Effects of Climate Change on Biodiversity within Conservation Halton's Watersheds – Full Report

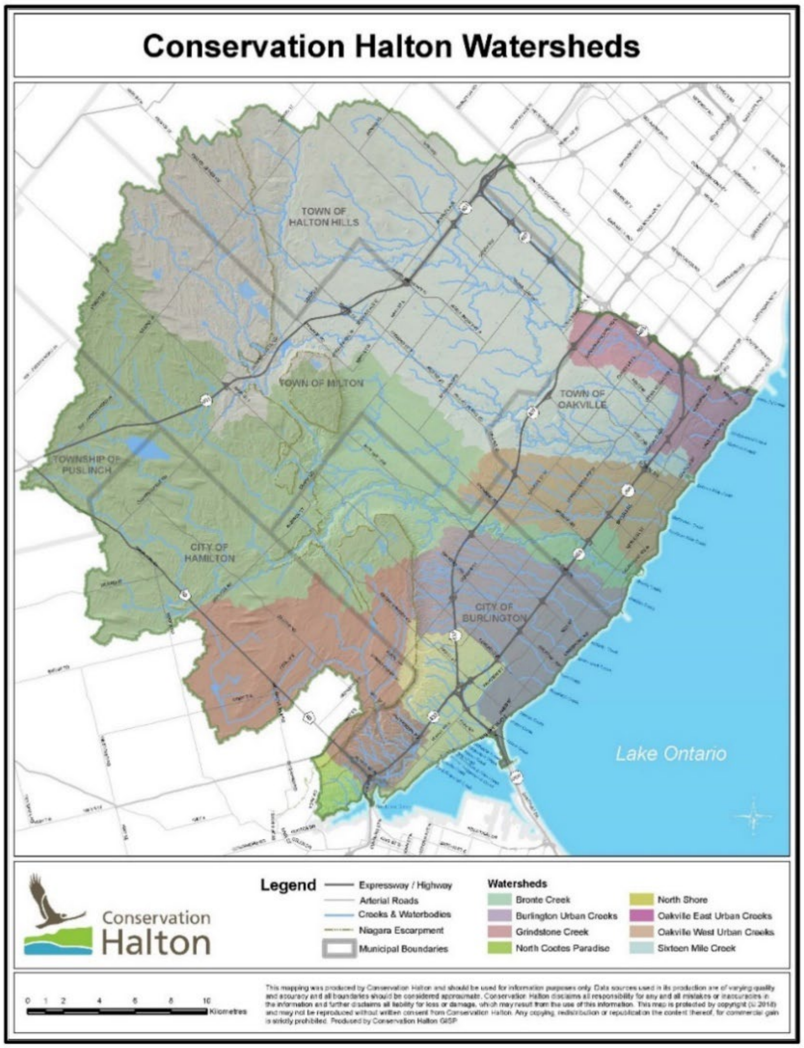
Conservation Halton

September 2023
Version 1.0

OBJECTIVE	The purpose of the **Effects of Climate Change on Biodiversity within Conservation Halton's Watersheds** is to: • **Identify the effects** of climate change on the habitats, animals, and plants that inhabit Conservation Halton's watersheds. • **Recommend mitigation and adaptation measures** for Conservation Halton and others that can be undertaken to sustain biodiversity.
APPLICATION & USE	This report has been developed for: • **Decision makers and program managers** at Conservation Halton. • **Municipalities and managers** of ecologically significant and biodiverse properties. • **Property owners, businesses, individuals and others** who are want to undertake or promote actions, big or small, to sustain biodiversity.
ADDITIONAL REFERENCE MATERIALS ON BIODIVERSITY	• Celebrating a Diverse Colonial Waterbird Community https://storymaps.arcgis.com/stories/d5c39c8f3ae3481c97ede4374ae5541b • How Much Habitat is Enough? https://storymaps.arcgis.com/stories/449373496c20412c8dcc2d2f9ac8f75a • Monitoring Watershed Health https://camaps.maps.arcgis.com/apps/MapSeries/index.html?appid=ad0c736957fb401794b5d5b1ab4d7eb5 • Watershed Report Card 2023 https://www.conservationhalton.ca/watershed-report-card/ • Aquatic Monitoring https://gis.conservationhalton.net/AquaticMonitoring/ • Terrestrial Monitoring https://camaps.maps.arcgis.com/apps/MapJournal/index.html?appid=5c5b47db21fb4d6dbd2e348fc14d93e3 • Marsh Monitoring https://camaps.maps.arcgis.com/apps/MapJournal/index.html?appid=2efe2c3ba26d42cabbfe1cc096db262f
VERSION	**Version 1.0** This version of the **Effects of Climate Change on Biodiversity within Conservation Halton's Watersheds** was endorsed by the CH Board of Directors in September 2023. This report may be updated from time to time.

Executive Summary

Conservation Halton was established as a conservation authority more than 60 years ago to protect our communities from natural hazards such as flooding and erosion and to manage and restore the natural resources of the watershed on behalf of its municipalities.



Conservation Halton's jurisdiction of more than 1000 square kilometres is watershed-based. It includes the Grindstone, Bronte, and Sixteen Mile Creek watersheds and 18 smaller urban watersheds that enter Lake Ontario (herein referred to as Conservation Halton's watersheds).

Introduction

The report entitled "*Effects of Climate Change on Biodiversity within Conservation Halton's Watersheds*", dated September 2023, explores how local biodiversity is and will continue to be affected by climate change and provides local examples.

It describes what actions Conservation Halton is currently undertaking to address the impacts of climate change on biodiversity and provides eight recommendations for additional action.

The report acknowledges the efforts of others, including local municipalities, to address climate change implications and offers suggestions for action.

This report was prepared by Conservation Halton with input from municipalities and is based on available scientific research, technical reports and ecological monitoring data collected by Conservation Halton and others.

Biodiversity and Climate Change

Declining biodiversity and the effects of climate change are interrelated crises at a global scale. Up to one million species are under threat of extinction and climate change plays an increasingly important role in their decline.

There is evidence that ecosystem changes due to climate change have already occurred in Canada and we are witnessing some of the effects within our local watersheds. We are now experiencing conditions that are on average warmer, wetter, and wilder than what we have experienced historically in Conservation Halton's watersheds. Together with the loss of biodiversity through degraded habitats, declining species due to impacts of climate change is a critical issue in Conservation Halton's watersheds. Local examples of species that were formerly present but are no longer found include Loggerhead Shrike, Passenger Pigeon, and Timber Rattlesnake.

When biodiversity is impaired, the services provided by nature that benefit society are also impaired. These services include:

- filtering contaminants from surface and groundwater;
- absorbing rainwater during severe weather events to prevent flooding, erosion, and drought;
- reducing air temperature during heat waves; and
- capturing and storing carbon to mitigate the impacts of climate change.

Climate change is often referred to as a 'threat multiplier' because it exacerbates other issues. For biodiversity in Conservation Halton's watersheds, climate change is one of many other stressors (including invasive species) acting on an already degraded habitat network.

- Habitat is highly fragmented, and few large habitat patches remain. Many remaining natural corridors between terrestrial habitat patches are associated with watercourses.
- Wetland and forest cover are unevenly distributed across the watersheds and are concentrated above the Niagara Escarpment. These areas also generally coincide with subwatersheds with the best water quality.
- Except for wetland cover in Grindstone and Bronte Creek watersheds, forest, wetland, and riparian cover are generally below recommended thresholds for ecological health.

Climate change already affects species such as the endangered Redside Dace in Conservation Halton's watersheds. Current climate projections suggest these effects will continue.

Climate Change Impacts on Biodiversity

Several general conclusions can be drawn about how climate change is impacting biodiversity in Conservation Halton's watersheds.

- **Climate Change is Impacting Biodiversity**— The impacts of climate change cause shifts and changes to the status, health, and range of many species.
- **Winners and Losers**— Climate change affects every species differently. Some species will increase in population size and/or expand their distribution, while others will experience the opposite effect. In general, species with highly specialized requirements (dietary, reproductive, habitat, etc.) such as Redside Dace are most vulnerable to the effects of climate change.
- **Dependence on Other Species**— All species interact with others, but some rely directly and specifically on other ecosystem species to complete their life cycles. Changes to

other species because of climate change amplifies these interactions. Examples include mussels that rely on certain fish for their larval life stage and butterflies whose larvae feed only on a specific host plant, like Mottled Duskywing.

- **Use of More than One Habitat Type** - All local amphibians except Red-backed Salamanders rely on aquatic habitat during their tadpole/larval stage, with most moving to terrestrial habitat for the adult portion of their life cycle. This is also the case for many insects, such as dragonflies. This augments exposure to climate change effects and can amplify species vulnerabilities because of differing effects on different habitat types.
- **Migratory Species** – Long-distance migrant species, like the Bobolink, spend part of each year in areas like South America that may experience climate effects differently than our local conditions. As such, temperature cues for migration may result in a mismatch with conditions at their destination. For example, birds triggered to migrate too soon may face inhospitable temperatures or lack of available food once they arrive resulting in increased mortality rates.
- **Cold-blooded Species** - The physiological processes of cold-blooded species (reptiles, amphibians, freshwater mussels, fish, insects, and benthic macroinvertebrates) are affected by their ambient (i.e., surrounding) temperature. These species may actively move around to select warmer or colder microhabitats to suit physiological needs. However, their inability to internally regulate their body temperature increases their vulnerability to climate change, specifically, temperature increases.
- **Fragmented Habitat** - All species inhabit a landscape that is highly fragmented. Roads, buildings, and certain land uses are barriers to wildlife movement and can prevent plants (through seed dispersal) and animals from moving to more suitable habitat. This can result in reduced gene flow and thus reduced diversity at the genetic level. Lower genetic diversity is generally unfavourable for plant and wildlife populations because it reduces the probability of outliers that might be better equipped to handle changing conditions.
- **Mobility** - Mobility is related to all the above factors. Plants with animal or wind-dispersed seed can shift their range more quickly than species with gravity-dispersed seed that simply drops to the ground beneath the parent plant. Cold-blooded species like snakes and fish are better able to move to favourable micro-climates than more sedentary species like freshwater mussels.
- **Highest Climate Change Vulnerability** - Redside Dace is the only species identified in the highest category of Extremely Vulnerable. As such, this species will continue to be a focus of ongoing work by Conservation Halton as it serves as an umbrella or indicator species for climate change effects on other species.

General Principles Supporting Biodiversity

Despite the variability of the biodiversity in Conservation Halton's watersheds, there are four general principles for action that will benefit all species.

- **Guiding Principle #1: Keep what you have.** Protect and restore specialized habitats and ecosystem functions.
- **Guiding Principle #2: Allow for adaptation.** Maintain and enhance connectivity of the natural heritage system.
- **Guiding Principle #3: Multiply the value.** Use nature-based approaches that benefit both biodiversity and climate change resilience.
- **Guiding Principle #4: Monitor and adjust**. Natural systems are dynamic and constantly changing.

Recommendations for Strengthening Conservation Halton's Programs and Services

Conservation Halton plays a central role at the watershed level in protecting local biodiversity from the effects of a changing climate, with many programs and services related to climate change, biodiversity, or both. For example, the size, location, and quality of natural features in the watershed influences how the system responds during storm events, thus connecting biodiversity and ecosystem health to flood forecasting and operations of our water management infrastructure such as dams, reservoirs, and channelization works.

Key projects being implemented include:

- studying and reporting on the value of ecosystem goods and services such as carbon storage and sequestration to emphasize the value of nature-based approaches that both benefit biodiversity and address climate change;
- advancing the implementation of Grindstone Creek Municipal Natural Assets Initiative (MNAI) report recommendations;
- completing a Watershed-Based Resource Management Strategy (Watershed Strategy);
- undertaking a Climate Change Vulnerability and Risk Assessment and Climate Resiliency Strategy for Conservation Halton's watersheds;
- mitigating Conservation Halton's corporate emissions to reduce the magnitude of climate change on our ecosystems, through projects targeting fleet electrification, building efficiencies and sustainable procurement practices; and
- completing installation of low impact development improvements to stormwater management at Conservation Halton's Administrative Office that provide habitat for pollinators.

While Conservation Halton currently implements many programs and services that help to sustain biodiversity and moderate climate change impacts, available science and data show that additional efforts at the watershed-scale are needed. Based on this review, the following recommendations to enhance programs and services are made.

1) Assess the watershed monitoring program to determine whether it adequately represents biophysical functions and sensitive sentinel species that can provide early detection of climate change impacts and, if required, adjust the monitoring program to include those that are most susceptible to the effects of climate change.
2) Provide additional data analysis, through a climate change lens, that connects physical (hydrometric, meteorologic, and hydrologic) data and observed biological responses to better understand biodiversity conditions, trends, and risks linked with climate change.
3) Establish a regular cycle to report on climate change conditions, trends, risks, and management outcomes to inform watershed planning and management actions.
4) Partner with researchers from post-secondary institutions to advance scientific research on climate change impacts relevant to Conservation Halton's watersheds and guide management actions which promote climate change mitigation and adaptation through nature-based solutions.
5) Develop a Seed Strategy for Conservation Halton's tree planting program to ensure that planting stock is adapted to future climate conditions.
6) Assess and implement new technologies and best approaches that can provide insight into the connection between changes in the biophysical environment and biological responses (e.g., application of NatureServe's Climate Change Vulnerability Index to additional species, use of updated or more localized climate projections, predictive modeling, etc.).
7) Develop species-specific monitoring and restoration strategies for target species at risk and climate-vulnerable species on Conservation Halton lands.
8) Develop a restoration prioritization tool to support watershed planning and allow for more strategic selection and identification of restoration opportunities to address specific goals related to climate change and other watershed stressors.

Other Actions Suggested for Municipal Partners, Property Owners, and Individuals

<u>Municipalities</u>

Municipalities play a complementary role in addressing climate change and biodiversity conservation. Examples of municipal projects that support biodiversity include development of biodiversity strategies and plans, assessment of natural capital, establishment of Natural Heritage Systems, achieving designations as bee- and bird-friendly municipalities, development of innovative large-scale restoration approaches, regular assessment of natural areas, tree planting, tree strategies, municipal bylaws, invasive species management plans, and programs to assist farmers with improved practices that benefit biodiversity.

The following suggestions are offered to municipalities for consideration, if not already implemented.

- Maintain a robust, connected Natural Heritage System to allow plants and animals to disperse and migrate safely to new areas.
- Include biodiversity as an important component of a new or updated Climate Change Strategy.

- Combine innovative stormwater management pond design with proactive and regular inspection and maintenance of stormwater management ponds to ensure optimal storage and treatment capabilities are maintained.
- Use a diverse assemblage of native species for all tree planting and landscaping on municipal lands, with an emphasis on Carolinian species.
- Integrate nature-based solutions and natural infrastructure into asset management plans to the extent possible for multiple co-benefits, including biodiversity support.
- Design and maintain designated trail networks through public natural areas to direct human use to areas that are less sensitive to disturbance.

Property Owners

Property owners, including businesses, can play an important role in promoting biodiversity by undertaking actions that promote good land stewardship and habitat improvement.

The following actions are suggested.

- Use local native species for gardening and landscaping rather than ornamental species that originate elsewhere.
- Manage stormwater by disconnecting downspouts (where appropriate), installing and using a rain barrel, planting a rain garden or installing a permeable driveway.
- Restore or disconnect online ponds which cause water temperature increases in streams because of surface exposure to sunlight.

Individuals

There are many actions, large and small, that individuals can take to support biodiversity protection and climate change mitigation and adaptation.

- Learn more about how climate change affects biodiversity and support or join groups or organizations that promote actions to protect and enhance local biodiversity and mitigate or adapt to climate change.
- Keep your cat indoors. Cats are estimated to kill between 100-350 million birds each year in Canada, in addition to small mammals, reptiles, amphibians and insects.
- Be a conscious consumer. Choose products and services that help mitigate against climate change.

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Preamble

About Conservation Halton

Conservation Halton is a conservation authority established more than 60 years ago to protect our communities from flooding and erosion and to manage and restore the natural resources of the watershed[1]. It is also our responsibility under the *Conservation Authorities Act* to protect drinking water sources, prepare our communities for the impacts of climate change, support our partners in creating more sustainable communities, manage our natural areas and resources within the watershed, monitor and enhance the environmental health of our watershed and create opportunities to connect with nature through recreation and education.

Together, Conservation Halton and its partners are working to ensure a healthy watershed with clean streams, abundant forests and natural habitats that are in balance with our growing communities and engaged residents[2].

Conservation Halton's jurisdiction is watershed-based, as illustrated in Figure 1. Conservation Halton is responsible for an area of more than 1000 square kilometres. This includes the Grindstone, Bronte, and Sixteen Mile Creek watersheds and 18 smaller urban watersheds that enter Lake Ontario, from Grindstone Creek in the west to Joshua's Creek in the east (herein referred to as Conservation Halton's watersheds).

Conservation Halton uses the knowledge gleaned from environmental science, collaborative research, and collective data to inform us about conditions, trends, and risks. This, in turn, informs our decisions about practices and approaches to manage natural hazards, protect and strengthen ecosystem integrity and resilience, and support development that sustains the environment.

Why?

Why should we be concerned about the effects of climate change on biodiversity? Simply put, the impacts of climate change on biodiversity threaten the long-term health and prosperity of our communities. For example, the pollination provided by insects and animals supports 30% of global food production and is valued at EUR 153 billion annually (Khalifa et al. 2021).

This report explores how local biodiversity is and will continue to be affected by climate change. It describes what actions Conservation Halton is currently undertaking to address the impacts of climate change on biodiversity and provides eight recommendations for additional action.

This report also acknowledges the efforts of our municipalities to address climate change implications and offers suggestions for enhancing the municipal actions already being undertaken. In addition, suggestions for actions which will support biodiversity are offered at the property and individual level.

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[1] A watershed is an area of land where rain and snowmelt drains into a body of water, such as a stream, creek, river, or lake.

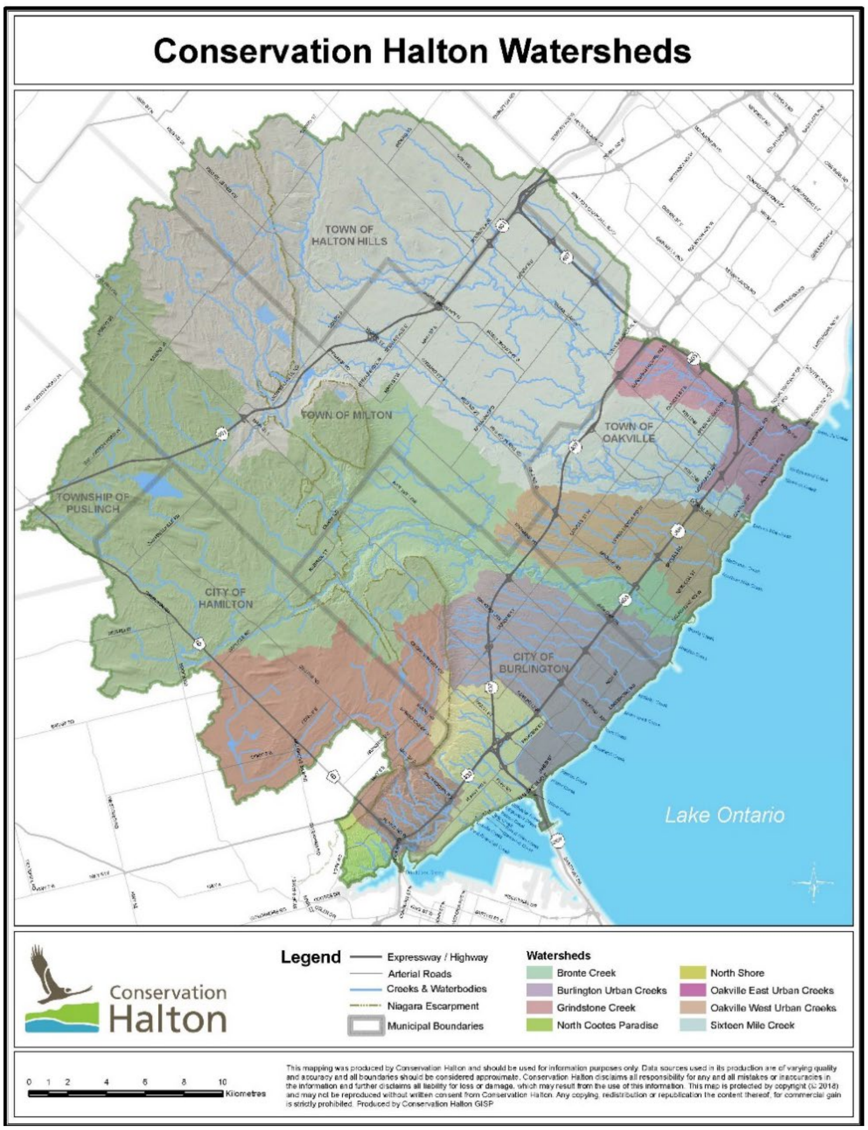
[2] Refer to Conservation Halton's strategic plan, Momentum (https://www.chmomentum.ca/).

It is hoped that this report will also assist readers in understanding the connections between climate change and biodiversity at both the landscape and site-specific scales and the importance of sustaining and enhancing biodiversity as a critical component of an integrated climate change adaptation strategy.

Approach

This report was prepared by Conservation Halton staff who relied on available scientific research, technical reports, and advice from municipal staff. In addition, staff reviewed and analyzed years of ecological monitoring data collected by Conservation Halton and others to identify changes in local biodiversity and provide examples of how these changes may be related to climate change. Municipal staff provided input to Section 5.3.

Figure 1: Conservation Halton Watersheds



Source: Conservation Halton

Section 1 Introduction

Biodiversity includes all various life forms on earth, including humans. However, for this report, the term "biodiversity" is used to refer to flora and fauna only.

This report explores how our local biodiversity is and will continue to be affected by climate change, why it is a concern, and what we can collectively do about it. It outlines what is required at both the landscape and site-specific scales to protect and enhance biodiversity in Conservation Halton's watersheds – a critical step which will help us adapt and strengthen our resilience to expected changes driven by climate change.

Declining biodiversity and the effects of climate change are interrelated crises at a global scale, with up to one million species threatened with extinction and climate change playing an increasingly important role in their decline (United Nations 2023). Ecosystems that have experienced biodiversity loss are less resilient to the effects of climate change (Cleland 2011). In turn, biodiversity loss, such as the removal of trees that would otherwise mitigate greenhouse gas emissions, can worsen the impacts of climate change.

The effects of climate change on local biodiversity are varied and not fully understood because there are many factors that affect species' sensitivity to climate change. The most vulnerable species are those exposed to large and/or rapid climate change-driven changes to habitat, with a high degree of sensitivity to those changes and a low adaptive capacity (Foden and Young 2016). A local example is Redside Dace. This endangered fish is exposed to increased water temperature, flows and associated changes to its habitat from climate change, to which it is sensitive because it requires coolwater conditions to survive.

Section 2 focuses on the observed and anticipated effects of climate change on habitat (water, wetlands, and forests), showing that these major ecosystems will be adversely affected across Conservation Halton's watersheds.

Section 3 provides an in-depth description of the sensitivity and ***adaptive capacity***[3] of broad taxonomic groups (birds, reptiles and amphibians, freshwater mussels, mammals, fish, insects, and ***benthic macroinvertebrates***) to climate change.

Section 4 presents conclusions, summarizing the factors that affect the adaptive capacity of local species and the consequences of biodiversity loss on communities.

Section 5 offers guiding principles for biodiversity conservation biodiversity in the face of a changing climate.

Section 6 describes current actions being undertaken in support of biodiversity by Conservation Halton and municipalities within our watersheds.

Section 7 highlights eight recommendations for additional action by Conservation Halton.

Section 8 offers suggestions to municipalities, property owners and individuals for improving local biodiversity.

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[3] ***Adaptive capacity*** refers to the ability of a system to adjust to climate change.

A glossary of technical terms and references are also provided. The terms defined in the glossary are italicized and bolded within this report.

Appendix 1 outlines the factors included in a species-specific climate change vulnerability assessment (Canadian Version v.3.0, Young and Hammerson 2015).

Appendix 2 provides the results of applying the climate change vulnerability assessment outlined in Appendix 1 to a subset of local species (Brinker et al. 2018).

1.1 Biodiversity Trends

Globally, populations of mammals, fish, birds, reptiles, and amphibians have declined by an average of 69% since 1970 (WWF 2022). Worldwide, 49% of bird species have declining populations and over 3 billion birds have been lost across North America and the European Union in the last 50 years (Bird Life International 2022). Patterns of loss observed at global scales hold true in Canada, Ontario, and Conservation Halton's watersheds. Local examples of species that were formerly present but are no longer found in Conservation Halton's watershed include Loggerhead Shrike, Passenger Pigeon, and Timber Rattlesnake.

This report focuses on the major taxonomic groups that are routinely surveyed and studied by Conservation Halton. Knowledge of biodiversity in Conservation Halton's watersheds has been established though successive studies on Environmentally Sensitive Areas beginning in the 1970s and more recently the completion of Natural Areas Inventories for Halton (Dwyer 2006a, 2006b) and Hamilton (Schwetz 2014a, 2014b), as well as ongoing work in Peel (Credit Valley Conservation 2022). Conservation Halton has a species database containing these records (currently over 170,000) and continues to add annual results of field surveys and monitoring (Table 1-1). Citizen science platforms such as iNaturalist[4] and eBird[5] also provide increasingly accurate and prolific information on local biodiversity.

