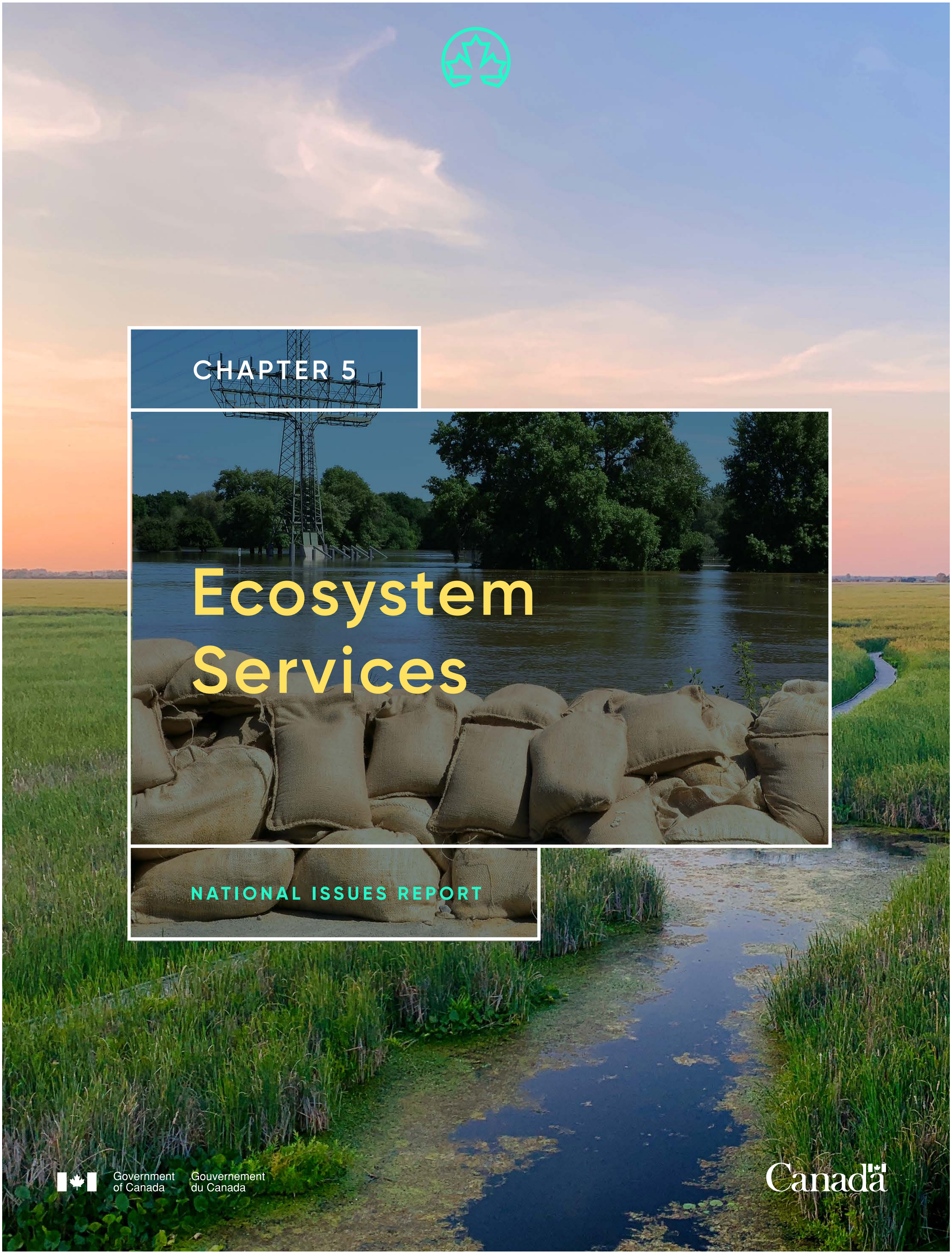

CHAPTER 5

Ecosystem Services

NATIONAL ISSUES REPORT

Government of Canada Gouvernement du Canada

Canada

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Key messages

Climate change is threatening Canada's ecosystems and the services they provide (*see* Section 5.2)

Climate change is already affecting the capacity of Canada's ecosystems to provide services. Extreme weather events, in particular, and shifts in seasonal climate patterns are interacting with other pressures on ecosystems causing a range of impacts. These will continue to intensify.

Impacts will vary across Canada's ecosystems and regions (*see* Section 5.3)

Ecosystem responses to climate change across Canada's regions will vary. Northern, mountainous and coastal regions are especially vulnerable to climate change impacts on ecosystem services, due in large part to limited adaptation options. Strengthening the adaptive capacity of people and communities living in these regions is vital to maintaining ecosystem services.

Indigenous Knowledge is vital to maintaining ecosystems (*see* Section 5.4)

Indigenous Knowledge is critical for maintaining ecosystems and the services they provide in a changing climate. Indigenous Knowledge Systems encompass different perspectives for understanding environmental complexity, and provide strategies to reduce, manage and adapt to environmental change in a place-based and holistic manner.

Nature-based approaches to adaptation maximize benefits (*see* Section 5.5)

Nature-based approaches to adaptation reduce climate change risks to communities, and are often cost-effective and flexible compared with engineered alternatives. They also deliver a wide range of social, environmental and economic co-benefits, and help to strengthen the adaptive capacity of communities.

5.1 Introduction

Ecosystems play an important role in supporting society through the goods and services they provide, such as food, clean water, air purification and climate regulation. They also contribute to climate change mitigation, by sequestering carbon from the atmosphere. The services provided by ecosystems are impacted by multiple factors, including land-use change and overexploitation, which can reduce their capacity to deliver benefits in the short and long term. As the climate continues to change and ecosystems shift in response to changing environmental conditions, their capacity to provide these services will be affected. Maintaining, restoring and managing ecosystems to address climatic and non-climatic stressors are key strategies for reducing their vulnerability in the face of climate change, by enhancing their resilience to changing conditions. Considering the important connections between Indigenous communities and nature, Indigenous Knowledge is vital to understanding how climate change is affecting ecosystems and to the design and implementation of approaches for their preservation and management.

Ecosystems also play an important buffering role in reducing the severity of climate change impacts on society, including through services such as flood attenuation and storm surge protection. Increasingly, nature-based approaches to climate change adaptation are being explored and adopted at different levels as lower-cost measures (in comparison to engineered approaches) for reducing climate change risks, while also delivering a range of social and economic co-benefits.

5.1.1 Chapter scope and structure

This chapter explores the risks and complex impacts that climate change poses for Canada's ecosystems and the services they provide, as well as opportunities for adapting to climate change. It begins by presenting an overview of key concepts, definitions and considerations. The chapter then discusses the diverse ways in which climate change is currently affecting and is anticipated to affect ecosystems and their services in the future, with examples pertaining to different types of ecosystems and in various regions across the country. The chapter also discusses the role of Indigenous Knowledge in understanding and responding to climate change impacts to ecosystems. The chapter then addresses the growing role and rapidly evolving recognition of nature-based approaches to adaptation for reducing climate change impacts to society. Case stories are included throughout the chapter to provide practical, on-the-ground examples of adaptation in this field.

The chapter focuses on four key messages, which highlight the current state of knowledge on issues of priority. As such, it does not provide a comprehensive summary of climate change impacts and adaptation considerations across all regions, ecosystems and social groups. The author team recognizes that many knowledge gaps remain and that there are a number of emerging issues related to this topic, which are discussed towards the end of the chapter.

This chapter builds from the Biodiversity and Protected Areas chapter of *Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation* (Nantel et al., 2014). It is, however, the first chapter within Canada's national knowledge assessment process to examine ecosystem services and nature-based approaches to adaptation. As such, it is intended to serve as an initial input into the rich and rapidly-evolving dialogue around this topic. Future assessments will build from this chapter and endeavour to capture and reflect the learning and new knowledge that is being generated through the multitude of projects and research currently underway in this area.

5.1.2 Canadian context

Canada is home to a wide range of ecosystems, which deliver extensive services to society. The Canadian Council on Ecological Areas (2014) defines 18 terrestrial ecozones, 12 marine ecozones and one freshwater ecozone for the country, where an "ecozone" is the broadest level of ecological classification used in Canada (*see* Figure 5.1).

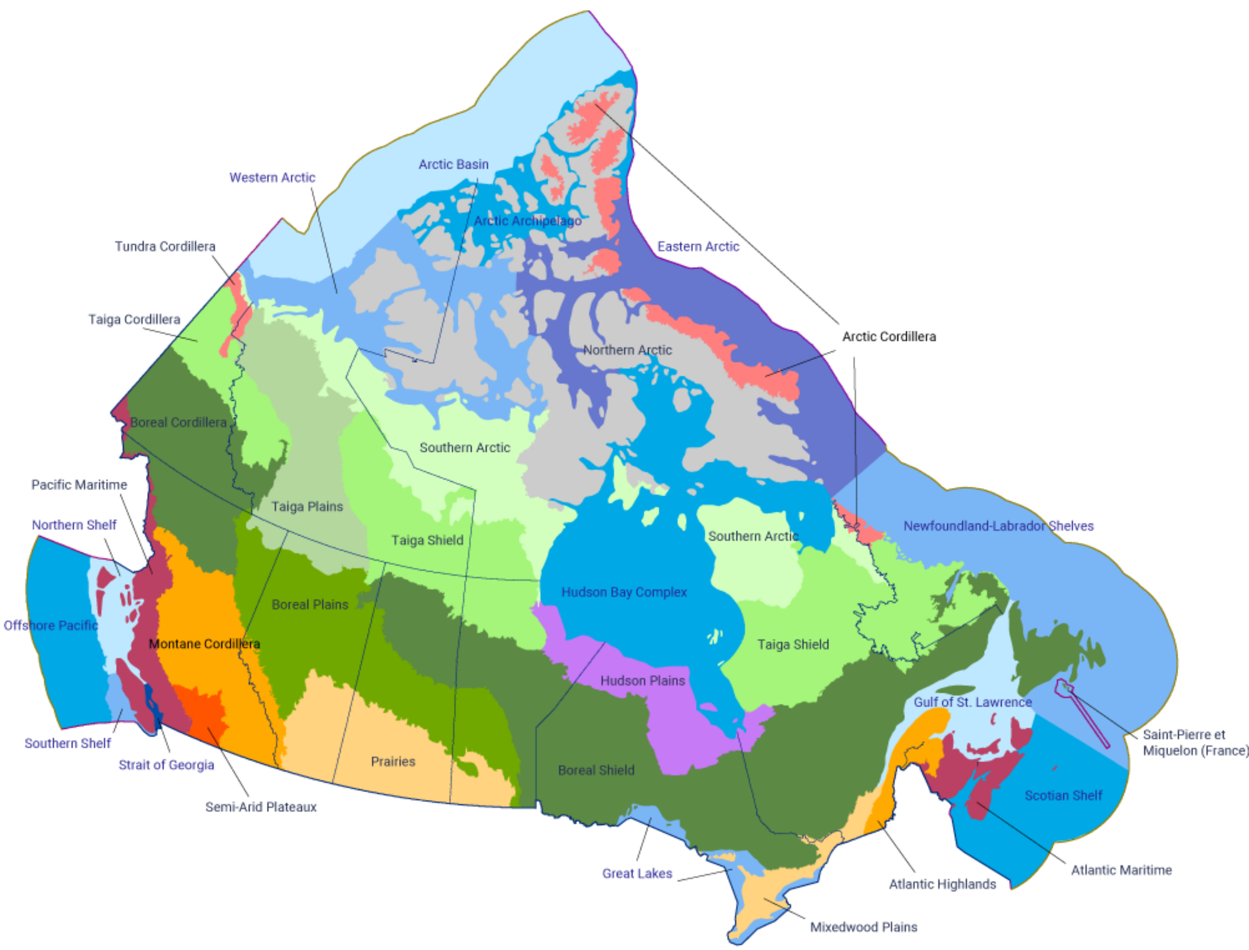


Figure 5.1: Map of Canada's terrestrial and marine ecozones. Source: Adapted from Canadian Council on Ecological Areas, 2014.

Canadians derive indispensable benefits from ecosystem services, which contribute to culture, economies, jobs, health and other dimensions of human well-being. The economic value of ecosystem services in Canada is estimated to be at least $3.6 trillion per year (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services [IPBES], 2018), which was more than double the nation's GDP in 2018. Canada is recognized as one of five countries that, together, host 70% of the world's remaining untouched wilderness areas (Watson et al., 2018), and is considered to hold a greater capacity to supply ecosystem services than the global average (IPBES, 2018). An estimated 285.8 million tonnes of biomass—agricultural crops, livestock and poultry, milk, maple products, honey, forestry and fisheries—were extracted for human use in 2010 from Canada's terrestrial and aquatic ecosystems (Statistics Canada, 2013). While Canada overall scores highly on the new Biodiversity and Ecosystem Services Index developed by Swiss Re Institute (2020), ecosystems in some parts of the country may be in decline, with resulting impacts to ecosystem services (*see* Box 5.1).

Box 5.1: The Swiss Re Institute's Biodiversity and Ecosystem Services Index

Recognizing nature's important contributions to quality of life and the economy, the Swiss Re Institute recently launched a Biodiversity and Ecosystem Services (BES) Index[1], which aggregates data from across ten different categories—including habitat intactness, local air quality and climate regulation, erosion control and coastal protection—at a resolution of 1 km² (*see* Figure 5.2). This approach allows for a localized analysis of ten categories of biodiversity and ecosystem services, as well as assessments at the countrywide and regional levels. The index is also helpful for highlighting connections between BES and economic sectors (Gray, 2020).

1 Patent pending.

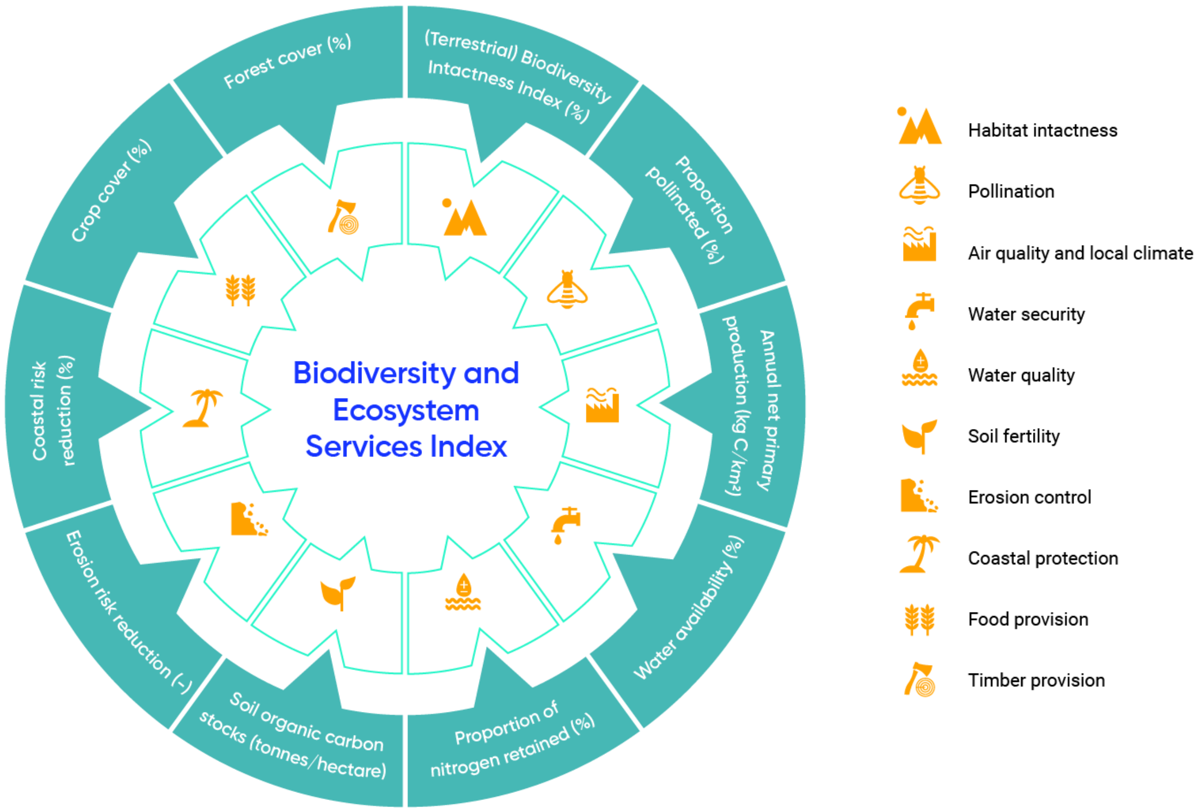
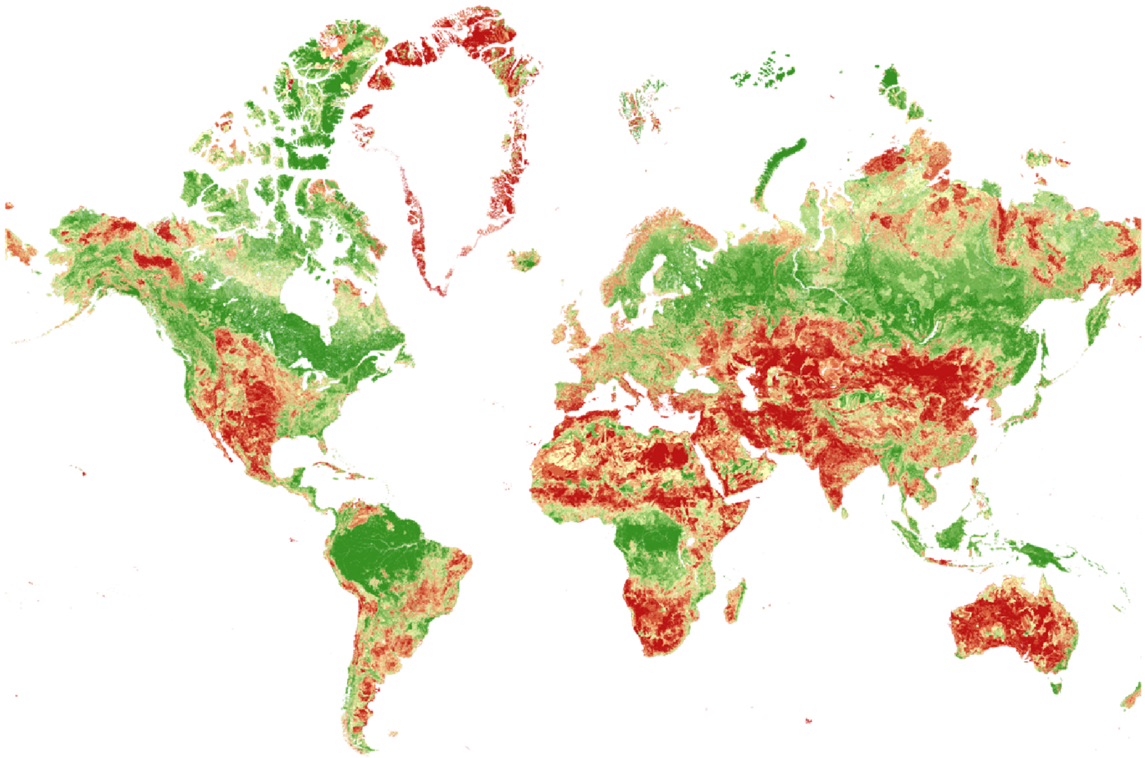


Figure 5.2: Ten categories that are considered within the new Biodiversity and Ecosystem Services Index developed by Swiss Re, which allows for country-wide or regional assessments of the state of biodiversity and ecosystem services. Source: Adapted from Gray, 2020.

