjoy various different opportunities (Fennell, 2014).

Green infrastructure (Soft infrastructure) - Green infrastructure (often referred to as natural or soft infrastructure) is a strategy that is based on nature-oriented strategies and refers to the ecological processes, both natural and engineered, that are the foundation for a healthy, natural and built environment in communities. It is often less costly and can offer aesthetic, environmental, health and recreational benefits. It includes strategies such as natural habitats and features designed to mimic natural processes such as mangroves, tidal marshes, biogenic reefs and beach or island barriers (Green Infrastructure Partnership, 2004). Blue/green infrastructure is a variation of green infrastructure that emphasizes both the importance of blue (water) and green (vegetation) infrastructures and the interaction between them. This means that natural environments are integrated into any infrastructure made such as building or retention ponds against flooding (Burdon et al., 2020).

Grey infrastructure (Hard infrastructure) - Grey infrastructure (also known as hard infrastructure) refers to human made infrastructure. For example, concrete infrastructure such as seawalls, barriers and dams would be considered grey infrastructure. (Bilkovic et al., 2016).

Important Bird Areas (IBA) - IBAs aim to increase awareness among governments and conservation practitioners on the importance of bird habitats worldwide. The IBA program was first established by the International Council for Bird Preservation in 1989. There are currently more than 12,000 IBAs in more than 200 countries. IBAs are identified using a systematic selection process, largely based on the presence of various trigger species. Trigger criteria are based on populations of species occurring in a defined area at certain population thresholds. The species may trigger one or more of the following criteria: globally threatened species, range-restricted species, biome-restricted species, and congregation. (Steven et al., 2015).

Integrated Coastal Zone Management (ICZM) - Integrated Coastal Zone Management starts with an analytical process in order to set objectives for the development and management of the coastal zone. ICZM should ensure that the process of setting objectives, planning and implementation involves as broad of a spectrum of interest groups as possible and that a balance is achieved in the overall use of the country's coastal zones. ICZM maximizes the benefits of coastal zones through consideration of the full range of both spatial and temporal scales. This approach minimizes the conflicts and harmful effects of activities on resources and on the environment (Post & Lundin, 1996; McFadden, 2008).

Intertidal zone – Intertidal zones exist anywhere that water meets the land, they consist of many different habitats with a variety of species. This area is critical when looking at coastal zone management and adaptation strategies.

Living shorelines – Living shorelines are categorized as a larger group of green infrastructure practices, which include a greater range of nature-based techniques for inland areas that address storm water control, nutrient retention, and habitat enhancement in place of hard infrastructure.

Examples of living shorelines include vegetation (such as seagrass), oyster beds, mussel beds, tidal marshes, coastal grasslands and wetlands (Woods Hole Group, 2017).

Managed retreat or Managed realignment – Managed retreat or realignment is the partial or total removal of man-made or hard infrastructure strategies. The objective is to permit reoccupation of former intertidal areas and to retreat the protected shoreline to a more landward position (Cooper & Pile, 2014).

Nature-based Solutions (NbS) - Nature-based Solutions (NbS) involve using all components of the ecosystem to solve societal challenges such as climate change. It recognizes that all components of the ecosystem are connected, and that the adaptation process can incorporate sustainable management, conservation and restoration of ecosystems. NbS is also important in providing services that can have a positive role in increasing resilience. NbS is an umbrella term that includes many different strategies such as ecosystem approach, ecosystem-based adaptation, protected areas, forest landscape restoration and ecological restoration (Colls, Ash, & Ikkala, 2009; Burdon et al., 2020).

Niagara Region - The Greater Niagara Region consists of 12 municipalities which are: Niagara-on-the-Lake, Niagara Falls, Fort Erie, Port Colborne, Welland, Thorold, St. Catharines, Lincoln, Pelham, Wainfleet, West Lincoln and Grimsby.

Ramsar site - Ramsar sites are designated by the Ramsar Convention and these are areas that are considered rare or unique wetlands, or wetlands that are important for conserving biological diversity. These sites mean that countries agree to establish and oversee a management framework which is aimed at conserving the wetland and ensuring its wise use. There are 9 criteria that the Ramsar Convention evaluates before designating an area with this title, the wetland must meet at least one of the criteria (Australian Government, n.d.).

Resilience – Resilience is the capacity of a system to undergo disturbance and maintain its function and controls. It can be measured by the magnitude of disturbance the system can tolerate and still thrive (Boesch, 2006).

Restoration - Ecological restoration is widely used to reverse the environmental degradation caused by human activities or through climate change. The purpose of restoration is to enhance the biodiversity and ecosystem services in the area while also providing new ideas and opportunities for biological conservation and natural resource management.

Riparian zone - A riparian zone is an area between the upland zone and the shoreline, often is considered the area next to rivers or smaller water bodies.

Scoping review - Scoping review is a type of methodology that provides an opportunity to identify key concepts, gaps in the literature, and options for potential adaptation solutions in the future. This approach has a broader scope than traditional systematic reviews and involves more extensive inclusion of criteria. Scoping reviews are also more commonly used when examining areas that are emerging, to clarify key concepts and identify gaps, as well as can also provide an opportunity to identify a topic for future systematic literature reviews (Tricco et al., 2016; Peters et al., 2015).

Shorebirds - Shorebirds can be described as birds that live, feed or nest near the shorelines. These birds are either permanent or seasonal residents or visit these areas during migration. In some areas, shorebirds can also be considered wading birds.

Shorelines - Shorelines coincide with the physical interface of land and water. Due to the shoreline position changing continually through time the definition must be considered in a temporal sense and not just a spatial (Boak & Turner, 2005).

Social-ecological systems - Social-ecological systems are complex and can have varying levels of adaptive capacity. They are not limited by spatial or functional boundaries surrounding particular ecosystems and their complex problems. Social-ecological systems consists of ecosystems and communities as well as the associated social actors and institutions. These systems also look at the interactions between living and non-living parts of the community (Engle, 2011).

Sustainability science - Sustainability science aims to understand the fundamental interactions between nature and society. Such an understanding must encompass the interaction of global processes with the ecological and social characteristics. There are three main pillars that sustainability science focuses on which are people, planet and prosperity. For sustainability science to be successful it must take all three pillars into consideration in order to create sustainable options for not only this generation, but also for future generations (Kates et al., 2001; Kates 2011).

Vulnerability - Vulnerability is the degree to which a system is susceptible to and is unable to cope with adverse effects (of climate change). In all formulations, the key parameters of vulnerability are the stress to which a system is exposed, its sensitivity, and its adaptive capacity (Adger, 2006).

INTRODUCTION

Human communities and wildlife located in the coastal zone are increasingly vulnerable to hazards and the impacts associated with climate change. Hazards, including extreme and sudden events like storm surges, hurricanes, and ice storms, can result in flooding or increased erosion (Galbraith et al., 2002; Mic, 2003; Thrush et al., 2008). Slow changes, such as water level fluctuations (WLF) and sea level rise, can lead to increased seawater infiltration in the water table and in some cases, erosion and flooding (especially for regions with high tides) (Mic, 2003; Thrush et al., 2008). In coastal communities with large waterbodies like the Great Lakes, water fluctuations can lead to water table contamination and weakening of the coastal infrastructure. These multiple stressors may push some coastal ecosystems to undergo sudden, rapid, and irreversible changes (Powell et al., 2019). They can also lead to land degradation and, reduce or remove species diversity as well as associated ecosystem functions and services (Allen et al., 2009).

Environmental shifts and cumulative impacts brought on by climate change may increase coastal degradation and cause habitat loss (Sparks et al., 2002; Crick, 2004). Habitat loss is widely used as a measurement for the risk of extinction of species and is considered an important factor for the decline of shorebird populations (Iwamura et al., 2013). The loss of these habitats results in a loss of resource rich areas and an increase in shorebird population decline. The ability of a site to support large numbers of shorebirds is largely determined by the quality of their habitats and the availability of food. The impacts of climate change and loss of land are detrimental to the feeding ground generally available (Galbraith et al., 2002). This results in a shift in many species' natural migration patterns, leading to a negative impact on shorebird population density. While the severity of the impacts on populations can vary among species based on their migratory or behavioural patterns, habitat loss can have important implications for organisms that depend on these sites, causing a shift in biodiversity (Galbraith et al., 2002; Iwamura et al., 2013; Thrush et al., 2008). Both climate change and coastal development can result in the loss of safe, resource-rich places to rest, refuel and breed for many shorebirds (Galbraith et al., 2002). Human infrastructure along coastal zones can also lead to land degradation and narrowing the shoreline due to erosion. The loss of an ecological buffer between humans and natural ecosystems can affect the success of shorebird populations, especially in nesting seasons. Removing pieces of prime intertidal acreage means fewer shorebirds (Myers, 1983).

Weather is the conditions of the atmosphere are over a short period of time and usually characterizes a daily condition, while climate is atmospheric patterns over relatively long periods of time (usually averaged over 30 years, IPCC 2014). Climate change presents a serious threat to the future of many shorebird species through slow changes in temperature and precipitation as well as climate variability, which represents extreme weather events such as heatwaves. Climate variability can have a significant effect on the metabolic rate of birds and can cause increased energy expenditure for body maintenance. Increasing temperatures associated with climate change are predicted to cause reductions in body size, a key determinant of animal physiology and ecology (Weeks et al., 2019). Several changes in the natural behaviour of shorebirds have also been documented, such as altitudinal shifts (Parmesan, 2006), earlier breeding (Sparks et al., 2002), timing of migration (Sims et al., 2013), breeding performance (egg size, nesting success) (Sparks et al., 2002), and population distributions (Crick, 2004). Variations in normal foraging behaviour and breeding success have also been documented, including chilling or starvation of young (Sarah et al., 2006; Crick, 2004). Temperature change and flooding caused by WLF may also affect the quality of the food supply available to shorebirds (Lawrence & Soame, 2004). A change in numbers at any particular site may be due to a shift in quality at other sites or in the total population size resulting from altered reproductive rates and/or overall mortality rates (Sarah et al., 2006).