TABLE 1-1: SPECIES IN CONSERVATION HALTON'S WATERSHEDS

Taxonomic Group	Number of Species Recorded in Conservation Halton's Watersheds
Plants	1,445
Birds	351
Fishes	93
Butterflies	89
Dragonflies & Damselflies	96
Mammals	45
Reptiles & Amphibians	37
Mussels	14
Total	**2,170**

[4] iNaturalist is an online social network of people sharing biodiversity information to help each other learn about nature (https://www.inaturalist.org/).

[5] eBird is the world's largest biodiversity-related citizen science project, with more than 100 million bird sightings contributed each year by eBirders around the world. (https://ebird.org/canada/home).

1.2 Species at Risk

Plants and animals (including an increasing number of invertebrates) may become designated as species at risk when they become rare and/or their long-term survival is in jeopardy. Species at risk often have specialised habitat requirements that may be uncommon on the landscape and sensitive to change, including that induced by climate factors.

Designated species at risk receive special protection under legislation including the provincial *Endangered Species Act* and the federal *Species at Risk Act.* Specific terms are used to describe the extent to which these species are at risk (Table 1-2).

TABLE 1-2: SPECIES AT RISK DEFINITIONS

Species at Risk Classification	Definition
Extinct	A species that no longer exists
Extirpated	A species that no longer exists in the wild in a specified jurisdiction (for example, Ontario or Canada) but exists elsewhere in the wild (for example, the United States)
Endangered	A species facing imminent extirpation or extinction
Threatened	A species that is likely to become endangered if steps are not taken to reverse the factors threatening it
Special Concern	A species that may become threatened or endangered because of a combination of biological characteristics and identified threats

Species at risk often serve as sensitive indicators of broader environmental change. One local example is the endangered Jefferson Salamander, which is threatened primarily by loss and degradation of its forest and wetland habitats (Linton et al. 2018). Other species at risk were formerly common, but their rapid decline provides an alert to specific emerging threats. A local example is the mass die-off of Butternut (now endangered) that signaled the arrival of Butternut canker, a fungal disease (Poisson and Ursic 2013).

1.3 Climate Change

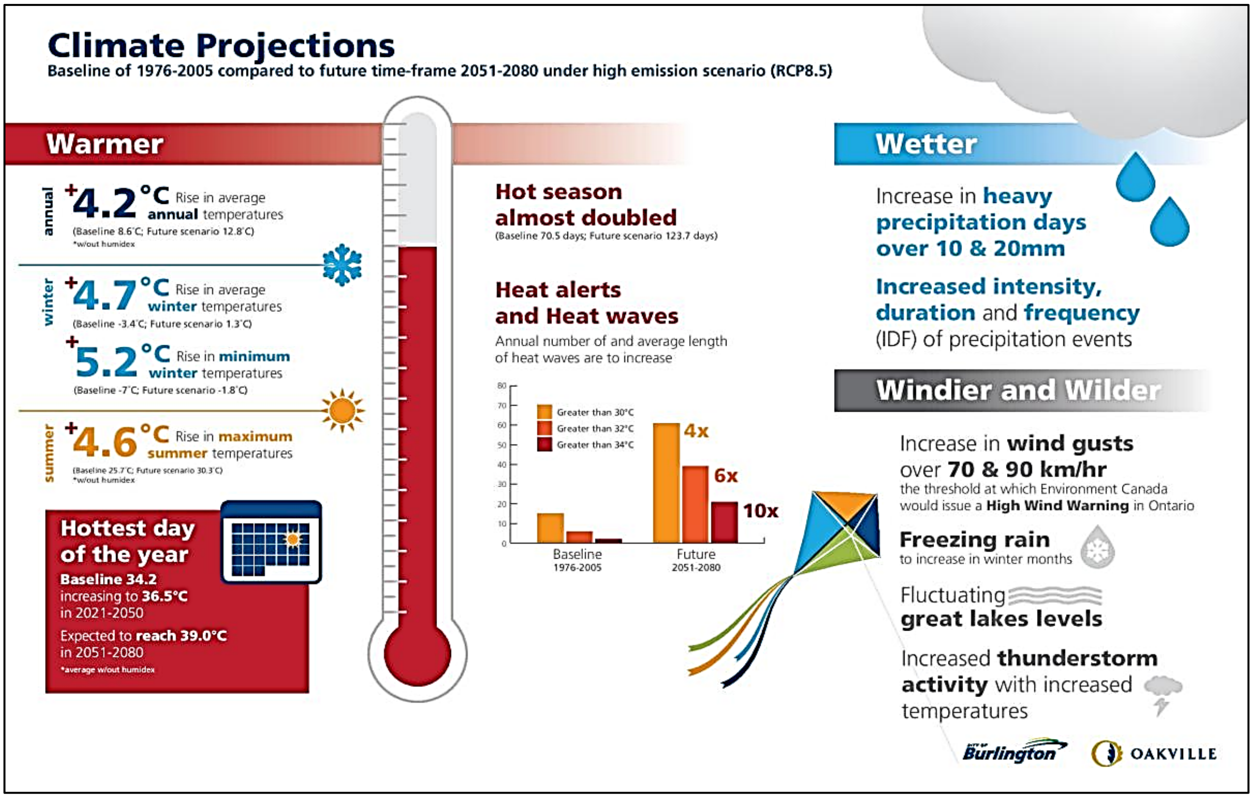
Recent studies show that Canada is warming at twice the global average (Bush and Lemmen 2019). Figure 1-1, prepared by the City of Burlington and Town of Oakville, shows that in Conservation Halton's watersheds, it is expected that average annual, winter and summer temperatures will rise; precipitation events will be longer, more intense, and more frequent and there will be increases in strong wind gusts, freezing rain and thunderstorm activity.

To understand how the changing climate is impacting our watersheds and natural assets[6] such as forests and wetlands, and how the services from forests and wetlands that we rely on may be

[6] The term *natural assets* refers to the stocks of natural resources or ecosystems that contribute to providing one or more services required for the health, well-being, and long-term sustainability of a community and its residents (e.g., water filtration, stormwater management, climate regulation).

impacted, this report focuses on the impacts of climate change on local biodiversity, and what can be done to protect and enhance biodiversity to increase resilience.

FIGURE 1-1: CLIMATE CHANGE IN CONSERVATION HALTON'S WATERSHEDS



Source: Used with permission from Town of Oakville and City of Burlington

There are many examples of recent local events that have been exacerbated by climate change, from extreme heat events and major flooding to intense storms with wind speeds of up to 119 km/hr (City of Burlington 2022). For example, the August 4, 2014 storm in Burlington, which dropped 191 mm of rain over a period of eight hours, resulted in severe flooding and damage localized to a few urban watersheds within the City (City of Burlington 2022).

Section 2 Climate Change Effects on Habitat

2.1 Habitat

Plants and animals need places to live where they can meet their basic needs for food, shelter, and reproduction. The quality and quantity of these habitats provide the foundation that supports biodiversity and all interactions that occur between species. Scientists widely accept that climate change will affect natural systems, plant and animal species and their habitats, and the risk of species extinction increases with every degree of warming (United Nations 2023). Indeed, there is evidence that ecosystem changes due to climate change have already occurred in Canada (Nantel et al. 2014) and we are witnessing some of the effects within our local watersheds.

The impacts are dependent upon the interaction of abiotic (i.e., physical) and biotic (i.e., biological) factors and subject to ***synergistic*** effects. It is therefore challenging to predict responses of individual species, and even more difficult to anticipate what our local ecosystems will look like in the future.

To help us respond to the coming changes, an understanding of the mechanisms that influence habitat can provide some guidance about how things are likely to occur, with the caveat that new combinations of species and ***novel ecosystems*** will likely arise that even the best models cannot predict.

Conservation Halton has compared the extent of forest, wetland, and stream habitat in its watersheds (Conservation Halton 2021) to recommended thresholds for a healthy ecosystem (Environment Canada 2013). This analysis, combined with the results of the most recent Watershed Report Card (Conservation Halton 2023), allows some general conclusions about the current extent and quality of habitat.

- As is the case generally in southern Ontario, habitat is highly fragmented, and few very large ***habitat patches*** remain. Many remaining natural corridors between terrestrial ***habitat patches*** are associated with watercourses.
- Wetland and forest cover are unevenly distributed across the watersheds, with the bulk of these features concentrated in rural areas above the Niagara Escarpment (Conservation Halton 2021).
- Only two watersheds (Grindstone and Bronte Creek) exceed the recommended minimum 10% wetland coverage (Environment Canada 2013); some of the urban watersheds, such as Upper and Lower Hager Creek in Burlington, no longer have any wetlands (Conservation Halton 2021).
- Overall forest cover is 25% (Conservation Halton 2021), which is predicted to support less than half of the potential species richness, and marginally healthy aquatic systems (Environment Canada 2013).
- Streams with the best water quality are generally located in areas of higher forest and wetland cover (Conservation Halton 2023).
- None of the watersheds reach the minimum threshold of 75% vegetated buffers along streams (Environment Canada 2013). Vegetated buffers help lower creek temperature by shading the water and are a useful tool to help mitigate rising temperature from climate change.

2.2 Water

Abiotic (physical) components are an essential part of aquatic ecosystems as they provide the environment in which the biological community resides and interacts. The impact of climate change on biological communities is highly influenced by its impact on abiotic processes. Temperature, precipitation, water quality, and stream habitat and form determine which species can reside in a stream reach. By examining the influence of climate change on these parameters, we can gain a stronger understanding of why and how the biological community will be affected by climate change.

2.2.1 Water Temperature

Surface water temperatures are influenced by natural, climatic, and anthropogenic[7] factors. Stream temperatures are spatially ***heterogeneous*** or diverse, with temperatures in the summer generally following a gradient of cooler waters upstream and warmer waters downstream (Poole and Berman 2001). In a riverine system, ***headwater streams*** at the top of the watershed are generally coldwater systems consisting of low species diversity and comprised of coldwater loving organisms such as ***salmonids***. These areas are cold due to higher concentrations of groundwater inputs, in addition to larger natural areas with a vast amount of forest cover.

When a stream flows downstream towards its connection with a waterbody, it crosses a variety of landscapes, which contribute to its changing ***thermal regime***. Channel structure along with influxes of groundwater, inflows from tributaries, and surface runoff increase a stream's thermal heterogeneity (Poole and Berman 2001, Webb et al. 2008). On a local scale, these changes in temperature can result from increased impervious areas, lack of forest and riparian vegetation, and prolonged periods of high air temperatures, which in turn increase sun exposure (solar radiation), resulting in higher water temperatures.

Regardless of location in the watershed, water temperatures are heavily influenced by and respond rapidly to changes in surrounding air temperatures because they are relatively shallow, with flowing, mixing water (Allan et al. 2005).

In urban areas with impervious surfaces and little natural shade, sun exposure can make urban streams extremely vulnerable to warming temperatures due to Urban Heat Islands (UHI). A UHI experiences much warmer temperatures than nearby rural areas (Voogt and Oke 2003). UHI occur due to the absorption of sunlight and the thermal and radiative properties of urban surface materials such as concrete and asphalt, combined with anthropogenic heat sources and a lack of evapotranspiration (Oke 1982). In warm summer months, local air and ground temperatures in UHI can be 10 to 12°C degrees warmer than the surrounding fields and forests (Galli 1990).

When precipitation hits hard urban surfaces, it cannot infiltrate naturally into the ground and cool off before re-entering the stream system. Instead, it hits the "superheated" surfaces and warms the water before entering the stream. With climate change, annual precipitation volume is likely to increase (Hayhoe et al. 2010) and the occurrence and length of precipitation events is anticipated to change to higher incidences of brief, concentrated rain events. Consequently, increased precipitation events with higher volumes, coupled with the expansion of urban surface materials, will have a drastic effect on stream temperatures.

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[7] Anthropogenic factors are those components of environmental change that are caused or influenced by people, either directly or indirectly.

Several climate-related articles discuss contemporary global warming in various parts of the world (Brázdil et al. 1994, Klein Tank and Können 2003, Beniston and Stephenson 2004, Moberg and Jones 2005, Brohan et al. 2006, IPCC 2007). Thermal increases are verified by both ground measurements and satellite measurements, which are not influenced by the effect of UHI. Folland et al. (1990) and Houghton et al. (1996) report an average annual temperature increase of 0.3–0.6◦C on earth from the end of the 19th century (Matuszko and Weglarczyk, 2014). The average annual temperature on earth in the century 1906–2005 increased by 0.74±0.18°C, according to the IPCC (2007) report. In addition to its direct effects on stream temperature, higher air temperature is expected to increase potential evapotranspiration and decrease water yield to rivers. This further degrades river water quality, due to less dilution (Luo et al. 2013). The ***hydrologic cycle*** may also be intensified by global warming, consequently leading to increased streamflow (Labat et al. 2004).

There is a direct relationship between sunshine duration and air temperature. During the summer, the surface warms up and accumulates heat in the daytime, which is then released into the atmosphere with a minor delay. Cloud cover can disrupt this relationship to some extent (Matuszko and Weglarczyk 2014). Convective clouds, typical of the warmer time of the year, permit solar radiation to reach the surface during the day. At night, when convection breaks, they convert into stratocumulus or altocumulus clouds, which hold in heat rather than letting it escape. A rise in air temperature results in an expanding occurrence of convective clouds, which contributes to further increases in both diurnal and nocturnal temperature (Matuszko and Weglarczyk 2014).

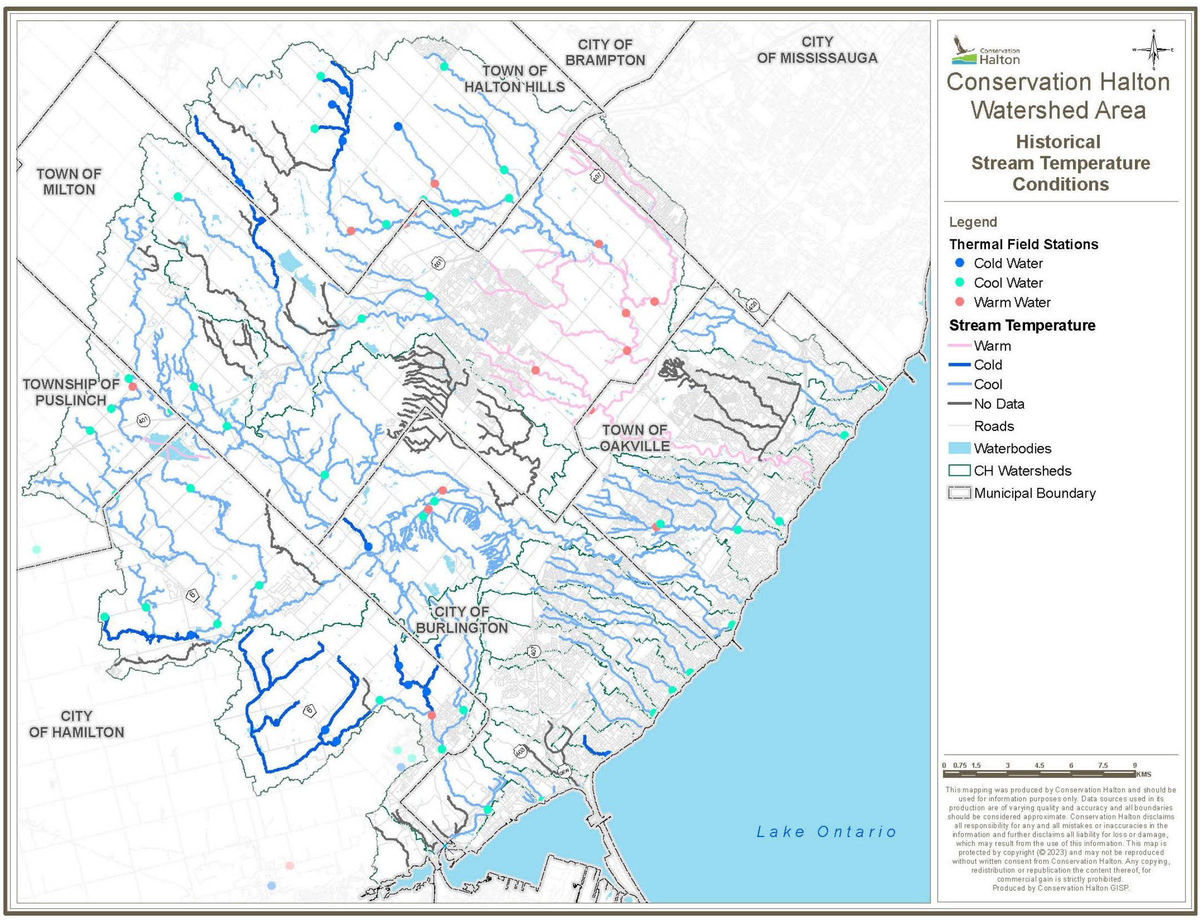
With climate change, fluctuations to solar radiation are intensified. Water temperature can change at a rate as high as 3°C per hour (Brown 1969 in Ryder and Pesendorfer 1988) while diurnal temperature variations up to 6°C can occur in response to the absorption of solar radiation or the release of heat from the water to the atmosphere (Hynes 1970). Solar radiation can also impact larger ***lentic systems***, such as lakes and ponds. Most heat energy enters ponds as solar radiation (Brönmark and Hansson 2005). Increases in precipitation will be associated with increases in water volume and consequently pond thermal mass (Brönmark and Hansson 2002). Heightened solar radiation and precipitation due to climate change will affect ***online ponds***, which will contribute to watershed-wide thermal warming.

Groundwater discharge is important for maintaining cooler temperatures in streams and provides ***coldwater refugia*** during summer (Kaya et al. 1977 in Meisner et al. 1988, Bilby 1984, Mortsch et al. 2003) and ***warmwater refugia*** in winter (Cunjak and Power 1987 in Meisner et al. 1988). This thermal moderation is important in maintaining optimal conditions for species where temperature conditions heavily influence their presence. The cooling effect that groundwater springs provide are especially important in reducing temperatures during heat stress periods of the summer. However, with climate change, this cooling effect could be reduced as groundwater temperatures increase in response to rises in air temperature (Meisner et al. 1988). Chu et al. (2008) found that streams in southern Ontario with high groundwater discharge may naturally offer more suitable habitat and thermal refugia for coldwater fishes as the climate changes. In more recent studies, the depth of groundwater has proved to be an integral part of offsetting climate change impacts.

Shallow groundwater is more influenced by land use practices and is susceptible to surface contamination (Hare et al. 2021). Groundwater depth is strongly correlated with annual thermal stability. Natural surface temperature variations are prominent within a shallow aquifer (the body of rock and/or sediment that holds groundwater), but quickly diminish with depth (Bundschuh 1993). Shallow groundwater can be quickly reduced through transpiration (water movement through plants back into the atmosphere) and irrigation withdrawals and is more susceptible to seasonal water table fluctuations during dry periods while discharge from deeper groundwater sources is more seasonably stable (Hare et al. 2021). Conservation of groundwater resources will be required to lessen climate change impacts on the thermal habitat and thermal diversity of stream fishes in southern Ontario watersheds (Chu et al. 2008).

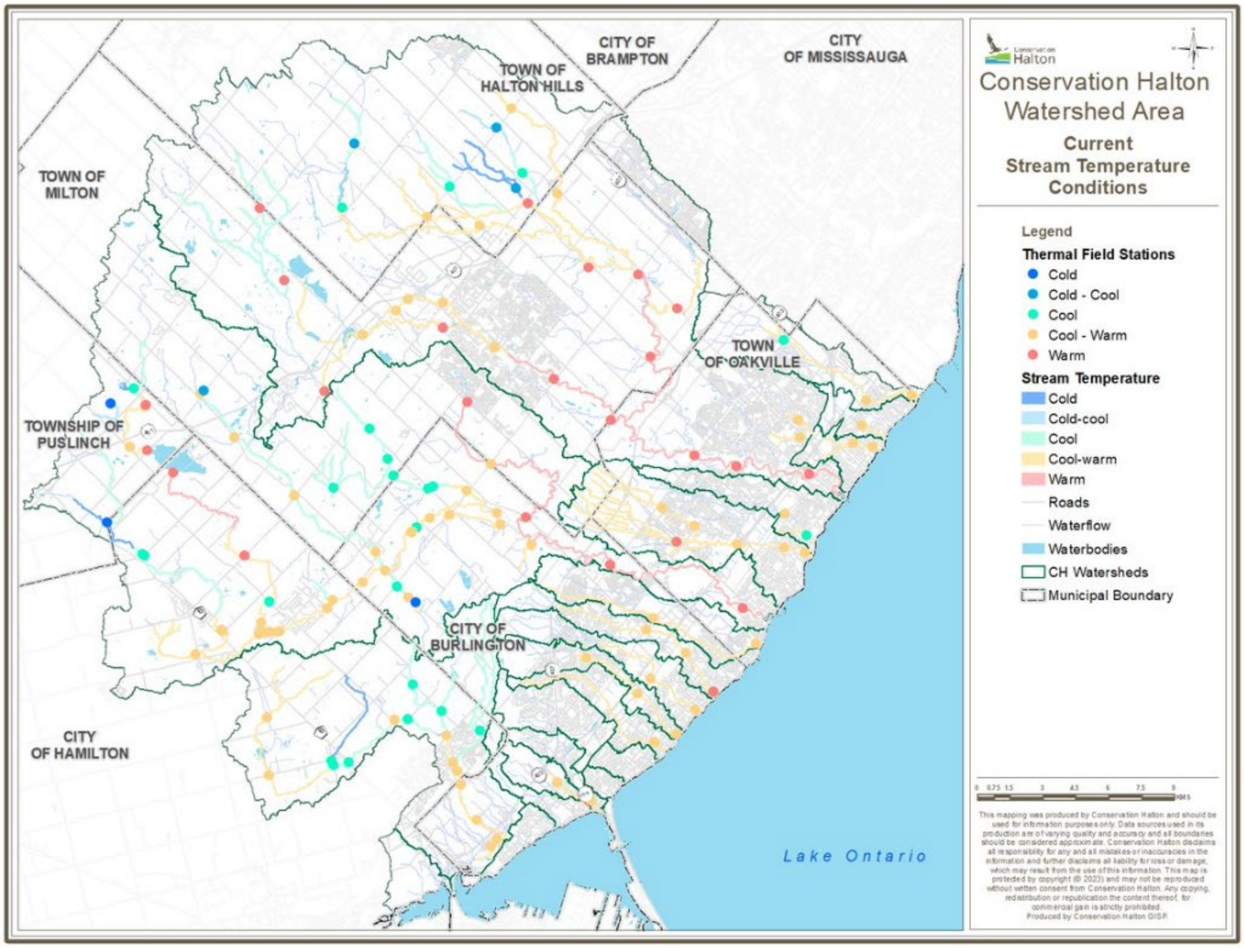
Surface water temperature monitoring across Conservation Halton watersheds has identified widespread increases in water temperature (Figures 2-1 and 2-2). Cold and coolwater headwater reaches typically associated with groundwater discharges and springs are still able to provide cool and ***coldwater refugia*** for a variety of species. However, many central and downstream reaches are exhibiting increases significant enough to raise the overall thermal classification of the streams. Precipitation events in the summer months also cause high spikes in temperature, which impact a stream's ability maintain cooler temperatures. Streams in urban areas or with limited to no riparian buffers or with additional human impacts (e.g., ***online ponds***) are experiencing added thermal impacts from climate change.

FIGURE 2-1: HISTORICAL 1997-2008 STREAM TEMPERATURE CONDITIONS WITHIN CONSERVATION HALTON'S WATERSHED



Source: Conservation Halton

FIGURE 2-2: CURRENT (2006-2021) STREAM TEMPERATURE CONDITIONS WITHIN CONSERVATION HALTON'S WATERSHEDS

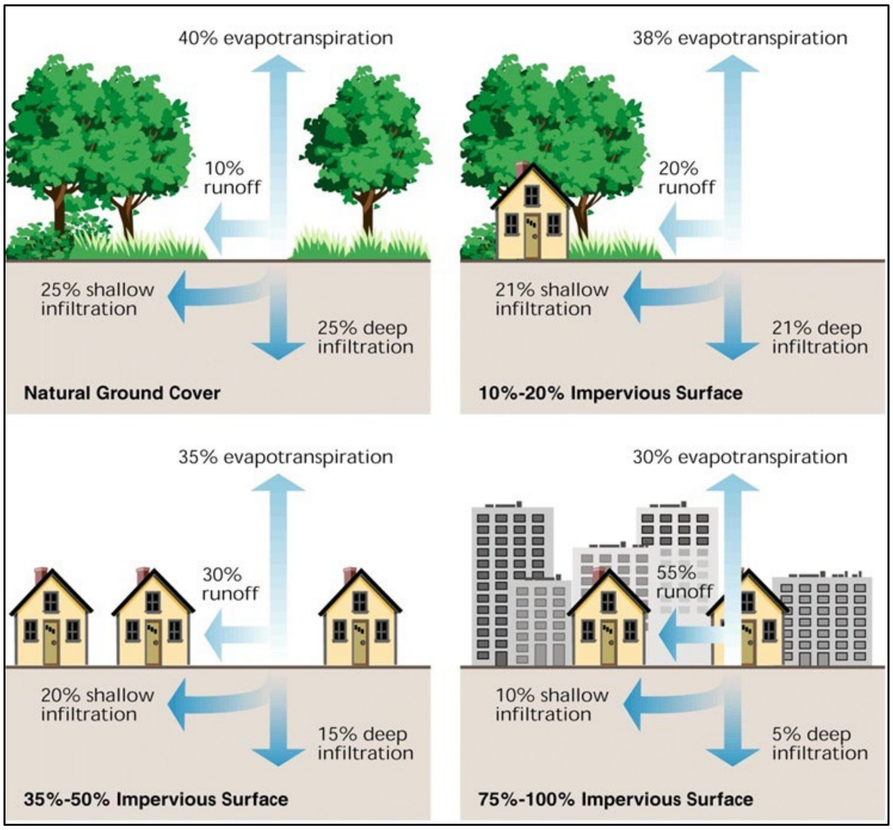


Source: Conservation Halton

Impervious cover can cause increased surface runoff. As little as 10 percent impervious cover in a watershed can result in runoff containing pollutants which degrade the water quality of streams (Figure 2-3). Conservation Halton and its partner municipalities use a variety of approaches to counteract the effects of urbanization, including:

- restricting development activities in natural hazard areas such as stream valleys, wetlands, and shorelines,
- undertaking subwatershed planning to identify and prioritize measures to protect water resources which must be implemented prior to construction of new urban development,
- restoring and enhancing degraded natural features and processes, and
- designing, implementing, and monitoring the effectiveness of stormwater management approaches, including the use of low impact development techniques such as bioswales, rain gardens, infiltration trenches, permeable pavement and rainwater harvesting, where feasible.