Swiss Re considers locations with high BES Index values (i.e., in the upper 15th percentile globally) to be "intact" ecosystems, with high capacity to provide ecosystem services. In contrast, locations with low BES Index values (i.e., in the lower 15th percentile globally) are considered to be "fragile" ecosystems, whose capacity to deliver services has been comparatively compromised due to biodiversity loss and ecosystem degradation. Although Canada has a very high BES Index value overall, some areas within the country score very low (*see* Figure 5.3; Retsa et al., 2020).



Biodiversity and Ecosystem Services (BES) Index

- Very low (< 15)
- Low (15–30)
- Moderate (30–45)
- Moderate (45–60)
- Moderate (60–75)
- High (75–90)
- Very high (> 90)

Figure 5.3: Map indicating Biodiversity and Ecosystem Services Index values for different parts of the world. Source: Adapted from Gray, 2020.

The BES Index can help to guide decision making on the use of natural assets for making businesses and investments more resilient to climate change impacts by assessing the state of biodiversity and ecosystem services, as well as the dependence of economic activity on these services (Retsa et al., 2020). The BES Index can also be helpful for informing government decision making on efforts to restore and preserve ecosystems, thereby safeguarding the services they provide.

The preservation of ecosystem services in the face of climate change and the application of nature-based approaches to climate change adaptation, as discussed throughout this chapter, may be a strategy to help achieve multiple goals. For instance, Canada has made a range of climate- and ecosystem-related commitments as a signatory to the Convention on Biological Diversity, the United Nations Framework Convention on Climate Change, the UN Sustainable Development Goals and the Paris Agreement, is also a participant and supporter of the Global Commission on Adaptation, and is co-leading the Nature-based Solutions Action Track with Mexico. Reporting on progress made towards these commitments is a federal requirement and can be a leverage point for mobilizing coordinated efforts across government agencies and non-government organizations that are working to reach similar goals.

5.1.3 Ecosystems, ecosystem services and biodiversity

Ecosystems are a dynamic complex, composed of living organisms—plants, animals and micro-organisms—and their environment, which interact in a multitude of ways as a functional unit (Minister of Supply and Services Canada, 1995). Biological diversity, also known as biodiversity, refers to the variability among living organisms—including those living in terrestrial, marine and other aquatic ecosystems—as well as the ecological complexes of which they are part; this includes diversity within and between species, as well as diversity across ecosystems (Convention on Biological Diversity, 1992). Nantel et al. (2014) provide an overview of climate change impacts on biodiversity in Canada.

Biodiversity and ecosystems produce a rich assortment of benefits that people depend upon and value, which are often referred to as “ecosystem services” (Millennium Ecosystem Assessment, 2005) or “nature’s contributions to people” (IPBES, 2018). Examples of ecosystem services include climate regulation, regulation of freshwater and coastal water quality, carbon sequestration (*see* Box 5.2), and regulation of hazards and extreme events (*see* Table 5.1; IPBES, 2018). While ecosystem services and biodiversity are related, they are distinct concepts. For instance, managing ecosystem services can sometimes result in positive outcomes for biodiversity (e.g., promoting regulating services such as erosion control can positively influence biodiversity by safeguarding habitat), whereas other management actions can have negative repercussions for biodiversity (e.g., the selection of tree species based solely on optimizing carbon sequestration, which can lead to changes within an ecosystem that negatively affects biodiversity).

Ecosystem services are generated through an ecosystem’s organization and structure, as well as through ecological processes and functions (*see* Figure 5.4). Ecological processes refer to any change or reaction (physical, chemical or biological) that occurs within an ecosystem, such as decomposition and nutrient cycling (Millennium Ecosystem Assessment, 2005). Ecosystem functions—a subset of the interactions between biophysical structures, biodiversity and ecosystem processes—represent the potential or capacity of an ecosystem to deliver services (TEEB, 2010). For example, wetlands (an ecosystem structure) offer a form of regulation (an ecosystem function) that helps to limit the negative impacts of flooding or extreme weather events on nearby communities (an ecosystem service) (de Groot et al., 2010a).

Ecosystem services can be classified in different ways, but for the purposes of this chapter, three categories are used: 1) regulating contributions (i.e., functional and structural aspects of organisms and ecosystems that may modify environmental conditions as experienced by people or that sustain or regulate material and non-material benefits); 2) material contributions (i.e., substances, objects or other material elements taken from nature that help to sustain people’s physical existence and infrastructure, and that are typically consumed or consciously perceived); and 3) non-material contributions (i.e., services that affect people’s subjective or psychological quality of life, individually and collectively) (*see* Table 5.1; IPBES, 2018).

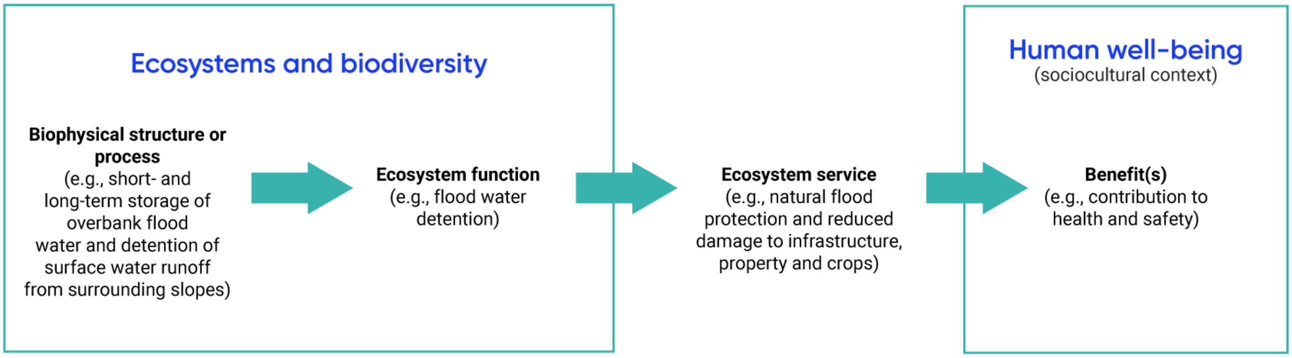


Figure 5.4: The interdependencies of ecosystems, biodiversity, biophysical process, ecosystem function and service, and human well-being. Source: Adapted from de Groot et al., 2010b.

Table 5.1: Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services (IPBES) classification of ecosystem services

CLASSIFICATION	ECOSYSTEM SERVICE	DESCRIPTION
Regulating contributions	Habitat creation and maintenance	Maintaining the ecosystem structures and processes that allow the other of nature's contributions to people to be provided.
	Pollination and dispersal of seeds and other propagules	The ways that nature contributes to the productivity of plants through fertilizing and dispersing seeds and other vegetative propagules (IPBES, 2016).
	Regulation of air quality	Regulation of CO_2/O_2 balance, ozone for ultraviolet-B absorption and polluting gases.
	Regulation of climate	Including regulating albedo, some aspects of greenhouse gas emissions and carbon sequestration (see Box 5.2).
	Regulation of ocean acidification	Maintaining the pH of the ocean through buffering the increases and decreases of carbonic acid, caused mainly by the uptake of CO_2 in the oceans.

CLASSIFICATION	ECOSYSTEM SERVICE	DESCRIPTION
Regulating contributions (continued)	Regulation of freshwater quantity, location and timing	For direct uses by people and indirect use by biodiversity and natural habitats (*see* Water Resources chapter).
	Regulation of freshwater and coastal water quality	Capacity of healthy terrestrial and aquatic ecosystems to regulate the delivery of water supply and/or filter and retain nutrients, sediments and pathogens affecting water quality (*see* Water Resources chapter).
	Formation, protection and decontamination of soils and sediments	Sediment retention and erosion control, soil formation and maintenance of soil structure, decomposition and nutrient cycling.
	Regulation of natural hazards and extreme events	The role of preserved ecosystems in moderating the impact of floods, storms, landslides, droughts, heat waves and fire.
	Regulation of organisms detrimental to humans	Including pests, pathogens, predators and competitors.
Material contributions	Energy	Biomass-based fuels.
	Food and feed	Wild and domesticated sources, feed for livestock and cultured fish (*see* Sector Impacts and Adaptation chapter).
	Materials and assistance	Production of materials derived from organisms in crops or wild ecosystems for construction, clothing, printing, ornamental purposes or decoration.
	Medicinal, biochemical and genetic resources	Plants, animals and microorganisms that can be used to maintain or protect human health either directly or through organism processes or their parts.

CLASSIFICATION	ECOSYSTEM SERVICE	DESCRIPTION
Non-material contributions	Learning and inspiration	Opportunities from nature for the development of the capabilities that allow humans to prosper through education, acquisition of knowledge and development of skills.
	Physical and psychological experiences	Opportunities for physically and psychologically beneficial activities, healing, relaxation, recreation, leisure, tourism and aesthetic enjoyment (*see* Rural and Remote Communities chapter and Sector Impacts and Adaptation chapter).
	Supporting identities	Basis for religious, spiritual and social cohesion experiences, for narrative and story-telling, and for sense of place, purpose, belonging, rootedness or connectedness (*see* Rural and Remote Communities chapter).
	Maintenance of options	Continued existence of a wide variety of species, populations and genotypes to allow yet unknown discoveries and unanticipated uses of natures, and ongoing evolution.

Source: IPBES, 2018.

Box 5.2: Storage of carbon by ecosystems

Many ecosystems sequester and store carbon, helping to reduce the accumulation of greenhouse gases in the atmosphere. Within Canada, the soils of the tundra, forests, wetlands and grasslands are of particular importance for carbon storage. Once ecosystems are disturbed, however, stored carbon—which may have built up for decades, centuries or millennia—is released to the atmosphere (IPBES, 2018). The northern permafrost region contains 1672 Petagram (Pg) of organic carbon, mostly stored in permafrost (i.e., soil or rock that remains frozen from one year to the next), which accounts for approximately 50% of the global belowground carbon pool (Tarnocai et al., 2009). Thawing permafrost due to climate change, however, increases microbial decomposition of organic carbon, releasing it into the atmosphere and triggering a positive feedback process (Schuur et al., 2008). Forest growth can sequester carbon for up to 800 years (Luyssaert et al., 2008); while boreal forests, for instance, store an immense amount of carbon, climate change is threatening their carbon storage capacity (Balshi et al., 2009; Kurz et al., 1999). Wetlands and peatlands also deliver critical services related to carbon capture, and store approximately 450 Pg of carbon (Mitsch and Gosselink, 2015; Lal, 2008). Grasslands store large amounts of carbon in plant biomass and soil, but the degree of storage is dependent on how grasslands are managed, particularly for livestock (Wang et al., 2014).

5.1.4 Direct and indirect drivers of change in ecosystem services

Ecosystems and their services are affected by a range of direct and indirect drivers. The most prominent direct drivers for the degradation of ecosystem services include habitat conversion, fragmentation and overexploitation/overharvesting, with climate change exacerbating the impacts of other drivers and poised to become the leading driver soon (IPBES, 2018). Climate change threatens the viability and resilience of some natural ecosystems and the human societies that depend upon them (Malhi et al., 2020). However, understanding of the complex ways in which ecosystems and the services they provide are affected by climate change is currently incomplete (IPCC, 2019a).

Climate change affects biodiversity and ecosystem services in a multitude of ways. Since biodiversity is critical to ecosystem resilience and functioning, it is important to consider ecosystem services within the context of broader life support systems when investigating climate change impacts, ecosystem responses, climate change adaptation and green house gas (GHG) emissions reduction (Biodiversity Adaptation Working Group, 2018). Appendix 1 provides a more comprehensive review of how climate change threatens different types of ecosystem services, the social and economic consequences of these climate change impacts, and the ways that we can harness ecosystems to adapt to new environmental conditions and reduce GHG emissions. Figure 5.5 illustrates how climate change could impact the extent to which different types of physical, social and economic drivers result in changes to various ecosystem services globally by 2050.

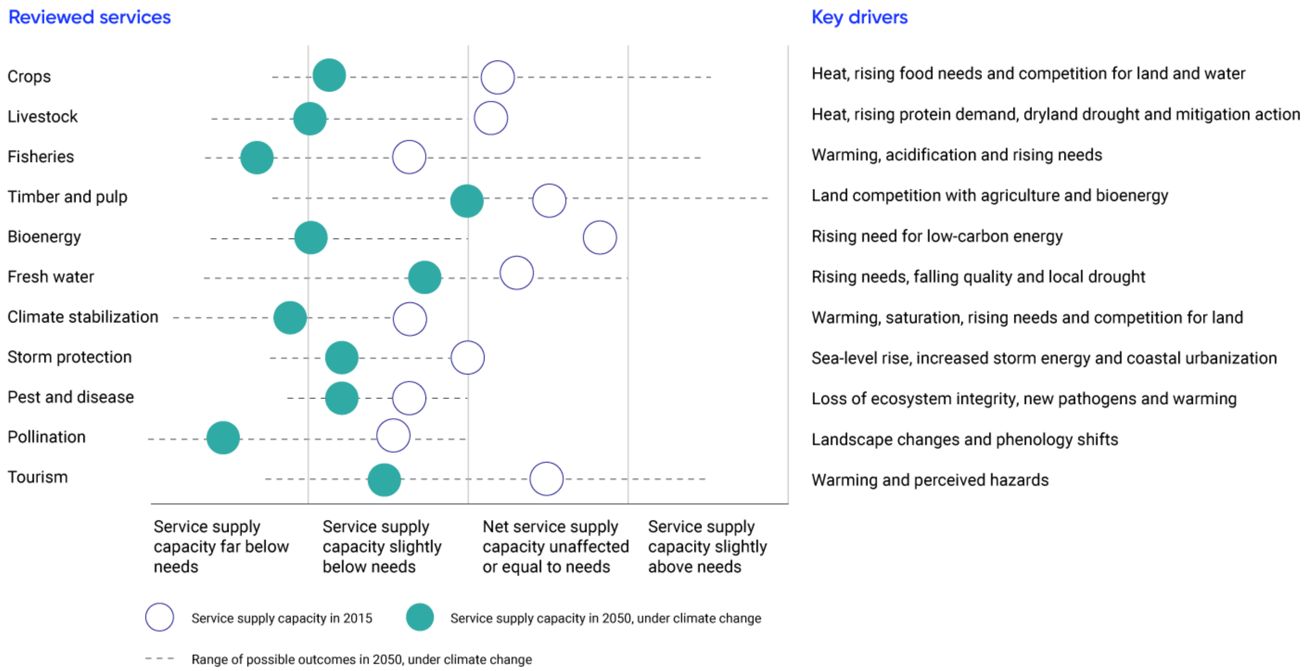


Figure 5.5: A visual summary of the relationship between supply and demand for the ecosystem services surveyed by Scholes (2016), both at the present time (open circles) and around 2050 (filled circles), under climate change. The range of possible outcomes around the year 2050 is depicted with a horizontal bar. Source: Adapted from Scholes, 2016.

Other drivers of ecosystem change include human activities such as land-use change, overexploitation of resources, pollution and changes in water balance. At the global level, infrastructure, farms, settlements and road networks occupy more than 75% of the habitable surface of the Earth (Ellis et al., 2010). Human activities have also affected oceans through, for example, eutrophication and fish stock depletion (Halpern et al., 2008), leaving only about 13% of the ocean that has not experienced human impacts (Jones et al., 2018).

Indirect drivers of ecosystem change include population and demographic trends, patterns of economic growth, weaknesses in governance systems and inequality (IPBES, 2018). Failure to account for the full economic value of ecosystem services in decision making has been identified as a key contributing factor to their loss and degradation (Organisation for Economic Co-operation and Development, 2019).

5.1.5 Feedbacks, thresholds and tipping points

It is critical to recognize that drivers of change, including climate change, do not act on ecosystem services in a linear manner. Ecosystems respond to climate change through: 1) feedbacks that can limit, reduce or further magnify impacts on ecosystems and people; 2) thresholds, where a relatively small change or disturbance (e.g., change in temperature) in external conditions causes a rapid change in an ecosystem; and

3) tipping points that identify the particular threshold where an ecosystem shifts to a new state, significantly changing biodiversity and ecosystem services.

With respect to climate change, a feedback loop is something that accelerates or decelerates a warming trend—these are two-way interactions between climate and ecosystems that amplify or dampen the climate's initial response to elevated GHG concentrations or other external climatic forcings (Kueppers et al., 2007). If the impacts of climate change result in accelerated warming, then this is called a "positive feedback"; if it results in decelerated warming, on the other hand, then this is called a "negative feedback" (*see* Figure 5.6). An example of a positive feedback loop related to climate change is the northward advance of forest vegetation with climate warming, which reduces land surface albedo and thereby promotes additional warming (*see* Figure 5.7).

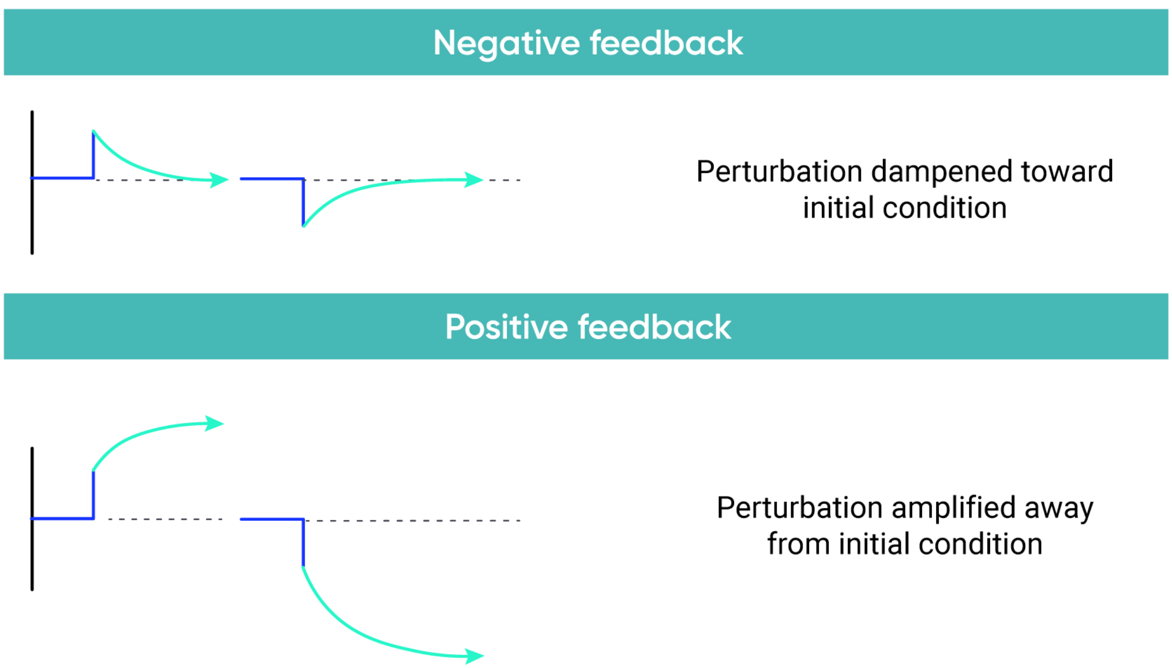


Figure 5.6: Illustration of positive vs. negative feedback loops related to climate-ecosystem interactions. Source: Adapted from Kueppers et al., 2007.