Due to the increased stressors of climate change and human intrusion, there has been irreversible shifts in the populations of coastal shorebird species (Myers, 1983). Shorebirds are among the bird groups of highest conservation concern in the world with three times as many species declining as increasing (Watts & Turnin, 2016). Climate change is predicted to cause approximately 400–550 bird species extinctions, and an additional 2150 species may be at risk of extinction by 2100 (Sekercioglu et al., 2008). Population decline does not only affect species at risk such as sanderling, brown pelican, and least tern, but also common migratory species including bank swallow, least bittern, piping plover and the black tern (Devitt, 2018; Audubon, 2019; Piersma et al., 2017; Corell et al., 2017). Shorebirds must undertake energetically demanding migrations covering thousands of kilometres between breeding and non-breeding sites, and several species will interrupt their journeys to rest and refuel at stopover sites along the way (Baker et al., 2004). They rely on these coastal ecosystems for feeding, rest and breeding areas during their migrations (Galbraith et al., 2002; Myers, 1983). With the decline of many species, conservation is critical for maintaining healthy communities that consist of many diverse species as well as maintaining healthy ecosystems. The status of shorebirds is becoming a concern throughout coastal communities; thus, conservation of these species is becoming a main priority in many wildlife management plans.

It is therefore evident that there is a need to determine which adaptation measures could be used to improve shorelines and increase shorebird protection, especially in the face of climate change. The purpose of the study was to examine how Nature-based Solutions (NbS), specifically Ecosystem-based Adaptation (EbA) strategies, could be applied to protect the biodiversity of avian species in coastal communities with a focus on the Greater Niagara region. More precisely, the objectives were to evaluate how effective these strategies could be to help reduce the impacts of climate change as well as determine their strengths and weaknesses for such ecosystems. This study included a scoping review using key terms such as shore, bird Ecosystem-based Adaptation and climate change. Using a scoping review as a type of research allowed to map the literature related to EbA to protect biodiversity of avian species in coastal communities. This methodology also identified potential adaptation strategies and potential gaps in the literature, providing opportunities for future research (Tricco et al., 2016).

Climate Change and the Great Lakes

According to the research conducted by the Great Lakes-St. Lawrence River Adaptive Management (GLAM) Committee in 2017, the water supply conditions of Lake Ontario are highly variable and unpredictable. There is a strong uncertainty regarding these changes and further research is needed to evaluate the effects that climate change will have on these regions and create effective adaptation plans (Gronewold & Stow, 2014; GLAM, 2018). While water levels in the Great Lakes have been historically highly variable, climate change is a concern as it may lead to an increase in this variability. This uncertainty is affecting many factors including ice conditions and wave actions. During the winter to spring months, ice conditions may not follow a simple sequence; rather they may highly vary as a result of changes in winter temperatures (GLAM, 2018). This has affected how water levels usually rise in the spring as snowmelt enters the lakes and drop in late summer and fall as surface water evaporates and the weather turns drier. In both Lake Ontario and Lake Erie, the seasonal rises and falls of water level are occurring one month earlier than before (Mic, 2003). In addition, fast moving water with frigid temperatures generates what is known as frazil ice, where the ice crystals suspended in water are too turbulent to freeze solid. This can also result in ice jams, which can cause flooding and property damage (GLAM, 2018).

Focusing this study on the Great Lakes and the Greater Niagara Region is of importance due to water level fluctuations and extreme storm events being amongst the greatest concerns for coastal communities in the area. While most of the water level increase in 2017 was due to increased precipitation, extreme storm surges also exemplified the potential for water levels to increase as well as the risk of hazards such as coastal erosion (McInnes et al., 2003; GLAM 2018). In 2017, storm surges accounted for approximately 3 to 5 cm of the water level rise on Lake Ontario alone (GLAM, 2018). These combined uncertainties related to water level fluctuations can have dramatic effects on coastal communities such as land degradation and can affect associated ecosystem functions and services (Allen et al., 2009).

Conservation of shorebird communities in the Greater Niagara Region

The conservation of shorebirds is especially important in the Niagara Region as it is a major support area for seasonal and migratory shorebirds (Black & Roy, 2010). The Niagara region sits right in between Lake Ontario and Lake Erie making it an ideal corridor for migrating birds. This region is home to six sites that are designated as Important Bird Areas (IBA). All of these IBA's either extend over water or lie adjacent to water, which demonstrates the importance of lakes, rivers and creeks for the breeding of migratory birds in Niagara (Black & Roy, 2010). One of these sites is the Niagara River and it is considered a globally significant IBA. The Niagara River is a major support area for birds, consisting of approximately 20,000 water birds, and consists of approximately 1% of the world's water birds (NPCA, 2019). The Niagara River is also a Ramsar site in the United States and an aspiring one in Canada. Its designation as a Ramsar site underlines the importance of this migratory flyway. It is also where the Niagara Escarpment Biosphere begins. In the Greater Niagara Region, there are many shorebirds being affected, with most impacts being placed on the piping plover, black tern, bank swallows and the least bittern (Audubon, 2019).

Nature-based Solutions and Ecosystem-based Adaptation strategies

For this scoping review, the main purpose is to focus on EbA. As EbA usually falls under

NbS, it is crucial to understand the importance of the relationship between NbS and EbA. NbS can be defined by the International Union for Conservation of Nature (IUCN) as actions towards protecting, sustainably managing, and restoring natural or modified ecosystems while simultaneously providing human well-being and biodiversity benefits (Cohen-Shacham et al., 2019). The concept of NbS is an umbrella term that includes various strategies including ecosystem approach, forest landscape restoration, ecological restoration, protected areas and EbA. With considerable effort being invested into developing a global standard (Andrade et al., 2020) for which ecosystem management strategies fall within NbS, there is a corresponding need to ensure that the concept is clearly understood.

Eight core principles define what NbS may look like (Table 1, Cohen-Shacham et al., 2019). In this research, these core principles were used when evaluating the various EbA strategies. Certain NbS principles directly relate to sustainability such as principles 3, 4 and 5 as they correspond of the three main pillars of sustainable development: improving environment sustainability, social equity and economic viability. Principle 8 focuses on the importance of working within national policy, which is critical to ensuring the long-term sustainability in NbS (International Union for Conservation of Nature, 2020). The IUCN and its Commission on Ecosystem Management (CEM) have developed this NbS definitional framework and principles in order to clarify NbS which will allow it to be understood in a wider context of sustainable development (Cohen-Shacham et al., 2019).

NbS is a useful approach to addressing multiple sustainability crises, including climate change, food and water security, land degradation and biodiversity loss. It is important to clarify that while NbS complement nature conservation, the International Union for Conservation of Nature (2020) states the main objective of NbS is to address one or several societal challenges, while benefiting both biodiversity and human well-being. Along with climate change, coastal development is also detrimental to shorebird species. Coastal development is expanding and has resulted in infrastructure being closer to the coast. Due to the impacts related to both climate change and coastal development, we need to find ways to preserve these coastal communities by using sustainable adaptation strategies. EbA strategies are a suitable method for adapting to multiple social-ecological challenges such as the combination of coastal development and climate change. As EbA is a sub-category of the NbS, evaluating the NbS principles of each EbA strategy allows for identification of the effectiveness of each individual strategy and how they benefit social-ecological systems. Evaluating the NbS principles also assists with the initial planning of adaptation management as well as identifying which areas of each strategy need to be improved, overall this has the potential to improve the success of EbA strategies.

Table 1. Nature-based Solution Principles used in evaluation Ecosystem-based adaptation strategies. Nature-based Solution core principles were evaluated from a paper done by Cohen-Shacham et al., (2019).

Nature-based Solution (NbS) Principles	
Principle 1	NbS embrace nature conservation norms (and principles)
Principle 2	NbS can be implemented alone or in an integrated manner with other solutions to societal challenges (e.g., technological and engineering solutions)
Principle 3	NbS are determined by site-specific natural and cultural contexts that include traditional, local and scientific knowledge.
Principle 4	NbS produce societal benefits in a fair and equitable way in a manner that promotes transparency and broad participation.
Principle 5	NbS maintain biological and cultural diversity and the ability of ecosystems to evolve over time.
Principle 6	NbS are applied at a landscape scale.
Principle 7	NbS recognize and address the trade-offs between the production of a few immediate economic benefits for development, and future options for the production of the full range of ecosystem services.
Principle 8	NbS are an integral part of the overall design of policies, and measures or actions, to address a specific challenge.

Ecosystem-based adaptation

According to the Convention on Biological Diversity (CBD, 2018), EbA is an umbrella term that is defined as various approaches of adaptation and disaster risk reduction that utilizes ecosystems and biodiversity to integrate climate change adaptation, disaster risk management and development planning. Sustainable adaptation involves NbS strategies such as EbA which incorporates sustainable management, conservation and restoration of ecosystems. The goal is to provide services that can have a positive role in increasing resilience while helping organisms and ecosystems adapt to climate change (Colls, Ash, & Ikkala, 2009).