FIGURE 2-3: RELATIONSHIP BETWEEN IMPERVIOUS COVER AND SURFACE RUNOFF



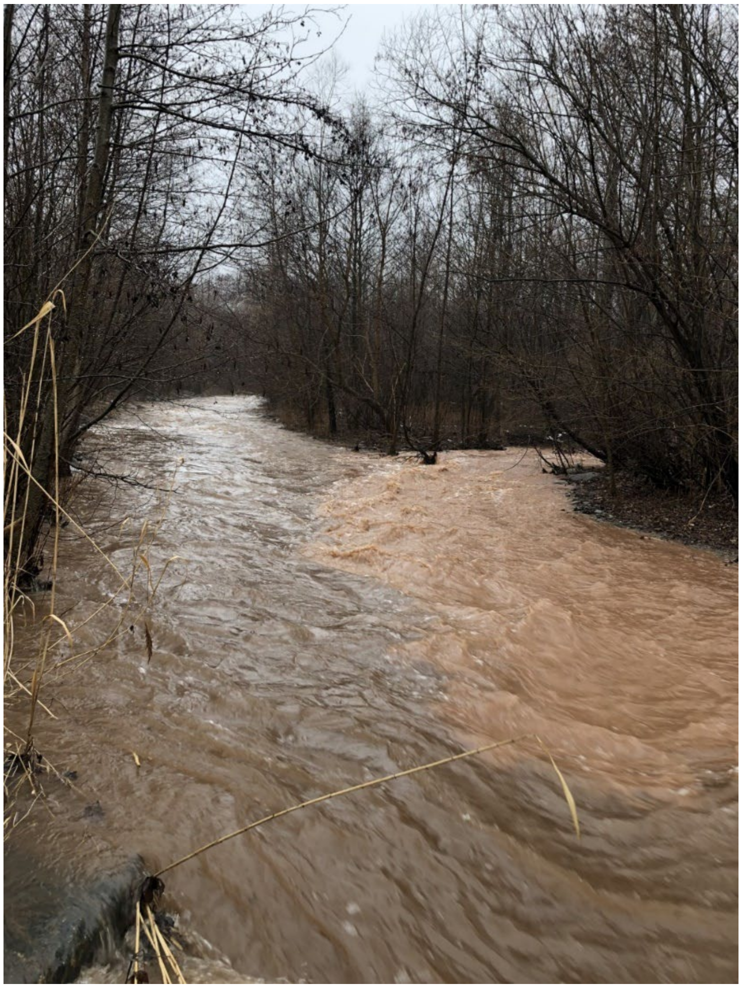
Source: Stream Restoration: Principles, Processes and Practices (fisrwg 1998), Massachusetts Department of Environmental Protection [Accessed February 2021]

2.2.2 Precipitation

Under a business-as-usual emissions scenario, climate change in Conservation Halton's watersheds is projected to result in an average annual temperature increase of 4.2°C between 1976-2005 and 2051-2080 (Prairie Climate Centre 2019). A warmer climate will have direct impacts on the ***hydrologic cycle***, with increased evaporation rates, more extreme rain events, and a higher proportion of winter precipitation falling as rain instead of snow (Murdoch et al. 2000, Delpla et al. 2009, Alamdari et al. 2017, White et al. 2018).

These changes, in turn, are expected to cause an earlier spring ***freshet*** (snow and ice melt or heavy rain event), and an increase in runoff occurring during the winter (Luo et al. 2013, Davis et al. 2013). Figure 2-4 shows the response of the main branch of Grindstone Creek (on the left) and a smaller tributary (on the right) to a spring storm. The smaller tributary is full of sediment eroded from the steep slopes of the Niagara Escarpment. Extreme rain events accelerate erosion, which in turn can lead to property loss, deterioration of water quality, and other damage to ecosystems and biodiversity.

FIGURE 2-4: GRINDSTONE CREEK AFTER SPRING STORM



Source: Conservation Halton

Annual precipitation volume is likely to increase (Hayhoe et al. 2010, City of Burlington et al. 2021) and the frequency and duration of individual precipitation events are expected to shift to a higher frequency of short, intense rain events (City of Burlington et al. 2021). This will result in periods of drought between intense storms.

If intense precipitation events occur after longer periods of drought and soil moisture is low, runoff can move to a stream more quickly, resulting in stream water levels rising quickly. In instances where intense events have occurred more periodically allowing soils to hold more moisture, runoff will occur more slowly, but stream volume and water levels will increase even more due to saturated soils. These changes in flow regime will then increase overland flow (e.g., surface runoff) causing erosion, runoff, and floods (Penna et al. 2011).

During periods of drought stream water levels will decrease, reducing habitat availability for the biotic community, and increasing the concentration of pollutants within a stream (Booty et al. 2005). In larger streams such as Grindstone Creek, occasional drought conditions (as seen in Figure 2-5) have resulted in significant reductions in flow which causes a reduction in available fish habitat for resident species. This also directly impacts the upstream movement of migratory spawning fish during breeding, further impacting population success in subsequent years. In smaller watersheds and tributaries, drought conditions result in creeks becoming completely dry and unable to support aquatic life.

FIGURE 2-5: FALL DROUGHT CONDITIONS IN GRINDSTONE CREEK

Source: Tys Theysmeyer, Royal Botanical Gardens

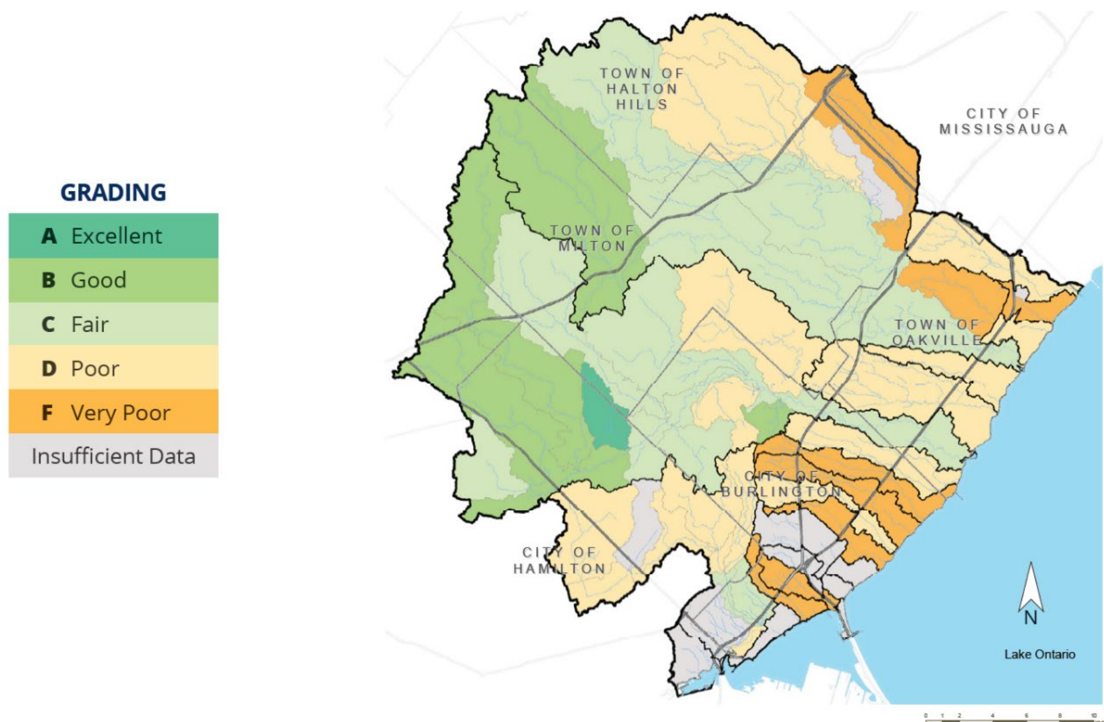
2.2.3 Water Quality

The quality of water within a stream is linked to surrounding land uses, temperature, and precipitation (Allan and Castillo 2007). In turn, water quality has a strong influence on the ability of some species to survive within a stream; those sensitive to pollution can survive only in streams with pristine water quality, while tolerant species can survive a wide range of pollutants. Surrounding land uses determine the chemical and nutrient inputs to a stream from both point and non-point sources. Streams within forested areas are influenced by surrounding vegetation, with trees providing shade as well as nutrient inputs through leaf litter and woody debris (Allan and Castillo 2007). The vegetation helps to stabilize banks and the abundance of pervious surfaces helps to filter out pollutants and insulates against flooding and erosion.

Streams within agricultural and urban environments generally experience harsher conditions because they often have little shade and receive high volumes of runoff during rain events. This is due to lack of riparian vegetation and an increase in impervious surfaces (Walsh et al. 2005, Wenger et al. 2009). Significant pollutants in agricultural areas include nutrients such as phosphorus and nitrogen from fertilizers which are spread on land to improve crop yield (CCME 2012). In urban areas, chloride, metals, and nutrients often contribute to poor water quality. Chloride compounds, used to de-ice roads during the winter months, can degrade water quality throughout the year (Lawson and Jackson 2020).

Conservation Halton assessed surface water quality in its 2023 Watershed Report Card (Conservation Halton 2023). Conservation Halton watersheds received an average grade of 'C'. Subwatershed grades ranged from A to F (Figure 2-6). Subwatersheds with lower scores tended to be in agricultural or urban areas. In agricultural areas, riparian vegetation is often minimal which allows nutrients and sediments to easily run off fields into streams. In urban areas, impervious surfaces limit infiltration and can result in higher volumes of runoff entering streams if inadequately treated. Conversely, subwatersheds with higher scores tended to be in areas with more natural cover, including higher amounts of forest cover. Natural cover, especially when located adjacent to streams, helps to filter water by removing excess nutrients and sediments before they reach the stream. This helps to protect and improve overall water quality.

FIGURE 2-6: SURFACE WATER QUALITY 2023



Source: Conservation Halton

Warmer water temperatures affect water quality by impacting levels of dissolved oxygen and nutrient cycling. The ability of water to hold dissolved gases decreases as temperature rises, which lowers **dissolved oxygen levels** (Murdoch et al. 2000, Delpha et al. 2009). Sensitive species often require high concentrations of dissolved oxygen due to their inability to efficiently pull oxygen from the water. With warmer temperatures reducing the amount of available oxygen, sensitive species are stressed and may be lost from an ecosystem**.**

Nutrient levels are also influenced by warmer temperatures which expediate the release of nitrogen and phosphorus from soils, resulting in increased nutrient loads within streams (Delpla et al. 2009). Increases in temperature, nitrogen, and phosphorus stimulate plant and algae growth, further altering dissolved oxygen levels and impacting habitat availability. Although initial increases in plant growth can be beneficial by increasing dissolved oxygen through photosynthesis during the day, nocturnal use of oxygen can result in anoxic conditions (oxygen deficiency). Plant death and decomposition further impairs oxygen levels (Dosdall and Giberson 2014) and the shift in plant growth rates leads to a decrease in sensitive species within an ecosystem (CCME 2004).

Changes to precipitation can also influence water quality. Research reviewed by the Intergovernmental Panel on Climate Change (IPCC) found that climate change had a negative impact on water quality, with runoff increasing pollutants within streams (Jiménez Cisneros et al. 2014). Climate change is expected to affect precipitation, resulting in more floods due to higher intensity rain events, and more droughts due to longer periods without rain (Murdoch et al. 2000, Bartolai et al. 2015).

Greater intensity of rain events will cause increased runoff to receiving streams. In urban areas, some stormwater management facilities may be overwhelmed by increased flow volumes and their effectiveness may be reduced (Alamdari et al. 2017). Heavy storms may also increase the number of combined sewer overflow events with more untreated sewage entering aquatic environments (Patz et al. 2008, Delpla et al. 2009). Within Conservation Halton's watersheds, combined sewers are found in older parts of the City of Hamilton between Mohawk Road and Hamilton Harbour. As precipitation in winter shifts from snow to rain, higher amounts of runoff are anticipated due to precipitation falling on frozen ground and being unable to percolate into the soil. This is expected to result in increased nutrients entering the stream (Delpla et al. 2009). Lower flows in summer and an increase in the frequency of drought conditions will increase the concentrations of various chemicals and nutrients (Murdoch et al. 2000, Booty et al. 2005, Bartolai et al. 2015).

Drought conditions may also allow nutrients to build-up on land with a large flush entering a stream during the next rainstorm (Wilby et al. 2006) resulting in pulses of concentrated pollutants. For sensitive species this may create conditions in which they are unable to survive, forcing them to move to new areas or face extirpation.

2.2.4 Stream Habitat

The structure of a stream is determined by both external and internal landscape forces. External forces include geology, climate and human influences, while internal forces include sediment supply, stream discharge and riparian vegetation (Hogan and Luzi 2010). Each external force can influence each internal force with additive effects occuring if multiple forces are combined.

Stream flow and discharge determine the amount of erosion and the size of sediment that can be moved in a stream. Higher velocities, such as those experienced during flooding, are able to carry larger sized sediment, and cause bed scour and bank erosion. The amount and location of both erosion and deposition of sediment depend on the size of the stream as well as the riparian vegetation, with well vegetated streams being more resistant to erosion (Allan and Castillo 2007). Warmer air temperatures are predicted to increase the amount of precipitation falling as rain, instead of snow, during winter months. This, in turn, will increase the amount of runoff occuring in the winter, with more winter floods and an increase in erosion during these months (Boyer et al. 2010). The shift in temperature and precipitation will also cause the spring ***freshet*** to occur earlier in the year, resulting in higher winter flows and lower spring flows (Boyer et al. 2010, Davis et al. 2013, Luo et al. 2013).

The potential impact of erosion is difficult to predict and highly variable as it depends on both the amount and timing of precipitation and the type and spatial distribution of sediment (Phillips and Jerolmack 2016). As sediment shifts within a stream in response to erosion and deposition, the habitat availability for aquatic species will be impacted. An increase in silt and organic material can create a blanket on the stream bed that kills fish eggs and suppresses benthic production (Dove-Thompson et al. 2011).

Shifts in the timing of the spring ***freshet*** will also impact fish spawning with a decrease in available habitat during the spawning season due to lower water levels (Boyer et al. 2010). Floods can cause changes to the structure of a particular stream reach. They can also carry large volumes of sediment which increases turbidity and can affect feeding and respiration of fish (CCME 2002). As a result, diverse fish communities may be limited in streams prone to erosion and high levels of turbidity. Figure 2-7 illustrates the erosive power of water in Indian Creek, a small creek which flows through the central portion of the City of Burlington, where high velocity stream flows have resulted in considerable erosion of the stream banks, further impacting aquatic habitat.

FIGURE 2-7: SEVERELY ERODED BANKS IN INDIAN CREEK IMPACTING FISH HABITAT

Source: Conservation Halton

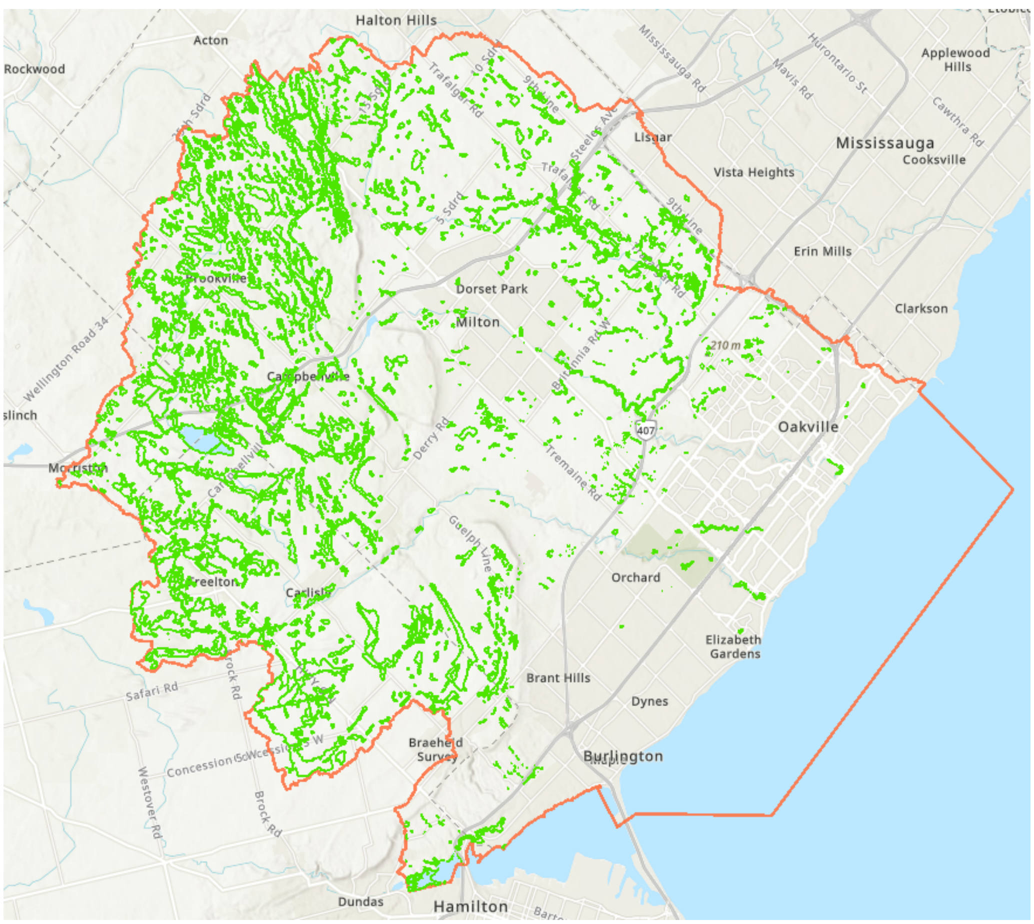
2.3 Wetlands

Climate change affects wetlands in a variety of ways, with the most important effect to biodiversity being changes to and/or extremes in water levels (Cunderlik and Simonovic 2005). These hydrological modifications may lead to changes in the species that use the habitat.

Wetlands are important for the retaining and cleaning of water. They are also an important component in the carbon cycle and due to their complex nature, wetlands can be both a sink and a source of carbon. Wetlands can be carbon sinks because they contain a large amount of organic matter. However, if wetlands are dried out, the carbon (and methane) contained in the organic matter may be released from the sink (Burkett and Kusler 2000). Changes in weather patterns may alter the amount of carbon stored or released in a wetland because of changes to the ***hydroperiod*** of the wetland (meaning the number of days per year that the wetland is wet or the length of time that there is standing water).

Overall, wetland cover in Conservation Halton's watershed is 9%, with 2% being marsh habitat and 7% being swamp habitat. As is the case across much of southern Ontario, it is thought that up to 69% of the wetland area that historically occurred in the local area has already been lost (Ducks Unlimited Canada 2010). Most wetlands in Conservation Halton's jurisdiction lie above the Niagara Escarpment (Figure 2-8).

FIGURE 2-8: WETLANDS IN CONSERVATION HALTON'S WATERSHEDS



Source: Conservation Halton

2.3.1 Abiotic

Wetlands can hold significant amounts of water and act as a contaminant filter to improve water quality. During the time water is held in wetlands, the settling of suspended sediments and the uptake of nutrients by plants helps to improve water quality. The slow release of water from a wetland to a stream helps to regulate stream flows and moderate flooding. In addition, some water can infiltrate the ground, helping to replenish or recharge groundwater. Extreme changes in water levels will affect the amount of water that can infiltrate and over the long-term may affect recharge capabilities and ultimately groundwater levels (Erwin 2009).

The deviations from past water levels or extremes in water levels can alter the wetland plants present and influence the abiotic factors that shape natural wetland processes. For example, the loss of wetland plants can lead to erosion. This erosion can change the functions of the wetland habitat and compound effects from the weather extremes, causing even more erosion to occur with each extreme weather event.

The loss of wetland plants will affect the amount of carbon or nutrients stored in the wetland and drying of wetlands can lead to a release of carbon, nitrogen or other materials formerly stored in plant material or hydric substrates.

The loss of wetland plant cover will also have a negative effect on the water temperatures as more water is exposed to the sunlight. This will lead to increased water temperatures, both within and downstream of the wetland as well as increased evaporation from the wetland itself (Erwin 2009).

In Southern Ontario drier conditions and more frequent and more severe droughts are expected to occur because of climate change (Lenihan and Neilson 1995 in Erwin 2009). These drier conditions will have a negative effect on wetland communities and may drastically change the plant composition. Extended periods of drought can lead to the release of carbon that was formerly held in the wetland soils and alteration in the wetland vegetation communities.

2.3.2 Biotic

Wetland plants will die off if their life-cycle requirements are no longer met and new species gain prominence (Wetlands International 1999). Where wetlands experience extremes in water levels for an extended period, plants may be killed or weakened resulting in degraded habitats and species loss. Many at-risk plants occupy wetlands and will be negatively impacted by hydrological changes. Local examples include the provincially Endangered Black Ash and regionally rare Cotton Grass, Purple Fringed Orchid, and Bog Willow.

Wetlands are important components for many wildlife species' life cycles, therefore changes to wetlands can have a significant effect on other species. Changes in the wetland plant community may make habitats unsuitable for other species that formerly occupied them and may result in a reduction or loss of habitat for species such as marsh breeding birds and amphibians. Wetlands can be vital for fish spawning and therefore, their loss will affect fish populations (Wetlands International 1999).

Wetland habitat loss will also affect species that rely on ***habitat patches*** of a certain size (specific breeding birds). If wetland habitat loss is such that the habitat no longer meets minimum size requirements for specific species, those species can no longer utilize the wetland.

2.3.3 Phenology

Phenology is the study of the timing of life-cycle events in plants and animals relative to changes in seasons and climate. Wetlands are often dependent on specific wet-dry cycles. These wet-dry cycles, as well as the depth of the water during each cycle, will determine the composition of the wetland. Changes to the timing of these cycles can greatly affect the wetland health and composition, as well as affect the many species that use wetlands as habitat. Regeneration within wetlands is dependant on periodic drying which allows seeds to be exposed and germinate at the right time of year. Changes to the wet-dry cycle may prevent seeds from germinating, kill young plants before they can become mature, or alter the types and number of species regenerating in the wetland.

It is expected that with climate change, snow cover will arrive later and disappear earlier (IPCC 2001). A lack of snow cover in wetlands may have a negative effect on the species hibernating in the mud or may expose deeper areas to freezing than have previously occurred (Pauli et al. 2013). Unusual warming may also wake hibernating species earlier than expected. Alternatively, a warmer, shorter winter may benefit some amphibian species and allow greater survival over winter, allowing them to emerge from hibernation in better condition than if they had gone through a longer, colder winter (Üveges et al. 2016).

2.3.4 Distribution and survivorship

With changes in rainfall and snow events expected to be significant in Southern Ontario, trends towards more frequent and longer droughts are anticipated (Lenihan and Neilson 1995 in Erwin 2009). This may result in a loss of wetlands in some areas of our watersheds. If wetlands remain, there may be changes in species composition and loss of biodiversity, with the greatest losses likely to occur in rare or sensitive species. A fragmented landscape, such as southern Ontario, will limit the ability of plants to spread to new locations. The highly developed nature of Southern Ontario may also hinder the natural establishment of new wetlands and will limit areas that could be restored into new wetland habitats.