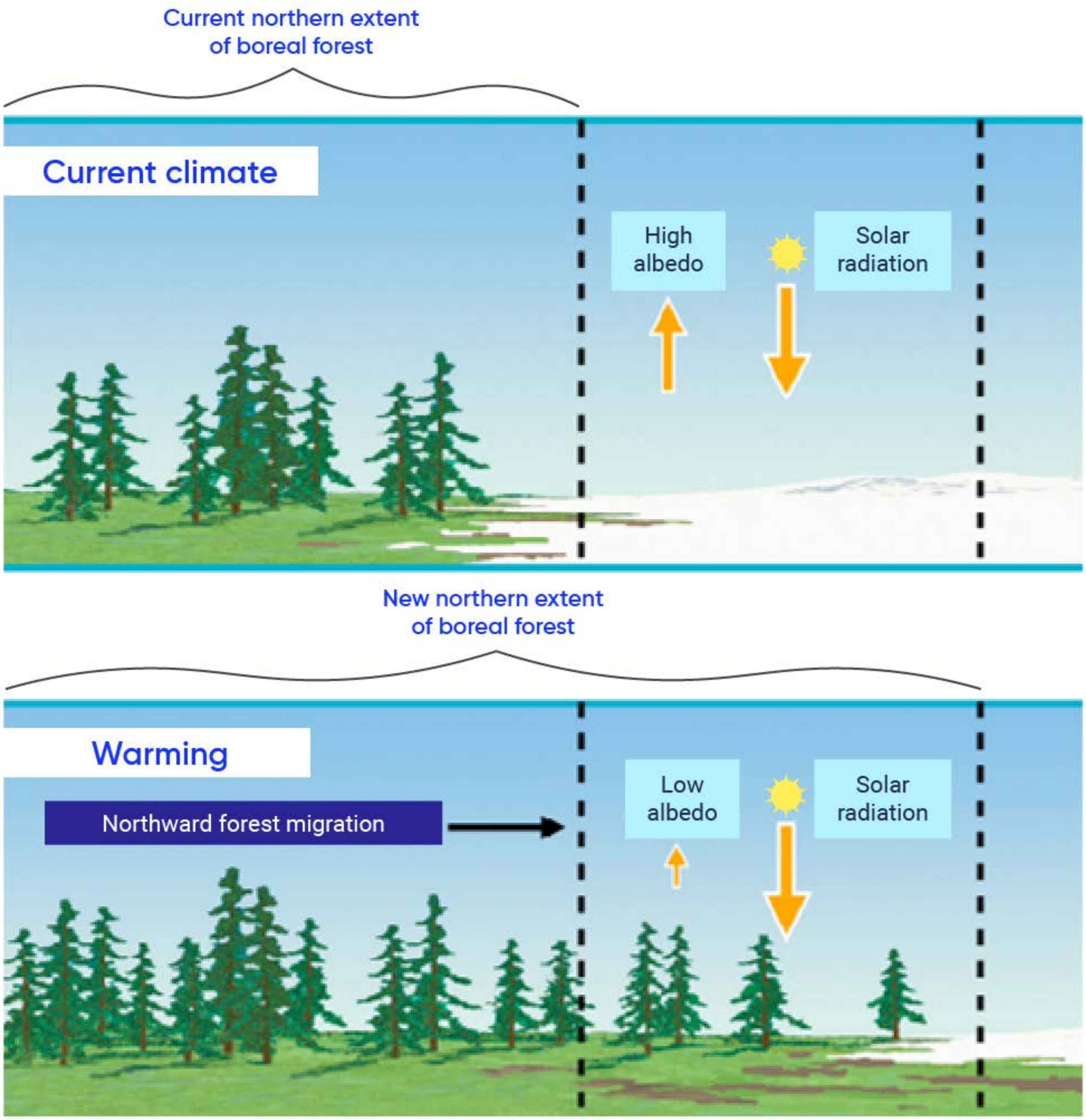


Figure 5.7: Example of a positive feedback loop, whereby the northward advance of forest vegetation due to climate warming reduces land surface albedo, thereby promoting additional warming (a positive climate-ecosystem feedback). Source: Adapted from Kueppers et al., 2007.

Ecosystems are only able to absorb pressure to a particular threshold or tipping point. Beyond these points, large and abrupt changes in ecosystem structure and function occur. Regime shifts caused by the crossing of thresholds tend to be persistent, costly to reverse (if reversal is possible) and can profoundly impact ecosystem services, as well as social and economic well-being (Leadley et al., 2014; Folke et al., 2004;

Scheffer et al., 2001). Improving our understanding of how climate change affects ecosystems and their services, combined with conservation and efforts to maintain ecosystems services (*see* Section 5.2.4), can help to minimize the negative impacts associated with changing conditions.

5.2 Climate change is threatening Canada's ecosystems and the services they provide

Climate change is already affecting the capacity of Canada's ecosystems to provide services. Extreme weather events, in particular, and shifts in seasonal climate patterns are interacting with other pressures on ecosystems causing a range of impacts. These will continue to intensify.

Climate change is already reducing the capacity of ecosystems to deliver services in the long term, including food, water, air purification and climate regulation. Impacts from extreme weather events and changes in climate patterns are of particular concern, both now and as they continue to intensify in the future. Maintaining, restoring and managing ecosystems are key strategies for reducing climate change impacts on the services that they provide.

5.2.1 Introduction

Canada's climate is changing and will continue to change. Ecosystems are sensitive to the changes outlined in *Canada's Changing Climate Report* (Bush and Lemmen, 2019), including higher temperatures, shifting precipitation patterns, increased risk of floods, drought and wildfire, and loss of sea ice and glaciers. These changes affect species distribution and ecosystems in several ways. First, changes in climate alter the growth of individual species and the timing of critical life events for plant and animal species—a phenomenon known as phenology (Körner and Basler, 2010; Yang and Rudolf, 2009). Second, species generally shift their spatial distributions northward in response to climate change (Chen et al., 2011), but can also shift in multiple directions (VanDerWal et al., 2013), thereby altering biodiversity, and ecosystem composition and functioning (Van der Putten et al., 2010). Third, increased frequency of extreme weather and disturbance events (e.g., heat waves, droughts, storms, fires, pest and disease outbreaks) related to climate change (Dale et al., 2001) can alter species composition and ecosystem functioning (Weed et al., 2013). Disturbances to specific ecosystems and their services are discussed in more detail in Section 5.3.

These climate-related impacts are already affecting the ability of ecosystems to supply services, both negatively and positively, and in many cases are projected to increase in severity as the climate continues to change into the future (Kareiva et al., 2012). Climate change impacts also combine with non-climate stressors (e.g., pollution, overharvesting and habitat loss) to reduce the capacity for species and ecosystems to provide services for human well-being (Nelson et al, 2013; Staudt et al., 2013; Hansen and Hoffman, 2011a).

5.2.2 Phenology

Species rely on a range of natural cues to signal changes in their life cycles—the study of which is referred to as phenology—and some of these cues can be impacted by a changing climate. For example, warmer temperatures can send a signal to migrating birds to arrive at breeding grounds earlier than usual, which is problematic if what they eat is dependent upon seasonal changes and not available until well after their arrival (Møller et al., 2008). At the global scale, there is strong evidence that climate change impacts on phenology are already affecting the timing of migration and breeding, and leading to asynchronies between interacting species (Cohen et al., 2018). Nantel et al. (2014) provide a summary of observed climate change impacts on phenology in Canada. These include earlier flowering of plants in the parklands of Alberta by up to two weeks (Beaubien and Hamann, 2011), delayed emergence from hibernation of Columbian ground squirrels in the Rockies (Lane et al., 2019) and extended autumn flight periods of boreal butterflies by up to one month in Manitoba (Pohl et al., 2014). While species may be able to apply adaptive response strategies to deal with phenological mismatches, these are not always ideal alternatives. For example, puffins in the Maritimes have started eating butterfish instead of herring, which has led to reports of increased juvenile starvation due to the larger butterfish being more difficult to consume (Kress et al., 2016).

The impacts of phenological changes on the provision of ecosystem services have not been widely documented across Canada, but have the potential to be widespread and significant. Consider the predicted increase in the interaction between eastern spruce budworm and black spruce lifecycles, which can lead to loss of biodiversity and potentially reduce the supply of ecosystem services (Donnelly et al., 2011). Another example is how species, such as polar bears and seals, are negatively affected by the loss of sea ice for hunting and mating (Stirling and Derocher, 2012). Also, caribou populations could decline with the loss of important lichen forage habitat or extreme weather events (Joly et al., 2012; Festa-Bianchet et al., 2011). These examples have the potential to negatively impact food webs, including threatening food security for northern communities (*see* Case Story 5.3; Stern and Gaden, 2015) and nature-based recreation in the North (Hall and Saarinen, 2010), even as warmer conditions and sea ice loss lengthen the tourist season (Stewart et al., 2012). There is also evidence of climate change disrupting plant-pollinator interactions, with studies showing complex and uneven responses of pollinators to climate warming (Morton and Rafferty, 2017). Bumblebees, for example appear less able to shift their ranges northward in response to warming, leading to shrinking distributions (Kerr et al., 2015), with implications for the many crops they pollinate.

5.2.3 Changing distributions

Ecosystems and species are shifting in response to changing climate conditions. Place-based observations, meta-analyses and models indicate that climate shifts have already begun to alter the geographical range of plant and animal species on land and in marine systems (IPCC, 2019a, b; 2014), which has implications for ecosystem composition and ecosystem service delivery. Mobile species are likely to shift over longer distances (e.g., birds, pollinators, etc.). Changes in tree species distributions and the poleward migration of freshwater fish appear to be affecting where and how timber harvesting and freshwater fishing occurs in Canada (Poesch et al., 2016; Ste-Marie, 2014).

Range shifts for a variety of tree species in Canada have been observed, including northward shifts in red maple, sugar maple and paper birch (Boisvert-Marsh et al., 2014). There is limited evidence of southward shifts for balsam fir, white spruce and black spruce based on sapling establishment; however, this may be related to the effects of natural or human-induced disturbances (Boisvert-Marsh et al., 2014). In the north, northward shifts in the sub-Arctic tree line have been observed (Rees et al., 2020; Gamache and Payette, 2005), and shrubification is causing an irreversible shift from tundra to shrubland (Fraser et al., 2014, Hill and Henry, 2011; Myers-Smith et al., 2011). These range shifts have implications for a variety of forest-associated ecosystem services, including timber production, carbon storage (*see* Box 5.2), nature-based recreation, the provision of wild food and water quality regulation. Range shifts of forest insects (Nantel et al., 2014) and agricultural pests (*see* Sector Impacts and Adaptation chapter; Campbell et al., 2014) are also likely to impact these services, but in often unpredictable ways (Scheffers et al., 2016), as the exact nature of these changes over space and time is uncertain.

Similarly, range shifts in lake-dwelling fish species have been observed, such as the northward shift in sunfish species of 13 km per decade to occupy more northern lakes in eastern Canada (Alofs et al., 2014). Changing ocean conditions due to climate change have led to substantial geographic shifts in marine animals, a pattern that is expected to continue or accelerate in the future. With rising ocean temperatures, marine species are already shifting poleward (Palacios-Abrantes et al., 2020; Poloczanska et al., 2016) or into deeper water (Dulvy et al., 2008) to stay within their preferred temperature range. Movements can be temporary; for example, greater proportions of Pacific hake (whiting) migrated northward into Canadian waters during the warm 1998 and 2015 El Niño events (Berger et al., 2017). Shifts are also associated with ecological responses and altered food-web interactions, which increase uncertainty of stock productivity and the vulnerability of fish to pollution and exploitation (Cheung, 2018; Cheung et al., 2016). These distribution shifts may simultaneously lead to the loss of native fish (e.g., Arctic cod) and opportunities for new fisheries (Stern and Gaden, 2015). Similar patterns with variable effects across economically-valuable species are expected for other locations in Canada, including the Pacific Coast (Okey et al., 2014) and the Great Lakes (Collingsworth et al., 2017).

Other potential changes to ecosystem services due to shifts in species and ecosystem distributions include the loss of berry production in the Arctic due to shrubification (Stern and Gaden, 2015), tree range expansion (Pearson et al., 2013), increased risk of diseases (such as Lyme disease) as host species (e.g., deer tick) expand their ranges northwards (Ogden et al., 2014; Leighton et al., 2012) and reduced diversity of crop pollinators (Kerr et al., 2015).

The capacity of ecosystems and individual species to adapt to climate change through range shifts, however, is not without limits. Organisms are limited in the range of environments to which they can adapt. Many have limited dispersal ability and there is not always access to newly suitable habitat in which to colonize (Lipton et al., 2018). In coastal regions, for example, beaches, dunes, sand spits, barrier islands and their associated coastal marshes can adjust to increasing sea levels by continuous landward migration (Savard et al., 2016). In some cases, however, this migration is impeded by infrastructure (such as sea walls) or by naturally-rising land (Pontee, 2013). This leads to coastal squeeze, and can result in the loss of coastal marshes and other valuable ecosystems (*see* Case Story 5.1).

Case Story 5.1: Addressing sea-level rise in Boundary Bay, B.C. through a "Living Dyke" approach

Boundary Bay, located in the greater Vancouver area on the west coast of British Columbia, is an important marine ecosystem that provides many ecosystem services to the surrounding communities of Surrey, Delta, White Rock and Semiahmoo First Nation. With 400 ha of salt marsh, the area provides habitat for many species, including juvenile salmon, and is recognized as an Important Bird Area of the Pacific Flyway (IBA Canada, n.d.). The Boundary Bay marsh also provides flood regulation, by reducing the level of wave energy that reaches the approximately 15 km of coastal dykes installed to protect the surrounding communities and regional infrastructure (Carlson, 2020). However, it is projected that by 2100, the salt marsh may be completely inundated and lost due to coastal squeeze (Carlson, 2020)—the intertidal habitat loss that arises due to the high water mark being fixed by the dyke and the low water mark migrating landwards in response to sea-level rise (Pontee, 2013). To prevent this from happening, the City of Surrey, the City of Delta and the Semiahmoo First Nation are collaborating to find an innovative solution.

The "Living Dyke" concept, led by West Coast Environmental Law, seeks to elevate areas of the salt marsh habitat by gradually delivering salt marsh material, coupled with the recurring planting of salt marsh vegetation (SNC-Lavalin Inc., 2018). By raising the marsh slowly over the course of 25 to 30 years, organisms will be able to adapt as they migrate southward, while the marsh continues to provide ecosystem services such as wave protection (SNC-Lavalin Inc., 2018). A roundtable of representatives from federal, provincial and local governments, as well as First Nations, will continuously monitor and evaluate the progress of this pilot project (Carlson, 2020).

5.2.4 Protected and conserved areas

Protected and conserved areas constitute a key component of Canada's approach to climate change adaptation and GHG emissions reduction, and are important tools for maintaining ecosystems and their services (Mitchell et al., 2021). By providing habitat and refuge for biodiversity and sequestering carbon (*see* Box 5.2), protected and conserved areas increase adaptive capacity and the resilience of ecosystems as a whole, while also conserving their ability to deliver ecosystem services. Understanding where ecosystem services are produced and where people benefit from them is another factor to consider when it comes to effectively conserving ecosystems services (Mitchell et al., 2021).

As a party to the Convention on Biological Diversity, Canada has committed to protecting at least 17% of terrestrial areas and inland water, and 10% of coastal and marine areas by 2020 (Biodivcanada, 2020). At the end of 2019, 12.1% of Canada's terrestrial area (land and freshwater) was conserved (including 11.4% in protected areas), and 13.8% of Canada's marine territory, was conserved (including 8.9% in protected areas), having surpassed the original target for marine areas (Government of Canada, 2020).

There are many types of protected and conserved areas, allowing for different activities and resource uses at the national, provincial, territorial and local level. Examples include:

- Indigenous Protected and Conserved Areas (IPCAs) (*see* Case Story 5.4), which are a classification developed through the 2020 Biodiversity Goals and Targets for Canada (Biodivcanada, 2020), in response to Canada's commitment under the Convention on Biological Diversity. This classification recognizes the important leadership role played by Indigenous people in managing their land, as well as the importance that such areas can play in biodiversity conservation and the protection of cultural heritage.
- Large forested national and provincial protected areas, which can serve as an important carbon sink at the global level, while also providing a range of ecosystem services (e.g., improved water and air quality, recreational opportunities for people, refugia for migrating species and pollinators, etc.).
- Protected and conserved areas at the local level—including urban greenspaces, municipal parks and wetlands—which deliver a range of services, such as benefits to human health by reducing the impacts of extreme heat related to climate change (*see* Case Story 5.7 and Section 5.5.2.4).

The national network of protected and conserved areas takes into account diversity across ecosystems and species, and at the genetic level. For instance, more biodiverse forests can sequester more carbon and are better equipped to resist invasions and disease (Bunker et al., 2005). Habitat connectivity is another important consideration for protected and conserved areas in the face of climate change, as species ranges respond and adapt to changing conditions. For instance, the Yellowstone to Yukon initiative is an international effort to link conserved land, and maintain and connect substantial suitable habitat for wildlife to migrate and adapt as needed in a changing climate (Yellowstone to Yukon Conservation Initiative, n.d.). As viable habitats move northwards, it may be necessary to reconsider park and refuge boundaries to continue to protect species, while providing habitat and services for nature and people (Graumlich and Francis, 2010).

5.3 Impacts will vary across Canada's ecosystems and regions

Ecosystem responses to climate change across Canada's regions will vary. Northern, mountainous and coastal regions are especially vulnerable to climate change impacts on ecosystem services, due in large part to limited adaptation options. Strengthening the adaptive capacity of people and communities living in these regions is vital to maintaining ecosystem services.

Climate change is affecting Canada's ecosystems in different ways, affecting their ability to deliver services to the communities that rely on them. Ecosystem responses will also vary depending on their exposure and sensitivity to climate change impacts, and their particular thresholds and tipping points. Understanding, assessing and mapping ecosystem changes, threats to ecosystem services and the vulnerability of communities to these changes can help to identify priority areas and pathways for adaptation. Strengthening the adaptive capacity of the communities that rely on ecosystem services is important for their preservation in the face of a changing climate, and also for minimizing the consequences to these communities in terms of human health, well-being and livelihoods.