EbA uses several strategies, such as green infrastructure, to integrate the use of biodiversity and ecosystem services as an overall strategy to adapt to the adverse impacts of climate change. Green infrastructure (often referred to as natural or soft infrastructure) is a strategy of EbA considered a fundamental approach when dealing with the effects of climate change. Green infrastructure refers to the ecological processes, both natural and engineered, that are the foundation for a healthy, natural and built environment in a landscape. It is often less costly and can offer aesthetic, environmental, health and recreational benefits (Green Infrastructure Partnership, 2004). Green infrastructure includes natural habitats and features designed to mimic natural processes such as mangroves, tidal marshes, biogenic reefs and beach or island barriers. This adaptation strategy can serve as an alternative management approach to traditional grey infrastructure (often referred to as hard infrastructure). To manage climate change in a sustainable way, we must shift from the traditional grey infrastructure which can further lead to habitat fragmentation, as well as decline in biodiversity (Bilkovic et al., 2016).

Traditional grey infrastructure is sometimes needed but can have adverse effects that degrade or inhibit ecosystem services and is increasingly recognised as an unsustainable strategy to climate change adaptation (Bilkovic et al., 2016). EbA strategies have been shown to help with restoring or enhancing ecosystem services and increase ecosystem resilience after implementation (Reid et al., 2019). Through these adaptation strategies such as green infrastructure, it has the potential to provide ecological benefits such as critical nesting, foraging and resting habitat for many wildlife species of high conservation concern (Powell et al., 2019). While green infrastructure is currently being successfully implemented in many coastal adaptation actions to enhance the resilience of socio-ecological systems, this paper will look at many adaptation options including integrated coastal zone management for the Greater Niagara Region (Powell et al., 2019; Audubon 2019; Reid et al., 2019).

Figure 1 illustrates the elements that should be included when determining which strategies are considered EbA and which strategies are to be assessed and included in this scoping review. For the strategy to be considered an EbA, it must have met all these categories of EbA classification to some degree.

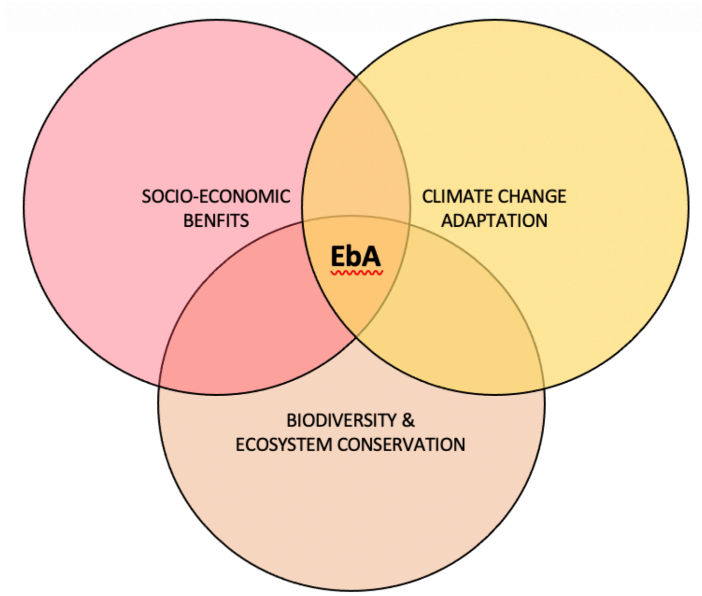

Figure 1. These three categories were listed as EbA can be viewed as a three-way synergy between socio-economic benefits, climate change adaptation and biodiversity and ecosystem conservation. Figure recreated from the Convention on Biological Diversity (CBD, 2018).

Sustainable adaptation strategies in coastal communities

In general, sustainability strategies aim to make combined improvements related to the environment, society and the economy This project has the potential to contribute to all three aspects through a social-ecological perspective. Social-ecological benefits include the conservation of shorebird populations and restoration of their habitats which in turn can better the economy. Avitourism is one of the faster growing subsectors of ecotourism and is recognized for its economic value. The economic value of avitourism revolves around bird festivals, migration events, or well-known birdwatching sites (Callaghan et al., 2018). Many individuals travel far distances for avitourism, thus contributing economically to local communities by increasing traffic to these areas. These economic contributions include areas such as local hotels, restaurants, nature and outdoors shops, and conservation parks.

The impacts of climate change have also caused financial burdens on coastal communities due to loss of land and degradation. Through appropriate adaptation strategies the goal is to reduce these costs. Green infrastructure can help maintain both social-ecological systems and ecosystem services thus building resilience to environmental and climate changes. EbA has been shown to increase adaptive capacity to vulnerability caused by climate change, as well as increase resilience and community governance (Reid et al., 2019). Using sustainable adaptation strategies, it is often less costly and can offer aesthetic, environmental, health and recreational benefits (Green Infrastructure Partnership, 2004). This study will also evaluate adaptation strategies that have the potential to provide ecological benefits such as critical nesting, foraging and resting habitat for many wildlife species of high conservation concern, thus encouraging the conservation of shorebird species (Powell et al., 2019). Due to the emphasis on social, economic and environmental importance on the conservation of shorebirds and coastal communities, this research is a great example of how using appropriate adaptation strategies is relevant to sustainability.

METHODOLOGY

Framework of the MRP: Applying Ecosystem-based Adaptation strategies to shorelines

This research focused on identifying sustainable adaptation strategies that could be implemented along shorelines to encourage the conservation and biodiversity of shorebird species. The project examined various NbS such as EbA in order to determine which strategies would be most appropriate for the Greater Niagara Region. These adaptation strategies were assessed based on the eight core principles of NbS (Table 1) and the strengths and weaknesses of each strategy were assessed. These strategies were then compared using case studies to determine how they could be used in the Niagara Region.

Niagara Region as a study case for the MRP

The Greater Niagara Region in Southern Ontario is comprised of 12 municipalities – St. Catharines, Thorold, Welland, Pelham, Niagara Falls, Niagara on the Lake, Port Colborne, Wainfleet, Grimsby, West Lincoln, The Town of Lincoln and Fort Erie (Figure 2). The Niagara region sits right in between Lake Ontario and Lake Erie making it an ideal corridor for migrating birds. This region is also home to six sites that are designated as Important Bird Areas (IBA's) (Figure 2). These sites are located on the Niagara River, Port Colborne, Point Albino, West End of Lake Ontario, Beamer Conservation Area and Twelve Mile Creek Headwaters. All of these IBA's either extend over water or lie adjacent to water, which demonstrates the importance of lakes, rivers and creeks for the breeding of migratory birds in Niagara (Black & Roy, 2010). Due to the importance of the Niagara Region for migratory shorebirds and the continuing negative effects of climate change on shorelines, sustainable adaptation plans are critical for the conservation of these areas and species.

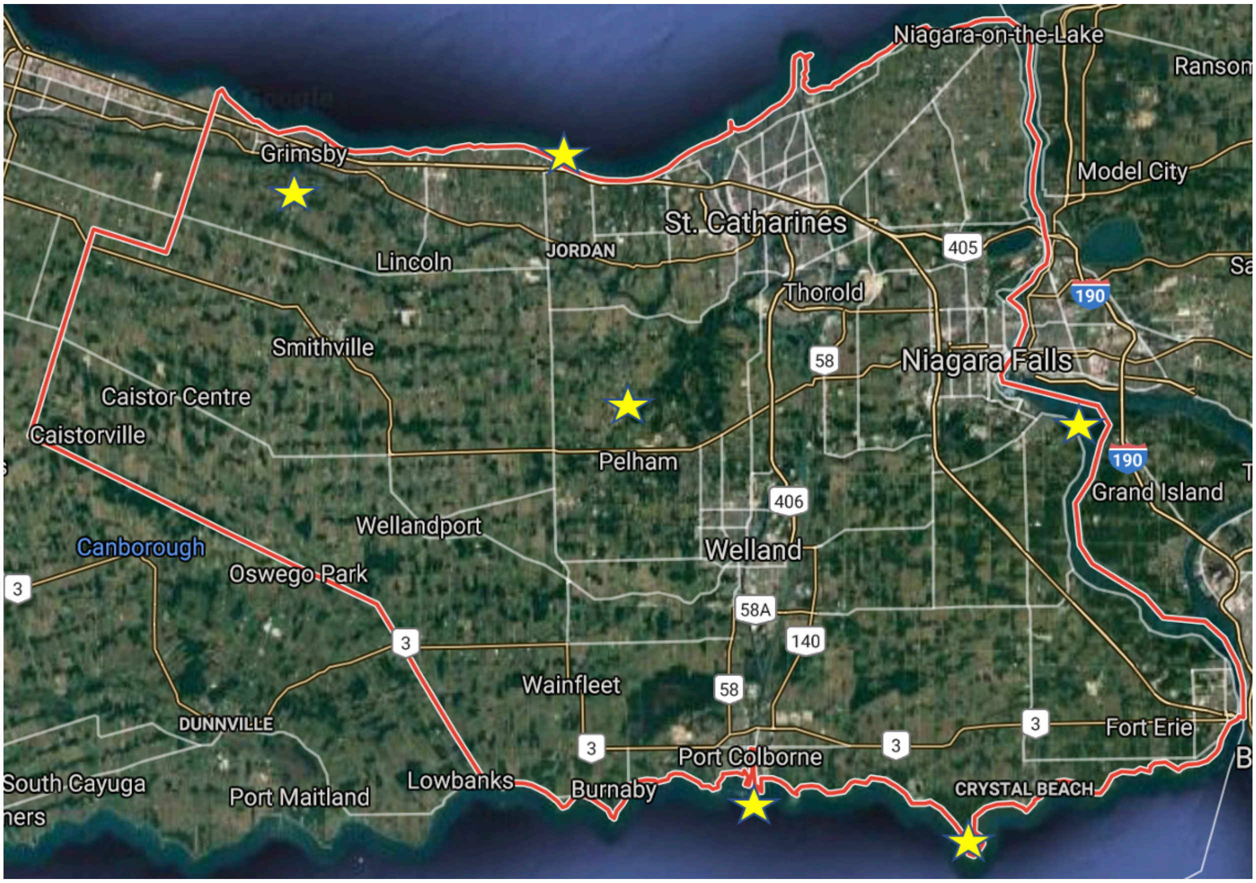

Figure 2. Satellite view of the case study site: Niagara Region. Each yellow star represents an Important Bird Area.