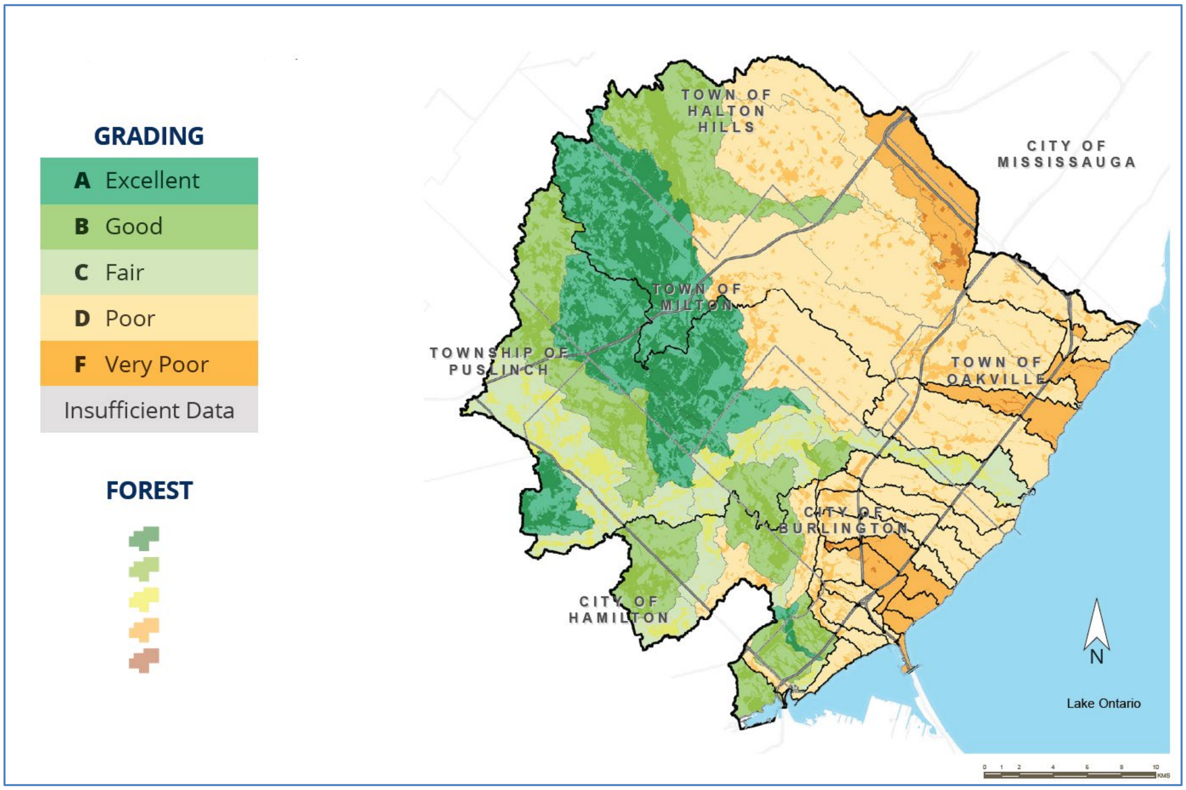
The extremes will weaken the wetland habitat, leaving it susceptible to invasive species. Wetlands are one of the most biologically diverse habitats, their loss directly impacting the complete biodiversity of an area (Wetlands International 1999).

2.4 Forests

Forests are important elements in the carbon cycle. They are carbon sinks which help to absorb carbon dioxide from the atmosphere which helps to mitigate climate change and reduce the impacts of climate change. Forests with high diversity store more carbon that those with low diversity (Chen et al. 2023). Factors which alter the composition and health of forests and cause increases in tree mortality can lead to higher carbon emissions and reduce our ability to combat climate change. Changes to the health and composition of forests also impacts all the plants and animals that rely on these ecosystems.

Conservation Halton assessed forest conditions in our watersheds in its 2023 Watershed Report Card (Conservation Halton 2023). An overall grade of 'D' was assigned. Subwatershed grades ranged from A to F (Figure 2-9). Forest cover across the watersheds is concentrated above the Niagara Escarpment, with cover below the Escarpment mostly in stream valleys and smaller urban woodlots surrounded by residential and commercial development.

FIGURE 2-9: FOREST COVER AND 2023 WATERSHED REPORT CARD GRADES



Source: Conservation Halton

2.4.1 Abiotic

Atmospheric changes that increase temperatures and affect weather have effects on soils, the building block of terrestrial systems. Soil type, moisture and condition influence the types of plants that can grow in an area. Plant types, in turn, influence habitat conditions for animal species and their ability to carry out their life processes.

Abiotic processes affect biota. Similarly, biotic systems affect abiotic systems in a ***feedback loop***. Forest composition can modify carbon and nutrient cycling and hydrologic processes. For example, a decrease in growth reduces the amount of water a tree takes up and transpires, which in turn increases the amount of moisture that remains in the soil (Weed et al. 2013). Increased soil moisture enhances conditions for the reproduction and spread of fungal organisms that attack trees (Williams et al. 2000).

The species composition of trees within a forest influences nutrient cycling (Sanders-DeMott et al. 2018). Changing climate will influence what trees survive in a location. Combined with largescale disturbances that may affect only certain species (e.g., loss of ash trees to Emerald Ash Borer), forest composition can be expected to change thus feeding back into nutrient cycling.

Conservation Halton initiated a ten-year program in 2016 to manage ash trees on lands owned by Conservation Halton that have succumbed to the invasive Emerald Ash Borer (EAB). This program represents a $8.4 million investment in visitor safety and forest cover replacement. The treatment of stumps which prevents them from resprouting, and the underplanting with native tree and shrub species, are two essential activities of this program. This prevents the establishment and spread of invasive species, such as buckthorn, and replaces forest cover lost to EAB.

Climate change can impact forest disturbance regimes[8] by influencing the abundance and distribution of forest pests and pathogens (and those of their natural enemies) and affecting the ability of trees to defend against these disturbances (Ayres 1993, Bidart-Bouzat and Kliebenstein 2008, Lindroth 2010, and Sturrock et al. 2011 in Weed et al. 2013). Biotic disturbances such as pest and pathogen outbreaks can trigger widespread tree mortality. This, in turn, can activate the release of carbon stored by these trees into the atmosphere, contributing to climate change (Weed et al. 2013).

Much focus has centred on increasing temperatures and their influence on the growing season. However, soil biological processes continue throughout winter. Winter is an important time for fluxes of greenhouse gases (Groffman et al. 2006). In fact, winter (through temperature, snow depth and the variability of these parameters) is a key driver of many processes in terrestrial ecosystems (Williams et al. 2015).

The biodiversity of temperate forests such as those remaining in Conservation Halton's watersheds, is highly influenced by whether soil remains unfrozen with a sufficient snowpack. Under optimal conditions, snow accumulates early in the season and remains in place to insulate the ground from freezing temperatures. The timing of snowfall is a critical factor which either contributes to maintaining soils in an unfrozen state if snowfall occurs early in the season, or keeping soils frozen if they freeze prior to snow accumulation (Cleavitt et al. 2008).

Soil freezing can damage or kill fine surface tree roots and affect microbial activity (Cleavitt et al. 2008), reduce the ability of forests to remove methane from the atmosphere, and contribute to higher nitrous oxide emissions (Groffman et al. 2006). Thaw-freeze events can reduce sap flow and sap volume and the ability of a tree's ***xylem*** to carry water and minerals throughout the tree (Moreau et al. 2020) and put early emerging seedlings at high risk of mortality (Solarik et al. 2016). After a severe freeze event, a tree will reallocate resources to damaged roots and shoots which is likely to result in a reduction in radial growth of the tree in the years following (Moreau et al. 2020). Soil freezing events have been linked to declines in sugar maple (Cleavitt et al. 2008), an abundant species in our watershed.

Climate models by the IPCC predict that winter precipitation will increase in northeastern North America, much of it as rain, and that the snow we get will tend to accumulate later in the winter season. Therefore, soil freezing will likely increase and there will be more freeze-thaw events during winter (IPCC 2001). However, statistically downscaled climate projections for Hamilton

[8] Disturbances in forest ecology refer to events of tree damage and mortality, which release growing space and resources, and change micro-climate. Natural disturbances are caused by factors such as fire, windthrow, insects and fungi. These occur at different spatial scales, from single trees to large-scale impacts. Disturbances also vary in their frequencies and severities. The functioning of varying disturbances in a landscape and over a prolonged time-period is called the disturbance regime.

suggest that freeze-thaw cycles will decrease over time (Prairie Climate Centre 2019). Increased winter precipitation in the form of severe storms (such as the ice storm that occurred in Ontario in 2013) also causes mechanical damage to trees which makes them more susceptible to pests and pathogens (Dukes et al. 2009).

2.4.2 Biotic

Increasing large-scale disturbances to forests due to climate change may alter the composition of forest habitats and affect forest regeneration (Anderson-Teixeira et al. 2013). Disturbances thin the tree canopy which allows more sunlight to reach the forest floor. Canopy gaps are an important aspect of forests and forest regeneration, however frequent large gaps can change conditions within the forest by drying out soil and favouring regeneration of shade intolerant trees. If a forest is subjected to additional stressors and vectors of invasive plant ***propagules***, disturbance can be a pathway for colonization by generalist and invasive plant species. Animals and plants that rely on mature forests will lose habitat as these forest disturbances shift the tree age composition to younger forests (Weed et al. 2013). Maintaining healthy biodiversity within forest ecosystems will be an important tool in protecting the essential functions of these habitats (Matthews et al. 2014).

2.4.3 Phenology

Forest ***phenology*** is very sensitive to spring temperatures and the speed at which warming occurs. ***Leaf out*** for eastern temperate forests is almost entirely driven by temperature (Friedl 2014). Temperature is the strongest predictor of the timing of flowering for ***spring ephemerals*** (Petrauski et al. 2019). Early thaws may force trees to bud, putting new growth at risk of dying should they be exposed to a subsequent freeze event (Moreau et al. 2020). While some ***spring ephemerals*** may benefit from more light and moisture and less competition for pollinators as a result of an earlier spring, warming could also be detrimental. Warming can disrupt interactions between plants and their pollinators (Petrauski et al. 2019), causing a mismatch between the timing of flowering and timing of insect emergence and feeding.

On the other side of the growing season, temperatures that remain warm longer into fall and extend the growing season can also delay leaf drop, decrease production of anthocyanin (a chemical which helps to protect leaves) (Moreau 2020), and cause a tree to use up its stored carbohydrates, instead of resorbing them to use for growth the next spring (Solarik et al. 2016).

The regeneration of forests is likely to be affected by ***phenology***, starting at the level of the seed. The seeds of trees and other plants in temperate forests generally require a period of cold dormancy under certain conditions and of sufficient length to break that dormancy and germinate. Sudden changes in temperature associated with rapid spring warming can interfere with this process and reduce germination (Solarik et al. 2016). There are various other mechanisms that contribute to a decline in successful germination including freeze-thaw events, loss of seed viability due to higher temperatures, warmer more favourable conditions for fungal and bacterial growth that affects seeds and seedlings, and changes to soil moisture (Solarik et al. 2016).

Changes to insect ***phenology*** will also affect forest health. Warmer temperatures typically lead to insects becoming more active. Consequently, they eat more and develop faster, which negatively impacts vegetation. Because insects have shorter generation times, they are more adaptable than trees (Dukes et al. 2009) and their response to climate change may outpace that of trees.

2.4.4 Distribution and survivorship

Distribution and survivorship of desirable species (trees native to the local area) and their pollinators, pests, and pathogens will be important in determining the future composition of our forests. Reduced reproductive success of trees is expected in many cases, where they are limited by temperature and when the local ***genotype*** becomes unsuitable for the new environmental conditions of the area (Dukes et al. 2009). On the other hand, an increase in annual temperatures will allow many pests and pathogens to survive the winter in new places and stay active for a greater portion of the year. This will allow them to expand their ranges northward as climate envelopes shift and they are no longer exposed to killing temperatures. Warmer winters can also allow for outbreaks of native insects that are not historically known to contribute greatly to forest disturbance (e.g., Mountain Pine Beetle in western Canada) (Weed et al. 2013), and warmer winters are one of several factors that can exacerbate spongy moth outbreaks in Conservation Halton's watersheds. When trees are under multiple stressors due to climate change, secondary organisms such as Armillaria root rot will have the advantage (Dukes et al. 2009).

Forests within transition zones of tree species composition, or just north of these zones, are more vulnerable to climate change as ranges of various species expand or contract (Matthews et al. 2014). In Conservation Halton's watersheds, we are near the northern limit of the species-rich Carolinian Life Zone and the southern limit of the Great Lakes – St. Lawrence Forest region. As such, we can expect to see profound impacts on our biodiversity due to climate change effects on our forests.

Section 3 Climate Change Effects on Biodiversity

The effects of climate change on biodiversity are complex. All species are interrelated in food webs and biological communities. Climate change uniquely affects each species and individual within a species in ways that are highly dependent on the surrounding biophysical context.

Appendix 1 lists the factors assessed in NatureServe's Climate Change Vulnerability Index for Canada (Young and Hammerson 2015), ranging from dietary versatility and genetic variation to predicted impact of land use changes resulting from human responses to climate change.

Section 3 presents a review of available information arranged by major taxonomic groups, pulling from global literature, and providing local references (within Conservation Halton's watersheds) where such information is available. While a species-by-species assessment specific to Conservation Halton's watersheds is beyond the scope of this report, Appendix 2 provides a summary table of local species that have been assessed by Brinker et al. (2018) using the methodology in Appendix 1. Of note, Redside Dace was assessed at the highest possible level of "Extremely Vulnerable". Other local species considered "Highly Vulnerable" include Louisiana Waterthrush, American Hart's-tongue Fern, and Chinese Hemlock Parsley.

3.1 Birds

3.1.1 Habitat

The composition of a forest at every level, from the canopy to the ground, affects the suitability of forest habitat for birds. Changes in forests thus impact the habitat of forest birds and the habitats of other species. Large-scale and more frequent forest disturbances reduce the amount of mature forest habitat and are predicted to happen more frequently due to climate change (Ayres 1993, Bidart-Bouzat and Kliebenstein 2008, Lindroth 2010, and Sturrock et al. 2011 in Weed et al. 2013). This will affect birds that breed exclusively in these habitats.

Birds of other habitats will also be affected. Wetland birds will likely experience a further reduction in habitat, which has already been drastically reduced due to land conversion (Meyers et al. 2006). Wilsey et al. (2019) found that most grassland birds in North America are susceptible to climate change, with nearly 50% of species considered highly vulnerable with the projected 3°C global temperature increase. Highly vulnerable species include Bobolink, a species at risk, and Savannah Sparrow, a common species, both found in our watersheds. Conversely, Brinker et al. (2018) classified Bobolink as "Less Vulnerable" to the effects of climate change in the Ontario Great Lakes basin.

3.1.2 Phenology

Phenology is critical in understanding climate change impacts to migrating birds, especially for long-distance, neotropical[9] migrants. A long-distance migrant must balance the benefits of arriving early enough to secure the best territory with arriving when food resources are

[9] Neotropical regions include Central and South America, including the tropical southern part of Mexico and the Caribbean. Neotropical birds breed in Canada and the United States and winter in warmer climates. Some examples of neotropical birds include Barn Swallows, Chimney Swifts, Hummingbirds, Sandhill Cranes, and Scarlet Tanagers.

adequate. These potentially contrasting needs make long-distance migrants most vulnerable to climate change (Wilson 2013). They may also have less ability to adapt to a changing climate due to the role that ***photoperiod*** plays in triggering migration (Newton 2008) and their inability to predict temperatures and conditions in their breeding habitat. This may be further exacerbated by warmer temperatures on their wintering grounds which may also influence their departure dates (Wilson 2007).

Phenological changes to ***leaf out***, insect emergence, and timing of flowering can create mismatches with migrant arrival on breeding grounds and the availability of resources (Visser et al. 2006). Migrants face additional risk from an increase in severe weather events on their way to their breeding grounds (Hedenstrom et al. 2007).

Increased temperatures during the breeding season may negatively impact breeding bird productivity through changes in predator-prey interactions. Warmer temperatures increase the metabolism of both. Predators require more prey, and birds need to forage more frequently which exposes them to greater risk of predation (Cox et al. 2013).

3.1.3 Distribution and survivorship

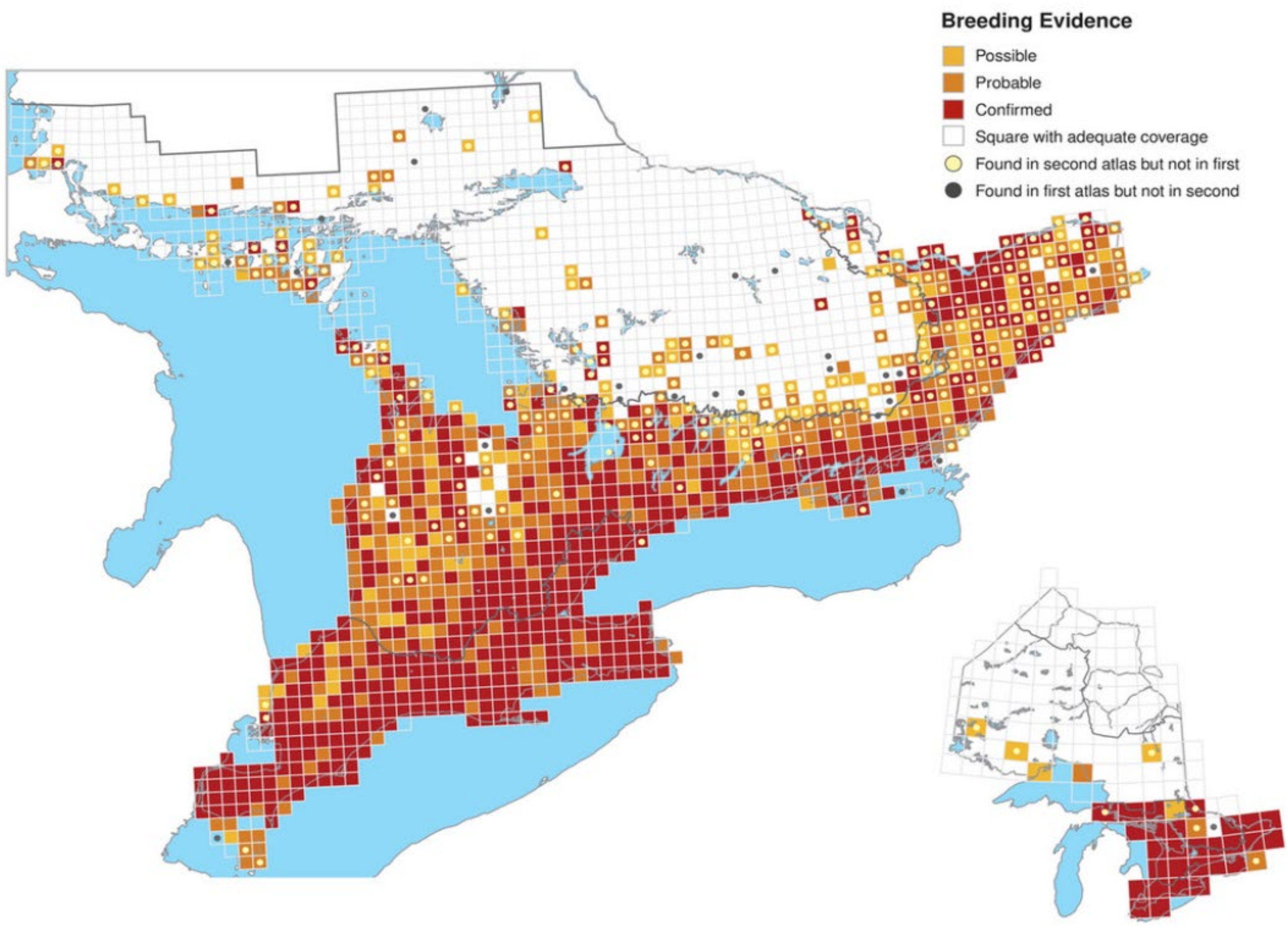
In periods of low water, coastal marsh birds may be impacted by a reduction in the amount of suitable habitat. Many obligate marsh birds,[10] as well as other bird species, are limited by the size of their habitat. A reduction in overall marsh size may shift the community from marsh obligates to facultative[11] and more generalist species. Lower water levels also favour ***monocultures*** of species such as cattails and phragmites (Meyers et al. 2006). These dominating species make habitats less diverse in structure and composition, and lower water levels simplify the habitat by reducing areas of open water that many species depend on. While water levels may be generally lower with the effects of climate change, more severe weather events that cause flooding and storm surges are projected to increase, and these can either flood nests that exist above water level or strand floating nests once they subside (Meyers et al. 2006).

Resident bird species do not face the same challenges as migrants, although they are susceptible to changes to habitat features that result from climate change. Since resident birds are typically limited in range by how cold their habitats are in winter, an increase in winter temperatures may allow them to increase their range as they take advantage of this climatic shift and expand northward (Matthews et al. 2011). Such a pattern is evident in the range expansion of the Northern Cardinal between the first (1981-1985) and second (2000-2005) Ontario Breeding Bird Atlases (Cadman et al. 2007). Figure 3-1 shows a northward and eastward shift in the breeding range between these two time periods (indicated with yellow dots), which tracks the isotherm for the January mean minimum temperature of minus 16^{o}C (McLaren 2007). In short, the range of Northern Cardinal in southern Ontario has expanded to new areas that were formerly too cold for them.

[10] An obligate marsh bird almost always occurs in marshes (>99% of the time).

[11] Facultative means primarily occurring in one type of habitat but having the capacity to live under more than one specific set of environmental conditions.

FIGURE 3-1: BREEDING EVIDENCE FOR NORTHERN CARDINAL, SHOWING CHANGE IN DISTRIBUTION FROM 1981-1985 TO 2000-2005



Source: McLaren, M.A. 2007. Northern Cardinal, pp. 578-579 in Cadman, M.D., D.A. Sutherland, G.G. Beck, D. Lepage and A.R. Couturier, eds. Atlas of the Breeding Birds of Ontario, 2001-2005. Bird Studies Canada, Environment Canada, Ontario Field Ornithologists, Ontario Ministry of Natural Resources and Ontario Nature, Toronto, xxii + 706 pp.

Regardless of whether a species is migratory or resident, extreme rainfall and heat events during the breeding season can have negative effects on productivity by reducing egg viability and increasing nestling mortality (Cox et al. 2013).

As climate change reshapes forests, the complement of species will shift drastically in the coming decades, most notably during the breeding season (Langham et al. 2015). These shifts will occur both geographically in terms of species ranges, and in response to changes at the local level such as loss of habitat features.

The Great Lakes in particular, are predicted to experience one of the largest shifts in non-breeding season bird communities in North America (Langham et al. 2015). Furthermore, a study of 147 North American breeding birds projected that by the year 2100, the geographic mean-centres of habitats for all the species studied would shift an average of 98-203 km to the north and northeast in response to climate change (Matthews et al. 2011). This is confounded by habitat fragmentation and loss, which could interfere with species that are shifting their ranges northward (Opdam & Wascher 2004), highlighting the importance of land management and conservation considerations in planning for climate change (Cox et al. 2013).

3.2 Reptiles and Amphibians

3.2.1 Habitat

Many amphibian and reptile species require two or more habitat types to complete their life cycles, which increases their exposure to climate change effects. In Conservation Halton's watersheds, most salamander and frog species such as Spotted Salamander and Wood Frog require aquatic habitats for larval or tadpole stages, in addition to upland habitat for foraging and overwintering. One of the main expected impacts of climate change will be changes in rainfall patterns. This will result in altered hydrologic regimes, which may affect the suitability of breeding habitats with areas that were suitable previously becoming not suitable in the current and future conditions (Montronea et al. 2019). Shorter ***hydroperiods*** may lead to lower numbers of young amphibians surviving to metamorphosis or lead to lower fitness levels of the young (Lowe et al. 2019).

Changes in water levels may reduce or remove available hibernation sites for turtles or frogs as they require stable water temperatures below the frost line for the duration of the winter (Feldkamp 2017). Lower water levels may cause those areas to be unsuitable for successful hibernation. Warming winter temperatures may also negatively affect turtle hibernation if temperatures reach a warmth that interrupts hibernation. This interruption could be deadly to turtles as at lower temperatures they can survive without oxygen but if they are exposed to warmer temperature during hibernation, they need oxygen and resources to survive (Jackson 2002).

Changes in the hydrology of habitats will also lead to vegetation changes that may affect the suitability of the habitat (Butler 2019). Many amphibians prefer to lay eggs on small twigs in the water. Changes in the vegetation can reduce these preferred egg laying locations. Higher water levels may flood sites previously used as turtle egg laying sites and make them unavailable for egg laying.

Changes to the habitat surrounding the breeding pond caused by climate change can also have negative effects on salamanders. Loss of forest cover can lead to more sunlight hitting the ***vernal pools*** causing warming water temperatures, increasing evaporation, and changing the ***hydroperiod.***

Climate changes may also cause a shift in habitats and contribute to overall loss of habitats. Many species of amphibians will not be able to keep up with the habitat shift caused by climate change (Butler 2019). The fragmented nature of habitats in southern Ontario will compound the effects of climate change as fragmentation provides little or no migratory options for the species or the habitats.

3.2.2 Phenology

Salamanders and frogs may be especially affected by climate change since they rely on key spring indicators to trigger the breeding cycle. Climate change will cause unpredictable weather patterns such as mid-winter warming, or overall earlier springs, that could cause amphibians to migrate and attempt to breed earlier than normal. In some cases, early attempts to breed may fail or result in the death of breeding adults. For example, a warm spell brings amphibians out to breed, then a cold snap kills the eggs and/or adults (Harris 1980). In an extreme situation the salamanders may leave hibernation to start migration far too early (in a mid-winter thaw) and be trapped mid migration and freeze before they are able to reach either the pond or a suitable hibernation site. Some amphibian species can adjust to the trends of earlier springs (Riddell et al. 2018), including Yellow-spotted Salamanders (Kirk et al. 2019) which occur in Conservation Halton's watersheds, however, each species may react to climate change differently.

3.2.3 Distribution and Survivorship

<u>Winter</u>

As ***ectotherms***, amphibians and reptiles are dependent on the surrounding environment to control their body temperature, making them highly vulnerable to climate change. Because each species uses different physiological and behavioural methods to survive winter, climate change will affect each species differently.