5.3.1 Introduction

Climate change impacts on Canada ecosystems will be unevenly distributed across the country (*see* Figure 5.8). Similarly, responses of ecosystems to these changes will also vary (Breshears et al., 2011). In particular, Canada's northern, mountain and coastal regions are projected to *see* large and rapid changes due to climate change (Bush and Lemmen, 2019; IPCC, 2019a; IPBES, 2018). In many of these locations, impacts from climate change are overwhelming the capacity of ecosystems to buffer variability, with accompanying changes to ecosystem services. Managing these changes will challenge the ability of social-ecological systems to react adaptively.

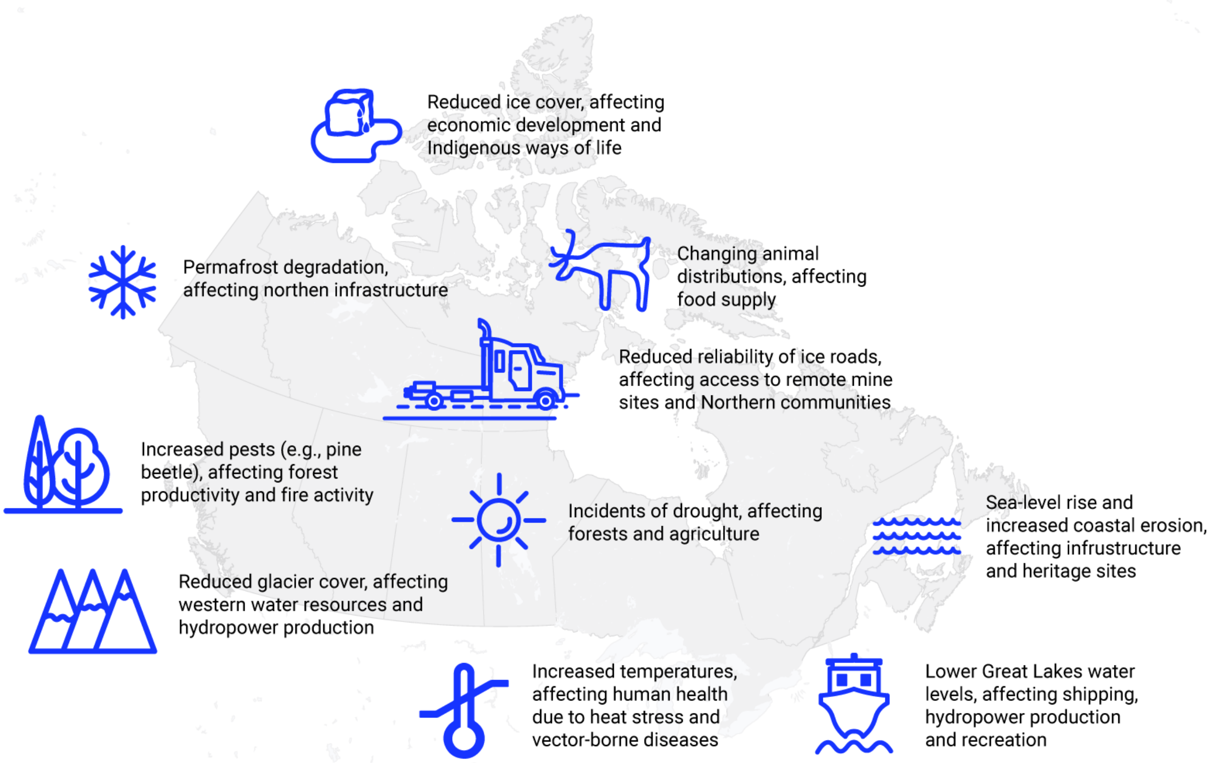


Figure 5.8: Climate change impacts in different regions across Canada, many of which have implications for ecosystems and their services. Source: Adapted from Government of Canada, 2014.

At the same time, certain segments of the Canadian population are more vulnerable to changes in ecosystem services due to their physical location, reliance on these services or socioeconomic status (Pearce et al., 2012; Ford and Pearce, 2010). Examples include Indigenous communities; communities that depend on natural resources for livelihoods (see Rural and Remote Communities chapter); communities located in Arctic, alpine or coastal areas; and individuals that are socioeconomically disadvantaged. While often resilient and adaptive, many of these communities have limited resources, access to technology and alternatives to ecosystem services that they can use to efficiently adapt to changes in ecosystem service provision. Various tools exist that can help to enhance the adaptive capacity of these communities, including by facilitating the integration of biophysical and socioeconomic data into risk identification processes and to support management decisions (see Box 5.3).

Box 5.3: Tools for measuring ecosystem flows

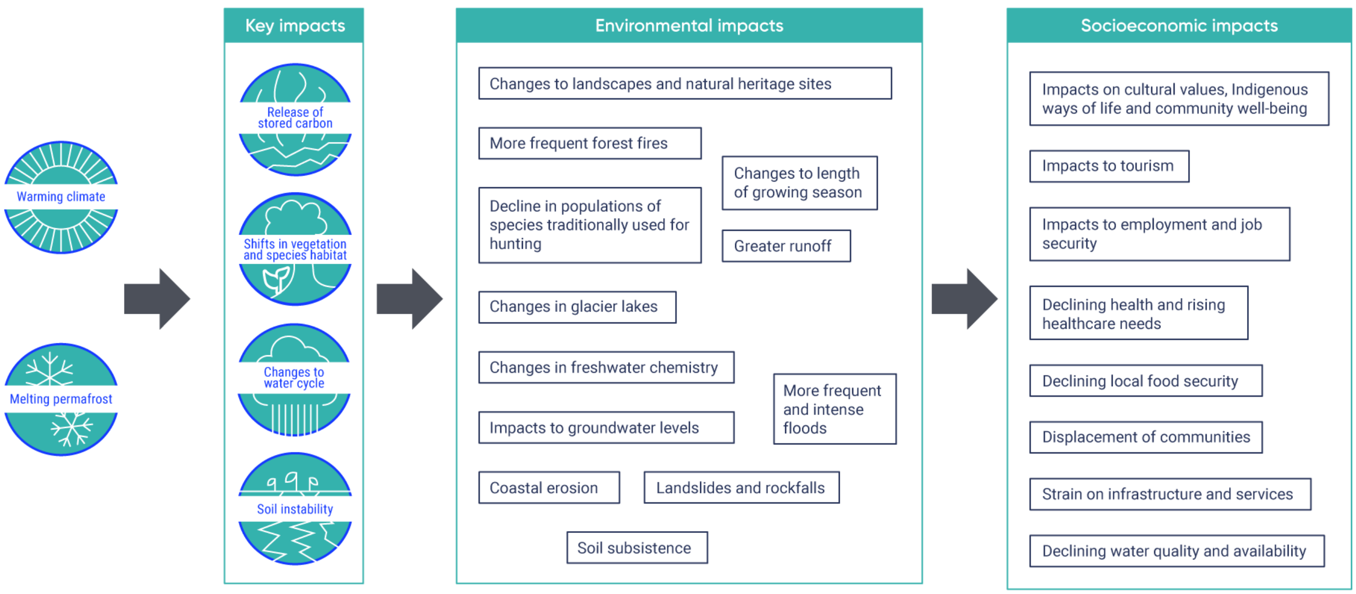
Measuring ecosystem service flows can be challenging due to the many interactions and feedback loops within ecosystems, as well as the influence of political boundaries, jurisdictional regulations and economic factors on management decisions and ultimately ecological outcomes. A variety of strategies have emerged to address measurement challenges, including using ecological boundaries (such as watersheds), proxy indicators, modelling and seeking expert input, as well as using tools to combine different types of ecosystem data. More comprehensive assessment tools and approaches are being sought, including a range of different expertise and types of knowledge (Wei et al., 2017). Threat assessment frameworks are among the various tools that can help to identify how multiple stresses are intensifying climate change impacts and to locate hotspots where ecosystem service supply is decreasing and demand is increasing (Mace et al., 2012). Likewise, ecosystem service maps that include supply and demand, as well as watersheds, economic data and other important values, are useful decision-support tools (Haines-Young et al., 2012; Naidoo et al., 2008).

5.3.2 Northern regions

Northern Canada has warmed and will continue to warm at more than double the global rate (Bush and Lemmen, 2019), with implications for biodiversity and ecosystem functioning (Pithan and Mauritsen, 2014; Screen and Simmonds, 2010). Canada's North is projected to experience increased temperature and precipitation, and decreased snowfall (Cohen et al., 2019; Vavrus et al., 2012; Callaghan et al., 2011), with associated changes in permafrost, sea ice and glaciers (Derksen et al., 2018). Rapid, widespread and significant ecosystem changes that have been observed and/or are expected, include:

- Increased growth of shrubs (shrubification), vegetation shifts and loss of Arctic tundra (Pearson et al., 2013; Myers-Smith et al., 2011);
- Poleward shifts in species and ecosystem distributions, including animal and plant species, and forest ecosystems (Kortsch et al., 2015; Brommer et al., 2012);
- Changes in snow cover, snowmelt, water availability and quality (Evengard et al., 2011);
- Invasions of new fish species and changes to freshwater and marine fisheries (Wassmann et al., 2011);
- Decline in caribou (*see* Case Story 5.3; Cressman, 2020; Mallory and Boyce, 2017), related to reduced access to food due to earlier and faster snowmelt and increasing freeze-thaw cycles, and increased harassment by insects (Cressman, 2020; Johnson et al., 2012; Hansen et al., 2011b).
- Loss of sea ice and negative impacts on polar bear and seal populations (Stirling and Derocher, 2012);
- Thawing of permafrost, destabilizing infrastructure and loss of soil carbon (Schuur et al., 2015); and
- Increases in net primary productivity in some areas in the western Northwest Territories and Yukon (Boone et al., 2018; Stralberg et al., 2018), with implications for carbon dynamics and carbon storage.

These ecological changes will have cascading impacts that affect a wide range of ecosystem services, including food provision, freshwater supply and quality, climate regulation, community health and recreation opportunities (Stern and Gaden, 2015; Allard et al., 2012; Kelly and Gobas, 2001). Cascading impacts are when a hazard generates a sequence of secondary events in natural and human systems that result in physical, natural, social or economic disruption, and where the resulting impact is significantly larger than the initial impact (IPCC, 2019b). Such impacts are complex and multi-dimensional. For example, projected thawing of permafrost in the Arctic is anticipated to affect plant and animal distributions, which could lead to a decline in hunting species and negative impacts on local food security (*see* Figure 5.9).



Note: This figure provides examples of the cascading environmental and socioeconomic impacts associated with a warming climate and melting permafrost, and is not intended to be comprehensive.

Figure 5.9: The effects of climate change on permafrost and their cascading impacts throughout society and environment. Data source: IPCC, 2019b.

Northern communities are especially vulnerable to ecosystem shifts and the corresponding changes to ecosystem services. Many northern and Indigenous communities rely on provisioning services for their food security—including wild game, marine mammals, fish and plant species (Hoover et al., 2016)—which climate change is already threatening (*see* Case Story 5.3 and Rural and Remote Communities chapter; Beaumier and Ford, 2010; Wesche and Chan, 2010). Alternatives to these food sources are limited and also extremely expensive given transport costs to the North (Mead et al., 2010). As a result, climate change may increase food insecurity in the North. Nature-based recreation, sport hunting and wildlife viewing are important components of northern economies (Chanteloup, 2013); the loss of wildlife species and shifts in their distributions may make these activities more difficult and unpredictable, while also threatening traditional cultural activities (Ford and Pearce, 2010).

Due to their remoteness, small populations and being located near the northern range limits of many species, northern communities tend to have fewer options available for adapting to changes in climate—such as extreme weather events, sea ice decline and thawing of permafrost (with resultant impacts on infrastructure)—thereby affecting their adaptive capacity (Meredith et al., 2019). While Indigenous communities are highly adaptive, limited financial resources and organizational capacity can further constrict adaptation options (*see* Northern Canada chapter; Meredith et al., 2019).

5.3.3 Mountain regions

Canada's mountainous regions are vulnerable to changes in climate, including increased temperatures and rainfall, more extreme weather events, more variable snowfall (Kohler et al., 2014; Gonzalez et al., 2010) and increased frequency of wildfires (Rocca et al., 2014). Alpine species and ecosystems are considered to be especially vulnerable to climate change, as their ability to move to higher altitudes and track climate conditions is limited by the physical height of the mountains where they are located (Rudmann-Maurer et al., 2014). Climate change is projected to result in changes to snowpack (Würzer et al., 2016), loss of mountain glaciers (Shugar and Clague, 2018), the upward movement of the tree line, and the loss of alpine species and ecosystems (Rudmann-Maurer et al., 2014). For example, glaciers of the Columbia Icefield in the Canadian Rocky Mountains experienced dramatic changes from 1919 to 2009, losing 22.5% of their total area while retreating more than 1.1 km on average over this time period (Derksen et al., 2019; Tennant and Menounos, 2013).

These changes are expected to impact key ecosystem services in these regions. In particular, loss of glacier and snow cover in mountain areas and thawing of permafrost, in combination with more extreme rainfall events, is predicted to result in increased rock fall and mudslides in some alpine areas (Huggel et al., 2011). Changes to mountain forests may also compromise their ability to protect against flooding, debris flow, landslide, rock fall and avalanches (Lindner et al., 2010). In addition, increased frequency of disturbances such as fires, wind throws and pest infestations would affect water runoff and quality (Lindner et al., 2010). Finally, landscape aesthetics may be impacted by glacier retreat and the loss of snow-covered areas for significant portions of the year, as well as shifting patterns of recreation as new areas for tourism emerge and people seek out mountain areas as refuge from heat waves (Palomo, 2017). For example, the Canadian Rockies are predicted to see a tourism increase of up to 36% by 2050 driven by warmer weather, but a potential decrease by 2080 as environmental impacts and glacier disappearance reduce the area's suitability for nature-based recreation (Palomo, 2017).

5.3.4 Forested regions

Climate change impacts on forest ecosystems and services will vary across Canada's forested regions and will often be cumulative (*see* Sector Impacts and Adaptation chapter). Climate change is a critical driver of progressive disturbances—such as pest infestations, which influence the likelihood of immediate disturbance events—while also affecting long-term forest structure and composition (van Lierop et al., 2015; Sturrock et al., 2011; Burton, 2010). Increasing disturbance is likely also affecting carbon storage (*see* Box 5.2; Arora et al., 2016; Kurz et al., 2008), recreation and water quality regulation (Ford, 2009).

Increased wind throw risks in eastern Canadian forests, as a consequence of decreased soil frost duration (Saad et al., 2017), and the die-off of aspen from drought in Alberta and Saskatchewan are also anticipated (Michaelian et al., 2010). A similar regional vegetation die-off occurred in the southwestern US due to drought and a bark beetle outbreak in 2002–2003 (Breshears et al., 2005). In this case, tree die-off led to decreased firewood and piñon pine harvesting, reduced soil erosion regulation, altered viewsheds and reduced recreation quality, although it did increase fodder production for cattle (Breshears et al., 2011). Similar changes to forest ecosystem service provision in Canada as a result of climate change may occur in specific regions.

There is an increased risk of wildland fire and drought, in the short term (Boucher et al., 2018; Boulanger et al., 2017a), as increases in temperature are projected to surpass the moderating effects of increasing precipitation on fire weather (Zhang et al., 2019). Across Canada, fire dynamics and resulting impacts on forest ecosystem services will vary substantially (Boulanger et al., 2017a; Hope et al., 2016). This spatial variation in fire activity will have significant impacts on forest ecosystem services and costs of fire suppression across Canadian provinces. For example, the Fort McMurray wildfire of 2016 cost over $3.9 billion (Insurance Bureau of Canada, 2019) and has resulted in long-term and widespread effects on rivers in the region, with resultant impacts on water quality (*see* Water Resources chapter; Emmerton et al., 2020). The potential for “mega-fires” in temperate and boreal forests due to climate change and forest management (e.g., fire suppression) will also increase with climate change (Adams, 2013). These types of large fires can shift vegetation from conifer-dominated boreal forest ecosystems to deciduous ones, or could have the potential to change temperate forests in certain locations to non-forested vegetation (Boulanger et al., 2017b). Such thresholds, if crossed, would have significant impacts on ecosystem services such as carbon storage, timber supply, climate regulation, water provision (since vegetation regrowth reduces available water) and recreation (*see* Sector Impacts and Adaptation chapter; Mina et al., 2017; Adams, 2013).

Various approaches are being used to reduce the impacts of climate change on forest ecosystems and species, such as reducing the risk of fire through active fuel management (e.g., thinning, debris removal and prescribed burning) (Astrup et al., 2018; Schroeder, 2010), planting a greater proportion of fire-tolerant species and deciduous trees (Bernier et al., 2016) and, in certain cases, pursuing assisted migration of vulnerable and important species (*see* Case Story 5.2)

Case Story 5.2: Assisted migration of Whitebark Pine in B.C. and Alberta in response to climate change

As suitable habitat for certain tree species shifts northward under a changing climate, natural migration of tree populations may not occur at the speed required for populations to remain coupled with the ecosystems in which they have evolved (Sáenz-Romero et al. 2021). This decoupling results in abiotic and biotic stresses, such as drought stress, that lead to mass tree mortality (Sáenz-Romero et al., 2021). As climate change progresses, traditional conservation methods may no longer be sufficient for protecting populations and new adaptive strategies may be required (Hällfors et al., 2017)

Assisted migration—"the human assisted relocation of genotypes through reforestation and restoration intended to mitigate future impacts of climate change on forest health and productivity" (Sáenz-Romero et al., 2021, p. 2)—is an emerging adaptation strategy that is gaining attention globally. By expanding populations in the direction that climate change will eventually take them, forest health and the ecosystem services they provide can be maintained.

Whitebark Pine (*Pinus albicaulis*) is a tree species that is foundational to diverse high elevation and sub-alpine ecosystems in the mountainous areas of British Columbia and Alberta. Its root systems help to stabilize snow, moisture and soil, and its large nutritious seeds feed a variety of bird and mammal species including Clark's nutcrackers, red squirrels and bears (Government of British Columbia, 2021). The Whitebark Pine has been listed as "endangered" under Canada's Species at Risk Act since 2012, due to its population being in steep decline over much of its range (*see* Figure 5.10). This is resulting from the combined effects of drivers such as the Mountain Pine Beetle, an introduced pathogen that causes white pine blister rust (*Cronartium ribicola*), and climate change (Government of Canada, 2011). It is projected that Whitebark Pine will be largely extirpated from its current range over the next 70 years (McLane and Aitken, 2012).