Scoping review of the literature

The methodology applied in this MRP was a scoping review of scientific literature in the domain of shorebird conservation and EbA strategies. For this study, a scoping review was used because it has a broader scope than traditional systematic reviews and involves a more extensive inclusion of criteria (Tricco et al., 2016). A scoping review aims to identify key concepts, gaps in the literature, and options for potential adaptation solutions in the future (Tricco et al., 2016). This scoping review was performed by following the PRISMA-ScR (Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews) checklist. This checklist outlines a minimum set of requirements for researchers to include in a report in order to ensure the scoping review is completed in a systematic process, while also maximizing the uptake of research findings (Tricco et al., 2018).

Despite the abundance of relevant studies on this topic, the majority of the literature focused on adaptation strategies in the Southern Hemisphere. Due to the gap in the literature when dealing with the Greater Niagara Region, this scoping review provided an ideal platform to research existing adaptation strategies and apply them to the Greater Niagara Region. By using a scoping review methodology, followed by case studies, the intent was to create a summary table of the various EbA strategies and evaluate them for the Greater Niagara Region. Each strategy was assessed using the eight core principles of NbS (Table 1) in order to determine the sustainability of each option. Case studies were then reviewed to provide successful examples of where these techniques were used, and to help evaluate their strengths and weaknesses. This summary table allowed us to provide suggestions on improvement for each of these individual strategies, in order to create more sustainable options for the future, as well as to determine which techniques would be most beneficial for the Greater Niagara Region.

The academic databases that were used to search for scientific literature were the "Academic Search Complete" and "Web of Science: Core Collection" accessible from the Brock Library. The search for literature was carried out on September 12th, 2020, on both databases. This search required a specific set of key terms in order to find sufficient data for this scoping review and are listed in Table 2. The use of asterisks ensured that words with same roots would be obtained and that the database search was a comprehensive as possible. For example, shore* would allow results such as "shorebirds" or "shorelines." For the Academic Search Complete database, all existing publication years were considered (1965- 2020), and filters included: English language only, peer-reviewed and academic journals only. This was followed by excluding non-relevant industries such as food security, forestry, agriculture productivity, and business, to obtain a final of 1469 results. Additionally, for the Web of Science: Core Collection, all existing publication years were considered (1990-2020), and filters included: English language only and peer-reviewed articles only. This was followed by excluding non-relevant categories, such as anthropology, agriculture, law, political science, telecommunications, and computer science, to obtain a final of 1939 results. The search for scientific literature on the above-mentioned databases is further described in Appendix A.

The full electronic search strategy for Web of Science: Core Collection, including the excluding factors and limitations, are included in Appendix B. In addition, non-peer reviewed literature and case studies were acquired from multiple sources, including the International Union for Conservation of Nature (IUCN) and website searches on Google using the same search parameters.

After the scientific articles were obtained, they were exported into Zotero for removal of duplicates and for further screening to identify the most relevant articles for this MRP. All possible efforts were made to obtain the full-text versions of the articles that passed the screening process. There were a few articles (n=12) that the full text could not be obtained in spite of all reasonable efforts and had to be excluded from the analysis. A complete screening process was performed using inclusion and exclusion factors (Table 3), which resulted in a total number of 85 articles being used for this scoping review. The entire scoping review process for the study is shown in Figure 3 as a flowchart.

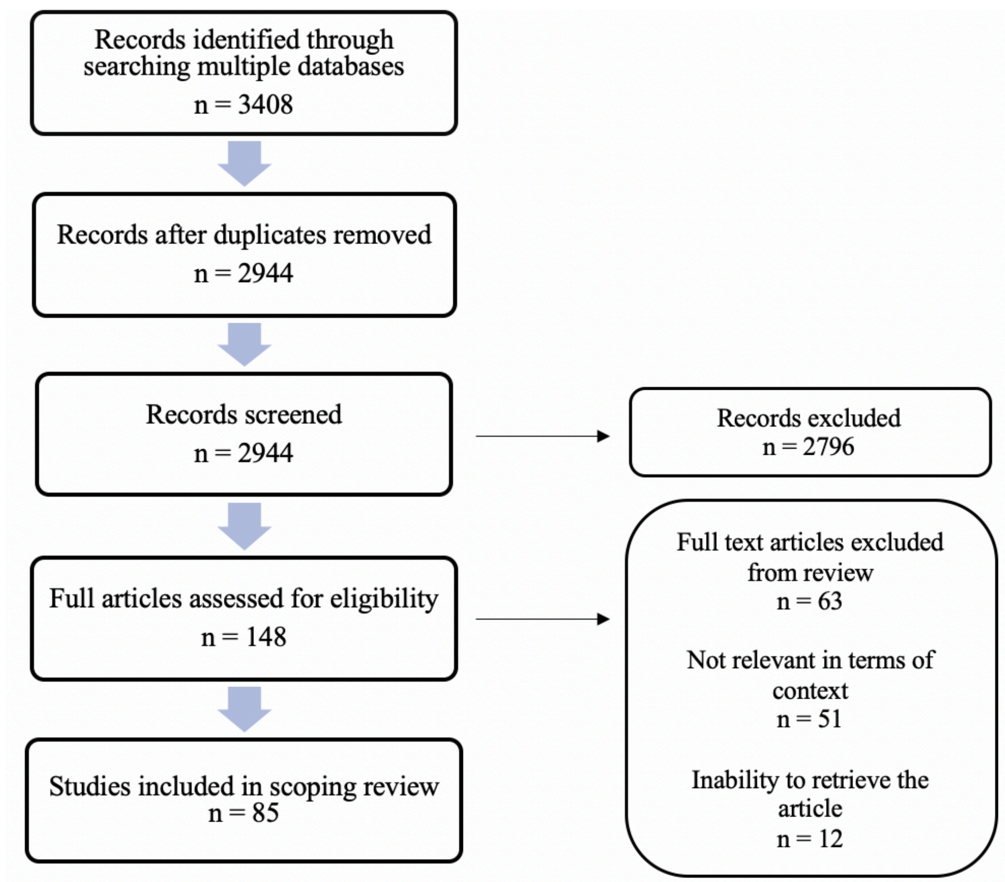

Figure 3. Flow diagram illustrating the selection literature sources used in the scoping review process. This flow diagram was adapted from the PRISMA ScR guidelines (Tricco et al., 2018)

Table 2. Final list of keywords for 'Academic Search Complete' and 'Web of Science: Core Collection' databases

Shore	+	Bird	+	Climate change OR ecosystem-based adaptation

Table 3. Inclusion and exclusion categories used for deciding the final list of articles for the scoping review. This table was adapted from the PRISMA ScR guidelines (Tricco et al., 2018)

Inclusion factor	Exclusion Factor
- Climate change and SLR	- Policies, law and decision making
- Ecosystem-based adaptation strategy evaluations	- Geographical location (mountains, urban spaces, grasslands)
- Ecosystem-based adaptation strategies in coastal communities	- Coastal Risk Assessment/Vulnerability Assessments
- Grey infrastructure	- Water resource management and quality
- Integrated Coastal Zone Management	- Wind energy
- Ecotourism	- Global temperature rising and CO_2 levels
- Biodiversity and climate change	- Food webs
- Shorebird declines	- Public health
- Nature-based Solution evaluations	- Evolution of morphology
	- Genetics

RESULTS

Scoping review analysis

The 85 articles that were reviewed all took place in coastal communities in almost all eight geographical continents including Asia, Europe, North America, South America, Africa and Oceania. There were no existing articles in this scoping review that were performed in the continent of Antarctica. There were 19 articles (22%) that were not specific to any geographical zone and addressed adaptation strategies for a global context. The complete range of articles geographically was from South America (3.5%), Africa (6%), Oceania (8.5%), Asia (9%), Europe (25%) and North America (26%). Of the 22 articles that were focused on North America only one article was from Canada, further representing the gap in literature regarding EbA in Canadian coastal communities. The detailed geographical distribution of the articles can be shown in Figure 4.