Overwintering success of ***herptiles*** may also be affected by changes from historic trends in winter temperatures caused by climate change. More frequent freeze-thaw cycles are possibly the most damaging effect because they may interrupt hibernation mid-winter or awaken ***herptiles*** too early in the spring. A lack of snow cover will further expose ***herptiles*** to the fluctuating temperatures as thicker snow depth provides better insulation and regulates the temperature of the soil more effectively (Pauli et al. 2013).

The loss of snow cover or the formation of ice (rather than snow) due to increased freeze-thaw cycles during the winter can negatively affect the forest rodent population (Korslund et al. 2006) which salamanders rely on for burrows to get underground and shelter from the heat during the summer and for hibernation in the winter.

Alternatively, there may be some benefits to ***herptiles*** from climate change effects on overwintering. Warmer winter hibernation temperatures may allow some species to conserve metabolic resources (e.g., use less of their fat stores) by slowing their metabolism and emerging in a fitter state as compared to a colder winter (Üveges 2016). Trends towards earlier springs will reduce the amount of time needed to spend hibernating and may allow more individuals to survive hibernation periods (Üveges 2016).

<u>Active Season</u>

All but one amphibian species in Conservation Halton's watersheds (Red-backed Salamander) requires aquatic conditions during the egg and larval life stages. Water must persist for a period long enough for gilled larvae to complete metamorphosis to their air-breathing adult life stage, which for most species must occur prior to the first winter. Locally, Green Frogs and Bullfrogs overwinter as tadpoles for two, or more, years of development in aquatic habitat prior to transforming into adult frogs. Climate change may threaten conditions that support this complex life cycle. Changes which shorten the ***hydroperiod*** can reduce the number of young that survive to metamorphosis and the fitness of young that metamorphosize (Lowe et al. 2019). Conversely a longer ***hydroperiod*** may allow more young to survive to metamorphosis, but may also allow predators of salamanders and their larvae, such as fish, to survive in ponds where the shorter ***hydroperiod*** previously excluded them.

Changes in rain patterns or temperatures can also change the composition of the ponds and affect the food supply of the developing amphibian larvae. Many species that occupy ***vernal pools*** are specialists to that habitat, such as fairy shrimp, and changes to the ***hydroperiod*** will likely lead to the loss of these specialists (Montronea et al. 2019). Some of these specialist species are an important food source for larval amphibians. Without proper food available in the pond the amphibian larvae may turn to cannibalism or simply fail to develop properly.

Increasing summer temperatures may negatively affect amphibians as many species cannot tolerate high extremes of temperature and higher temperatures can cause them to expend more energy, resulting in smaller body size and lower body condition (Caruso et al. 2014). Body condition may, in turn, cause changes to the number of eggs/young produced.

In some reptile species, higher temperatures due to climate change may induce changes in sex ratios (Butler 2019). This changing sex ratio may be especially evident (and detrimental) to turtles as the sex of turtle young of all local species is determined by the temperature of the eggs during development. A warming climate may shift these ratios, with as-yet undetermined effects on population persistence. Turtles are one of the most threatened groups of vertebrates globally, and all four turtle species currently known to occur in Conservation Halton's watersheds including Midland Painted Turtle, Snapping Turtle, Blanding's Turtle and Map Turtle are species at risk.

Significant warming conditions and more frequent extreme heat events will negatively affect reptiles by forcing them to take refuge from the heat for longer periods of time and may significantly reduce the amount of time available for feeding activities (Sunday 2014).

Local Species Feature: Jefferson Salamander

The Jefferson Salamander (Figure 3-2) is a habitat specialist that is expected to be at risk from climate change effects due to its limited distribution, specific habitat needs, inability to migrate to new habitat and pond fidelity. The Jefferson Salamander requires temporary ***vernal pools*** surrounded by intact high-quality forest habitat and ample refugia for winter hibernation and escaping summer heat. Climate change could affect multiple components of this species' complex habitat needs and the loss of any one component could prove fatal to a population.

FIGURE 3-2: JEFFERSON SALAMANDER

Source: Conservation Halton

Jefferson Salamanders have been shown to be loyal to the pond in which they hatched as eggs and thus are not strong colonizers. Losing existing breeding ponds may cause unrecoverable loss in population size. They have specific habitat requirements which make dispersal to new areas especially difficult in the fragmented habitats that exist in southern Ontario. Climate change can lead to changes in spring triggers that may cause the salamanders to move to the ponds and attempt to breed.

In Conservation Halton's watersheds, Jefferson Salamanders are the first salamander to emerge from hibernation and move to breeding ponds in the spring and thus may be more susceptible to the risks of spring freezes causing the loss of adults or eggs (as discussed in the above sections). Jefferson Salamanders are very long lived, so the loss of any adults would be especially harmful to the population.

Salamanders that have to cross roads to reach their breeding ponds are at high risk of being run over by vehicles because they are small, dark (asphalt-coloured), slow-moving and tend to be active on rainy nights. This makes them very difficult for drivers to see and avoid.

To protect salamanders during their migration to breeding ponds adjacent to King Road in the City of Burlington, Conservation Halton staff works collaboratively with City staff to advise on the dates during which salamander migration to ponds is expected to be most active. City staff implement a temporary road closure in cooperation with the City of Hamilton and municipal emergency services. This has been an annual undertaking since 2012.

Local Species Feature: Snapping Turtle

Snapping turtles are a widespread and formerly common species in our watersheds that has been designated a species at risk due to sharp population declines. Snapping Turtles may be affected by climate change in a variety of ways. The trend towards shorter winters and earlier springs may benefit winter survival rates. Alternatively, wildly fluctuating temperatures during hibernation may interrupt their hibernation and could prove fatal to interrupted individuals because of the effect of temperature on metabolism.

A trend towards significantly warmer summers may alter the ratio of males to females in the population because of temperature-dependent sex determination. The long-term effects of such a change will depend in part on whether females alter their behaviour to select more shaded nest sites (Figure 3-3), which has been observed in Snapping Turtle populations at lower latitudes (Ewert 2005).

FIGURE 3-3 SNAPPING TURTLE NESTING ADJACENT TO DERRY ROAD

Source: Conservation Halton

Local Species Feature: Wood Frog

Wood Frogs are a common and widespread species that inhabit wooded wetlands in our watersheds. They are an early spring breeder and often rely on temporarily flooded areas for reproduction. These factors may make the Wood Frog more susceptible to the effects of climate change if rising temperatures reduce the ***hydroperiod*** of their breeding pond. If this was to occur, tadpoles will not have sufficient time to transform into frogs before the pond dries up. The potential for winter fluctuations could affect the Wood Frog significantly as it overwinters close to the surface of the ground and would be exposed to these fluctuating temperatures directly. Wood Frogs also could lose breeding areas if rainfall patterns change, or droughts become more frequent. Climate change may benefit Wood Frogs through a northern range expansion as the climate warms.

3.3 Freshwater Mussels

Introduction

Freshwater mussels are a group of animals that often go unnoticed and are understudied. Like many species in freshwater ecosystems, mussels are heavily impacted by climate change. North America has the most diverse freshwater mussel fauna in the world. However, 70% of these species are considered of special concern, threatened, endangered, or extinct (Bogan 1993). They are sedentary animals, travelling up to a metre throughout their lives (Toronto Zoo, Accessed March 16, 2021), and have life spans of several decades, some even reaching 100 years old. In Ontario, there are 41 species of freshwater mussels, fourteen of which reside within the Conservation Halton watersheds.

Freshwater mussels are an important part of our aquatic ecosystems. They provide valuable services. Freshwater mussels are filter feeders. This means that they aid in improving water quality and provide nutrients to the benefit of fish and aquatic insects as they feed themselves (Vaughn et al. 2004, 2008). They provide numerous ecological services to aquatic systems including linking pelagic (open water) and benthic (bottom-dwelling) food webs, increasing habitat complexity, and providing structural refugia for other aquatic invertebrates (Strayer et al. 1994, Vaughn et al. 2004, Spooner and Vaughn 2006, Zimmerman and de Szalay 2007). They are also ecosystem engineers that help to stabilize substrate for the benefit of other aquatic species (Howard and Cuffey 2006).

3.3.1 Phenology

Mussels are thermoconformers, with physiological processes restricted by water temperature (McMahon and Bogan 2001). Thermoconformers differ from thermoregulators as their body temperature changes according to the external temperature, in contrast to thermoregulators that undergo thermoregulation to adjust their body temperature within certain limits. Climate change is expected to affect mussels through altered temperatures which decrease survival, growth, and reproductive success as well as varied precipitation patterns which influence the relationship between recruitment (post-settlement survival) and stream flow (Hastie et al. 2003). Subsequently, climate change will have a fundamentally negative impact on their continued survival.

Freshwater mussels rely on fish (in some cases specific species) to host their larvae (glochidia). However, the specifics of freshwater mussel reproductive ***phenology*** are relatively unknown.

Researchers have documented different times for freshwater mussel glochidia release. For instance, Matteson, as cited in Downing (1989), concluded that glochidia are released in mid to late July. However, Nedeau (2008) suggests that glochidia can be released during the entire summer season. In a study done in Otsego County, NY on the Eastern Elliptico mussel, it was concluded that the peak time for brooding and release of glochidia in this species begins in mid to late May and persists for several weeks before tapering off in late June – early July (Franzem et al. 2016). It was believed that certain Ellipticos would brood and release glochidia before and after this time frame, but the majority of glochidia production and release for the Elliptico is within this period (Franzem et al. 2016).

3.3.2 Distribution

Freshwater mussels may be particularly susceptible to climate change because of their patchy distribution, limited mobility (Figure 3-4), specialized reproductive requirements, and fragmented populations (Ganser et al. 2013). Freshwater mussels are unique because both their life history traits and distribution rely heavily on host species. All freshwater mussels in Ontario have a parasitic life stage on fishes (or an amphibian in the case of the Salamander Mussel) during their larval stage (Metcalfe-Smith et al. 2005). Consequently, if the host fish species (or amphibian) is displaced by climate change, or anthropogenic reasons, the mussel species that relies on this host will ultimately suffer.

FIGURE 3-4: MUSSEL TRACKS IN SIXTEEN MILE CREEK (DRUMQUIN PARK)

Source: Conservation Halton

In addition to climate change, anthropogenic factors such as dams affect mussel distributions. Dams change the physical, chemical, and biological environment of streams, both upstream and downstream of the structure, to the point that approximately 30% to 60% of the mussel fauna is destroyed (Layzer et al. 1993; Williams et al. 1992). The destruction of habitat by siltation, dredging, channelization, the creation of impoundments, and pollution is the most significant cause of the decline of freshwater mussels across North America (Williams et al. 1993). Construction of reservoirs has eliminated the extensive reach of running water that is necessary for freshwater mussel survival. Downstream, water velocity and temperature are altered by dams, thus upstream populations of mussels are isolated from their fish hosts (Biggins et al. 1995).

Erosion caused by deforestation, inadequate agricultural practices, and urban development cause increased siltation which can suffocate mussels, hinder their feeding capabilities, and establish unstable substrates (Dennis 1984). Since increased air temperature and annual precipitation volume due to climate change are predicted to increase (IPCC 2007, Hayhoe et al. 2010), this will consequently intensify these anthropogenic influences.

3.3.3 Survivorship

Invasive species, habitat loss, and pollutants are all thought to contribute to mussel declines (Strayer et al. 2004). Global climate change and associated higher water temperatures may further affect these organisms (Hastie et al. 2003, Spooner and Vaughn 2008). The effects of climate change coupled with increased human-induced impacts forecasts a gloomy future for freshwater mussels. The elevated water temperatures expected from climate change will have a devastating effect, especially to thermally sensitive species. Increases in temperatures may result in increased clearance rates[12], increased oxygen consumption rates, decreased viability of glochidia, and decreased survival of juveniles (Zimmerman and Neves 2002, Spooner and Vaughn 2008, Pandolfo et al. 2010).

Although some benefits could come from higher water temperatures, it is the drastic fluctuations that will lead to great mussel declines. Growth of juvenile mussels is also expected to increase with warmer temperatures, but instead may also be reduced by exposure to critical temperature thresholds or other sources of environmental stress (Bartsch et al. 2003, Bringolf et al. 2007b, Newton and Bartsch 2007). Populations of several mussel species already appear to be near their upper thermal limits (Pandolfo et al. 2010), and in some streams, species composition has shifted to more thermally tolerant mussel species (Spooner and Vaughn 2008, Galbraith et al. 2010).

These fundamental ecological differences probably will translate into predictable differences in thermal tolerance. However, drawing meaningful generalizations about patterns of thermal tolerance among species is difficult. For example, short-lived mussels, such as the Plain Pocketbook, are considered thermally sensitive, whereas the long-lived Washboard is considered thermally tolerant (Waller et al. 1999, Spooner and Vaughn 2008).

Climate change not only brings increased water temperatures, but more intense precipitation events, with heavy accumulation. This results in higher flows and increased transportation of sediment and pollutants from runoff and erosion. Siltation and contaminants, such as heavy metals and pesticides, have long been recognized as threats to mussels (Ortmann 1909, Ellis 1931) and may increase with higher runoff. In addition to climate change, population growth takes a toll on the natural environment in general. With expanding populations and increases in recreational water activities, invasive species are a growing problem in aquatic ecosystems.

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[12] Clearance rates are defined as the volume of water cleared of particles per unit of time.

The invasive Quagga Mussel and Zebra Mussel have already infiltrated Conservation Halton's aquatic ecosystems (Figure 3-5) and continue to pose a risk with increased dispersal. The ongoing range expansion of the non-native Zebra Mussel may push many of the remaining species and populations of native mussels to extinction (Neves 1993). River systems that once supported various species, inhabiting a wide variety of environments, are now overshadowed by fewer, pollution-tolerant species (Metcalfe-Smith et al. 2000).

FIGURE 3-5: DREISSENID MUSSELS FOULING A GIANT FLOATER MUSSEL FROM KELSO RESERVOIR

Source: Conservation Halton

3.4 Mammals

The mammals of Ontario encompass a wide variety of species including aquatic, semi-aquatic, terrestrial, and even flying mammals. As a result, there is a vast array of life histories, interactions, and ecological relationships both inside and outside the mammalian group that are sensitive to changes in the environment. Climate variables such as precipitation and temperature play a strong role in a species' ecological niche and their resulting distribution. When variables such as temperatures shift, and weather patterns change there is a strong impact on species' habitats, ecological relationships, and life histories.

While many Ontario mammals go unrecognized for their important biodiversity (e.g., rodents) and we don't see the obvious presence of large mammals observed in other parts of the world (e.g., Africa), the mammals of Ontario are a diverse group that will be vastly impacted by the environmental changes associated with climate change.

3.4.1 Phenology and Physiology

One of the most influential impacts from climate change on mammals is the impact on natural cycles and ***phenology***. In the mammalian world, this is most evident in species that hibernate. Several mammals hibernate to conserve energy and survive during difficult weather conditions when food is typically scarce. Hibernation is generally induced, maintained, and concluded by changes in both ***photoperiod*** and temperatures. Shifts in temperatures and increased snow melt associated with climate change have been shown to rouse hibernating species early, expediting spring emergence and increasing the length of their active season (Lane et al. 2012, Johnson et al. 2017). This may result in with resources and available prey being out of synchronization (Inouye et al. 2000).

In some species such as black bears, early arousals may also increase human-wildlife conflicts as they become more reliant on anthropogenic food sources, such as garbage (Johnson et al. 2012). Early arousal from hibernation and disruptions during hibernation have been found to impact fitness in both the individual and populations of many mammals resulting in reduced population viability (Lane et al. 2012). In bats, if food stores are insufficient, they may not be able to survive the hibernation period. The likelihood of this increases if they are roused from hibernation due to mild winters and warmer temperatures (Humphries et al. 2002). Similarly, if they are roused early and food sources are limited or unavailable, or if there are further cold periods after arousal, it may lead to significant mortality (Locke 2008).

In addition to changes in ***phenology*** related to hibernation, climate change has been shown to impact mammalian migration. In southern Ontario, North American bat species have been shown to migrate and initiate the summer reproductive cycle two weeks earlier, when monitored over a 22-year period (Stepanian and Wainwright 2018). Similar to hibernation, these shifts in migration patterns produce asynchrony, which can result in reproductive and metabolic impacts and overall decreases in fitness and biodiversity (Hetem et al. 2014).

3.4.2 Distribution

The impacts and changes thrust upon mammals resulting from climate change will not be uniform. While some species will be severely impacted, other species, specifically those that are able to disperse successfully to new habitats, may benefit (Varrin et al. 2007). Winter temperatures in Ontario appear to be a limiting factor for mammalian range expansions. This is largely related to winter survival mechanisms including hibernation, the build up and use of fat stores and ability to store and retrieve food (Varrin et al. 2007). As winter temperatures increase, winter survival of southern species may increase and where connectivity will allow, ranges expansions are expected. This will be especially evident in the arctic and northern habitats of Canada where over the next 55 years a massive influx of species from the south is expected to move northward (Kerr and Packer 1997) by as much as 300 to 700 kilometres over the next century (Nituch and Bowman 2013). Species at the northern limit of their range are likely to benefit due to increases in annual temperatures which allow them to move further north, whereas species at the southern limit of their range are likely to feel more pressure as other species move northward, competing for resources and habitat (Walpole and Bowman 2011).

In southern Ontario, range expansions from habitats further south have occurred and are predicted to increase. In the 1990's the Virginia Opossum, whose range is limited by winter temperatures, was largely associated with Carolinian habitats with a northern range limit of the Greater Toronto Area (GTA) (Dobbyn 1996). With increasing winter temperatures this species has expanded its range (Walpole and Bowman 2011, Nituch and Bowman 2013) with observations recorded as far north as Huntsville and Thunder Bay (Thunder Bay Field Naturalist 2018, iNaturalist 2020). Range expansion in bats have also been noted shifting northward and North American species including Little Brown Bat have been predicted to shift their ranges significantly due to preferences in winter hibernation temperatures (Loeb and Winters 2013).

Newer mammals to Ontario, including Gray Fox and Eastern Fox Squirrel whose northern range currently barely extends into Ontario, will be species to monitor for future range expansions as climate change drives species northwards (Walpole and Bowman 2011). Overall, in southern Ontario, range expansions may increase biodiversity due the introduction of new species, however range expansions into northern regions of Ontario will be more prevalent resulting in range reductions and species loss (Nituch and Bowman 2013). With these shifts come changes in ecological relationships that will inevitably further impact biodiversity.

3.4.3 Survivorship

Mammalian survivorship is greatly influenced by climate change. With shifting ecological cues, mismatched timing and increased temperatures, food resources, availability and predator-prey relationships are impacted.

One of the best examples of the importance of predator-prey relationships is exemplified in the restoration of Gray Wolves in Yellowstone National Park. Gray Wolves, considered a keystone species, were largely extirpated from the park by the 1920's-1930's, with many of the ecological roles and benefits of this species ignored. In the absence of their main predator, Elk exceeded the park's carrying capacity, impacting vegetation and local habitats. In the 1990's successful efforts were made to restore populations of Grey Wolves, with numerous cascading ecological benefits. With the return of the wolves, Elk populations were maintained at manageable levels, resulting in healthier vegetation that could support other species such as beavers. With increases in beavers, new ponds and wetlands were created. This improved stream hydrology and water quality and reduced impacts from storm events, flooding and erosion while also creating habitat for a variety of flora and fauna (Farquhar 2020).

When these relationships are disrupted by climate change, cascading impacts will be observed across a variety of species groups. Species will be further stressed by food availability, habitat alterations, stress and disease (Varrin et al. 2007). Milder winters may increase survivorship of parasites and disease and result in increases in transmission. This has been predicted for species such as ticks, which may benefit from a higher winter survival of deer and mice, which may then increase both the range and prevalence of ticks carrying Lyme disease (Varrin et al. 2007). Similarly, potential range expansions bring additional opportunities for the spread of disease, such as the parasite *Parelaphostrongylus tenuis* found in the brains of infected deer.

Deer and moose ranges are typically separated due to heavy snow cover, but milder winters may allow deer survival and mixing of ranges. Deer infected with the parasite are unaffected. However, in moose the parasite causes increased paralysis and eventual death (Rodenhouse et al. 2009). In bats, White-Nose Syndrome is caused by a fungus that thrives in dark, damp spaces and grows on the wings and muzzles of bats. While no direct link between White-Nose Syndrome and climate change is clear (US National Parks Service 2011), warmer temperatures and fluctuating winter weather patterns could impact hibernating bats, which may use energy resources, increase stress, and make the bat more susceptible to the fungus (US National Parks Service 2011). Additionally, warmer temperatures associated with climate change may lessen the detrimental impacts of White-Nose Syndrome but, may come at a time where winter hibernacula suitability may already be impacted (McClure et. al 2022). Increases or variability in disease and pests such as this, will greatly impact survivability of many species and may potentially have a significant impact on biodiversity.

3.5 Fish

Studies suggest that freshwater biodiversity will be highly vulnerable to impacts from climate change, largely due to the reliance on water, groundwater, ***thermal regimes***, and dispersal (Brinker et al. 2018). Many aquatic species, including fish, are ***ectothermic*** or "cold-blooded" species, meaning they require external sources of heat to complete life processes. As a result, they are heavily influenced by changes in water temperature, snowpack, and frozen conditions which influence their ***phenology*** and physiology, distribution and survivorship (Poesch et al. 2016). These attributes make it especially difficult for fish to adapt to climate change.

3.5.1 Phenology and Physiology

As ***ectotherms***, fish and fish communities are strongly influenced by changes in seasonality, precipitation, and water temperatures. These natural cycles influence ***phenology*** and physiology which drive fish species to migrate and spawn and influence the habitats in which they reside. This is most evident in spring and fall spawning fish. For spring spawning fish, increasing water temperatures cue reproductive development while physical conditions (flow, precipitation) drive a fish to migrate upstream. Conversely in fall spawning fish, a decrease in temperature combined with similar physical conditions drive fall spawning fish to migrate and spawn.

With climate change, fluctuating and rising temperatures impact spring conditions resulting in early, smaller melts that alter timing and spawning cues (Pooesch et al. 2016). These changes result in numerous, early, and ***asynchronous*** spawning runs which may later impact reproductive success. If conditions are favourable after spawning, warmer temperatures may be advantageous for some species, resulting in higher egg hatch rates and increased growth (Sternecker et al. 2014). This may make some young fish more competitive.

In the fall, the extended warm temperatures associated with climate change delays spawning cues in fall-spawning fish (Pankhurst et al. 2011, Warren et al. 2012) and potentially reduces the number of redds (nests) created (Warren et al. 2012). With warming temperatures, over-wintering eggs may be affected, resulting in shorter incubation periods, reduced growth, delayed fry emergence and early outmigration of juveniles (Russel et al. 2012, Warren et al. 2012, Poesch et al. 2016). This may hinder overall reproductive success, influence synchrony with prey, and impact long-term population sustainability (Warren et al. 2012).

3.5.2 Distribution

Changing water temperatures can influence the distribution of fish by eliminating thermal barriers and altering available habitats (Van Zuiden et al. 2016). As waters warm, the distribution of fish in some rivers and lakes will experience a significant shift to an abundance of warmwater species (Casselman 2002, Casselman et. al. 2002, Kling et. al. 2003, Shuter and Lester 2004, Chu et al. 2005). While eurythermal species (those with a wide thermal tolerance) will become better suited to a wider range of habitats and be able to extend their range northward (Poesch et al. 2016), it is expected that stenothermal (coldwater) species will be most affected.

Coldwater species specifically rely on high quality, groundwater fed, coldwater conditions with high dissolved oxygen to complete their life processes. With the increased water temperatures associated with climate change, oxygen levels may become depleted and water quality degraded. This increases stress on species, forcing them to move. As a result, it is expected that coldwater species may lose suitable habitats and be forced to expand northward, should connectivity to available habitats exist (Sharma et al. 2011).

In areas such as southern Ontario where coldwater habitats are already limited, a significant decline in coldwater summer habitat and increase in fragmentation is predicted (Meisner 1990). Across Ontario, Chu et al. (2008) predicted a further decrease in the distribution of coldwater stream fishes by 60-100% by 2055 due to climate change.

Conversely, coolwater and warmwater species are expected to benefit from the increased temperatures and warmer waters associated with climate change. As cool and coldwater streams and lakes warm in areas of northern and central Ontario, warmwater predator species will be able to take advantage of more available habitats, moving northwards as warmer temperatures allow for increased growth and range expansion (Dove-Thompson et al. 2011).

Almost thirty years of observations have already noted range expansions for some warmwater sportfish, shifting northward at a rate of 12.9-17.5 kilometres per decade (Alofs et al. 2014). Further predictions estimate northward range expansions of up to 500 kilometres for some species under different climate scenarios (Magnuson 1987, Allan et al. 2005). Overall, range expansions of warmwater species may increase their distribution in streams and throughout southern Ontario by at least 60% by 2055 (Chu et al. 2008). This shift in distribution has the potential to increase species richness in several watersheds (Minns and Moore 1995) however, it will likely come at the expense of unique and sensitive cool and coldwater fish species and their habitats.

3.5.3 Survivorship

It is expected that successful species will be those that can colonize new habitats, migrate long distances, survive within a broad range of biophysical conditions and tolerate human activity (Gray 2005). As fish species expand their ranges, they invade new areas competing with resident species for food and refugia and impact predator-prey relationships. Range expansions of warmwater Bass and Sunfish, have been shown to impact the distribution and abundance of minnows (Mandrak and Jackson 2002) and percids (fish in the perch family) (Fayram et al. 2005, Van Zuiden et al. 2016).