The recovery strategy for the Whitebark Pine in Canada (ECCC, 2017) reports that assisted migration techniques may need to be part of the approach used to combat habitat loss as a result of climate change, and that suitable habitat for growth needs to be identified. Field tests have been initiated to assess the capacity for assisted migration of Whitebark Pine within predicted future ranges (Sáenz-Romero et al., 2021; McLane and Aitken, 2012). One study found that the successful establishment of Whitebark Pine outside of its current range is possible, but there are certain factors that must be considered (Sáenz-Romero et al., 2021), including the potential for natural seed dispersal (i.e., whether the bird species responsible for most of the dispersal in the current species range will follow the assisted range shift) and the degree of public support for assisted migration outside of the current range (e.g., there may be resistance by local and/or Indigenous communities in introducing a non-native species into the proposed areas).

Despite the ongoing debate on the long-term success or appropriate methods of assisted migration, there is a general agreement that more field studies are needed to better evaluate and quantify the effectiveness of this approach as a long-term climate change adaptation strategy (Bucharova, 2017).

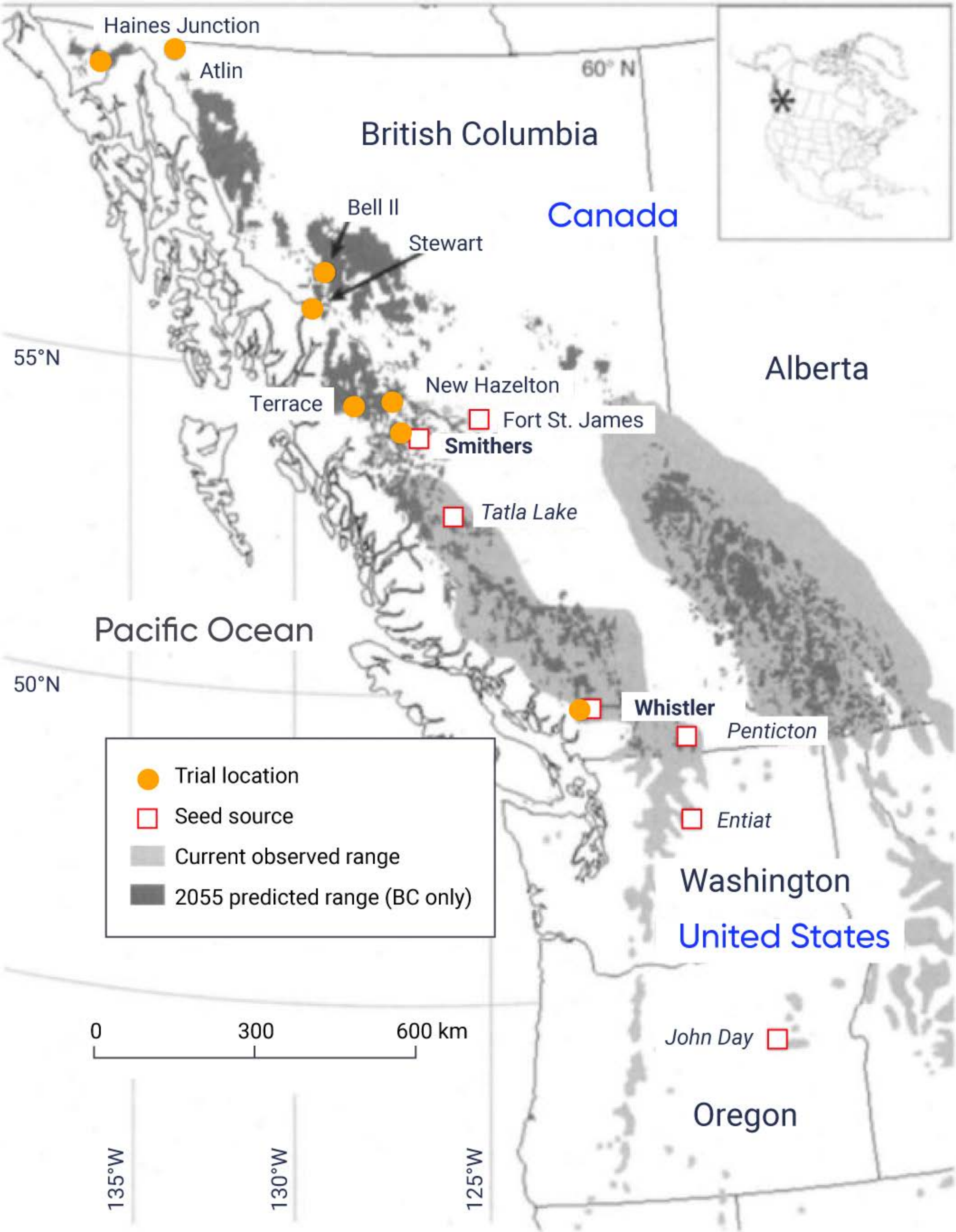


Figure 5.10: Map of the current observed range and predicted future range in 2055 for Whitebark Pine (*Pinus albicaulis*), as well as trial locations for the assisted migration experiment. Source: Adapted from Sáenz-Romero et al., 2021.

5.3.5 Coastal regions

Canada has the world's longest coastline, measuring over 240,000 kilometers (Taylor et al., 2014). Coastal regions are home to approximately 6.5 million Canadians and are a defining element of our national identity (Lemmen et al., 2016), as well as critical contributors to the economy (Association of Canadian Port Authorities, 2021, 2013). Given the importance of coastal ecosystems for coastal protection, erosion control, marine fisheries, carbon storage, habitat-fishery linkages and recreation (Barbier et al., 2011), the loss and degradation of coastal areas are likely to have substantial impacts on the provision of ecosystem services from these regions (Bernhardt and Leslie, 2013). The extent of impacts to ecosystems and people will depend on the success of adaptation measures.

Although the impacts of climate change on marine ecosystems remain poorly quantified (Lemmen et al., 2016), documented climate risks within Canada include higher temperatures and changing precipitation patterns, more intense storm surge events, changing sea levels, diminishing sea ice, changes to hydrology (including glacier melt) and changes to ocean-water properties (e.g., temperature, salinity, acidification and hypoxia) (Lemmen et al., 2016). The impacts of changes in sea ice, sea level changes and ocean acidity are briefly reviewed in the Sector Impacts and Adaptation chapter.

Rising sea level can lead to the reduction and loss of important coastal habitats such as salt marshes through a process known as "coastal squeeze" (Savard et al., 2016; Hartig et al., 2002). This occurs when ecosystems are unable to migrate landward in response to sea level rise due to a barrier, such as a sea wall or cliff (*see* Case Story 5.1; Atkinson et al., 2016). Projections of changes in sea level up to 2100 fluctuate from a rise of almost 100 cm in some East and West Coast regions, to an equivalent fall in sea level (i.e., of almost 100 cm) in some central North Coast regions (Lemmen et al., 2016), due to differences in vertical land motion (e.g., Atkinson et al., 2016). Rising sea levels will lead to increased risk of flooding, inundation and, in some instances, will threaten the viability of low-lying communities, particularly when coastal storms intensify the effects of sea-level rise (Yang et al., 2014).

The North and East Coast regions are experiencing changes to the extent, thickness and duration of sea ice, with declines in extent ranging from about 2.9–10% per decade in the North and 2.7% per decade since 1969 in areas of the East Coast (Canadian Ice Service, 2007). Impacts to people are most pronounced in the North, where changes to sea ice have made travel more dangerous, affected subsistence species (*see* Figure 5.11), compromised traditional harvesting activities and impacted well-being (Lemmen et al., 2016). Lastly, increasing ocean acidity threatens shellfish and other aquatic organisms, which can impact food provision from fisheries and aquaculture operations in the East and West Coast regions.

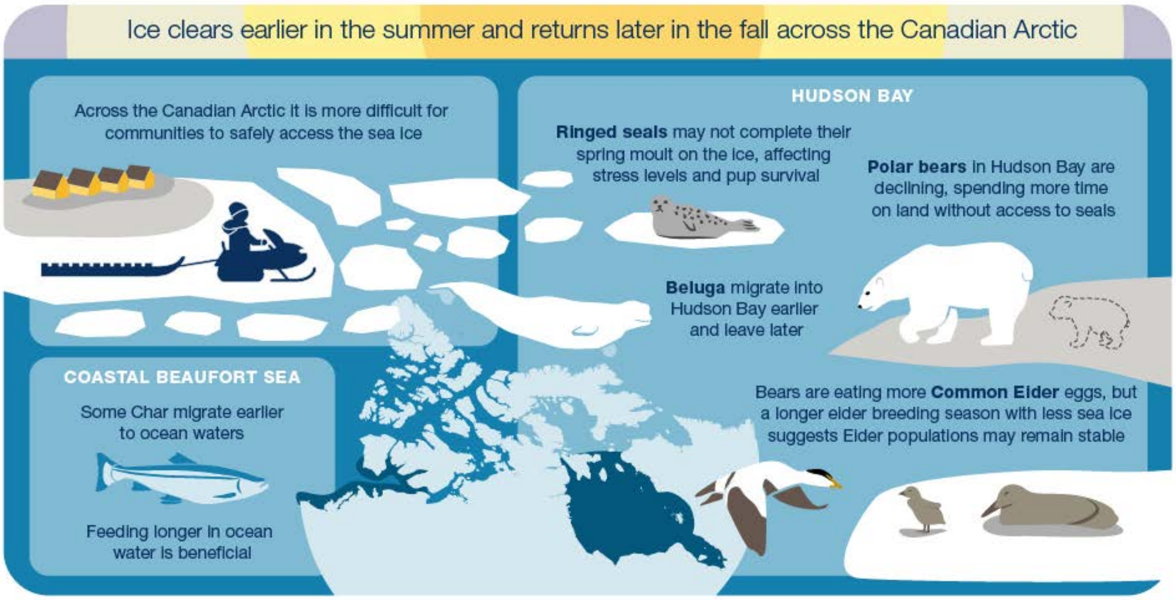


Figure 5.11: Impacts of changes in sea ice on species used for food or other purposes (subsistence species). Source: Department of Fisheries and Oceans Canada, 2019.

5.3.6 Enhancing adaptive capacity

Strengthening the capacity of vulnerable communities to adapt to climate change (i.e., adaptive capacity) is key to facilitating successful adaptation to changes in ecosystem services resulting from climate change. Adaptive capacity can take a variety of forms. Indigenous Knowledge has provided and will continue to provide an important foundation for climate change adaptation (Pearce et al., 2015) in the face of changes to ecosystem services (*see* Section 5.4 and Case Story 5.3). Diversified sources of livelihood and economic support, and regional planning initiatives that work to collectively conserve and manage ecosystem services also increase adaptive capacity (*see* Rural and Remote Communities chapter).

Increased educational, logistical and financial resources to support the management and restoration of key ecosystems that provide ecosystem services enhance adaptive capacity (Keesstra et al., 2018). Maintaining and restoring coastal ecosystems, for instance, can reduce the vulnerability of coastal areas to climate change impacts and to the associated loss or reduction in ecosystem services (*see* Case Story 5.1 and Case Story 5.6). These measures are most effective when specific climate change and ecosystem service risks and hazards are identified and incorporated into nature-based approaches to adaptation (*see* Section 5.5; Wamsler et al., 2016).

It is also important to address barriers to adaptive capacity. Comprehensive assessments of vulnerability to changes in ecosystem services and capacity to adapt to future climate change impacts have not been completed for Canada (e.g., Ford and Pearce, 2010). These could, however, help to identify opportunities for enhancing adaptive capacity with respect to ecosystem services (Boyd, 2010). In particular, most studies focus on the biophysical impacts of climate change and ecosystem services, but few studies consider the equally important socioeconomic aspects (Ford and Pearce, 2010) or seek to understand how to incorporate this information into management decisions (Keenan, 2015). This lack of information and knowledge will make it difficult for vulnerable communities, which often have limited resources and information, to adapt to the ecosystem service impacts of climate change.

5.4 Indigenous Knowledge is vital to maintaining ecosystems

Indigenous Knowledge is critical for maintaining ecosystems and the services they provide in a changing climate. Indigenous Knowledge Systems encompass different perspectives for understanding environmental complexity, and provide strategies to reduce, manage and adapt to environmental change in a place-based and holistic manner.

Indigenous peoples are increasingly taking a leadership role in addressing the challenges of climate change and environmental degradation. Given their close connections to nature and the land, Indigenous peoples are closely attuned to, and often directly affected by, changes in ecosystems and their services, which can have important ties to their culture and identity. Future land-use management practices can be better informed by Indigenous Knowledge in a way that optimizes ecological, cultural and economic benefits across their traditional territories and beyond.

5.4.1 Introduction

Indigenous peoples in Canada—including First Nations, Inuit and Métis—have been leading the protection and conservation of their traditional territories and homelands for millennia. Today, this continues through the work of Indigenous Water Protectors, Guardians, Watchmen and many other Indigenous-led initiatives to champion resiliency and harmony with Mother Earth. Indigenous peoples have strong cultural and spiritual connections to land and water, as well as long histories of adapting to social and environmental changes. They have often resided for millennia in their territories through the learning and sharing of adaptive knowledge (Houde, 2007), and this has led in many cases to increases in local biodiversity (Harlan, 1995; Blackburn and Anderson, 1993). For instance, a recent study found that Indigenous-managed lands in Canada have slightly greater levels of vertebrate biodiversity than protected areas, while also supporting a greater number of threatened vertebrate species (Schuster et al., 2019). Partnerships between Indigenous communities and other government agencies could further enhance biodiversity conservation efforts.

However, the decoupling of Indigenous lifestyles from traditional lands and the degradation of the environment can erode cultural practices, language and local ecological knowledge, ultimately compromising the sustainability of both cultural and environmental systems. Worldwide and within Canada, significant portions of Indigenous populations live in regions—such as coastal, low-lying and flood-prone areas—that are particularly vulnerable to the impacts of climate change. Indigenous populations also tend to practice resource-based livelihoods; depend upon the land as a source of food, traditional medicine and identity; and continue to live with the impacts of colonization and historical trauma. Climate change often exacerbates these pre-existing conditions (Pearce et al., 2015; Berrang-Ford et al., 2012; Nakashima et al., 2012).

5.4.2 Indigenous ways of knowing

It would be misleading to imply that a list of common cultural traits could describe the richness and diversity of Indigenous peoples. Within Canada, there exists a wide variety of nations, customs, traditions, languages and worldviews. Nonetheless, there are similarities between Indigenous Knowledge Systems (ways of knowing). These relate to in-depth knowledge of place accumulated over long timeframes, as well as a framework for understanding complexity.

Indigenous Knowledge has been described as a process that explores how constituent parts of a system interrelate, and how the systems they are a part of change over time and relate to larger systems (Berkes, 1998). It is a cumulative body of knowledge, practice and values, which are acquired through experience and observations on the land or from spiritual teachings, and handed down from generation to generation (Noongwook et al., 2007; Government of Northwest Territories, 2005; Cruikshank, 1998; Huntington, 1998). This may include an understanding of the interrelationships that occur among species, their connections within the biophysical environment, the spatial distributions and historical trends of spatial and population patterns. This form of knowledge evolves over long time periods and involves constant learning-by-doing, experimenting and knowledge-building (Houde, 2007; Neis et al., 1999; Nickels, 1999; Duerden and Kuhn, 1998; Ferguson and Messier, 1997; Mailhot, 1993; Freeman, 1992; Johnson, 1992a, b). Indigenous Knowledge provides insights, for example, to:

- Understand the condition of, and changes to, ecosystem service functions within traditional territories, serving as a means of measuring ecological integrity and resilience;
- Provide early warnings of stressors to the natural environment (e.g., changes among plant or animal species), including to the impacts of climate change (Olsson et al., 2004); and
- Create an expanded and multidimensional picture of adaptation related to concepts such as flexibility (e.g., responding to changes in seasonal cycles of harvest and resource use), hazard avoidance (from detailed knowledge of the local environment and understanding of ecosystem processes) and emergency preparedness (e.g., knowledge of how to respond in emergency situations) (Pearce et al., 2015).

The growing realization that many management policies fail to account for the complexity of ecosystems or local contexts has driven the need for new adaptive processes to cope with change (Houde, 2007; Gunderson, 1999; Holling and Meffe, 1996). Indigenous Knowledge provides insights into implications for livelihoods, cultures and ways of life, as well as locally-appropriate and culturally-relevant adaptation strategies (*see* Case Story 5.3 and Rural and Remote Communities chapter; Pearce et al., 2015; Ford and Pearce, 2012; Pearce et al., 2011) by building quantitative and qualitative data from a large number of variables (Berkes and Berkes, 2008). Recognizing that Indigenous Knowledge Systems differ from non-Indigenous Knowledge and that they form an equal part in policy development, programs and decision making yields richer and more balanced outcomes for maintaining ecosystems and their services, upon which many Indigenous communities rely.

Case Story 5.3: Preserving Tłı̨chǫ culture in the face of declining Barren ground caribou populations

The Tłı̨chǫ people are working to build resilience in the face of climate change impacts on their land and culture. The Tłı̨chǫ people, whose traditional territory lies within the Northwest Territories, have witnessed dramatic climate change impacts on their most culturally and socially important animal, the ekwǫ̀ or barrenland caribou (also referred to as the Barren ground or Bathurst caribou). The Tłı̨chǫ people depend on the caribou herd not only for food, but also for clothing and equipment (*see* Figure 5.12 and Figure 5.13). This keystone species, located at the centre of Tłı̨chǫ culture, is in rapid decline and climate change is playing a significant role (Cressman, 2020; Mallory and Boyce, 2017). Earlier, quicker snowmelt and increasing freeze-thaw cycles throughout the year have decreased food availability and increased harassment by insects, compounding stresses on the herd and resulting in higher instances of starvation and calf mortality (Cressman, 2020; Johnson et al., 2012; Hansen et al., 2011b).

Surveys of the caribou population show that the barrenland herd has been declining sharply for decades, from 472,000 animals in 1986 to only 8,200 animals in 2018 (Government of Northwest Territories, n.d.). To protect the barrenland caribou, and in turn the Tłı̨chǫ culture, the Tłı̨chǫ Government and the Government of the Northwest Territories placed a ban on barrenland caribou harvest in 2015, which is still in effect. Due to the decline of caribou, the Tłı̨chǫ people do not go to the barrenlands as often, where they share traditional knowledge, learn the language and go hunting with their families (Galloway and Arvidson, 2020). Losing the caribou entirely poses even greater risks to a part of the Tłı̨chǫ identity and culture. It is important for these communities to have agency in adapting to these changes and support in undertaking their approaches to adaptation.

The Tłı̨chǫ Government, with support from Indigenous Services Canada, initiated the Tłı̨chǫ Dǫtaàts'eedı program ("to share food among the people") in 2018 in all four Tłı̨chǫ communities. The program pairs young adults with experienced harvesters to go fishing, hunting, trapping, snaring and berry picking. Food that is harvested is brought to the community and distributed by the youth to Elders. The program not only addresses the impacts of climate change, but also does so in a way that reinforces food security, and Tłı̨chǫ values and culture (Cressman, 2020). Young people who participate in the program spend time on the land learning traditional skills and provide a service to their communities, while interacting with Elders. When the Tłı̨chǫ Dǫtaàts'eedı program concludes in March 2021, more than 100 youth and 60 harvesters will have collectively distributed approximately 4,000 kg of fish and meat to community Elders. The program enables communities to adapt to the impacts of climate change with cultural knowledge transfer, working with the land, using traditional skills and empowering youth (Cressman, 2020).