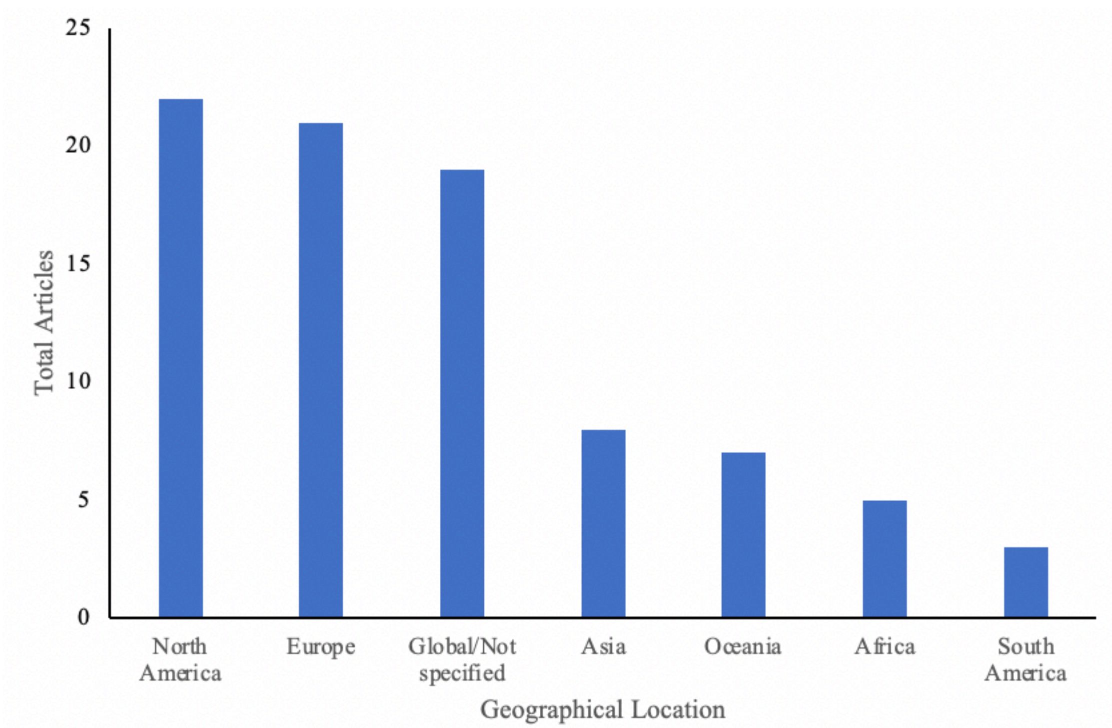

Figure 4. Geographical distribution by continent of the 85 articles included in the scoping review after analysis of the full text of 148 articles on coastal adaptation to climate change using Ecosystem-based Adaptation strategies

The years of publications of the various articles included in this scoping review analysis ranged from 1997 to 2020 (Figure 5). Over 55% (47 out of 85) of the articles were published in the last five years, i.e. between 2016 and early 2020, and almost 86% of the articles in the last ten years (between 2011 and early 2020). With the remaining 14% of articles published between 1997 and 2010, this reflects the growing importance of climate change adaptation as a climate action for the coastal communities globally and its relevance for the future. Many articles focused on one specific adaptation strategy while others focused on EbA strategies or NbS as a whole.

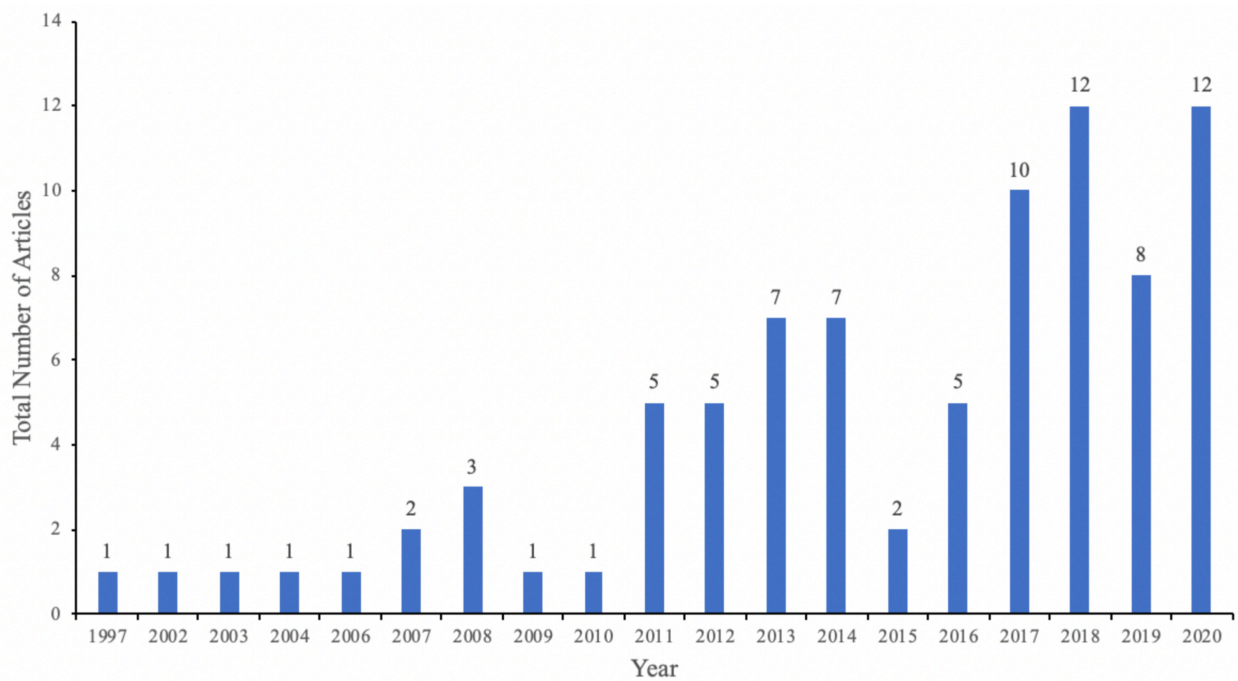

Figure 5. Years of publication of the 85 articles included in the scoping review after analysis of the full text of 148 articles on coastal adaptation to climate change using Ecosystem-based Adaptation strategies

Analysis of Ecosystem-based Strategies for the Greater Niagara Region

To determine whether each EbA strategy would be appropriate for the Greater Niagara Region, each of them was evaluated based on their advantages and disadvantages and were then compared to case studies around the world (Table 4). When examining the case studies, several strategies (e.g. conservation of coral reefs and mangrove forests) were found not suitable in the Greater Niagara Region as they were related to a specific and different climate than this area. However, the idea of forested ecosystem may be more interesting. Forest cover has been used commonly in riparian zones and along rivers in some areas of Canada to reduce flooding from ice melt. This strategy may be suitable for the Greater Niagara region but not alone. It could be used in combination with other strategies providing benefits depending on the geological and topological characteristics of the location.

Managed realignment and retreat have shown promise as a sustainable strategy in many areas. This strategy was beneficial in low impact conditions where wave attenuation might not be as high and these realigned habitats, such as salt marshes, creating important biodiversity benefits for many shorebird species. However, this option may not always be feasible especially in areas that are highly developed. Overall, the results from this scoping review indicate that a combination of living shorelines and beach nourishment would be most beneficial for the Greater Niagara Region as EbA. Case studies showed that both strategies could increase habitat for shorebirds, which would be beneficial for many of the surrounding beaches in the Niagara Region. Marshes and coastal grasslands provide feeding ground for many migrating shorebirds, while beach nourishment can increase the area for nesting birds.

Analysis of Ecosystem-based Strategies with Nature-based Solution Principles

To determine whether each EbA strategy would be appropriate for the Greater Niagara Region, each strategy was compared with the NbS principles (Table 4). Overall, the strategies identified by the scoping review met on average 4.25 of the NbS principles. These results showed that the majority of the EbA strategies did not meet all eight of the NbS core principles including coral reefs, mangrove forests, forest cover, managed retreat and realignment, and beach nourishment and sand dunes. Only living shorelines met all of the eight core principles. Figure 6 illustrates the number of strategies meeting each individual principle. Only two strategies met Principle 3 categorizing these strategies as site-specific natural and having cultural contexts such as traditional, local and scientific knowledge, making it the least relevant principle in regard to EbA strategies. Principles 2 and 6 were met by all six strategies identified by the scoping review stating that these strategies can be implemented alone or in an integrated manner with other solutions to societal challenges as well as can be applied at a landscape scale.