This range expansion is due to climate change, competition, predation and the disruption of food webs in ***salmonids*** (Vander Zanden et al. 1999). Furthermore, competition has the potential to displace species and induce a southward shift in prey and baitfish distribution (Mandrak and Jackson 2002, Alofs et al. 2014). If temperatures exceed optimum conditions and prey species are then reduced, it may drastically impact long-term population sustainability for some species (Dove-Thompson et al. 2011).

In addition to competition, fish subject to a changing climate will have to endure additional threats to their health. In combination with warmer temperatures, new and invading species bring increased opportunities for the spread of more virulent pests or disease as species ranges expand (Wrona et al. 2006, Marcogliese 2008) and food sources and availability shift (Grifenhagen and Norland 2003). Increases in temperature may further impact immune responses to pest and diseases, and decreases in oxygen, especially in rivers with low flow, will severely limit activity and overall survival of species (Reiger et al. 1996). Reduced oxygen may further impact biological processes such as delaying egg hatching time and success, emergence, and recruitment (MNRF 2017).

In some instances, fish productivity and success may increase due to a longer growing season and resulting plant productivity, food supply, and growth rates (Mortsch et al. 2003). However increased productivity may also result in higher levels of detritus and increased frequency and size of algal blooms (Dove-Thompson et al. 2011), which may further exacerbate anoxic conditions.

The unique characteristics of some species, including feeding or habitat requirements, make them inherently ecologically sensitive. Combined with small ranges, these species tend to already be at risk from changes in the environment due to other human impacts. Non-climate habitat fragmentation poses one of the biggest threats to aquatic biodiversity during a rapidly changing climate (Poff et al. 2001).

If the combination of anthropogenic impacts in a watershed is combined with those of climate change, dramatic declines in the distribution and abundance of sensitive species may result in decreases in genetic variation and an overall loss of aquatic biodiversity (Poff et al. 2001).

Local Species Feature: Redside Dace - Unique Life History

The Redside Dace (Figure 3-6) is a small colourful member of the minnow family that inhabits cool streams and rivers in southern Ontario, many of which flow primarily into Lake Ontario (Fisheries and Oceans Canada 2020).

This endangered species favours small streams and tributaries, with riparian zones consisting of grasses and shrubs. It feeds by jumping out of the water to capture terrestrial insects and forms parasitic relationships with other minnow species for reproduction (Holm and Mandrak 2010). Due to feeding, reproductive and habitat requirements, the Redside Dace is a unique species and is sensitive to environmental change.

FIGURE 3-6: REDSIDE DACE

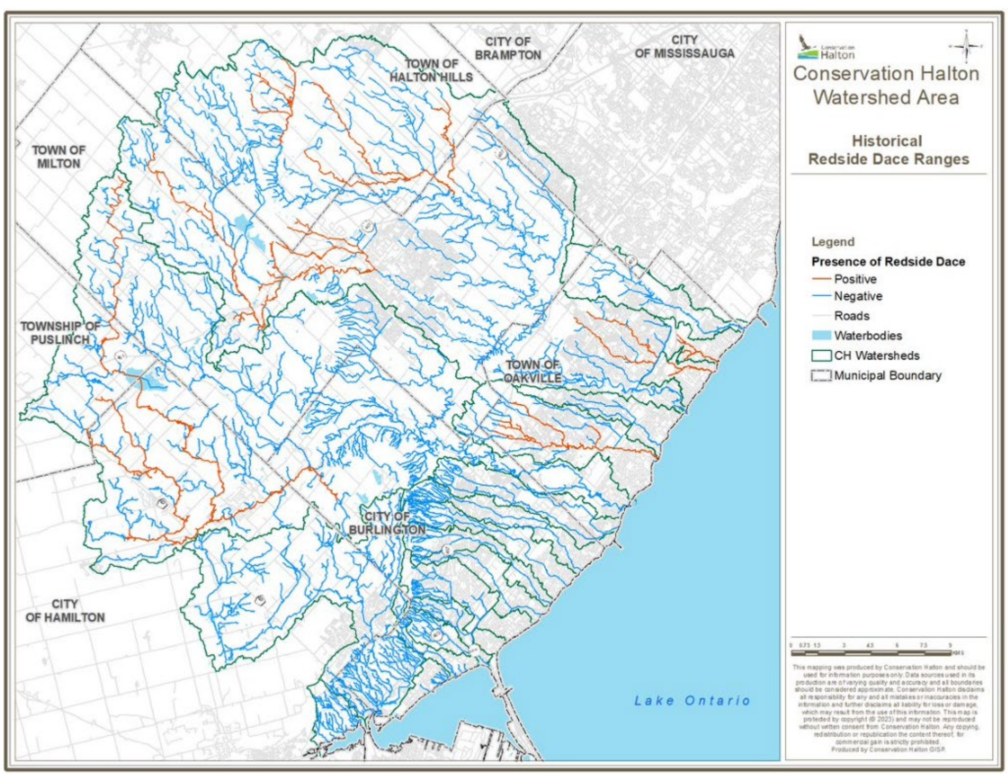
Photo: Conservation Halton

Redside Dace is considered extremely vulnerable to changing climate, largely due to current distribution, small populations, and a limited ability to disperse (Brinker et al. 2018). Like many species they are reliant on coolwater temperatures to live out their life cycles. With climate change, coolwater temperatures may be altered. Fluctuating groundwater levels resulting from changes in precipitation will impact springs and refugia and limit available habitat (Brinker et al. 2018). Habitat alterations will be exacerbated by more intense rain events, flooding and changes to the ***hydrological cycle*** which will increase erosion and sedimentation further impacting feeding and reproductive capabilities.

The impact of invasive species will be increased due to range extensions, thereby increasing competition and predation (Brinker et al. 2018). Other anthropogenic factors already affecting the species, such as urbanization and agriculture, will increase stress on Redside Dace and further limit dispersal resulting in additional fragmented populations, local extirpations, and loss of the species.

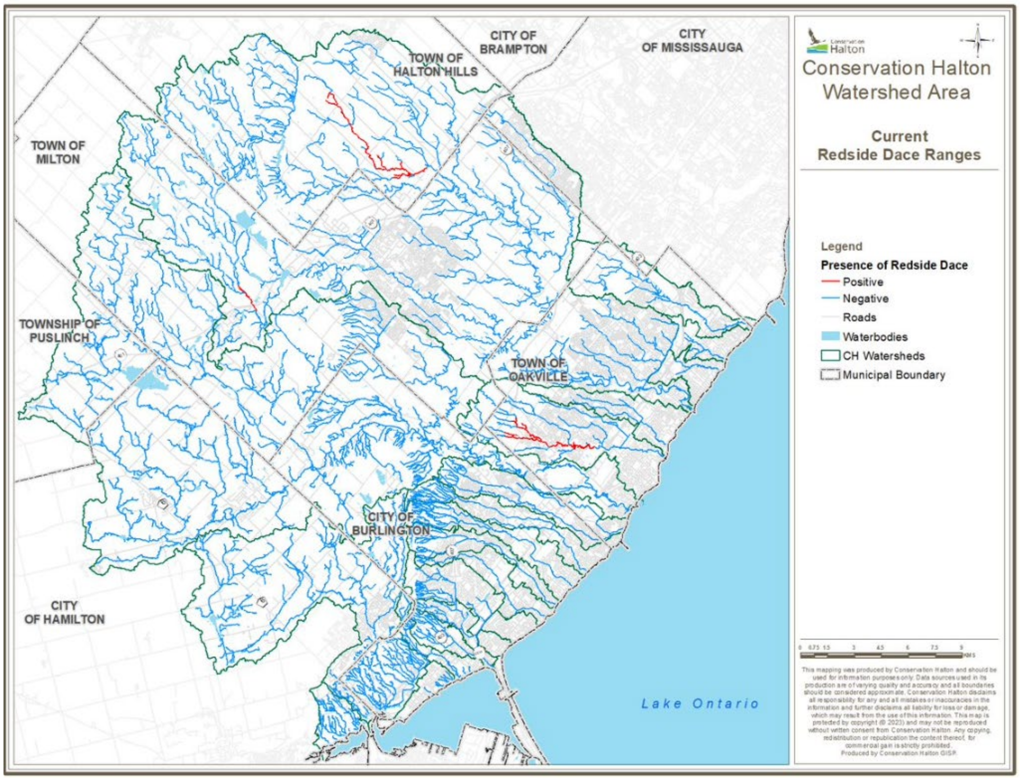
Within Conservation Halton's watersheds, Redside Dace is the most imperilled minnow species. Years of monitoring by Conservation Halton has shown drastic declines due to changes in habitat. Impairments to water quality and temperature have resulted in extirpation in a number of local stream reaches as shown in Figures 3-7 and 3-8. Population strongholds are largely within Fourteen Mile and Sixteen Mile creeks. However, increased urbanization and the associated impacts to hydrology and habitat are resulting in continued declines in these areas. Conservation Halton is monitoring Redside Dace populations and habitats. The analysis of this data supports management decisions such as the implementation of specific restoration projects to help protect the species from further extirpations.

FIGURE 3-7: HISTORICAL DISTRIBUTION OF REDSIDE DACE IN CONSERVATION HALTON'S WATERSHEDS



Source: Conservation Halton

FIGURE 3-8: CURRENT DISTRIBUTION OF REDSIDE DACE IN CONSERVATION HALTON'S WATERSHEDS



Source: Conservation Halton

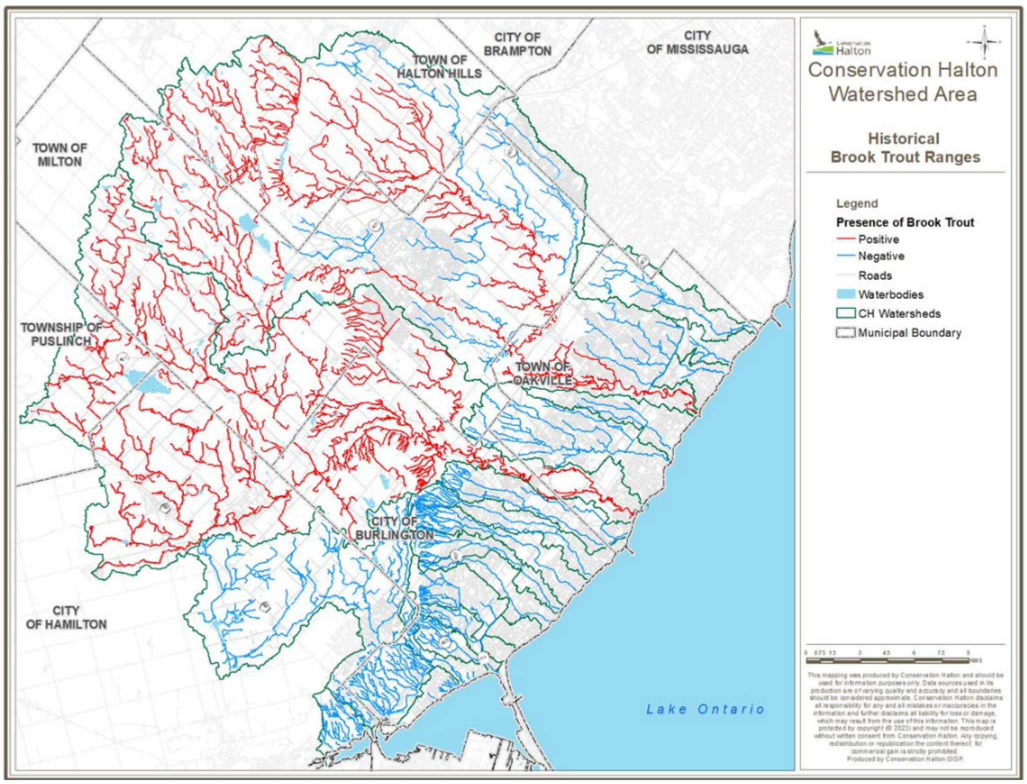
Local Species Feature: Brook Trout - Coldwater

The Brook Trout is a coldwater member of the Trout and Salmon family (Salmonidae) native to ***headwater streams*** and large rivers across Ontario. Many populations of Salmonidae reside in inland lakes and ponds (MNRF 2017). This species requires cold, clean, well-oxygenated water largely linked to groundwater discharge to live out its life processes. In southern Ontario, these habitats are already limited. When combined with the species' poor competitive ability, the Brook Trout is highly sensitive to both small scale changes such as site-specific sedimentation, habitat alteration, pollution, and large-scale influences from urban and agricultural development, invasive species, and climate change (MNRF 2017).

The threats associated with climate change that impact the Brook Trout most are related to steam temperatures and flow stability. Temperature is critically important for Brook Trout survival across all habitat types and life history stages (MNRF 2017). While they may withstand short-term increases in temperature where groundwater-fed refugia are present, long-term increases in water temperatures are lethal to the species. When waters warm with climate change, Brook Trout are forced into the headwater reaches severely restricting suitable habitat (Meisner et al. 1998), which may already be limited by anthropogenic factors.

These reaches may be further impacted by a lack of precipitation, resulting in decreased groundwater levels and discharge, and ultimately intermittent stream conditions (Dove-Thompson et al. 2011). In the absence of climate change, groundwater discharge is consistent in temperature and flow, typically resulting in consistent egg incubation times (Warren et al. 2012). In a changing climate, precipitation patterns and winter melts reduce ice cover, alter flow regimes, and result in higher, faster flows. These flows can impact young Brook Trout not yet able to handle faster flows (Dove-Thompson et al. 2011). They may also result in increased erosion and siltation which may impact habitat, smother eggs, and impair reproductive success. These alterations to thermal and flow regimes, combined with habitat alterations and/or range expansions from invading species impact Brook Trout survival. As a result, it is expected that Brook Trout will be greatly impacted by climate change and its distribution is expected to decrease by 49% across Canada by 2050 (Chu et al. 2005).

FIGURE 3-9: MODELLED HISTORICAL BROOK TROUT DISTRIBUTION IN CONSERVATION HALTON'S WATERSHEDS
(ADAPTED FROM TROUT UNLIMITED CANADA, 2018)

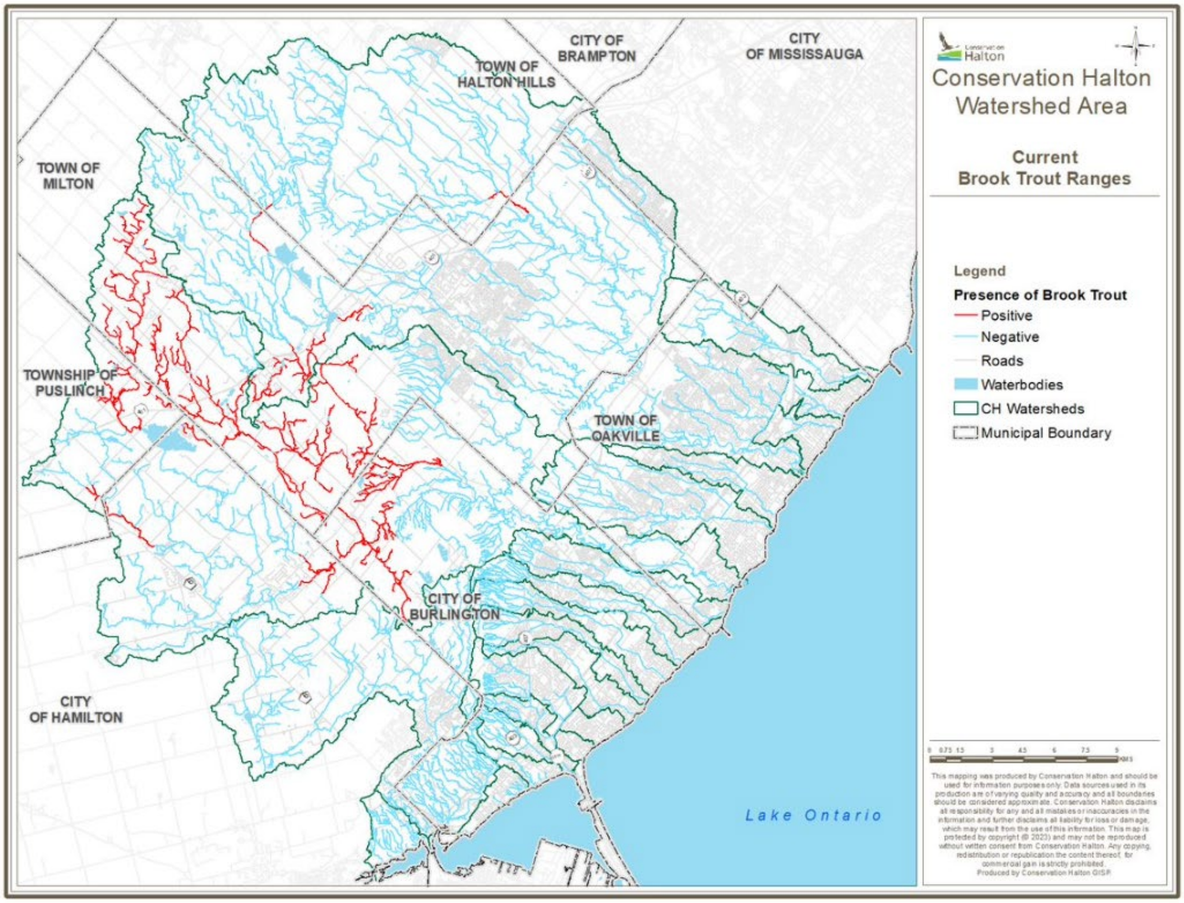


Source: Conservation Halton

Within Conservation Halton's watersheds, Brook Trout are on the decline as shown by Figures 3-9 and 3-10. Warmer temperatures and habitat conditions are pushing Brook Trout to the headwaters of Bronte and Sixteen Mile creeks where significant groundwater springs help to regulate warming waters. Reaches with cold to cool water thermal conditions in many creeks are not sufficient to maintain healthy Brook Trout populations.

For example, within the Sixteen Mile creek watershed, Brook Trout have been reduced to a handful of low order streams. Without significant restoration efforts, it is expected that these isolated populations will be extirpated (TUC 2018). In Bronte creek, healthier populations occur within their historical range. However, continued efforts to reverse and prevent further loses of Brook Trout in the watershed will still be required (TUC 2018).

FIGURE 3-9: CURRENT BROOK TROUT DISTRIBUTION IN CONSERVATION HALTON'S WATERSHEDS (BASED ON CH MONITORING DATA 2000-2023)



Source: Conservation Halton, Adapted from Trout Unlimited Canada, 2018

Local Species Feature: Smallmouth Bass - Warmwater Species with a Big Appetite!

Smallmouth Bass is a warmwater species of the Sunfish family and is native to the Great Lakes-St. Lawrence watershed mainly through southern Ontario (Dove-Thompson et al. 2011). The species can thrive in cool-warm to warmwater temperatures and is found in rivers, ponds, and large lakes.

Smallmouth Bass are successful predators within their habitats, feeding on minnows, juvenile fish, and other aquatic life (e.g., frogs etc.). As with other fish species that are tolerant of a broad range of water temperature, as waters warm with climate change this species will be able to expand its range northward. This will result in larger ranges and more success than other species (Shuter et al. 2002). In Ontario, one third of currently available habitat is suitable for Smallmouth Bass. Climate projections estimate that two thirds of available habitat will become suitable by 2050, leaving all but the extreme north free of Smallmouth Bass (Magnuson et al. 1997). This trend will trigger increased competition and predation on native species.

Smallmouth Bass and other cool-warm and warmwater species are those that may stand to benefit and thrive in a changing climate. Early ice-out conditions in lakes may increase prey availability and extend the growing season. This could increase winter survival, especially in northern locations (Shuter and Post 1990, Casselman et al. 2002). Where Smallmouth Bass may see negative impacts is in riverine habitats where greater variability in precipitation and winter melts will alter flows. This may impact egg development, increase egg displacement and mortality of young bass, (Dove-Thompson et al. 2011) and alter habitats suitable for all life-stages of Smallmouth Bass.

Within Conservation Halton's watersheds, Smallmouth Bass have long been observed in the main branches of Sixteen Mile and Bronte creeks where the thermal conditions and stream substrates provide suitable spawning conditions for Lake Ontario bass to move upstream and spawn, with some residing in the lower reaches of the watersheds. Range expansions are occurring as a result of increased water temperatures and introductions to upstream reaches, ponds and stormwater management infrastructure. Smallmouth Bass have now been observed beyond the main branches of the two creeks in smaller tributaries within Conservation Halton's watersheds. While they are still relatively uncommon, population increases especially in creeks such as Limestone Creek, a tributary of Bronte Creek, the Middle East and Upper West branches of Sixteen Mile Creek, and Fourteen Mile Creek may greatly affect native species that are currently on the decline in those reaches.

3.6 Insects

There are almost 7,000 species of insects confirmed from Ontario to date (iNaturalist 2023). As with other taxonomic groups, climate change will affect species differently. The greatest negative effects will be on the species that are habitat specialists, species that are not highly mobile, and species with restricted ranges or hosts (Van Swaay et al. 2010, Filazzola et al. 2020). Insects have remarkable regenerative abilities. Some species may be able to rebound very quickly from losses, provided the negative conditions are only temporary, or single events (Gandhi 2007, Chen 2019).

3.6.1 Habitat

Climate change is likely to benefit ***habitat generalists*** (Van Swaay et al. 2010, Filazzola et al. 2020) and may benefit non-native species more than native species.

Because the life cycle of dragonflies and damselflies involves aquatic and terrestrial stages, they are doubly at risk from climate change. Climate change may alter their aquatic habitat and also affect the adults after emergence (McCauley et al. 2018). Larval dragonflies and damselflies may be at risk from severe weather events changing their aquatic habitat through sedimentation, temperature changes, and water level or ***hydroperiod*** changes. After emergence, adults can be at risk of early mortality from extreme weather events or longer periods of inclement weather which may prevent feeding or egg laying. Most dragonflies and damselflies are sufficiently mobile to re-colonize areas making those species more resilient to some climate change effects.

About one third of Canada's butterfly species are at risk (Hall 2009). Southern Ontario's Carolinian Zone is one of Canada's richest butterfly conservation hotspots with 13 species at some level of risk and three species that have been extirpated (Hall 2009). This area is under intense development pressure and habitat is highly fragmented. This puts populations at greater risk of extirpation because fragmentation may prevent some species from re-colonizing. These threats will compound the effects of climate change and could lead to further extirpations of species at risk insects in southern Ontario by limiting species distribution opportunities.

3.6.2 Phenology

Changes in climate may cause a timing mismatch between the insect and its food source. Insects may emerge too soon and find themselves without a food source, such as a butterfly emerging before nectar flowers are available to feed on or its host plant is still dormant and not available for egg laying.

Climate change can affect dragonfly and damselfly adults by altering the timing of emergence and limiting food sources (McCauley et al. 2018). Changes in spring temperatures can alter the water temperature. Since the emergence of dragonflies and damselflies is closely tied to the temperature patterns within the waterbodies in which they live, increased water temperature may alter the emergence times of dragonflies and damselflies (Catling 2016, McCauley et al. 2018). Altered emergence time may put them out of sync with their prey. Larval habitat temperature increases may also increase the need for food in order for these species to survive.

Some butterfly, dragonfly and damselfly species are migratory. The triggers of migration are not well understood, but temperature and sun orientation are known factors in butterfly migration (Reppert et al. 2016). Climate change may alter migration timing through delayed or early temperature triggers. The increase in extreme weather events on summering and wintering grounds can have a significant effect on the numbers that survive the migration. This can subsequently have a significant effect on future population numbers. Repeated years of extreme weather events can prevent populations from rebounding or even lead to the loss of the population.

3.6.3 Distribution

Climate change may alter the distribution of insect species locally and throughout their entre range. Some species of insects can be highly mobile and easily re-colonize and move into new areas, while others are not mobile and will not be able to alter their range as the climate changes. An increase in winter temperatures may allow some species to expand their ranges northward (such as the Giant Swallowtail).

3.6.4 Survivorship

The changing climate can affect the abundance of insects in any given year. Insects can be much more resilient to population changes than many other groups but extremes in climate could lead to extinctions or local extirpation (Duffy et al. 2022). Abiotic factors that affect insects are primarily changes in temperature. Changes in weather patterns can also greatly affect insects directly because inclement weather will shorten insect lives or inhibit breeding activities (Gandhi 2007, Chen 2019). The loss of breeding adults too early in the season may greatly reduce the population of insects the following year.

Increased winter temperatures may allow more individuals to survive the winter than in the past. This can benefit pest species as well and increase the range and numbers of pests (such as ticks or mosquitoes carrying diseases). An increase in winter temperature may negatively affect insects that overwinter as an adult by causing them to be more active with a higher metabolic rate while not having any (or enough) source of replenishment.

Increased temperatures overall may also cause predators to be more active and may increase predation mortality. Increased temperatures will also cause insects to feed more for energy.

Climate change may cause changes in the plant communities towards lower quality non-native flower species (Young 2016). Several native pollinators such as bees are specialists which feed on one family of plants. If a habitat is degraded and the specialist plants become rare, then these specialist bees will disappear from the landscape due to lack of food that supports proper development of the young.

The increase of invasive and non-native species can compound the negative effects of climate change on our native species. Non-native species can increase pathogen loads or introduce new pathogens (Fürst et al. 2014). Climate change is likely to also increase pathogen survivorship which will negatively affect native species. Effects from introductions are unpredictable and could cause direct competition, predation or could cause habitat changes. An example of this is the Emerald Ash Borer causing a decline in ash composition in the forest reducing this host plant's availability for the native insects and other species that rely on it.