Figure 5.12: An Elder from Wekweètì teaches a younger member of the community to scrape and tan Caribou hides. Hides are soaked and stretched over a board before being scraped with a k'edze, a tool made from a Caribou's lower leg bone. Photo courtesy of Vanita Zoe.

Figure 5.13: Clothing and tools made by artisans in Wekweètì from tanned Caribou hide. Photo courtesy of Pat Kane.

5.4.3 Co-management and Indigenous-led natural resource management

Co-management arrangements that are designed to involve Indigenous peoples from the initial, strategic stages of planning allow for improved, holistic decision making and Indigenous empowerment over the activities taking place on their land (Houde, 2007). This may require flexible legal frameworks to allow for co-management arrangements that change and adapt over time, as trust builds between partners (Houde, 2007). Indigenous ownership and control of their Indigenous Knowledge must be respected. Recognizing the fundamental rights of Indigenous Knowledge holders includes sharing of the monetary benefits obtained from the use of this knowledge (Mauro and Hardison, 2000).

Knowledge co-production—the contribution of multiple knowledge sources and capacities to co-create knowledge—requires open partners who are willing to proceed with humility (Moller et al., 2009b). It is also important to recognize that there are limits to the extent to which scientific and Indigenous Knowledge Systems can be combined. Given that they are based on different methodologies and world views, care must be taken to ensure that knowledge is not blended or extracted from its cultural context so that it retains its own integrity (Moller et al., 2009a; Parlee et al., 2005; Davidson-Hunt and Berkes, 2003). One knowledge system does not need the other to corroborate it in order for it to be perceived as valid (The Indigenous Circle of Experts, 2018).

Canada's response to the Convention on Biological Diversity (Minister of Supply and Services Canada, 1995) provides guidance on applying Indigenous Knowledge through a code of ethical conduct, which advises to:

- Respect, preserve and maintain the knowledge, innovations and practices of Indigenous and local communities, embodying traditional lifestyles relevant to the conservation of biological diversity and sustainable use of natural resources;
- Promote the wider application of Indigenous Knowledge with the approval and involvement of the holders of such knowledge; and
- Encourage the equitable sharing of the benefits that arise from the utilization of such knowledge.

Indigenous peoples across Canada are playing an important role in demonstrating leadership on climate action, stewardship and the maintenance of ecosystem services. This can be seen through efforts to safeguard carbon sinks and the development of adaptation solutions—including nature-based approaches and the development and management of Indigenous Protected and Conserved Areas (*see* Case Story 5.4)—as well as through the implementation of innovative GHG emissions reduction technologies and approaches.

Case Story 5.4: Maintaining ecosystems and their services through Indigenous Protected and Conserved Areas

Indigenous Protected and Conserved Areas (IPCAs) refer to lands and waters where Indigenous governments have the primary role in conserving and maintaining ecosystems through Indigenous laws, governance and knowledge systems (*see* Figure 5.14; The Indigenous Circle of Experts, 2018). They aim to support ecosystems and biodiversity while safeguarding Indigenous rights, including the right to exercise free, prior and informed consent. Examples include Tribal Parks, Indigenous Cultural Landscapes, Indigenous Protected Areas and Indigenous conserved areas.

The need for restoration of the land and the culture is often an important component of IPCAs. Indigenous peoples are beginning to lead the call for restoration of lands that have been heavily affected by industrial development and degradation from human activities. Driven by the recognition that people, culture and their lands are inseparable, priority restoration areas are being identified for wildlife, as well as degraded cultural values. IPCAs can also provide safe, nurturing places for people to gain strength and heal from a legacy of intergenerational trauma and the ongoing stress of biological and cultural loss, while deepening their relationship to and understanding of the land.

The IPCA model is rooted in the exercise of constitutionally-upheld Indigenous rights in accordance with Indigenous laws. Exercising agency in how these lands are managed, restored and protected resonates with Section 35 of Canada's Constitution, as well as international declarations that Canada has pledged to support—such as the United Nations Declaration on the Rights of Indigenous Peoples—securing a space where communities can actively practice Indigenous ways of life. The model also aligns with the Government of Canada's Federal Adaptation Policy Framework, which promotes the consideration of Indigenous Knowledge in decision making.

IPCAs can also deliver important benefits to Canadians. Increasing the amount of protected and conserved areas in Canada has positive implications for biodiversity and ecosystems, which in turn contributes to maintaining the important ecosystem services that many communities rely on. However, much work remains to enable IPCAs as a viable option for protecting natural areas and to secure these areas from development pressures.

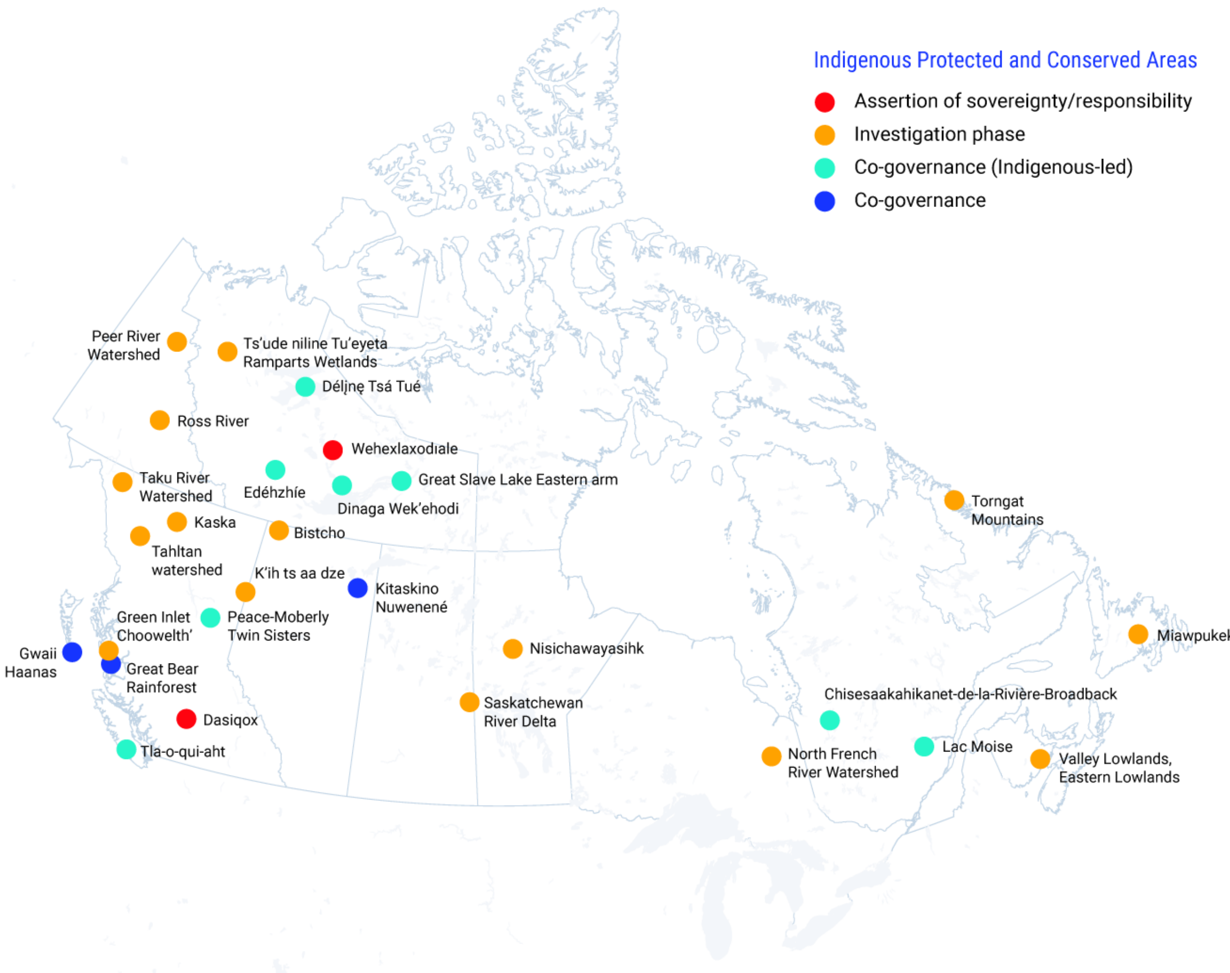


Figure 5.14: Map of Canada outlining locations of existing and proposed Indigenous Protected and Conserved Areas (note: the map is not a complete picture and some areas remain missing and disputed). Source: Adapted from David Suzuki Foundation.

5.5 Nature-based approaches to adaptation maximize benefits

Nature-based approaches to adaptation reduce climate change risks to communities, and are often cost-effective and flexible compared with engineered alternatives. They also deliver a wide range of social, environmental and economic co-benefits, and help to strengthen the adaptive capacity of communities.

There is a rapidly growing interest in nature-based approaches to climate change adaptation in Canada. Nature-based approaches for addressing climate change impacts—such as marshland restoration, low impact shoreline development and urban forests—are wide-ranging and tend to offer significant benefits over engineered adaptation options. They have embedded flexibility that allows for greater degrees of uncertainty in future climatic and environmental conditions, and have been shown to deliver a wide range of social, environmental and economic co-benefits, maximizing overall returns on investment. Furthermore, nature-based approaches contribute to strengthening the adaptive capacity of the communities that they are intended to serve, while reducing risks associated with a changing climate.

5.5.1 Introduction

Ecosystems and nature-based approaches to adaptation can play an important role in reducing climate change risks to communities by providing buffering capacity, strengthening the adaptive capacity of society and social-ecological systems, and contributing to GHG emissions reduction efforts through carbon storage (*see* Box 5.2). However, the potential and limits of nature-based approaches to adaptation are generally not well understood or quantified (Malhi et al., 2020).

5.5.2 Nature-based approaches to adaptation

Within the context of this section, "nature-based approaches" is used as an umbrella term for the range of approaches to adaptation that are nature-driven—including nature-based solutions, natural infrastructure, ecosystem-based approaches, natural asset management and protected areas. These approaches are rooted in the knowledge that healthy ecosystems, whether natural or managed, provide a diverse range of services that benefit human activity, health and well-being. These approaches also allow for flexibility and learning, which is important when addressing uncertainty and complexity in decision making. Nature-based approaches to adaptation are a rapidly growing area of interest in Canada and are also gaining international recognition. Leading economic and environmental organizations—including the IPBES, Intergovernmental Panel on Climate Change (IPCC), Global Adaptation Commission, United Nations and World Economic Forum—are just a few that have endorsed the approach.

Nature-based approaches encompass strategies that integrate the management of land, water and living resources (Convention on Biological Diversity, 2020). Such approaches position decision makers to manage for multiple benefits and build resiliency to change by considering ecosystems as a whole. For example, managing forests for timber production alone would produce different results than also managing for biodiversity and species at risk, while also considering erosion and carbon sequestration. Similarly, a nature-based approach to commercially-valuable seafood considers the range of interactions within and between coastal ecosystems.

Multiple benefits can be gained through the use of nature-based approaches, for both climate change adaptation and GHG emissions reduction, including (*see* Figure 5.15; IISD, 2019; Raymond et. al, 2017):

- Reduced impact of flooding;
- Protection from storm surges and saline intrusion;
- Provision of habitat and biodiversity preservation;
- Carbon sequestration;
- Protection against erosion;
- Drought mitigation;
- Regulation of water flow and supply;
- Improvement of place attractiveness;
- Improvements to health, well-being and quality of life; and
- Creation of green jobs.

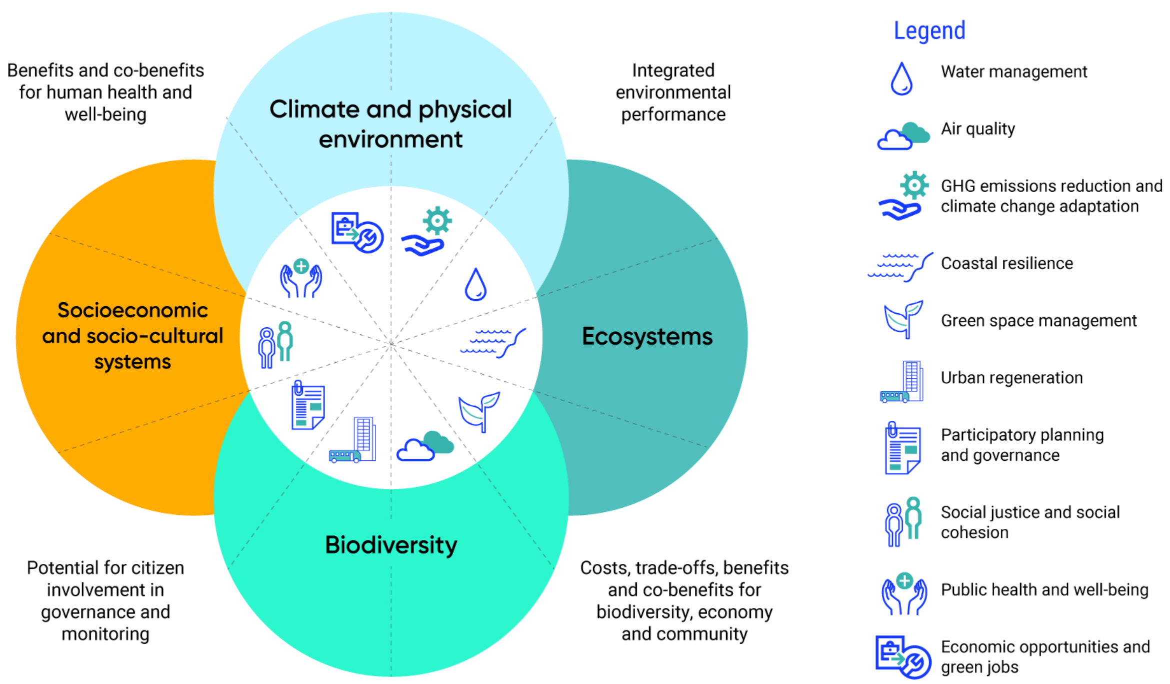


Figure 5.15: Framework used by Raymond et al. (2017) for the assessment of co-benefits from nature-based approaches. Source: Adapted from Raymond et al., 2017.

The role of nature-based approaches is evolving rapidly, as interest and the knowledge base grows. This section discusses different types of nature-based approaches and includes a series of case stories describing these approaches in practice. Future assessments will have a more robust body of existing knowledge to draw from and will discuss the topic in greater detail.

5.5.2.1 Marshland restoration in response to sea-level rise

Restoration of riparian zones and riverine buffers support water infiltration, reduce erosion and regulate water availability throughout a season. Municipalities are increasingly acquiring and restoring land in floodplains (*see* Case Story 5.5), as well as restricting development in flood-prone regions through insurance regulation (e.g., in Montreal). For example, the Tantramar Marshlands near Sackville, NB, are an ecologically and culturally significant region that is at risk from sea-level rise and increased inland flooding events (Wilson et al., 2012). Traditional infrastructure in the form of dykes are being installed to alleviate flooding, alongside salt marsh restoration—a nature-based approach to adaptation. Restored salt marsh can provide flexible protection from certain climate change impacts (*see* Case Story 5.1 and Case Story 5.5; van Proosdij et al, 2016). In addition to addressing water level concerns, salt marshes provide habitat for birds and marine species, trap sediment and distribute nutrients to key coastal species (Deegan et al., 2012). Recognizing the important role of wetlands in combating climate change and its impacts, an allocation of $1.8 million from the $75 million federal Coast Restoration Fund was announced in 2018 for further wetland and marsh restoration of 75 hectares in the Bay of Fundy, NB.

Case Story 5.5: Restoring tidal wetlands and their ecosystem services in Truro, Nova Scotia

Tidal wetlands form the first line of defense during severe storm events; however, the development of Nova Scotia's coastlines has led to the loss of nearly 85% of tidal wetlands (Hanson and Calkins, 1996). In the Upper Bay of Fundy—the area with the highest tides in the world—projected sea-level rise, under a high emissions scenario, is close to 1.2 m by 2100 (Greenberg et al., 2012). A large portion of the wetland habitat loss can be attributed to hardened coastal protection measures (such as dykes, berms and shore armouring), which are already beginning to fail with current storm surges and sea-level rise (Sherren et al., 2019).

Truro, Nova Scotia is a town of 12,000 people, located on the floodplain of the Salmon River that flows into the Bay of Fundy, and is part of a large network of dykes along the Salmon River. These dykes were originally constructed to protect agricultural lands from flooding. Due to increased development over the years, however, they are now also protecting residential, commercial and transportation infrastructure (Sherren et al., 2019). The confluence of the Salmon River and North River creates complex patterns of water, sediment and ice movement in the area, making this site very challenging to manage and resulting in high maintenance costs for dyke and aboiteau infrastructure (Sherren et al., 2019). Although Truro regularly experiences frequent and severe flooding from the combined effects of rainwater accumulation, high tides and ice jams, a particular flooding event in 2012 breached a dyke in several places, which resulted in significant damage to infrastructure. The Province of Nova Scotia performed emergency repairs on the dyke, but there is concern about the long-term maintenance and functionality of the dyke system (Cottar, 2019).

To ensure the long-term protection of the community and to maintain the coastal ecosystem, a Joint Flood Advisory Committee was formed, with representatives from the County of Colchester, Town of Truro, Millbrook First Nation and provincial government departments and the public. The committee commissioned a comprehensive flood risk study of Truro that recommended several options for reducing flood risk (CBCL Ltd., 2017). Of the options provided, no single solution was found to be effective and no measure under CAD$100 million was found to protect more than 20% of the priority areas (Sherren et al., 2019). This led to the stakeholders' decision to opt for managed retreat, allowing for the shortening and realignment of the dyke and restoration of the tidal wetland (*see* Figure 5.16). The restored tidal wetland will foster a range of ecosystem services—fish nursery habitat, storm buffer and carbon sequestration to name a few (ICF, 2018). It is estimated that within three years post-breach, the restored North Onslow tidal wetland will be operating as a near optimum salt marsh habitat and regulating (e.g. acting as a storm buffer) ecosystem services.