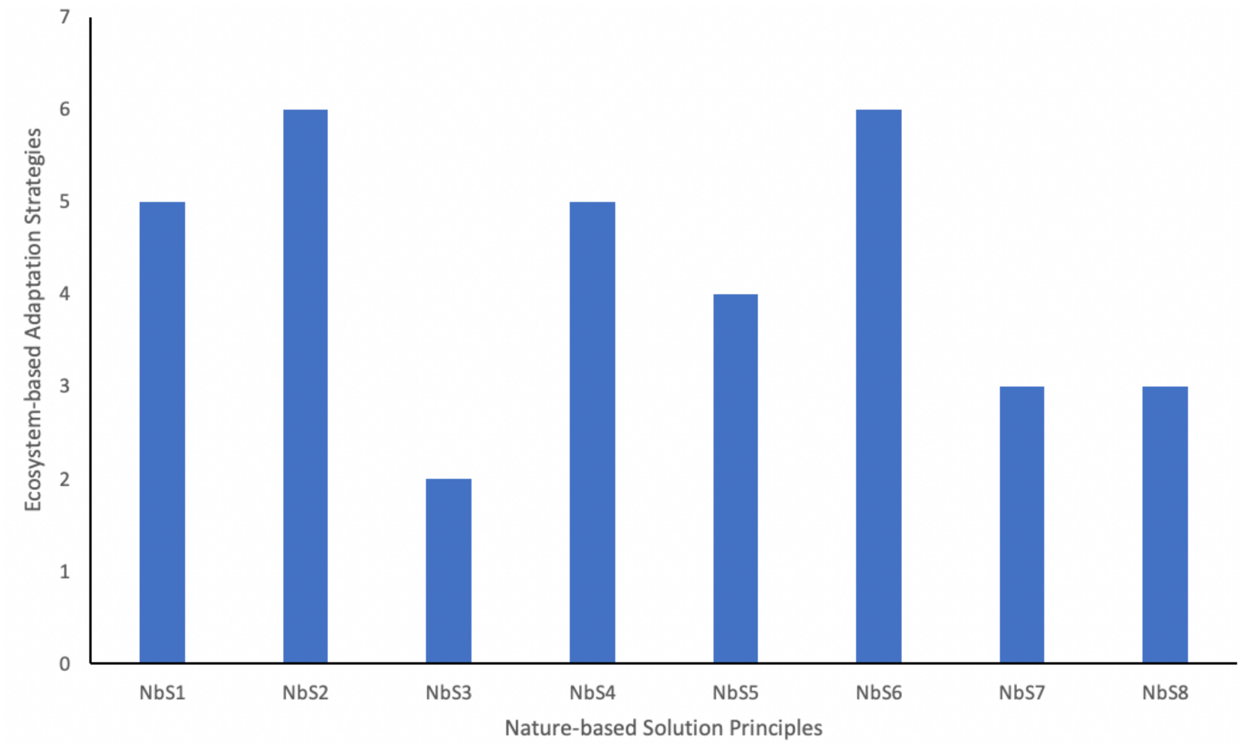

Figure 6. The overall trend of how many EbA strategies met each individual NbS principle evaluated in this scoping review as seen in Table 4.

Table 4. Results from analyzing various EbA strategies. A full list of references can be seen in Appendix C. NbS core principles were evaluated from a paper done by Cohen-Shacham et al., (2019).

EbA Strategy	NbS Core Principles	Pros	Cons	Application	Evaluation
Coral reefs	NbS2, NbS4, NbS5, NbS6 Source: 1, 11, 16, 24	- Natural ecosystem resilience developed in response to SLR - Can rise in response to SLR - Reduces wave strength and protects shorelines Source: 1, 11, 16, 21, 24	- Threatened by ocean acidification and human development - Requires specific water conditions to survive Source: 1, 27	Tropical areas – Coral reef restoration and management is used often in beach restoration following events causing erosion. Source: 21, 27	Not suitable for the Greater Niagara Region. Source: 21, 27
Mangroves	NbS1, NbS2, NbS4, NbS5, NbS6, NbS7, NbS8	- Provides ecosystem goods - Increase fishery yields by providing habitat for aquatic juvenile stages - Cost effective and can provide net economic benefits - Shoreline protection - Occur in a wide variety of coastal habitats	- Coastal development limits ecosystem services important to their survival - Complex geophysical interactions make management difficult - A variety of species with different requirements	Angola, Africa – Mangrove trees planted along 5 coastal protected areas which includes one IBA in Quicama National Park. These areas are vital nesting and feeding sites for many shorebird species.	In tropical climates only and therefore not suitable for the Greater Niagara Region.

		- Keep up with SLR through vertical accretion	- Cost to managing degraded mangroves - Storms damage trees through defoliation - Increasingly vulnerable to SLR	Used commonly for tropical cyclone protection in USA, China, India and Mexico.	
	Source: 1, 2, 13, 19, 24	Source: 1, 2, 11, 12, 19, 21, 24, 26	Source: 3, 13, 17	Source: 2, 19	Source: 17, 19
Forest cover	NbS1, NbS2, NbS3, NbS4, NbS5, NbS6	- Trap water reducing run off rate and erosion - Provides water filtration - Reduction in floods protecting human lives and properties - Increases habitat diversity - Can enhance tourism and recreation - Provides shade reducing temperature levels	- Heavily affected by increasing population density - Certain species are more tolerant - Often best suited for riparian areas and efficiency depends on location (upstream vs. downstream, etc.) - Extensive national regulations for buffer properties	Heavy forested area planted near shorelines or along riparian areas to provide canopy cover. India – Used in both coastal and agricultural areas with high population densities. Canada – Used along rivers to reduce flooding from ice melt.	More commonly used in riparian river zone, may not be best suitable alone for the Greater Niagara region. However, in combination with other strategies may provide benefits.

	Source: 4, 7, 11	- Enhances natural resilience Source: 4, 6, 7, 11, 26	- Tree falls can affect resilience of shorelines Source: 4, 6, 7, 8	Source: 4, 26	Source: 26
Living shorelines	NbS1, NbS2, NbS3, NbS4, NbS5, NbS6, NbS7, NbS8	- Address erosion through restoration and protection - Either enhance existing habitats or create new natural habitats which increases biodiversity -Rough surface reduce wave height and strength - Enhance water quality through filtering the water - Roots retain sediment and organic matter - Ability to adapt to environmental change and SLR - Provide water storage areas - Supports economy through tourism and	- Higher energy sites may require hybrid approaches (sometimes involving grey infrastructure) - Design and setting of area may limit restoration potential - Lack of pilot project and proper planning framework on incorporating these strategies to coastal protection - Success depends on vegetation characteristics and width of vegetation belt	North Carolina – Living shorelines proved to be more effective than grey infrastructure (bulkheads) and more cost-efficient. German coast – Tidal marshes used along 2 study areas to battle the impacts of SLR Gulf of Mexico – Oyster reefs used to prevent vegetation retreat and to stabilize shorelines Examples of living shorelines include vegetation, coastal grasslands, and wetlands	Wetlands and coastal grasslands provide habitat and feeding ground for many migrating shorebirds. Certain applications of living shorelines would be ideal for the Greater Niagara region such as vegetation, grasslands and wetlands. However, some applications of living shorelines such as oyster reefs are not appropriate for the Greater Niagara Region.

	Source: 5, 6, 12, 14, 24	supporting fish species. - Act as CO_2 sinks Source: 5, 6, 8, 9, 11, 12, 14, 16, 21, 24, 26	Source: 5, 6, 9	Source: 5, 9, 16, 26	Source: 14, 20
Managed retreat or managed realignment	NbS1, NbS2, NbS6, NbS7	- Enables restoration of salt marshes - Economically more feasible than continued defence - Creates or improves natural habitat - Good in low impact conditions - Allows natural sand transport processes	- Not a common adaptation process - Requires proper disposal of previous defense infrastructures - Difficult in areas that are highly developed - Can be costly and at times risky in terms of maintenance	Managed retreat or realignment moves the protected shoreline to a more landward position through the partial or total removal of man-made or hard infrastructure strategies. Norfolk, UK – Used often instead of maintaining hard infrastructure defense strategies. United Kingdom – Used to manage and restore saltmarshes. New York – Coastal retreat provided an increase in piping plover habitat.	Good in low impact conditions where wave attenuation may not be as high. These realigned habitats, such as salt marshes, create important biodiversity benefits for many shorebird species. May be suitable for some areas in the Greater Niagara Region, but application could be limited.

	Source: 10	Source: 10, 22, 27, 28	Source: 10, 23, 27	Source: 10, 22, 26, 28	Source: 22, 26
Beach nourishment and sand dunes	NbS1, NbS2, NbS4, NbS6, NbS8	- Cost efficient compared to hard measures - Capacity to enhance natural processes and biodiversity - Contribution to beach recreation and tourism - More promising long-term solution then alternative strategies. - Acts as a buffer between land and water to protect human and ecological communities - Accumulates sand from eroding areas	- Requires constant maintenance, monitoring and modeling - Can have negative effects on groundwater - Slow process - Main barrier is access to sediment and sand - Planning requires multiple stakeholders - Needs regular nourishment after storms - Degree of protection depends on height of dunes	Beach nourishment involves the addition of sand to existing shorelines. Georgia – Widening beaches through beach nourishment provides more nesting habitat, attracts foraging activity and reduces nest predation Dollard coast of the Wadden Sea – Implemented the wide green dike pilot program as flood protection	A case study in New Jersey shows that beach and dune construction can increase habitat for shorebirds, which would be beneficial for many of the surrounding beaches in the Niagara Region
	Source: 6, 11, 15	Source: 6, 8, 11, 15, 18, 21, 22, 23,	Source: 6, 11, 18, 21, 28	Source: 15, 18	Source: 15, 22

Source: 1. AlverSon (2012) 2. Amado et al., (2020) 3. Berger et al., (2008) 4. Bhattacharjee & Behera (2018). 5. Bilkovix et al., (2016) 6. Borsje et al., (2011) 7. Burdon et al., (2020) 8. Carro et al., (2018) 9. Carus, Paul & Schroder (2016) 10. Cooper & Pile (2014) 11. Dedekorkut-Howes, Torabi & Howes (2020) 12. Espeland & Kettenring (2018) 13. Gilman et al., (2008) 14. Hoggart et al., (2018) 15. Hunter et al., (2015) 16. Jones et al., (2020) 17. Khan et al., (2012) 18. Marijnissen et al., (2020) 19. Menéndez et al., (2020) 20. Möller (2019) 21. Morris et al., (2018) 22. Morris et al., (2019) 23. Mycoo & Chadwick (2012) 24. Powell et al., (2019) 25. Seavey, Gilmer & McGarigal (2011) 26. Seddon et al., (2020) 27. Spalding et al., (2014) 28. Weisner & Schernewski (2013)

DISCUSSION

EbA and shorebird conservation

This scoping review evaluated 85 articles, of which 22 articles addressed shorebird conservation and protection or restoration of their habitat. These articles focused on several cases studies looking at how climate change is affecting the populations and biodiversity of a variety of shorebird species. Adaptation to climate change is vital for shorebird populations and for this reason it is necessary to examine ways to encourage sustainable strategies of adaptation. When determining which strategies were beneficial for this region, several factors were considered including climate of the area, benefits for shorebirds and which NbS principles were met. The results showed that both mangroves and coral reefs would not be suitable due to the climate (as such species cannot grow here), vulnerability and complex geophysical interactions (Amado et al., 2020; Khan et al., 2012; Menéndez et al., 2020; Morris et al., 2018; Spalding et al., 2014).