Climate change has been shown to lower snow cover levels and increase the freeze-thaw events through the winter (Pauli et al. 2013). This could have negative effects on overwintering insects by reducing the insulating snow cover and exposing the insects to cold ambient temperatures. The lack of insulating snow cover may allow a temporary increase in temperature to interrupt diapause (suspended development) or may directly kill them through the repeated freeze thaw actions.

The increase in temperature has allowed at least two species of dragonflies and damselflies to expand their range further northward than historically occupied. Blue Dasher and the Eastern Amberwing were historically limited to far southern Ontario but are now established as far north as Ottawa. There are other species that are showing shifts in distribution and new species have arrived and may continue to show up in our watershed. Some species are adventive[13] and are only temporary residents, such as the Citrine Forktail. Others such as Double-striped Bluet are showing signs of establishing permanent breeding populations where they historically did not occur. Species like the Citrine Forktail continue to make appearances much farther north than historically noted.

While conservation of generalist species can be very effective at a landscape scale, species with more specialized habitat needs will require careful consideration and management of specific habitat with that species in mind to preserve their populations (Ellis et al. 2012).

Local Species Feature: West Virginia White

West Virginia White is a rare butterfly found in forested areas of the Niagara Escarpment within the Conservation Halton watersheds. This butterfly is especially vulnerable to climate change as it is one of the earliest butterflies to emerge in the springtime and it has a very specific habitat niche (Davis 2015). As a result, it is susceptible to weather extremes and disconnect from its larval host plant (which is New Jersey Tea in Conservation Halton's watersheds) (Linton 2015) or adult food plants (Davis 2015). The adults could be triggered to emerge early by a sudden, unusual, spring warm up while the plants are still dormant. In this case, the adults would perish from starvation or not have larval host plants available to lay eggs upon (Cappuccino and Kareiva 1985).

[13] Adventive means not native to and not fully established in a new habitat or environment.

Sudden changes in the spring weather or unusually long periods of rain could also cause a die off in adults (Cappuccino and Kareiva 1985). This species is also very sensitive to the amount of sunlight available so if there are long periods of overcast weather the adults will not be active and thus not lay eggs (Burke 2013). This species is also vulnerable to the threat of invasive species and habitat alterations caused by invasive species.

The presence of Garlic Mustard, which is widespread in Conservation Halton's watersheds, is a major threat to populations. The spread of this invasive species degrades more habitat each year. In addition to degrading the habitat, Garlic Mustard may be mistaken for the host plant (as it is taxonomically closely related to the host plant) so adults lay eggs on the invasive species and those larvae die (Burke 2013, Davis and Cipollini 2014, Davis 2015). Climate change can also affect the overall habitat, which may negatively affect this sensitive species.

Local Species Feature: Mottled Duskywing

Mottled Duskywing may be at risk from climate change, but factors affecting the Mottled Duskywing's decline are not well understood. It is believed that factors include habitat succession, habitat alterations, and habitat loss due to development, as well as some unknown biological factors (Hall 2009, COSEWIC 2012, Linton 2015). It is also thought that some small, isolated populations may have been lost due to spraying to control Spongy Moth populations (Hall 2009, COSEWIC 2012).

Extremes in weather will have a negative effect on this species, and populations within Conservation Halton's watersheds and across its range are at risk of local extirpation due to low population numbers at many sites (Linton 2015). The preservation of currently occupied habitats must be of utmost priority and expansion of ***habitat patches*** will help mitigate the negative effects of climate change on this species in our watershed. This species occurs in small patches over multiple properties with differing landowners so partnerships with landowners owning, or adjacent to, habitat would be beneficial. A co-ordinated approach to management of all ***habitat patches*** on all partner properties within the watershed would yield the highest results.

A habitat management plan for Conservation Halton lands has already been drafted for this species. Careful stewardship of the habitat with the needs and life cycle of Mottled Duskywing in mind will be critical to preserving this species in our watershed and on Conservation Halton lands.

3.7 Benthic Macroinvertebrates

Benthic macroinvertebrates (benthos) are a diverse group of small organisms that live on the bottom of stream beds. Their life span can range from months to years. They spend all or part of their life cycle within a waterbody. Unlike fish, ***benthic macroinvertebrates*** are unable to move long distances and must be able to find both habitat and food within a small area to survive. They are an important link in the food web as they break down organic materials, bacteria, and plant matter and are also a primary food source for fish and ***herptiles*** (Allan and Castillo 2007).

The impact of climate change on temperature, precipitation and water quality will have a variety of effects on ***benthic macroinvertebrates***. For some species this will be beneficial, increasing their distribution and providing conditions more favourable for their survival. However this benefit will come at the cost of other species that will find conditions worsening and survival more difficult (Haidekker and Hering 2007, Besacier Montbertrand et al. 2019).

The impacts of warming air and water temperatures have been well studied and show a change in benthic community composition (Haidekker and Hering 2007). This change will likely decrease both richness and abundance of ***benthic macroinvertebrates*** within streams (Durance and Ormerod 2007, Li et al. 2012, Besacier Montbertrand et al. 2019). The impact on specific species will depend on their life cycle, size, and life history traits with smaller, short-lived species more likely to survive than larger long-lived species (Li et al. 2012, Haper and Peckarsky 2006).

The impacts of changing precipitation patterns will be similar to those of temperature, with an increase in the intensity of rainfall causing decreases in richness and abundance (Lawrence et al. 2010, LeRoy Poff et al. 2010, Kim et al. 2018). Drought periods will reduce habitat availability and lower flow conditions will further exacerbate the impacts of warmer temperatures. Shifts within the benthic community are likely to have impacts further up the food chain as the availability of benthos as food for fish and ***herptiles*** changes.

3.7.1 Survivorship

Sensitive species will be unable to tolerate the changes in water quality caused by drought-induced increases in the concentrations of nutrients and chemicals through evaporation and decreased flow (Booty et al. 2005, Bartolai et al. 2015). In addition, intense rainstorms may transport nutrients that have accumulated on the landscape during drought periods, resulting in pulses of contaminants that exceed tolerance levels and decrease survival (Wilby et al. 2006).

Increasing pollutant loads may also be combined with warmer temperatures that will decrease the dissolved oxygen present within a stream. This will cause negative impacts on taxa requiring oxygen-rich water (Lawrence et al. 2010). Tolerant benthos are able to withstand a wide range of temperature and water quality conditions and will continue to survive within the shifting conditions caused by climate change. The largest impact of shifting conditions will be felt by sensitive benthos that require conditions to be maintained within a narrow range. Once conditions shift outside of this range, their ability to survive greatly decreases with many taxa likely to be lost from the ecosystem.

3.7.2 Distribution & Phenology

The ability of ***benthic macroinvertebrates*** to adapt to climate change is limited and generally occurs because of a change in life history traits or a shift in distribution (Bellard et al. 2012, Filipe et al. 2013). Life cycles may speed up with higher metabolic rates occurring in warmer temperatures, prompting immature larvae to emerge as adults sooner, providing there is the ability to escape streams during drought conditions (Bayoh et al. 2003, Filipe et al. 2013). While warmer temperatures may cue early emergence, the adults will die without completing the mating phase of their life cycle if this does not coincide with food availability. In the long-term this will result in declines in benthic community health as the abundance of various species declines.

Distribution changes will occur when the suitability of a stream for a given species changes. For tolerant species, this may increase their range as they can fill the ecological niche left behind by sensitive species that are no longer able to survive in harsher conditions. Species whose life cycle includes a winged adult phase out of water may be able to move to more suitable habitat within nearby stream reaches.

Local Species Feature: Perlidae Stoneflies

The impact of climate change on individual species of ***benthic macroinvertebrates*** has been poorly studied as these organisms are often considered in the context of a community (e.g. Cauvy-Fraunie et al. 2015, Besacier Montbertrand et al. 2019). The expected impact on the Perlidae family of stoneflies based on their life history traits and distribution is presented below.

Perlidae are both large bodied and long-lived ***benthic macroinvertebrates*** (Figure 3-11), with a life cycle within streams ranging from 2-3 years (Schmidt and Tarter 1985, Feely et al. 2009). Eggs are laid in undisturbed areas. Eggs hatch during the late spring and early summer. The larvae develop through the fall, often pausing development during the cold winter months. Individuals will continue to grow during the following year, eventually emerging in spring two years after hatching. They primarily feed on smaller invertebrates and require cool, clean, well-oxygenated water and are considered sensitive to pollution and disturbance (Dosdall and Giberson 2014).

FIGURE 3-10: PERLIDAE STONEFLY COLLECTED FROM BRONTE CREEK IN LOWVILLE PARK

Source: Conservation Halton

Changes in precipitation, stream habitat, temperature, and water quality will have an impact on Perlidae. Shifts in precipitation and flow regimes will affect their ability to survive within a stream in three main ways. First, they must be able to withstand the additional velocities without being swept downstream. Second, the changes in water clarity may affect their ability to find prey. Third, the erosion and deposition of sediment which may either remove or bury habitat. Temperature has an important role in signalling adult emergence and allowing for growth and development (Schmidt and Tarter 1985, Moreira et al. 1994). Changes to temperature will allow for earlier emergence and faster development, however this may not coincide with the availability of food resources.

With the warmest stream temperatures occurring in the summer, Perlidae may be eliminated from a stream during their first year of development if the temperatures are greater than their tolerance threshold. Deteriorating water quality conditions resulting from increased nutrients will impact Perlidae by increasing plant and algae growth. This will change habitat features and when the plants die and settle to the bottom, the decay process will consume dissolved oxygen (Dosdall and Giberson 2014). If dissolved oxygen levels decrease too much, Perlidae will be unable to survive.

Given the potential impacts of climate change on Perlidae, it is likely that their presence will decline in our streams over the next century. As fewer streams can meet the temperature and water quality thresholds, they may become extirpated. Conservation Halton monitoring data reveals that water temperatures in streams have experienced warming over the last decade, with fewer streams categorized in the cold and cool temperature ranges preferred by Perlidae. Loss of Perlidae from the aquatic ecosystem will impact the food chain by removing an important predator and decreasing prey for larger animals. Efforts to protect and restore coldwater habitat will be essential in maintaining a refuge for this species.

Section 4 Conclusions

The loss of biodiversity through degraded habitats and declining species due to the impacts of climate change is a critical issue in Conservation Halton's watersheds. When biodiversity is impaired, the services provided by nature that benefit society are also impaired. Creeks, streams, wetlands, forests, valleys, and other natural features that provide healthy habitat for species of flora and fauna, also rely heavily on those species to maintain natural features' form and functions as described in Section 3. In turn, humans are dependent on these important ecosystems to provide societal benefits, including:

- filtering contaminants from surface and groundwater,
- absorbing rainwater during severe weather events to prevent flooding, erosion, and drought,
- reducing air temperature during heat waves, and
- capturing and storing carbon to mitigate the impacts of climate change.

The consequences of diminished biodiversity on people are numerous and concerning. For example, if we lose grass species with finely branched roots that hold together the bank of a stream under flood conditions, the bank will more likely erode, and property will be lost. If we lose pollinators such as bees that support production of dozens of agricultural crops in Ontario, our food supply will be in jeopardy. If trees are stressed by drought and increased temperature, timber production will decline, less carbon will be sequestered, and the trees will also be more susceptible to disease from insect and fungal pathogens. Biodiversity and, more broadly, healthy ecosystems provide beneficial services to people, including flood and erosion attenuation, recreational opportunities, mental health benefits and carbon sequestration. Though beyond the scope of this paper, biodiversity is also of paramount significance to Indigenous peoples for medical, cultural, and spiritual purposes.

In Conservation Halton's watersheds, for example, the loss of ash trees to Emerald Ash Borer has resulted in reduced carbon storage in our forests as the dead trees decompose and release carbon back to the atmosphere. Neighbourhoods that were predominantly planted with ash street trees are now suffering from an increase in the UHI effect, whereas those that were planted with a more diverse mix of species have not been as hard hit. Ecosystems are comprised of different species (biodiversity) and, with few exceptions, diverse ecosystems are healthy, highly functioning ecosystems.

Several general conclusions can be drawn about how climate change is impacting biodiversity in Conservation's watersheds:

- **Climate Change is Impacting Biodiversity** – The impacts of climate change cause shifts and changes to the status, health, and range of many species.
- **Winners and Losers** - Climate change affects every species differently. Some species will increase in population size and/or expand their distribution, while others will experience the opposite effect. In general, species with highly specialized requirements (dietary, reproductive, habitat, etc.) such as Redside Dace are most vulnerable to the effects of climate change.

- **Dependence on Other Species** - All species interact with others, but some rely directly and specifically on other ecosystem species to complete their life cycles. Changes to other species because of climate change amplifies these interactions. Examples include mussels that rely on certain fish for their larval life stage and butterflies whose larvae feed only on a specific host plant, like Mottled Duskywing.
- **Use of More than One Habitat Type** - All local amphibians except Red-backed Salamanders rely on aquatic habitat during their tadpole/larval stage, with most moving to terrestrial habitat for the adult portion of their life cycle. This is also the case for many insects, such as dragonflies. This augments exposure to climate change effects and can amplify species vulnerabilities because of differing effects on different habitat types.
- **Migratory Species** – Long-distance migrant species, like the Bobolink, spend part of each year in areas like South America that may experience climate effects differently than our local conditions. As such, temperature cues for migration may result in a mismatch with conditions at their destination. For example, birds triggered to migrate too soon may face inhospitable temperatures or lack of available food once they arrive resulting in increased mortality rates.
- **Cold-blooded Species** - The physiological processes of cold-blooded species (reptiles, amphibians, freshwater mussels, fish, insects, and benthic macroinvertebrates) are affected by their ambient (i.e., surrounding) temperature. These species may actively move around to select warmer or colder microhabitats to suit physiological needs. However, their inability to internally regulate their body temperature increases their vulnerability to climate change, specifically, temperature increases.
- **Fragmented Habitat** - All species inhabit a landscape that is highly fragmented. Roads, buildings, and certain land uses are barriers to wildlife movement and can prevent plants (through seed dispersal) and animals from moving to more suitable habitat. This can result in reduced gene flow and thus reduced diversity at the genetic level. Lower genetic diversity is generally unfavourable for plant and wildlife populations because it reduces the probability of outliers that might be better equipped to handle changing conditions.
- **Mobility** - Mobility is related to all the above factors. Plants with animal or wind-dispersed seed can shift their range more quickly than species with gravity-dispersed seed that simply drops to the ground beneath the parent plant. Cold-blooded species like snakes and fish are better able to move to favourable micro-climates than more sedentary species like freshwater mussels.
- **Highest Climate Change Vulnerability** - Redside Dace is the only species identified in the highest category of Extremely Vulnerable. As such, this species will continue to be a focus of ongoing work by Conservation Halton as it serves as an umbrella or indicator species for climate change effects on other species.

Section 5 Guiding Principles

Some species may require very specific intervention to ensure their continued survival in Conservation Halton's watersheds. However, for other species, future climatic conditions may simply be incompatible with their needs. Where this is the case, the cost of managing individual species is high and can come with unwanted trade-offs. Nonetheless, the following guiding principles for action will benefit all species.

5.1 Guiding Principle #1: Keep what you have. Protect and restore specialized habitats and ecosystem functions.

Climate change is a broad, rapidly evolving field of study with successive advancements continually building on our collective knowledge base. While much is known or can be surmised about the responses of individual species, there remains much to learn and understand about how entire ecological communities will respond to climate change.

Some species will be affected more, or differently, than others, resulting in ***novel ecosystems*** with new combinations of species that don't yet exist in nature (Nantel et al. 2014). In any given woodland patch, for example, some new species may arrive, many will remain, and others will disappear.

As described in Section 3, species with specialized needs are at a higher risk from climate change than generalist species that can tolerate a wider range of conditions. The relationships and interconnectedness of nature are complex with interdependencies between predators and prey, pollinators and plants, parasites and hosts, competitors, biophysical conditions and keystone species with an outsized effect on communities.

With an incomplete understanding of species interactions, even within existing communities, biodiversity conservation (in other words, keeping as many species as possible) is key to ensuring sufficient diversity to respond and adapt to climate change without triggering an ecological collapse. Ecological restoration is a key tool in maintaining habitat for specialized species that might otherwise be lost to climate change or other impacts.

Changes to the species composition of a natural area can alter the amount of ecosystem services a given natural area is able to provide for people. A project feature on the ecosystem services of the Cootes to Escarpment EcoPark System is provided below.

5.1.1 Project Feature: Ecosystem Services in the Cootes to Escarpment EcoPark System

Conservation Halton is a partner in the Cootes to Escarpment EcoPark System, a collaboration among nine government and not-for-profit agencies that collectively protects nearly 2,200 ha of open space and nature sanctuary between Cootes Paradise Marsh, Hamilton Harbour and the Niagara Escarpment (Figure 5-1). Other partners in the alliance are Bruce Trail Conservancy, City of Burlington, Halton Region, City of Hamilton, Hamilton Conservation Authority, Hamilton Naturalists' Club, McMaster University and Royal Botanical Gardens.

FIGURE 5-1: COOTES TO ESCARPMENT ECOPARK SYSTEM

Source: Cootes to Escarpment EcoPark System

The EcoPark System commissioned a study to quantify the economic value of ecosystem services provided by partner-owned lands (Green Analytics and C. Talbot & Associates 2022). In total, the value of the seven ecosystem services quantified ranged from $112-232 million per year (Table 5-1).

Biodiversity is described in the project report as a foundational enabling asset that is essential for the generation of the ecosystem services upon which humans depend. It cautions that ecosystem service values are not guaranteed, and that careful management and investment in natural assets is needed to protect the flow of benefits, similar to other types of assets.

TABLE 5-1: SUMMARY OF SELECT ANNUAL ECOSYSTEM SERVICE VALUES FOR THE COOTES TO ESCARPMENT ECOPARK SYSTEM (VALUES IN 2020 CAD)

Service Value	Lower Estimate	Upper Estimate
Carbon Sequestration	$307,000	$526,000
Stormwater Management	$49.2 Million	$49.2 Million
Recreation	$58 Million	$157 Million
Education	$853,000	$8.5 Million
Habitat Preservation	$1.4 Million	$2.7 Million
Air Quality	$354,000	$354,000
Urban Heat	$1.4 Million	$12.9 Million
Total	**$111.5 Million**	**$231.5 Million**

Source: Green Analytics and C. Talbot & Associates 2022

5.2 Guiding Principle #2: Allow for adaptation. Maintain and enhance connectivity of the natural heritage system.

To preserve the genetic diversity of plant and animal populations and prevent the harmful effects that can arise from inbreeding, it is important to ensure that movement can occur between isolated species populations.

In Conservation Halton's watersheds, natural habitat is interspersed with other land uses that can prevent the movement of individuals, and their genes, across the landscape. As the climate warms, north-south connectivity will be particularly important to maintain so that plants and animals can migrate north to track their preferred ***thermal regime***.

There has been a shift in natural heritage protection in Ontario over the past few decades from a "natural feature-based" approach, to a "natural heritage systems" approach that emphasizes the importance of connectivity. Implementing a systems-based approach requires consideration of the spaces in between ***habitat patches***, and an understanding of how various species move across the landscape. Maintaining and where possible improving connectivity between protected areas is particularly valuable over the long term. Actions to improve species connectivity may include:

- Considering connectivity in developing watershed and subwatershed plans
- Installing new or enlarged culvert and bridge crossings that incorporate design considerations for terrestrial and aquatic wildlife movement
- Working with landowners within identified ecological corridors to enhance habitat conditions through restoration and ecology-friendly management practices
- Protecting and enhancing (via outright purchase, conservation easement, voluntary agreement, or other means) key properties that support or improve landscape connectivity for plants and animals

A project feature on ecological connectivity is provided below.

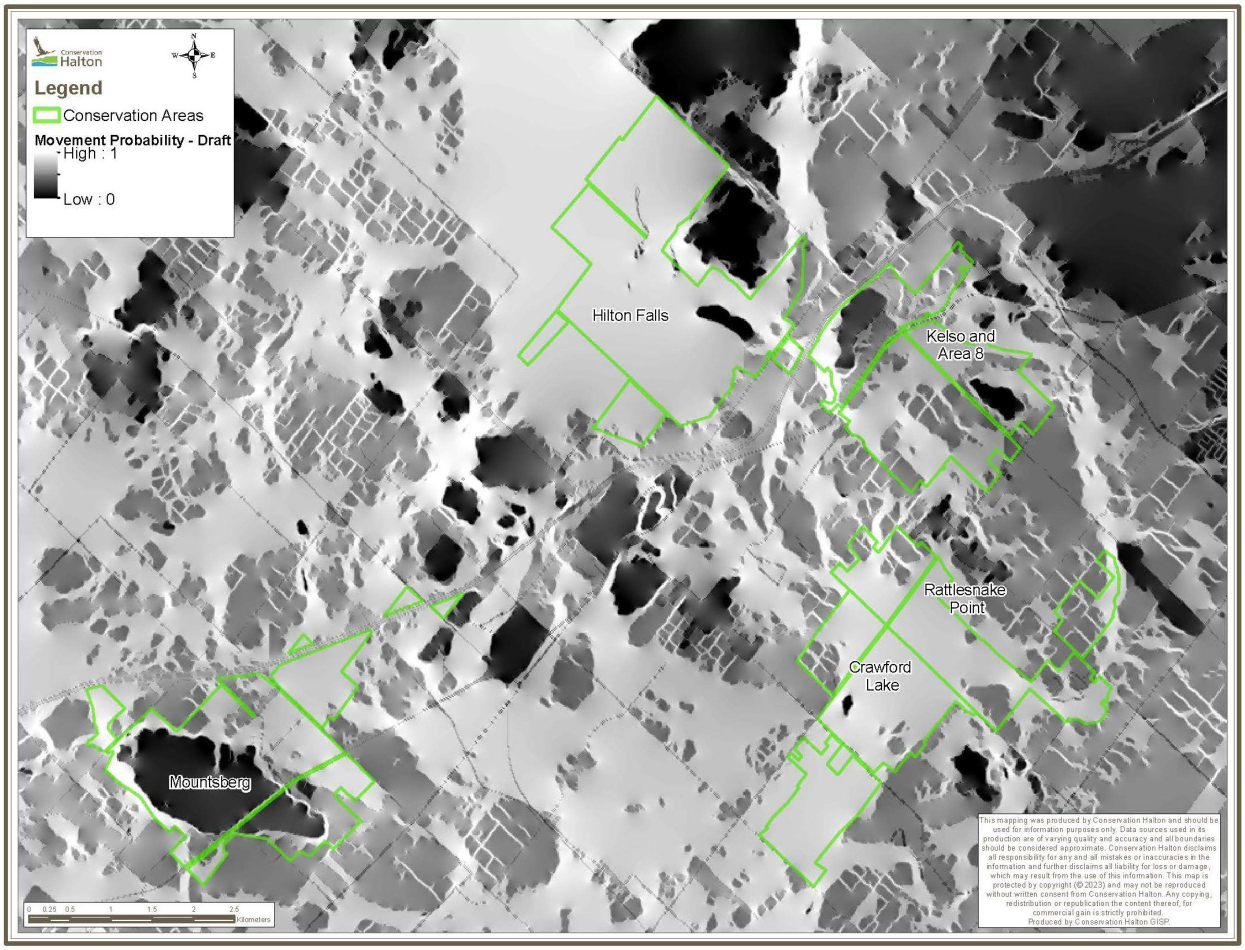
5.2.1 Project Feature: Ecological Connectivity Modelling

The ability of plants and animals to select and safely move to more favourable habitat is a key requirement for successful adaptation to a changing climate. Conservation Halton uses connectivity modeling to identify areas with a high probability of animal movement (i.e., probable wildlife corridors), based on work originally conducted within the Cootes to Escarpment EcoPark System (Apex Resource Management Solutions et al. 2021).

This mapping is produced using a program called Circuitscape that uses electrical circuit theory to find the "path of least resistance" across the landscape. It supports resource management decision-making such as prioritizing where to conduct landowner outreach and restoration projects and understanding the role of Conservation Halton lands in maintaining regional landscape connectivity.

Identifying probability of movement along corridors also helps Conservation Halton and other partners make planning decisions to protect or enhance these corridors through subwatershed planning and infrastructure design (new and replacement). Figure 5-2 illustrates, in lighter colours, areas predicted to have a higher degree of connectivity for wildlife.

FIGURE 5-2: ECOLOGICAL CONNECTIVITY AMONG HILTON FALLS, KELSO, AREA 8, RATTLESNAKE POINT, CRAWFORD LAKE AND MOUNTSBERG CONSERVATION AREAS



Source: Conservation Halton

5.3 Guiding Principle #3: Multiply the value. Use nature-based approaches that benefit both biodiversity and climate change resilience.

Though some of the anticipated threats to biodiversity are directly related to changes in temperature, precipitation and other climate factors, the most significant risk associated with climate change lies in its role as a threat multiplier. Climate change will exacerbate other threats that are already well-known and understood, such as habitat loss and fragmentation, spread of invasive species and road wildlife mortality. Interventions that address habitat issues make ecosystems more resilient to the effects of climate change, and those that directly address a climate change issue such as increased peak flows to a watercourse will render that watercourse more resilient to issues such as excessive erosion and siltation which directly alter habitats.

A project feature below on the Grindstone Creek Watershed Natural Assets project highlights the use of natural assets to address the effects of climate change while at the same time supporting biodiversity.