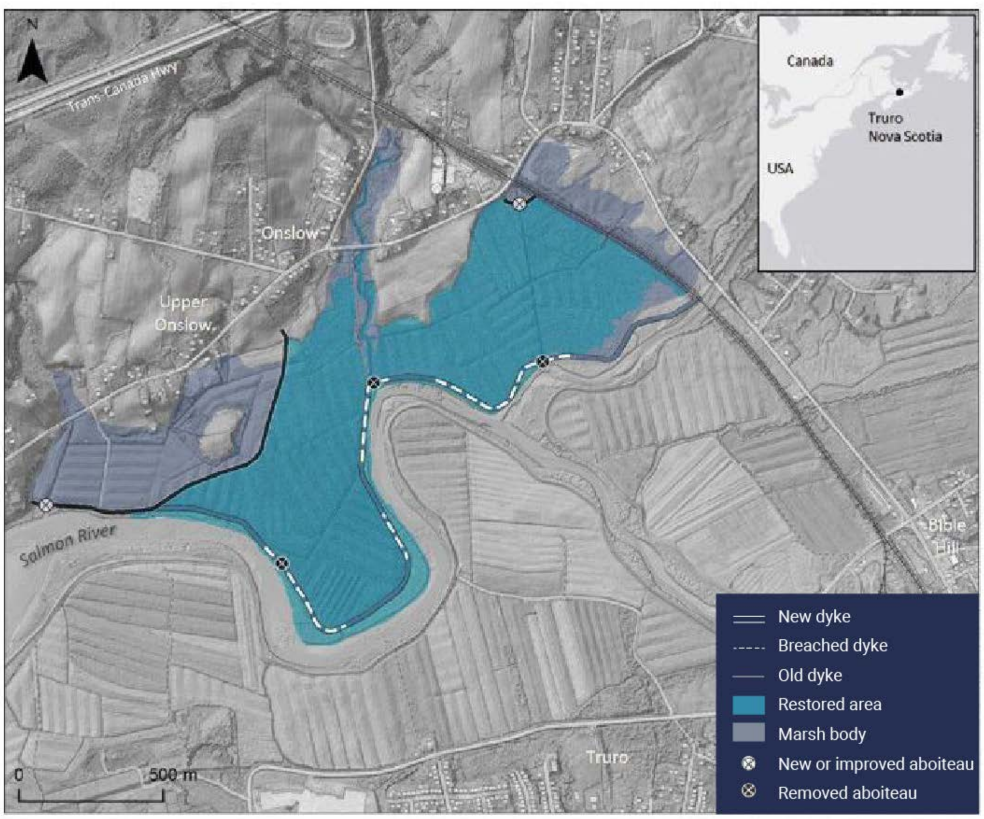


Figure 5.16: Map of the North Onslow marsh in Truro, NS illustrating the extent of the area to be restored as a tidal wetland. Source: Sherren et al., 2019.

5.5.2.2 Low impact shoreline development

Low impact shoreline development is an approach that can be used for waterfront property owners and managers to develop their properties in a shore-friendly way that helps to preserve or restore physical processes, maintain or enhance habitat function and diversity along the shoreline, prevent or reduce pollutants entering the aquatic environment, and avoid or reduce cumulative impacts (Green Shores, 2021). In B.C., the voluntary and incentive-based rating program, Green Shores, is providing training, credit and rating guidance, as well as certification for nature-based shoreline development that reduces impacts on ecosystems and increases resilience to climate change (*see* Case Story 5.6).

Case Story 5.6: Promoting ecosystem-friendly shoreline development through the Green Shores program

A large portion of Canada's coastline is developed, which has implications for the overall health of shoreline ecosystems and the services they provide. With climate change, Canada's coasts and coastal communities are vulnerable to climate change impacts such as sea level rise, storm surge, flooding and increased erosion. There is growing recognition that "hard" or engineered structures alone are not always the most appropriate or cost-effective approaches for reducing these risks. Programs like Green Shores and the Municipal Natural Assets Initiative (MNAI) are contributing to the evidence-base on the effectiveness of nature-based approaches for addressing impacts of climate change on coastal ecosystems, and several programs across Canada are now supporting the implementation of natural shorelines in developed areas (Eyzaguirre et al., 2020).

The Stewardship Centre for British Columbia (SCBC) runs the Green Shores program—a voluntary and incentive based rating program that seeks to reduce the impact of residential development on shoreline ecosystems (SCBC, n.d.). The program offers capacity building, tools and best practice standards to encourage approaches to shoreline development that protect the land from flooding and erosion (with consideration for projected sea-level rise of one metre or more by 2100 for coastal shorelines), increase the ability to access shorelines for recreation, and maintain and restore natural habitats (Eyzaguirre et al., 2020).

In 2018, SCBC and ESSA Technologies Ltd. released the findings from a joint study on the impact and social, environmental and economic value of the Green Shores program. The study also provided recommendations for improving the delivery of the program in BC, and on strategies for making the program available in Atlantic Canada. Recommendations for improving program delivery include (Eyzaguirre et al., 2020):

- Incorporating appropriate incentives for landowners (e.g., payment for ecosystem services or user pay models);
- Strengthening linkages with other change-makers in the system (e.g., identifying areas of overlap and complementary tools with leaders such as MNAI);

- Delivering targeted education and outreach to address barriers and opportunities (e.g., working with contractors to better share information about incorporating soft shoreline protection in development projects); and
- Enhancing learning and monitoring of current and planned Green Shores projects to increase acceptance of soft and hybrid shoreline approaches (e.g., enhancing long-term monitoring of projects).

The report also featured several successful projects that went through the Green Shores program, including the New Brighton Park Shoreline Habitat Restoration Project in Vancouver, BC (Eyzaguirre et al., 2020). This project achieved a Gold rating through the Green Shores program and involved elongating the original shoreline from 150 m to 440 m through the creation of tidal marsh channels (*see* Figure 5.17). The study also undertook an economic analysis of the project, finding that for every $1 spent, social welfare increased by $2.50 (Eyzaguirre et al., 2020).

The findings from this report add to the mounting evidence on the socioeconomic merits of using nature-based approaches to promote more sustainable and resilient shoreline management in Canada.

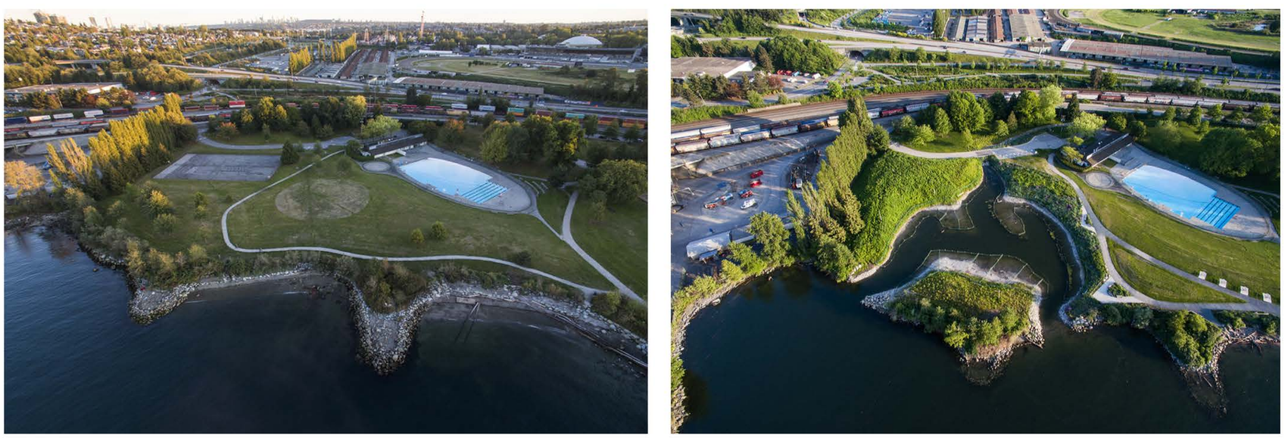


Figure 5.17: Photographs of the New Brighton Park Shoreline Habitat Restoration Project in Vancouver, B.C. prior to the project starting and in 2018, when the project was completed. Photos courtesy of the Vancouver Fraser Port Authority.

5.5.2.3 Urban forests

Urban forests provide ecosystem services evaluated at $330 million per year for Halifax, Montreal, Vancouver and Toronto, without including the value associated with tourism, recreation or increased property values (Alexander and DePratto, 2014). They also deliver a wide range of benefits and can help to reduce impacts associated with climate change impacts (*see* Case Story 5.7), such as higher temperatures and heat waves (Sinnett, 2018; Brandt et al., 2016; Livesley et al., 2016; Rahman et al., 2015), while also storing water and reducing stormwater runoff (Berland et al., 2017; Bartens et al., 2008) and contributing to carbon sequestration (Nowak and Crane, 2001). They also deliver a number of social and economic benefits, including (Bardekjian, 2018):

- Promoting physical activity by providing space for recreation and creating an appealing outdoor environment;
- Promoting mental well-being and stress reduction;
- Promoting social interaction and a sense of community, including stronger ties to neighbours, a greater sense of safety, and more use of outdoor public spaces;
- Making cities more beautiful and hiding unattractive features like walls, freeways, and parking lots;
- Reducing air pollution and provide oxygen; and
- Helping provide habitat for wildlife and preserve biodiversity.

Case Story 5.7: Addressing urban heat island in Kingston, Ontario by increasing the urban tree canopy

Canada's urban centres are projected to see an increase in the annual number of extreme heat days (over 30°C) as a result of climate change (Climate Atlas of Canada, 2019), which have a wide range of health-related implications for Canadians. Many urban surfaces continue to radiate heat captured throughout the day, which can result in as much as a 12°C difference between cities and their surrounding areas at night (Climate Atlas of Canada, 2019). Urban areas also tend to have fewer trees and less vegetation, which provide important cooling services through shading and increased evapotranspiration.

To help address the heat island effect, the City of Kingston, Ontario released their Urban Forest Management Plan (SENES Consultants Ltd., 2011) in 2011. The goal of the plan was to establish guidelines and actions for the City to maintain its urban forest cover at the time (21% coverage in 2009), to support the expansion of the urban forest and to ensure its long term preservation in line with the plan's 25 year vision. The City's official plan outlines a target of achieving 30% urban forest coverage (at a minimum) by 2025 (City of Kingston, 2019). Kingston's urban forest is estimated to generate roughly $1.87 million annually in environmental benefits (SENES Consultants Ltd., 2011). The increase in urban tree canopy will not only help to reduce the heat island effect in Kingston, but can provide:

- shade for buildings in the summer;
- habitat for animals;
- filtration of air pollution;
- filtration and reduction of the amount of stormwater runoff;
- bank stabilization along open watercourses;

- natural wind breaks; and
- an increase in the aesthetic beauty of the city.

The success of the Urban Forest Management Plan is supported by other City of Kingston policies and measures, including its Official Plan, Drought Protection Strategy, Tree Bylaw and a Tree Watering Alert system to engage the citizens (City of Kingston, 2021). The creation of a tree advisory board that included local stakeholders and representatives from the local conservation authority and Parks Canada has also contributed to the plan's implementation (Guilbault, 2016).

5.5.2.4 Greenways and greenbelts around urban areas

Several urban centres in Canada (e.g., the National Capital Region in Ottawa, Ontario; Calgary, Alberta; Saskatoon, Saskatchewan; and the Greater Toronto Area, Ontario) have developed greenways around the cities to conserve green space and maintain the ecosystems in the region and the services they provide (*see* Case Story 5.8).

Case Story 5.8: Ecosystem services provided by Ontario's Greenbelt

In Southern Ontario, where the rapidly growing urban area is home to more than one third of the Canadian population, there is concern associated with development risk to forests, wetlands and agricultural lands, which provide key food provisioning, carbon sequestration, water filtration and key habitat, including for species at risk. The Government of Ontario's Greenbelt Act (2005) led to the production of a land-use plan covering 7,200 km^2, which extends 325 km from the eastern end of the Oak Ridges Moraine in the east to the Niagara River in the west (Ministry of Municipal Affairs, 2017).

Although the Ontario Greenbelt was primarily created to guard against urban sprawl, it is aligned with Ontario's Climate Change Strategy (2015). The Greenbelt, while sensitive to changes in climate, also plays a role in adaptation by helping to protect biodiversity, allowing agriculture and food systems to adapt to climate change and providing a refuge from the heat of urban centres (Friends of the Greenbelt Foundation, 2011). While ecosystem valuations vary in their methodologies, one study has estimated the value of additional ecosystem services provided by the Greenbelt, including recreation, carbon sequestration and flood protection for private property to be over $3.2 billion dollars per year (Green Analytics, 2016).

5.5.2.5 Nature-based vs. engineered approaches

While adaptation is often associated with technological innovations or new infrastructure, strategic maintenance and management of natural systems can yield similar outcomes that are less expensive than engineered options and often deliver additional benefits beyond the targeted issue (Shreve and Kelman, 2014). Recent syntheses found that restored habitats for coastal defence (e.g., salt marshes and mangroves) are cost-effective alternatives to traditional infrastructure, with significantly lower costs for certain habitats (Morris et al., 2018; Narayan et al., 2016).

A 2014 study evaluated the effectiveness of three “soft” or nature-based approaches in BC for addressing sea-level rise, in comparison to equally appropriate “hard” or engineered approaches (Lamont et al, 2014). The “soft” approaches in question included a beach nourishment/shore replenishment alternative, use of nearshore intertidal rock features and use of a typical headland beach system to maintain a conventional beach. The study found that in the three case examples, the “soft” alternatives provided a significant cost advantage over the “hard” alternatives, with a margin of cost savings ranging from 30–70% of the cost of the “hard” alternative (Lamont et al., 2014). Other examples of cost-benefit analysis can be found in the Costs and Benefits of Climate Change Impacts and Adaptation chapter.

The Green Infrastructure Guide for Water Management discusses ecosystem-based management approaches for water-related infrastructure projects (UNEP, 2014). The guide outlines nature-based approaches that are relevant for water resources management—this also includes approaches that consist of built or “grey” elements, which interact with natural features to enhance water-related ecosystem services (*see* Table 5.2; UNEP, 2014). At the municipal level, the approach of natural asset management has also been gaining traction in recent years (*see* Case Story 5.9 and Cities and Towns chapter).

Table 5.2: Nature-based approaches for water resource management

WATER MANAGEMENT ISSUE (PRIMARY SERVICE TO BE PROVIDED)	GREEN INFRASTRUCTURE SOLUTION	LOCATION: WATERSHED	LOCATION: FLOODPLAIN	LOCATION: URBAN	LOCATION: COASTAL	CORRESPONDING GREY INFRASTRUCTURE SOLUTION (AT THE PRIMARY SERVICE LEVEL)
Water supply regulation (including drought mitigation)	Re/afforestation and forest conservation	■				• Dams and groundwater pumping • Water distribution systems
	Reconnecting rivers to floodplains		■			
	Wetlands restoration/ conservation	■	■	■		
	Constructing wetlands	■	■	■		
	Water harvesting*	■	■	■		
	Green spaces (bioretention and infiltration)			■		
	Permeable pavements*			■		
Water quality regulation — Water purification	Re-afforestation and forest conservation	■				Water treatment plant
	Riparian buffers		■			
	Reconnecting rivers to floodplains		■			
	Wetlands restoration/ conservation	■	■	■		
	Constructing wetlands	■	■	■		

WATER MANAGEMENT ISSUE (PRIMARY SERVICE TO BE PROVIDED)		GREEN INFRASTRUCTURE SOLUTION	LOCATION				CORRESPONDING GREY INFRASTRUCTURE SOLUTION (AT THE PRIMARY SERVICE LEVEL)
			WATERSHED	FLOODPLAIN	URBAN	COASTAL	
Water quality regulation (continued)	Water purification (continued)	Green spaces (bioretention and infiltration)			■		Water treatment plant
		Permeable pavements*			■		
	Erosion control	Re-afforestation and forest conservation	■				Reinforcement of slopes
		Riparian buffers		■			
		Reconnecting rivers to floodplains		■			
	Biological control	Re-afforestation and forest conservation	■				Water treatment plant
		Riparian buffers		■			
		Reconnecting rivers to floodplains		■			
		Wetlands restoration/ conservation	■	■	■		
		Constructing wetlands	■	■	■		

WATER MANAGEMENT ISSUE (PRIMARY SERVICE TO BE PROVIDED)		GREEN INFRASTRUCTURE SOLUTION	LOCATION				CORRESPONDING GREY INFRASTRUCTURE SOLUTION (AT THE PRIMARY SERVICE LEVEL)
			WATERSHED	FLOODPLAIN	URBAN	COASTAL	
Water quality regulation (continued)	Water temperature control	Re-afforestation and forest conservation	■				Dams
		Riparian buffers		■			
		Reconnecting rivers to floodplains		■			
		Wetlands restoration/ conservation	■	■	■		
		Constructing wetlands	■	■	■		
		Green spaces (shading of water ways)			■		
Moderation of extreme events (floods)	Riverine flood control	Re-afforestation and forest conservation	■				Dams and levees
		Riparian buffers		■			
		Reconnecting rivers to floodplains		■			
		Wetlands restoration/ conservation	■	■	■		
		Constructing wetlands	■	■	■		
		Establishing flood bypasses		■			

WATER MANAGEMENT ISSUE (PRIMARY SERVICE TO BE PROVIDED)		GREEN INFRASTRUCTURE SOLUTION	LOCATION				CORRESPONDING GREY INFRASTRUCTURE SOLUTION (AT THE PRIMARY SERVICE LEVEL)
			WATERSHED	FLOODPLAIN	URBAN	COASTAL	
Moderation of extreme events (floods) (continued)	Urban stormwater runoff	Green roofs			■		Urban stormwater infrastructure
		Green spaces (bioretention and infiltration)			■		
		Water harvesting*	■	■	■		
		Permeable pavements*			■		
	Coastal flood (storm) control	Maintaining/restoring mangroves, coastal marshes and dunes				■	Sea walls
		Maintaining/restoring reefs (coral/oyster)				■	

Note: Green infrastructure solutions marked with '*' consist of a hybrid of "green" and "grey" elements that interact to enhance ecosystem services.

Source: UNEP, 2014.

Case Story 5.9: Municipal natural asset management and service delivery

The Municipal Natural Assets Initiative (MNAI) was established in 2016 to refine, test and scale up natural asset management work that was first initiated by the Town of Gibsons, B.C. The initiative is changing the way in which municipalities across Canada deliver services and increase the quality and resilience of natural infrastructure in the face of climate change at lower costs and reduced risk.

The MNAI is testing how to manage natural assets such as woodlands, wetlands and creeks in urban areas as part of a sustainable infrastructure strategy. This approach identifies and determines the value of natural assets, and accounts for their contribution to municipal government services delivery—services that would otherwise need to be delivered by engineered assets. Municipal natural assets are defined by MNAI as the stock of natural resources or ecosystems that a municipality, regional district, or other form of local government could rely upon or manage for the sustainable provision of one or more local government services.

New approaches to manage natural assets are being driven by declining urban infrastructure that is expensive to replace, by the dramatic decline in natural ecosystems, and the urgency of addressing infrastructure challenges in the face of growing populations and climate change impacts such as floods and droughts. Canadian local governments that are seeking new strategies to better deliver core services in a financially sustainable manner are turning to asset management.

Evidence from the MNAI suggests that an asset management-based approach holds great promise for tackling the twin challenges of deteriorating quality of urban infrastructure and declining ecosystem health. For instance, Table 5.3 provides an overview of water-related municipal services that have the potential to be provided by natural assets and ecosystem services, instead of engineered approaches.