The coastlines of the 12 municipalities of the Greater Niagara Region vary significantly from place to place in terms of geology, topography, and habitats. Some strategies may be more suitable for some areas than for others. The case studies from this scoping review proposed several EbA strategies that could be used in combination and may be potentially beneficially in the coastal communities of the Greater Niagara Region. For example, forest cover has been shown to provide beneficial habitat for many shorebird species, but it best used low lying areas around lakes and in riparian zones (Borsje et al., 2011; Burdon et al., 2020). In the only case study done in Canada, forest cover along rivers helped to reduce flooding from the increased water levels due to melting ice during the spring months (Seddon et al., 2020).

Another strategy that could be beneficial in some locations along the coastline was managed realignment or retreat. A case study performed in New Jersey showed that managed retreat of the coastal zone increased the area for piping plovers to nest and rest during migration (Weisner & Schernewski, 2013). While this strategy could prove beneficial in some areas, it might become difficult to implement in areas of heavy development. Certain residential developments and tourist attractions are located too close to the coastlines in Niagara making this strategy more difficult to implement and at times entirely infeasible.

The two strategies that appear to be most feasible in the Greater Niagara Region when used in combination are living shorelines and beach nourishment. Living shorelines provide an analogous solution to mangroves as these provide similar benefits and can be customized to individual areas in the Greater Niagara Region. Several case studies in Canada have determined that living shoreline strategies such as salt marshes and coastal grasslands provide habitat and feeding ground for many migrating shorebirds (Hoggart et al., 2018; Möller 2019). This combined with a case study done in Jersey Shore indicate that beach and dune construction can increase habitat for shorebirds, which may be beneficial for many of the surrounding beaches in the Niagara Region (e.g. the dunes in Fort Erie) (Hunter et al., 2015). Both of these strategies also work well in hybrid situations where a combination of both grey and green infrastructure is required. There is a limitation to this combination as the term living shorelines include a variety of strategies (grasslands, vegetation). Future research would be needed to identify which living shoreline strategies provide the most benefits, and if these strategies should be used alone or in combination with each other.

This scoping review identified that while costs will vary according to the type of solutions, EbA strategies were more cost effective than grey infrastructure (Colls, Ash, & Ikkala, 2009; Mawdsley, O'Malley, & Ojima, 2009; Morris et al., 2018). EbA strategies also allowed for an increase in community governance and resilience while building a better understanding on the importance of managing human communities (Reid et al., 2019). This adaptation approach is important to build resilience in wildlife as it promotes conservation of biodiversity (Reid et al., 2019). EbA is currently being used by organizations such as Audubon's coastal resilience initiative, which is working towards protecting and restoring coastal habitats. It is promoted to reverse the decline of shorebird populations in coastal areas and to reduce the impacts of climate change (Audubon, 2019).

NbS principles

In order to determine whether each EbA strategy could be considered an NbS for the Greater Niagara Region, each strategy was compared with the NbS principles (Table 1). The results showed that the majority of the EbA strategies did not meet all of the eight NbS core principles including forest cover, managed retreat and realignment, and beach nourishment and sand dunes. However, according to the case studies, living shorelines met all of the 8 core principles, which provided further evidence as to why this strategy would be most beneficial for the Greater Niagara Region. Even though beach nourishment only met 5 of the 8 NbS core principles (Table 4), in combination with living shorelines, it could provide a full spectrum of the principles.

As many of these strategies did not meet the core NbS principles, EbA strategies might require improvements to enhance sustainability in the future and to be considered a NbS. The results from Figure 6 indicate that principle 3 was the least principle to be met with only two strategies related to site-specific natural and cultural contexts that include traditional, local and scientific knowledge. As NbS and EbA strategies fall among a variety of scales and include many different stakeholders, it is imperative that these strategies focus on all scales of knowledge including traditional, local and scientific in order to become more sustainable in the future (Seddon et al., 2020).

Contributions of shorebird conservation and NbS to sustainability in coastal communities

This scoping review examined strategies that could be implemented in order to achieve a more sustainable future in coastline areas of Niagara. This paper is beneficial to sustainability science as it covers many different Sustainable Development Goals (SDG) while also focusing on the three pillars of sustainability: people, planet and prosperity. The SDG are a collection of 17 interlinked goals set out by the United Nations General Assembly in 2015 in order to achieve a more sustainable future by 2030. This scoping review determined that through NbS and EbA strategies several of these goals can be achieved. NbS and EbA reduce the impacts of climate change (SDG 13) using sustainable strategies that have the potential to create safe communities for coastal residents while focusing on SDG 11 (sustainable cities and communities). These strategies also require resilient and sustainable infrastructure through innovative techniques and achieves SDG 9 (industry, innovation and infrastructure) (Amado et al., 2020).

Through focusing on adaptation strategies for the conservation of shorebird population and biodiversity specifically, this allows us to focus not only on SDG 13 (adapting to climate change) but also SDG 15 (protect and restore biodiversity) (Seddon et al., 2020; Amado et al., 2020). Through the conservation of shorebird population and biodiversity, it also encourages the growth of avitourism in many coastal communities. This results in increased levels of tourists visiting these coastal communities and can help contribute to SDG 8 (decent work and economic growth) in the touristry sector (Callaghan et al., 2018; Devitt, 2018).

Due to the large population of shorebirds found near the Niagara River, it is considered an important tourism attraction for bird watching. Ecotourism through bird watching allows coastal communities to improve their economic status while obtaining support for conservation of their natural areas (Glowinski, 2008). This study has the potential to contribute at assessing how EbA strategies can benefit IBA's in the Greater Niagara Region. These EbA strategies can help sustain IBA's through conservation of existing areas and restoration of areas at risk. Through the use of sustainable adaptation strategies, it has the potential to increase shorebird populations and biodiversity in Niagara's IBA's. Future research can be done to determine which strategy would be beneficial for each specific IBA and what benefits each strategy can bring to the shorebird ecosystem and biodiversity of each IBA.

The conservation of shorebirds has also been known to be important for maintaining some traditional activities for many people. Many communities in the Western Hemisphere rely on hunting certain species of shorebirds for food (Watts & Turrin, 2016). While this is sometimes necessary, some reports indicate that some species are being over hunted and draw concern when discussing shorebird population declines (Watts & Turrin, 2016). For this reason, many municipalities have incorporated sustainable harvest plans in hopes to create a balanced relationship between shorebirds and humans (Watts et al., 2015). In other communities, people rely on collecting the feathers or skins of certain species of shorebirds for clothes and income further contributing to SDG 8 (decent work and economic growth). For example, some Indigenous communities rely on the bird feathers of common eiders to create clothing for warmth during the winter months (Nakashima, 2002).

Limitations of natural infrastructure

Adaptation involves adjustment, decision making and transformation in communities that improve the capacity of people and their natural ecosystems to respond to climate change. In the context of climate-change planning, the term adaptation refers to human activities intended to minimize the adverse effects of climate change on the natural environment (Mawdsley, O'Malley, & Ojima, 2009). Conservation organizations and government agencies are working towards developing sustainable adaptation strategies to facilitate the adjustment of human society and ecological systems to altered climate regimes (Mawdsley, O'Malley, & Ojima, 2009). However, all adaptation strategies have their limitations including EbA and natural infrastructure.

Major limitations identified through the scoping review include barriers in regard to planning and implementation of NbS and EbA strategies. The planning and implementation of these strategies require from local and regional stakeholder involvement to connecting with the national scale (Morris et al., 2018). Collaboration among stakeholders is required in order to facilitate the necessary research needed to identify effective coastal defense and proper implementation (Morris et al., 2018). Integrated coastal zone management (ICZM) has the potential to resolve this issue. This approach can be beneficial as it integrates all aspects of the coastal zone, including geographical and political boundaries, and includes all stakeholders involved (Thia-Eng, 1993). ICZM addresses land-sea interactions of coastal activities in a coordinated way with a view to ensuring the sustainable development of coastal and marine areas while ensuring that management or development decisions are taken coherently across all sectors (Cialdea & Mastronardi, 2014). Using ICZM in combination with the NbS and EbA strategies recommended in this paper could increase the sustainability of these strategies in the Greater Niagara Region.

Funding is also required and through collaboration from a variety of sectors including both public, private and, even the federal government can help reduce the funding limitation (Seddon et al., 2020). However, NbS and EbA strategies may lead to some challenges with governance, unless a true participatory approach is used. For EbA and NbS to be successful, governance requires active cooperation and coordination between all stakeholders at all levels (Seddon et al., 2020). Measuring the effectiveness of these strategies also appears to be a major barrier. It is difficult to determine appropriate indicators and measurements for identifying the effectiveness of NbS (Seddon et al., 2020). Effectiveness can also be hard to determine due to the many different scales that NbS and EbA strategies are involved in, the level of efficiency could vary among the different scales involved. The lack of research in regard to long term success of both EbA and NbS also raises concerns for overall effectiveness (Morris et al., 2018).

EbA and NbS, in some cases, may not be possible due to the conditions of the natural infrastructure. In some areas of the Greater Niagara region, such as Lincoln, the shoreline erosion is too strong and natural infrastructure alone may not be enough to battle the effects of climate change. Hybrid solutions may be used, which is acceptable under the EbA principles. Hybrid infrastructure includes a combination of hard and natural infrastructure such as traditional concrete seawalls with water retaining features such as living shoreline vegetation (Morris et al., 2018). This provides an opportunity to maximize the strengths of both techniques while also minimizing the weaknesses of each other. Hybrid infrastructure is beneficial in coastal cities that are densely populated where there is not enough space to create or restore habitats. This is also beneficial in areas that may not have the financial resources for natural infrastructure (Morris et al., 2018).

CONCLUSION

This MRP was performed in order to assess various NbS adaptation strategies, specifically EbA strategies, that would be beneficial for the coastal communities of the Greater Niagara Region in order to protect and conserve the biodiversity of avian species. The process involved analysing the multiple strategies and comparing case studies to identify the most efficient strategies for the area. Due to the projected increase in climatic events from climate change such as stronger storms and rising water levels the coastal areas of Niagara are facing impacts such as erosion and flooding, this causes detrimental effects to the communities and the shorebirds in these areas.

After obtaining 3408 articles from the two databases, a total of 85 articles were chosen to be included in the analysis of this scoping review based on multiple inclusion criteria. Using a scoping review, this MRP analysed six different EbA strategies that could be relevant for the coastal communities of the Niagara Region. These adaptation strategies were evaluated based on which NbS principles were met and the pros and cons of all the relevant adaptation strategies for the Niagara Region were also presented. These strategies were also evaluated based on social, economic and environmental benefits for the area. It was determined that the most efficient strategies for the Greater Niagara Region were a combination of living shorelines and beach nourishment. Forest cover and managed realignment/retreat would also be beneficial in some areas, depending on geographical location and characteristics. To maximize the efficiency of sustainability of these adaptation strategies ICZM could be implemented to ensure the involvement of all stakeholders and levels of government.

Future research is required to determine how to maximize the integration of NbS principles into these EbA strategies and policy considerations have also been suggested for the future that can build upon the findings of this research. Further research can also be done to break down the various techniques of living shoreline to identify which techniques would be most suitable for the Greater Niagara region. In order to make a sound conclusion of which strategy would be best for the Niagara region, further research will be needed to identify the characteristics of the area including wave action, tidal height, sediment availability and salinity (Borsie et al., 2011). While future research is still needed and out of scope of this project, this MRP exemplifies the field of sustainability science towards adaption in coastal zones and advances the body of knowledge of sustainability science research.

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APPENDIX A: Process for search in the databases

<u>ACADEMIC SEARCH COMPLETE</u>

Keywords: *shore* AND bird AND climate change OR ecosystem-based adaptation
Results = 2073

After filters: Peer Reviewed only and Academic Journals only
Results = 2025

After filters: Language – English
Results = 1992

After filters: Excluding non-relevant industries such as food security, forestry, agriculture productivity, business etc.
Results = 1469

<u>WEB OF SCIENCE: CORE COLLECTION</u>

Keywords: *shore* AND bird AND climate change OR Ecosystem-based Adaptation
Results = 3645

After filters: Peer Reviewed only and Academic Journals only
Results = 2777

After filters: Language – English
Results = 2720

After filters: Excluding non-relevant industries such as anthropology, agriculture, law, political science, telecommunications, computer science, etc.
Results = 1939

Total = 3408

APPENDIX B: Web of Science: Core Collection search process

The complete strategy employed for searching articles on the Web of Science: Core Collection in this Scoping Review Process (includes all the limits and filters) – To meet the condition eight outlined in the PRISMA ScR Checklist

TOPIC: (*shore* AND bird AND climate change OR ecosystem-based adaptation)
Refined by: [excluding] **DOCUMENT TYPES:** (BOOK CHAPTER OR EDITORIAL MATERIAL OR BOOK OR REVIEW OR EARLY ACCESS OR DATA PAPER OR LETTER OR PROCEEDINGS PAPER) AND **LANGUAGES:** (ENGLISH) AND [excluding] **WEB OF SCIENCE CATEGORIES:** (DEVELOPMENT STUDIES OR GEOCHEMISTRY GEOPHYSICS OR COMPUTER SCIENCE INTERDISCIPLINARY APPLICATIONS OR MYCOLOGY OR TOXICOLOGY OR PARASITOLOGY OR ANTHROPOLOGY OR ASTRONOMY ASTROPHYSICS OR METEOROLOGY ATMOSPHERIC SCIENCES OR BIOCHEMICAL RESEARCH METHODS OR AUTOMATION CONTROL SYSTEMS OR FORESTRY OR FOOD SCIENCE TECHNOLOGY OR PUBLIC ENVIRONMENTAL OCCUPATIONAL HEALTH OR MATHEMATICS INTERDISCIPLINARY APPLICATIONS OR MICROBIOLOGY OR ENTOMOLOGY OR CELL BIOLOGY OR CHEMISTRY ANALYTICAL OR IMAGING SCIENCE PHOTOGRAPHIC TECHNOLOGY OR EDUCATION SCIENTIFIC DISCIPLINES OR COMPUTER SCIENCE SOFTWARE ENGINEERING OR HISTORY PHILOSOPHY OF SCIENCE OR COMPUTER SCIENCE THEORY METHODS OR IMMUNOLOGY OR ENGINEERING ELECTRICAL ELECTRONIC OR NEUROSCIENCES OR MATHEMATICAL COMPUTATIONAL BIOLOGY OR TELECOMMUNICATIONS OR POLITICAL SCIENCE OR GENETICS HEREDITY OR VETERINARY SCIENCES OR AGRICULTURAL ENGINEERING OR ENERGY FUELS OR CHEMISTRY MULTIDISCIPLINARY OR ENDOCRINOLOGY METABOLISM OR HEALTH POLICY SERVICES OR SOCIOLOGY OR INFORMATION SCIENCE LIBRARY SCIENCE OR BUSINESS OR INSTRUMENTS INSTRUMENTATION OR BIOCHEMISTRY MOLECULAR BIOLOGY OR EDUCATION EDUCATIONAL RESEARCH OR MATHEMATICS APPLIED OR AGRICULTURE MULTIDISCIPLINARY OR MEDICINE RESEARCH EXPERIMENTAL OR BIOTECHNOLOGY APPLIED MICROBIOLOGY OR PHARMACOLOGY PHARMACY OR LAW OR STATISTICS PROBABILITY OR FISHERIES OR VIROLOGY OR AGRICULTURE DAIRY ANIMAL SCIENCE OR AGRICULTURAL ECONOMICS POLICY OR ART OR INTERNATIONAL RELATIONS) **Timespan:** All years. **Indexes:** SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC.

APPENDIX C: References for scoping review shown in Table 4

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APPENDIX D: PRISMA-ScR Checklist

Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
TITLE			
Title	1	Identify the report as a scoping review.	Title Page
ABSTRACT			
Structured summary	2	Provide a structured summary that includes (as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.	ii
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach.	10
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives.	3
METHODS			
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number.	N/A
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.	12, 38
Information sources*	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed.	12, 38
Search	8	Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated.	39
Selection of sources of evidence†	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.	12-14
Data charting process‡	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.	N/A
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	N/A
Critical appraisal of individual sources of evidence§	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe the methods used and how this information was used in any data synthesis (if appropriate).	N/A
Synthesis of results	13	Describe the methods of handling and summarizing the data that were charted.	12-14

(Source: Tricco et al., 2018)

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
RESULTS			
Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.	13
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	15-23, 30-36
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12).	N/A
Results of individual sources of evidence	17	For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives.	15-23
Synthesis of results	18	Summarize and/or present the charting results as they relate to the review questions and objectives.	15-23
DISCUSSION			
Summary of evidence	19	Summarize the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups.	15-28
Limitations	20	Discuss the limitations of the scoping review process.	27-28
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps.	28-29
FUNDING			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review.	N/A

JBI = Joanna Briggs Institute; PRISMA-ScR = Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews.

* Where *sources of evidence* (see second footnote) are compiled from, such as bibliographic databases, social media platforms, and Web sites.

† A more inclusive/heterogeneous term used to account for the different types of evidence or data sources (e.g., quantitative and/or qualitative research, expert opinion, and policy documents) that may be eligible in a scoping review as opposed to only studies. This is not to be confused with *information sources* (see first footnote).

‡ The frameworks by Arksey and O'Malley (6) and Levac and colleagues (7) and the JBI guidance (4, 5) refer to the process of data extraction in a scoping review as data charting.

§ The process of systematically examining research evidence to assess its validity, results, and relevance before using it to inform a decision. This term is used for items 12 and 19 instead of "risk of bias" (which is more applicable to systematic reviews of interventions) to include and acknowledge the various sources of evidence that may be used in a scoping review (e.g., quantitative and/or qualitative research, expert opinion, and policy document).

From: Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation. Ann Intern Med. ;169:467–473. doi: 10.7326/M18-0850

(Source: Tricco et al., 2018)