The MNAI's lifecycle view of natural assets includes completing an inventory of a community's existing assets, determining the current state and value of those assets, and implementing asset management plans to maintain or replace them. The emphasis on asset management for sustainable service delivery—as opposed to the underlying asset that delivers those services—means that natural capital can form a core element of municipal asset management strategies.

The MNAI team developed a methodology and guidance documents to help local governments identify, valuate and manage natural assets within traditional financial and asset management planning frameworks. Encouraging early results from cohort communities across the country are providing support for this concept. The Gibsons' aquifer, for example, was found to provide sufficient water storage to supply about 70% of the town's projected population for the foreseeable future (Waterline Resources Inc., 2013), with no capital costs and operating costs of $30,000 per year for monitoring—a fraction of the cost of engineered water supply infrastructure.

The first cohort communities—the City of Nanaimo, B.C., City of Grand Forks, B.C., District of West Vancouver, B.C., Region of Peel, ON and the Town of Oakville, ON—assessed the value of stormwater services provided by a natural asset under various scenarios. While results from each project were unique, they shared some key findings: natural assets were found to provide equivalent stormwater management services to engineered ones, and all communities found that their natural asset of interest was meeting at least the 100-year flood storage requirements under current standards. The value of natural assets was also found to increase under scenarios associated with both climate change and intensified development. Overall, early results of the MNAI demonstrate that newly-recognized ecosystem service values are improving local government understanding of how nature is providing municipal services and impacting decision making.

Table 5.3: Examples of water-related municipal services that can be provided by natural assets and ecosystem services

MUNICIPAL WATER SERVICES	ECOSYSTEM SERVICE	NATURAL ASSET	ENGINEERED REPLACEMENT
Drinking water supply	Aquifer recharge	Aquifer and source water area	Pipes for bringing in water supply, water treatment plant
	Lake recharge	Lake watershed	
	River headwaters	Headwater lands	
Drinking water treatment	Water purification	Wetlands, forests, vegetation	Water treatment plant
	Water filtration		
Stormwater Management	Rainwater absorption	Wetlands, forests, vegetation	Stormwater pipes, culverts, storm drains, stormwater ponds
	Rainwater filtration		Water treatment plant
Flood Mitigation	Rainwater absorption	Wetlands, forests, vegetation	Dams, retaining walls, embankments

Source: Adapted from MNAI, 2019.

5.6 Moving forward

There are a number of emerging issues, knowledge gaps and research needs related to how climate change is affecting ecosystem services, and to help integrate ecosystem service considerations and adaptation opportunities into climate change planning.

5.6.1 Knowledge gaps

While there is ongoing research on biodiversity and ecosystem services across the country, there are areas where further knowledge is needed.

5.6.1.1 Climate change impacts to ecosystems and their services

Considering the complexity of ecosystems, it is challenging to anticipate the multitude of ways in which climate change will affect individual species, interactions between species, changes in ecosystem processes and functions, and how these various changes will translate to impacts for ecosystem services.

Additional research is also needed to better understand how changes to ecosystem services under a changing climate will affect the communities that rely on them for livelihoods, health and well-being. Comprehensive assessments of vulnerability to changes in ecosystem services and capacity to adapt to future climate change impacts would help to identify opportunities for enhancing adaptive capacity with respect to ecosystem services (Boyd, 2010).

5.6.1.2 Data and information

More open source data, national standards on what constitutes successful and sustainable nature-based approaches, metrics, approaches for monitoring and inventories, and improved collection and sharing of baseline data would support more cohesive and coordinated biodiversity research on climate change impacts and adaptation (Biodiversity Adaptation Working Group, 2018). Specific data and information needs include:

- Improvements of spatial datasets and indicators of ecosystem service flows;
- More data on the impacts of phenological changes on ecosystem services and non-monetary valuation of ecosystem service flows;
- Development of metrics and standards (beyond forests) to track rates of land-based and coastal carbon sequestration and storage;
- Better identification of hotspots of vulnerability and resilience; and
- Increased monitoring to understand the effectiveness of adaptation approaches.

Gaps also exist in the mechanisms for providing access to information and facilitating collaboration beyond government agencies. Accessible guidance, resources and tools are also needed to support decision makers in integrating adaptation and landscape-level resilience through ecosystem service approaches.

5.6.2 Emerging issues

Achieving and maintaining resilient ecosystems, communities and economies will benefit all Canadians. As research and implementation of climate change strategies emerge and evolve, there are several areas where progress may advance quickly, as well as issues that require further attention. This section highlights some emerging issues that may play key roles in the resilience conversation with respect to ecosystem services, as it moves forward.

5.6.2.1 Valuation of nature-based approaches

Valuing ecosystem services and natural assets, applying different approaches to decision making and assessing the costs and benefits of nature-based approaches to adaptation compared with engineered approaches are rapidly evolving areas of work that are gaining considerable interest and profile in Canada.

With increased incidences of flooding across Canadian urban centres and in coastal regions, there is renewed interest in valuing and utilizing nature-based approaches to meet needs that are normally provided by "grey" or engineered infrastructure. For example, forests and wetlands reduce the impact of floods, soil erosion and landslides, while improving water security (Seddon et al., 2020), as well as providing further ecological benefits (e.g., providing habitat, cultural services, etc.) and cost savings.

Municipalities are making economic arguments for maintaining natural systems to provide needed services, particularly those related to water provision and regulation (*see* Case Story 5.9). Currently, a range of approaches to valuation have been applied, including replacement cost (where services have the potential to align with Public Sector Accounting Board requirements), restoration costs (where Low Impact Development is utilized), and land value (where management requires transfer of ownership rights). In the process, it is important for municipalities to recognize that natural systems can be overwhelmed when their capacity is exceeded, and begin to consider natural systems as a component of a sustainable infrastructure strategy that includes both "grey" and natural components.

5.6.2.2 Improved integration of Indigenous Knowledge

As highlighted in Section 5.4, improved integration and consideration of Indigenous Knowledge will play an important role in addressing climate change impacts to ecosystems and their services, and for adaptation planning across Canada. This cannot be done without acknowledging the harms that have historically eroded trust between Indigenous groups and settler communities. As part of the national effort to commit deeply to the truth and reconciliation process, capacity building and empowering Indigenous leadership and autonomy are important elements in partnering and deeply engaging with Indigenous communities on climate change.

5.6.2.3 Growing role for citizen science

With mobile technology and applications that permit real-time data-sharing about natural phenomena to online repositories (e.g., for water quality, migrating birds, documenting flowering times, etc.), citizens can participate in improving the coverage of knowledge related to changes in ecosystem services, while also becoming involved in tracking changes across the country. Many tools are available to leverage human interest in monitoring information with a great deal of coverage, for very little cost. Interest in participating in unique activities has created opportunities to gather monitoring information in a number of places that could not feasibly be monitored previously, and this interest can be channelled as an effective tool for building knowledge and awareness. Furthermore, engaging local citizens in data collection can built adaptive learning, social capital, and encourage the ethos of stewardship and care of local ecosystems over the long term.

5.6.2.4 Broadening collaboration

Extending beyond traditional partners and seeking new collaborations in maintaining ecosystem services, and the design and implementation of nature-based approaches to adaptation will help to fuel innovation. In some cases, this may require overcoming barriers in communicating the value of biodiversity and ecosystem protection, particularly in terms of maintaining ecosystem services under a changing climate. The promotion of ecosystem services within the context of climate change adaptation measures could be tailored to different audiences using terminology that is familiar to them, while highlighting the relevance of these measures to target groups. The term “ecosystem services” is not understood by all, but the concept of deriving benefits from nature is widely recognized and is relatively easy to explain and connect to particular groups.

5.6.2.5 Innovative investments and partnerships

Innovative investments and partnerships are emerging for investments in nature-based approaches and the preservation of ecosystems and their services. For instance, the Government of Canada announced the $500 million Canada Nature Fund in late 2018, which will provide matching funds for provincial, territorial, municipal and NGO-led projects to achieve conservation goals. Other financing opportunities that blend public and private funds—such as green bonds, social finance models, and nature-based insurance mechanisms, among others—can be devised to provide needed investments in nature-based approaches and the preservation of ecosystems and their services. Major federal infrastructure funding also exists under the Disaster Mitigation and Adaptation Fund and the Adaptation, Resilience and Disaster Mitigation sub-stream of the federal Green Infrastructure Fund.

5.6.2.6 Growing private interest in nature-based approaches to adaptation

Globally, the private sector is increasingly acknowledging the importance of healthy and intact ecosystems. The World Economic Forum (2020) has listed biodiversity loss and environmental damage, failure to reduce GHG emissions and adapt to climate change, and extreme weather and natural disasters as the top three risks to the global economy over the past six years. Businesses are increasingly seeking enhanced understanding of operational risks, supply chain continuity, liability risks and market disruptions that could result from the loss and degradation of ecosystems and their associated services.

5.7 Conclusion

Climate change presents a multitude of risks, opportunities and trade-offs for Canada's ecosystems and the people that rely on them. The nature and severity of the impacts will depend on the rate and magnitude of climate changes in the years to come and in the success of adaptation measures. An improved understanding of the multiple drivers of change that affect ecosystem services, as well as the ways in which changes to ecosystem services affect communities and vulnerable segments of the population can help to target the most effective adaptation strategies. Natural systems can also play an important buffering role in terms of reducing the severity of climate change impacts. Nature-based approaches to adaptation have been shown to provide comprehensive, multi-disciplinary and flexible approaches that promote a suite of co-benefits, particularly compared with engineered approaches to adaptation. This is a rapidly growing field of interest and study in Canada, which promises to produce new knowledge and lessons learned in the years to come.

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5.9 Appendix 1

The following table was developed by the author team for this chapter and reflects their collective expert opinion on the ways in which climate change is affecting ecosystem services in Canada, the social and economic consequences of those impacts and related opportunities for nature-based approaches to adaptation and/or GHG emissions reduction.

Table 5.4: Ecosystem services, threats and opportunities

Ecosystem services	Climate change threats to ecosystem services	Social and economic consequences of climate change impacts on ecosystem services	Opportunities for nature-based adaptation and/or GHG emissions reduction
REGULATING CONTRIBUTIONS			
Maintenance of options (i.e., the ability of ecosystems to provide services and maintain options for present and future generations)	• Land-use change leading to loss of species and ecosystems, carbon storage • Degraded water sources	• Increased costs to society • Increased prevalence of disease • Limited options for future generation • Loss of local cultures, practices, languages and knowledge	• Protecting species and maintaining ecosystems (e.g., Indigenous Protected and Conserved Areas) • Ecosystem restoration

Ecosystem services	Climate change threats to ecosystem services	Social and economic consequences of climate change impacts on ecosystem services	Opportunities for nature-based adaptation and/or GHG emissions reduction
Climate regulation (i.e., the ability of ecosystems to sequester and store carbon)	• Land-use change and deforestation leading to reduced rates of carbon sequestration • Altered vector population dynamics • Impacts to water and food security • Reductions in biodiversity	• Loss of livelihoods (e.g., ecotourism, fishing and forestry) • Reduced water and food security • Economic losses associated with flooding, drought and loss of land • Emergence of climate refugees	• Green infrastructure • Reforestation and restoration of ecosystems • Climate friendly urban design, biomimicry
Regulation of freshwater quantity, flow and timing (i.e., the use of freshwater for domestic consumption, agriculture, industry, transportation and recreation)	• Changes to seasonal stability and timing of water supplies • Depletion of aquifers and base flows • Deglaciation • Loss of vegetative cover	• Increased reliance on technological solutions for water storage and transport • Impacts to human health • Impacts to livelihoods • Flooding and associated social, health, and economic costs	• Restoration of freshwater ecosystems • Improvements in efficiency of water use • Green infrastructure (e.g., creation of wetlands) • Decreasing impermeable surfaces • Increasing natural vegetation in urban and semi-urban areas

Ecosystem services	Climate change threats to ecosystem services	Social and economic consequences of climate change impacts on ecosystem services	Opportunities for nature-based adaptation and/or GHG emissions reduction
Regulation of freshwater and coastal water quality (i.e., delivery of high water quality for human consumption, biodiversity and economic development)	• Altered vector population dynamics • Increased prevalence of disease and pests • Land-use change in upland ecosystems • Contamination resulting from natural disasters including floods	• Impacts to public health • Increase of disease/ costs of health care from contaminated water. • Economic loss	• Maintaining upland ecosystems • Revise wastewater regulations to require tertiary treatment and resource recovery
Regulation of hazards and extreme events (i.e., biodiverse and healthy ecosystems reduce impact of fires, flood, landslides, drought and extreme heat)	• Loss of plant and animal communities • Reduction in long-term groundwater storage • Impacts of extreme heat, drought and fire to ecosystem functioning • Vulnerability of forest ecosystems to fire	• Mortality • Injury • Economic loss • Increased cost to society for mitigating hazards • Opportunity cost	• Green infrastructure to help buffer impacts of extreme events • Utilization of nature for refuge and recovery spaces after extreme events • Incentives to vacate flood areas and restore natural ecosystems instead of building dykes
Habitat creation and maintenance (i.e., sufficiently intact natural habitat to support biodiversity)	• Land-use change leading to loss of ecosystem services • Shifting species distribution ranges • Disturbance	• Opportunity cost • Reduction in population for species of cultural and economic importance to communities	• Increasing connectivity of ecosystems • Green infrastructure in urban areas • Connectivity across transportation routes

Ecosystem services	Climate change threats to ecosystem services	Social and economic consequences of climate change impacts on ecosystem services	Opportunities for nature-based adaptation and/or GHG emissions reduction
Regulation of air quality (i.e., the exchange of trace gasses and deposition of particulate matter by ecosystems)	• Reduced capacity to regulate from excessive pollution • Harvesting of forests	• Increased disease and mortality • Increasing healthcare costs	• Green infrastructure in urban areas to increase service (e.g., tree planting) • Reforestation and restoration of ecosystems
Regulation of organisms detrimental to humans (i.e., the contribution of biodiversity and ecosystems to human health)	• Habitat loss • Land-use change • Altered vector population dynamics • Increase in invasive alien species • Loss of biodiversity; shifts in species range	• Increased disease and mortality from extreme weather and water-borne diseases • Increasing healthcare costs • Economic loss	• Fostering greater biodiversity in all systems • Management of vector species
Pollination and dispersal of seeds and other propagules (i.e., the role of pollinator species in plant reproduction, food production and maintenance of terrestrial biodiversity)	• Habitat loss • Lack of diversity in systems • Environmental pollution • Introduction of alien species	• Economic loss • Loss of cultural traditions and diversity • Reduced food security • Loss of pollinated foods and medicinal plant crops	• Fostering greater biodiversity in all systems • Green infrastructure (e.g., to increase connectivity in systems, provide habitat and food sources) • Increase diversity in food systems

Ecosystem services	Climate change threats to ecosystem services	Social and economic consequences of climate change impacts on ecosystem services	Opportunities for nature-based adaptation and/or GHG emissions reduction
Regulation of ocean acidification (i.e., the contribution of ocean ecosystems to climate regulation)	• Loss of coastal ecosystems leading to loss of mitigation opportunities • Environmental pollution • Introduction of alien species	• Economic loss (decrease in commercial and subsistence shellfish fisheries) • Reduction in coastal tourism • Loss of livelihoods and entire economies in some places	• Protection of coastal habitats
Formation, protection and decontamination of soils and sediments (i.e., the role of soil in the provision of water and nutrients for terrestrial vegetation; global carbon and nitrogen cycles)	• Land-use change contributing to soil loss and erosion • Loss of carbon storage • Reduction in quality and quantity of water	• Economic loss • Increased risk of disease by pests and pathogens • Food security (less nutritious foods) • Flooding and relocation related to sea level rise	• Soil biodiversity management practices • Low input agricultural practices

Ecosystem services	Climate change threats to ecosystem services	Social and economic consequences of climate change impacts on ecosystem services	Opportunities for nature-based adaptation and/or GHG emissions reduction
	MATERIAL CONTRIBUTIONS		
Food and feed (e.g., crops, livestock, fisheries, aquaculture, wild foods)	• Competition for land, water and energy • Overexploitation • Availability of land with adequate climatic and soil conditions • Available sources of water for irrigation • Increased prevalence of pests and toxic contamination	• Loss of livelihoods and entire economies in some places • Reduced food security (from impacts on crops and fisheries) • Economic loss • Depression and reduced job security for workers	• Encouraging natural pest regulation • Managing regulating services for system resilience • Managing wetlands for flood control • Land-use management regulations that expand/retain areas for conservation and agricultural • Moving production further north when environmental requirements of species allow
Materials and assistance (e.g., timber and fibre for construction material, clothing and raw materials)	• Fire management • Soil degradation • Reduced water regulation and quality • Impeded carbon storage capacities • Overexploitation • Reduction in diversity of species • Compromised ecosystem integrity	• Loss of livelihoods and entire economies in some places • Loss of cultural traditions and diversity • Reduced security from increased fires	• Fire management • Natural pest management • Building Code requirements for timber construction

Ecosystem services	Climate change threats to ecosystem services	Social and economic consequences of climate change impacts on ecosystem services	Opportunities for nature-based adaptation and/or GHG emissions reduction
Energy (e.g., charcoal, hydropower, wind, biomass, solar power, geothermal)	• Increased reliance on renewable energy • Competition for land, water and energy • Impacts to biodiversity	• Impacts to food security and human health • Loss of livelihoods	
Medicinal, biochemical and genetic resources (e.g., medicines derived from biochemical and genetic resources)	• Climate-related biodiversity loss • Invasive species • Overexploitation	• Loss of cultural traditions and diversity • Impacts to human health • Risks associated with disease	
NON-MATERIAL CONTRIBUTIONS			
Learning and inspiration (i.e., nature-based opportunities for scientific research, art, restoration, and inspiration)	• Land-use change associated with urban areas • Overharvesting of resources • Loss of local cultures, practices	• Loss of culture, identity • Decrease in well-being	• Fostering greater biodiversity in all systems • Management focused on key ecosystems, biodiversity

Ecosystem services	Climate change threats to ecosystem services	Social and economic consequences of climate change impacts on ecosystem services	Opportunities for nature-based adaptation and/or GHG emissions reduction
Supporting identities (i.e., physical places that are symbolic and/or that are a part of social relationships that form cultural identities)	• Loss of local cultures, practices, languages and knowledge • Restricted availability of local resources • Loss of biodiversity of significance	• Impacts to culture, identity, emotional and social well-being • Decrease in well-being; impacts to mental health • Loss of subsistence economy	• Social-ecological modelling to understand impacts of climate change on Identity • Indigenous Protected and Conserved Areas (IPCAs)
Physical and psychological experiences (i.e., the importance of nature to physical and mental health)	• Land-use change leading to lack of access to nature • Loss of local cultures, practices	• Impacts to culture, identity, emotional and social well-being	

Source: This table is based on the expert opinion of the author team.