5.3.1 Project Feature: Grindstone Creek Watershed Natural Assets Project

The Grindstone Creek watershed drains about 91 km^2 in the Cities of Hamilton and Burlington. The creek empties into Hamilton Harbour/Burlington Bay (Figure 5-3). The entire watershed is within the jurisdiction of Conservation Halton.

Conservation Halton, the Cities of Hamilton and Burlington, Royal Botanical Gardens and the Municipal Natural Assets Initiative recently partnered to explore the value of natural assets in Grindstone Creek in addressing natural resource issues, with a focus on storm water management (Municipal Natural Assets Initiative 2022).

FIGURE 5-3: GRINDSTONE CREEK WATERSHED IN BURLINGTON

Source: Conservation Halton

Natural assets include natural resources such as forests and wetlands that contribute to the provision of one or more services required for the health, well-being, and long-term sustainability of a community and its residents.

The economic value of natural assets in the Grindstone Creek watershed was found to provide $2 billion in stormwater management services in terms of capital costs for replacement with traditional infrastructure not including operational costs. These same features provide an additional $34 million annually in other co-benefits such as recreation, soil retention and erosion control, climate ***mitigation***, habitat and biodiversity, and atmospheric regulation.

Another key goal of the study was to assist Project Partners in incorporating natural assets in local financial planning and asset management.

The City of Burlington included a dedicated section in their 2021 Asset Management Plan for the City's inventoried tree assets, with a one-time structural replacement value of nearly $300 million for the City's 71,000 inventoried trees (City of Burlington 2022).

By investing in natural assets as opposed to built infrastructure to help manage stormwater, benefits accrue to biodiversity conservation while at the same time helping communities adapt to climate change. Unlike some traditional grey infrastructure, natural assets or green infrastructure continue to increase in value over time as ecosystems continue to grow, mature and evolve. In addition, as noted in the EcoPark System study, natural assets provide many co-benefits of value to society. Through Board resolution, Conservation Halton has committed to implementing the recommendations of the report in continued collaboration with Project Partners.

5.4 Guiding Principle #4: Monitor and adjust. Natural systems are dynamic and constantly changing.

One only need look in the mirror to see evidence of a biological organism changing over time; growth and physiological modification, moving from one habitat to another, different needs and drivers that evolve over time. Just as individual organisms change over their lifespan, so too does their habitat and the interactions between biotic and abiotic components of ecosystems. The condition of individuals and ecosystems at any given point is a snapshot in time. Monitoring is critically important in providing current information to inform management decisions. Without current information, management decisions may address a problem that no longer exists, or fail to perceive an emerging threat. Both are costly.

To yield useful information, monitoring must be undertaken using sound methodology, in appropriate locations, by qualified practitioners. Conservation Halton supplements in-house data collection with data collected by others, such as municipalities, citizen science, government, and academia. Conservation Halton is both a user of, and a contributor to, the Great Lakes DataStream open access hub for sharing water data. Quality monitoring data is foundational to robust analysis and accurate reporting that turns data into knowledge.

The project feature below features Conservation Halton's Long-term Environmental Monitoring Program (LEMP).

5.4.1 Project Feature: Conservation Halton's Long-term Environmental Monitoring Program (LEMP)

Launched in 2005, Conservation Halton's Long-term Environmental Monitoring Program collects, analyses and reports on a variety of ecological parameters that together identify conditions, trends and risks to biodiversity and the broader environment in our watersheds. Standardized, replicable methodologies are used to allow for comparisons between our watershed and others, as well as to contribute to a broader pool of scientific information that is used in provincial and international analysis and decision-making. Methodologies used include:

- Marsh Monitoring Program
- Ontario Benthos Biomonitoring Network
- Forest Bird Monitoring Program
- Ontario Stream Assessment Protocol
- Ecological Monitoring and Assessment Network

Results are used to guide decision-making, for example in relation to the management of Conservation Halton lands, location and focus of restoration projects, alignment with land securement goals and establishment of timing windows for in-water works. Reporting occurs at a variety of scales, from social media to Watershed Report Cards to interactive story maps (Figure 5-4).

FIGURE 5-4: LONG-TERM ENVIRONMENTAL MONITORING PROGRAM STORY MAP

Source: Conservation Halton:https://storymaps.arcgis.com/stories/632834f548ce4f15aa7517102747b06e

Section 6 Current Actions in Support of Biodiversity

6.1 Conservation Halton

Conservation Halton plays a central role in protecting local biodiversity from the effects of a changing climate, with many programs and services related to climate change, biodiversity, or both. For example, the size, location, and quality of natural features in the watershed influences how the system responds during storm events, thus connecting biodiversity and ecosystem health to flood forecasting and operations of our water management infrastructure such as dams, reservoirs, and channelization works. Key programs that focus on understanding changes in biodiversity within our watersheds or protecting and enhancing biodiversity include the following:

6.1.1 Watershed Monitoring

Conservation Halton has a long-standing watershed monitoring program to inventory, monitor, assess, and report on watershed conditions, trends, and risks, including biodiversity (see Section 5.4.1). This information is used to support natural hazards management (e.g., flooding and erosion) to protect the health and safety of people. Monitoring also provides foundational direction for resource management decisions such as strategic implementation of terrestrial and aquatic restoration projects and supports watershed planning.

6.1.2 Water Control Operations

Conservation Halton is responsible for the management, operation, and maintenance of water control infrastructure with a capital asset value of more than $100 million, including dams and channels that provide flood protection and low-flow augmentation. This responsibility is integrated with our role in supporting the municipal emergency response to flooding by monitoring local watershed conditions and weather forecasts, predicting flooding potential, and providing flood messaging to watershed stakeholders. Dam and reservoir operations help local biodiversity by moderating the impact of extreme weather events, specifically within the Bronte and Sixteen Mile Creek watersheds.

6.1.3 Watershed Planning

As a watershed management agency, Conservation Halton is undertaking a watershed-based resource management strategy and renewing the watershed planning program to update individual watershed plans. These initiatives will identify management priorities and actions to address key natural resource issues, including climate change effects and biodiversity decline, based on good science and positive outcomes. Conservation Halton promotes sustainable management, restoration, and enhancement of natural systems within the watershed, including natural hazards. A climate change vulnerability and risk assessment for the Conservation Halton watersheds is underway to identify vulnerabilities and assist with prioritizing adaptation actions and providing a foundation for developing a Climate Resiliency Strategy which is slated to be undertaken in 2024.

6.1.4 Restoration

Conservation Halton collaborates with federal, provincial, and municipal governments, private landowners, community groups, and other organizations to undertake and fund restoration projects ranging in scale from small to large. These projects help manage natural hazards, improve natural heritage, and reduce or buffer the impacts of climate change such as flooding, erosion, and drought. Ecological restoration such as planting trees is a key tool to simultaneously support biodiversity and mitigate and adapt to climate change.

Projects are also implemented through agreement or contract with watershed clients to implement restoration projects on public and private lands.

6.1.5 Forestry

Conservation Halton delivers strategic forest management operations, tree planting services and supports the technical management of forests to enhance our watershed forest cover. This program has had a major influence on land cover within our watershed, having planted more than 4.5 million trees since our inception. These trees have provided habitat for countless species, mitigated the effects of greenhouse gas emissions by sequestering carbon and allowed for adaptation to increasingly intense rainfall by reducing soil erosion with their roots. This team also monitors invasive forest pests and delivers our Emerald Ash Borer program. Forestry staff provide an operational focus on forest management, hazard tree management and other arboricultural services across all Conservation Halton owned and managed lands.

6.1.6 Landowner Outreach

Conservation Halton has provided educational and stewardship services to watershed residents since 1994. One-on-one consultations are provided for private landowners to assist them with implementing restoration projects on their properties. Staff also provide hands-on educational programs and workshops to encourage landowners to take action on their properties. The popular “Healthy Neighboursheds” program is one example. This program promotes rainwater management and other sustainable practices that can be adopted by urban dwellers. Outreach is also undertaken through special events and media.

6.1.7 Hamilton Harbour Remedial Action Plan

Hamilton Harbour is one of 43 areas around the Great Lakes that have been designated as Areas of Concern because of the extent of environmental degradation. The Remedial Action Plan (RAP) secretariat is based at Conservation Halton and provides services to the Bay Area Implementation Team and associated committees. The team also prepares technical reports, organizes research and monitoring workshops and provides study support as key work projects are identified in committees.

6.1.8 Land Management

Conservation Halton owns and manages over 11,000 acres of land that supports a high proportion of the area's biodiversity. To support biodiversity, Conservation Halton monitors and manages forest health, including invasive species such as the Emerald Ash Borer, Garlic Mustard, Common Buckthorn and Spongy Moth. Master plans guide the management and ongoing stewardship of these significant watershed assets on behalf of both natural and anthropogenic communities. This includes consideration of sensitive species in park zoning and placement of trails.

6.1.9 Planning and Regulations

Conservation Halton administers O. Reg. 162/06 under the Conservation Authorities Act to restrict development activities within regulated areas such as valley systems, wetlands, shorelines, and other hazard lands to protect life and property from natural hazards such as flooding and erosion. The team also reviews a range of planning and development applications, as well as technical studies under the Planning Act, Niagara Escarpment Planning & Development Act, Environmental Assessment Act, Aggregate Resources Act and provides input on federal, provincial, regional, and municipal policies and initiatives. Maintaining these areas from development also helps preserve the biodiversity of these features.

6.1.10 Specific Projects

Specific projects currently being undertaken by Conservation Halton that support biodiversity and climate change include the following:

- Studying and reporting on the value of ecosystem goods and services such as carbon storage and sequestration to emphasize the value of nature-based approaches that benefit both biodiversity and climate change.
- Advancing the implementation of Grindstone Creek Municipal Natural Assets Initiative (MNAI) report recommendations.
- Completing a Watershed-Based Resource Management Strategy (Watershed Strategy)
- Undertaking a Climate Change Vulnerability and Risk Assessment and Climate Resiliency Strategy for Conservation Halton's watersheds.
- Mitigating Conservation Halton's corporate emissions to reduce the magnitude of climate change on our ecosystems, through projects targeting fleet electrification, building efficiencies and sustainable procurement practices.
- Completing installation of low impact development improvements to stormwater management at Conservation Halton's Administrative Office that provide habitat for pollinators.

6.2 Municipalities

Municipalities in Conservation Halton's watersheds play a key role in addressing both climate change and biodiversity conservation. There is a long history and many ongoing examples of collaboration between Conservation Halton, our municipal partners, and other agencies (Sections 5.1.1, 5.2.1 and 5.3.1).

Many municipalities have declared climate emergencies and have active climate change portfolios within their respective jurisdictions. Municipal natural heritage systems and tree conservation bylaws are important tools that can conserve natural areas that contribute to both biodiversity conservation and climate change mitigation and ***adaptation***.

Conservation Halton reached out to municipalities for their input on actions they are undertaking to support biodiversity and climate change. The following are examples of relevant recent and ongoing work by municipalities:

6.2.1 City of Burlington

"Thriving Natural Environment" is one of five themes in Climate Resilient Burlington (City of Burlington 2022), the City's plan to manage or reduce the risks associated with our changing climate. Specific actions supporting biodiversity include the following:

- Invest in full tree life cycle management balancing amount of planting and ongoing maintenance to improve tree survival outcomes.
- Incorporate a climate lens in recommendations of management decisions in the Urban Forest Master Plan (UFMP) to maximize co-benefits.
- Invest and support implementation of the UFMP.
- Invest in green infrastructure to reduce flood risk, enhance habitat connectivity and support other ecosystem services.
- Establish a City-Wide Biodiversity Plan.

6.2.2 Town of Halton Hills

The Town developed a Low Carbon Resilience Framework in 2020, with two main guiding strategies: the Low Carbon Transition Strategy (Town of Halton Hills 2021) and the Climate Change Adaptation Plan (Town of Halton Hills 2020). Both documents include protecting and enhancing natural assets to support local biodiversity, and a resilient and stable ecosystem. For example, managing natural and green spaces to provide stormwater management services, and moderating temperature during extreme heat events. These strategies are now in the implementation phase with additional work underway that relate to these strategies including the link between natural assets and the financial value they provide to the Town of Halton Hills.

6.2.3 Halton Region

Halton Region's Natural Heritage System was established to provide a high probability that biodiversity and ecological function of natural heritage in the Region will be protected in the long term (Halton Region 2020).

A 10-year Biodiversity Strategy for the Halton Regional Forests (Halton Region 2014) includes seven strategies:

- Implement strategic control of priority invasive species in Regional Forest Tracts.
- Expand the scope of restoration/enhancement activities beyond tree and shrub planting.
- Implement programs to monitor the biodiversity of Regional Forest Tracts.
- Promote Regional Forest Tracts as Living Laboratories.
- Engage the public in enjoying, characterizing and enhancing biodiversity resources in the Regional Forest Tracts.
- Engage in public awareness and educational activities to promote biodiversity.
- Continue to implement good forestry practices harvests in Regional Forest Tracts in accordance with the Forest Management Plan.

6.2.4 City of Hamilton

A Draft Hamilton Biodiversity Action Plan (City of Hamilton 2023) was released for consultation through the City of Hamilton Planning Committee in May 2023. The plan identifies seven key priorities:

- Develop an administrative framework to manage the on-going implementation of the Biodiversity Action Plan's Actions.
- Understand the current baseline state of Hamilton's biodiversity to inform future monitoring and priorities.
- Protect natural areas and their functions within Hamilton over the long-term to support diversity and connectivity.
- Enhance public awareness of the importance of biodiversity and explore opportunities to enhance biodiversity through stewardship.
- Protect Hamilton's biodiversity by implementing coordinated, city-wide efforts to control, remove, and manage invasive species.
- Enhance local aquatic habitats through sustainable stormwater management practices and restoration of degraded watercourses, waterbodies, and wetlands.
- Ensure impacts on or improvements to local biodiversity are clearly considered in all municipal decision making related to the development or use of urban and rural lands.

In June 2023, the City of Hamilton also adopted the Urban Forest Strategy (City of Hamilton 2021), which recommends a canopy cover target of 40% by 2050. The strategy focuses on increasing tree planting efforts on both public and private lands, development of a city wide woodlot protection by-law, and direction to develop and implement an Invasive Species Management Strategy.

Hamilton is designated as a Bee City and is committed to creating new habitats for pollinators and providing education and community outreach to the public. Staff work with local organizations from across Hamilton to enhance spaces for pollinators.

In April 2022, the City of Hamilton was recognized as a Bird Friendly City by Nature Canada. The City will work to achieve a more bird friendly approach to building and development through creation of the City's future Green Building Standards, and the City-Wide Urban Design Guidelines.

6.2.5 Town of Milton

Since the development of the 2015-2024 Urban Forest Management Strategy (Town of Milton 2014), the Town of Milton's Forestry Portfolio has evolved from a primarily reactive management approach to a more proactive approach. The Town plants hundreds of trees annually, with a focus on native, drought-hardy plant materials).

In 2016, the Town was awarded the Ontario Association of Landscape Architects Certificate of Merit for Service to the Environment in recognition of the *Restoration Framework: Stream Corridors and Natural Area Buffers for the Boyne and Derry Green Sub-watersheds of Sixteen Mile and Indian Creeks* (Town of Milton and Dougan & Associates Ecological Consulting & Design 2015). One of the key design principles of the framework is to maximize biodiversity at the outset of planting to provide core natural habitats that will be sustainable and robust over the long term. Restoration standards for natural areas and stormwater management ponds in new developments throughout the Town call for a seed mix that incorporates native wildflowers and plants that support pollinators.

6.2.6 City of Mississauga

The City of Mississauga is working to protect wildlife and natural ecosystems through a number of strategies, plans and programs.

- Natural Areas Study Program (North-South Environmental Inc. and City of Mississauga 2018), which updates the status of natural areas and documents information on floristics, fauna, impacts, boundary changes and management needs on a 4-year occurrence cycle.
- Climate Change Action Plan (City of Mississauga 2019), which includes actions to both mitigate and adapt to climate change.
- Invasive Species Management Plan (City of Mississauga 2021), which enhances native biodiversity and overall ecological integrity of the city's natural areas.
- Natural Heritage and Urban Forest Strategy (City of Mississauga 2014), which provides a framework for how to protect, enhance, restore and expand the city's natural heritage and urban forest.
- Urban Forest Management Plan (City of Mississauga 2014), which addresses environmental pressures that trees face.
- The One Million Trees Program seeks to plant more trees in Mississauga, expanding wildlife habitats within the city.
- Support for wildlife rescue and public education through the City's website (see Animal Services).

6.2.7 Town of Oakville

The Oakville Strategy for Biodiversity was developed in 2018. It provides 28 Management Opportunities and is framed around an approach to identify, protect, restore and enhance biodiversity.

"Natural Environment" is one of four key areas of focus in "Climate Action: Directions Report" (2022) that recognizes the importance of biodiversity, including a healthy tree canopy.

The Urban Forest Strategic Management Plan (UFSMP, 2008-2027) (Urban Forest Innovations Inc. 2008) identifies the main opportunities and challenges of Urban Forestry, provides criteria and indicators to assess the success of existing forestry programs, and provides recommendations and action plans for the Town south of Dundas Street. It also provides recommendations to reach a 40 percent canopy cover target by the year 2057.

The findings outlined in the Growing Livability - A Comprehensive Study of Oakville's Urban Forest report (Town of Oakville et al. 2016), are a result of an i-Tree survey conducted for the Town in 2015 to measure Oakville's tree canopy and compare it to a 2005 study.

Oakville's Planning and Development Council approved the innovative North Oakville Urban Forest Strategic Management Plan (Town of Oakville et al. 2012) on May 22, 2012, ensuring a sustainable and healthy urban forest for the lands located north of Dundas Street.

Over 30,000 trees are to be planted through the Town of Oakville's Woodland Regeneration program in 2023, in addition to the treatment of over 50 hectares of woodlands infested with buckthorn. The Town will also plant over 1400 caliper trees on its streets and parks to support its urban forest.

The forests owned and managed by the Town of Oakville have achieved Forest Stewardship Council® (FSC®) certification (FSC® C018800) through the Eastern Ontario Model Forest's Forest Certification Program. FSC® is an international, membership-based, non-profit organization that supports environmentally appropriate, socially beneficial, and economically viable management of the world's forests.

A third of Oakville's urban forests are assessed annually on a three-year rotational basis for signs of pests, disease and other disturbances. A report card of the woodlands surveyed in each year is produced to evaluate the health of the forest.

The urban forest is made up of all the trees growing in Oakville, including town-owned street and park trees, trees in forested areas, as well as trees on private property. Oakville has strengthened its Private Tree Protection By-law to help us preserve healthy trees and protect our community's urban forest. If you're making home or garden renovations, consider ways to make your trees part of your plan.

The Forest Health Ambassador program engages residents to help monitor neighbourhood street trees for invasive insects, disease and other issues related to forest health. The program runs through the summer months and Ambassadors can survey as many or as few trees as they like for tree health concerns.

In 2022, the Town of Oakville conducted an aerial spray program to manage Spongy Moth, as well as egg mass scraping and ground spraying of select street trees. Based on population surveys the year prior, 358 hectares (885 acres) of town woodlands would have experienced heavy to severe defoliation (loss of leaves) if no action was taken.

Given the recent positive findings of both Hemlock Woolly Adelgid and Oak Wilt in Ontario, the Town is actively surveying for their presence within its boundaries and modifying its operating procedures to avoid any possible spread. Currently neither has been detected within the Town.

6.2.8 Peel Region

The Credit River Watershed and Region of Peel Natural Areas Inventory provides an understanding of the biodiversity present in natural areas and how these areas function in the landscape to help maintain a healthy environment in the face of significant development pressure (Peel Region 2023). The Natural Areas Inventory was initiated in 2007 and field work continues in key locations each year.

6.2.9 Township of Puslinch

The Township of Puslinch recognizes the importance of forest conservation, control of noxious weeds and invasive species. Signage identifying several natural heritage features was posted in 2013 (https://puslinch.ca/culture-recreation/heritage/).

The Township utilizes the County of Wellington's Conservation and Sustainable Use of Woodlands By-law as well as the County's inspection services regarding this by-law.

6.2.10 Wellington County

Wellington County is home to The Green Legacy, the largest municipal tree planting program in North America.

The Wellington Rural Water Quality Program (RWQP), established in 1999, provides assistance to farmers in implementing voluntary projects to improve and protect water quality, which in turn supports biodiversity.

The Experimental Acres Pilot incentivizes and supports farmers who want to test regenerative farming practices on a small area of their farm. Similar to RWQP, the actions can support biodiversity by increasing crop diversity and lengthening growing by including multiple crops per year as well as cover cropping, intercropping, silvopasture, etc.

Section 7 Recommendations for Conservation Halton

7.1 Conservation Halton

Conservation Halton has undertaken programs and services related to biodiversity and climate change for over 60 years. While these programs and services help to sustain biodiversity and moderate climate change impacts, the data and science show that additional efforts at the watershed-scale are needed. In this regard, the following recommendations to support biodiversity are made, in no particular order.

1) Assess the watershed monitoring program to determine whether it adequately represents biophysical functions and sensitive sentinel species that can provide early detection of climate change impacts and, if required, adjust the monitoring program to include those that are most susceptible to the effects of climate change.
2) Provide additional data analysis, through a climate change lens, which connects physical (hydrometric, meteorologic, and hydrologic) data and observed biological responses to understand biodiversity conditions, trends, and risks linked with climate change.
3) Establish a regular cycle to report on climate change conditions, trends, risks, and management outcomes to inform watershed planning and management actions.
4) Partner with researchers from post-secondary institutions to advance scientific research on climate change impacts relevant to Conservation Halton's watersheds and guide management actions which promote climate change mitigation and adaptation through nature-based solutions.
5) Develop a Seed Strategy for Conservation Halton's tree planting program to ensure that planting stock is adapted to future climate conditions.
6) Assess and implement new technologies and best approaches that can provide insight into the connection between changes in the biophysical environment and biological responses (e.g., application of NatureServe's Climate Change Vulnerability Index to additional species, use of updated or more localized climate projections, predictive modeling, etc.).
7) Develop species-specific monitoring and restoration strategies for target species at risk and climate-vulnerable species on Conservation Halton lands.
8) Develop a restoration prioritization tool to support watershed planning and allow for more strategic selection and identification of restoration opportunities to address specific goals related to climate change and other watershed stressors.

Section 8 Suggestions for Municipalities and Others

8.1 Suggestions for Municipalities

Municipalities can and do play an important and complementary role in sustaining and enhancing biodiversity. The following suggestions are offered for consideration when municipalities are developing or renewing their climate change strategies. It is recognized that municipalities differ in their areas of local focus and capacity. Not all suggestions below will apply to every municipality, and some may already be fully implemented.

- Maintain a robust, connected Natural Heritage System to allow plants and animals to disperse and migrate safely to new areas.
- Include biodiversity as an important component of a new or updated Climate Change Strategy.
- Combine innovative stormwater management pond design with proactive and regular inspection and maintenance of stormwater management ponds to ensure optimal storage and treatment capabilities are maintained.
- Use a diverse assemblage of native species for all tree planting and landscaping on municipal lands, with an emphasis on Carolinian species.
- Integrate nature-based solutions and natural infrastructure into asset management plans to the extent possible for multiple co-benefits, including biodiversity support.
- Design and maintain designated trail networks through public natural areas to direct human use to areas that are less sensitive to disturbance.

8.2 Suggestions for Property Owners

Property owners can play an important role in promoting biodiversity by undertaking actions that promote good land stewardship and habitat improvement. Some suggested actions include:

- Use local native species for gardening and landscaping rather than ornamental species that originate elsewhere. These are more beneficial to wildlife, including pollinators.[14]
- Manage stormwater by disconnecting downspouts (where appropriate), installing and using a rain barrel, planting a rain garden or installing a permeable driveway.[15]
- Restore or disconnect ***online ponds*** which cause water temperature increases in streams because of surface exposure to sunlight. [16]

8.3 Suggestions for Individuals

There are many actions, large and small, that individuals can take to support biodiversity protection and climate change ***mitigation*** and ***adaptation***.

- Learn more about how climate change affects biodiversity and support or join groups or organizations that promote actions to protect and enhance local biodiversity and mitigate or adapt to climate change.

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[14] Conservation Halton has a list of native species suitable for planting, including information on their environmental tolerance for drought, salt, and shade (Conservation Halton 2018).

[15] Conservation Halton's Healthy Neighboursheds workshops provide guidance on low-impact landscaping practices (https://www.conservationhalton.ca/healthy-neighboursheds/) that also support biodiversity.

[16] Climate-friendly restoration options can include planting adjacent vegetation to provide shading, or inquiring with Conservation Halton about potential options for in-water intervention. Financial assistance may be available for stewardship projects undertaken by rural and urban landowners, farmers and businesses through Conservation Halton's various programs (https://www.conservationhalton.ca/financial-assistance-programs/).

- Keep your cat indoors. Cats are estimated to kill between 100-350 million birds each year in Canada (Blancher 2013), in addition to small mammals, reptiles, amphibians and insects.
- Be a conscious consumer. Choose products and services that help mitigate against climate change.

Glossary

The following table provides definitions of specialized terms used in this document.

Term	Definition
Adaptation	1. A heritable trait that increases the fitness of an organism and increases its ability to survive. 2. The anticipation of adverse impacts of climate change that results in the minimization of the damage they will cause.
Asynchronous	Objects or events that are not coordinated in time.
Benthic Macroinvertebrate	Invertebrates that inhabit aquatic environments. These include animals such as crustaceans and the larval forms of insects.
Coldwater Refugia	Sections of a water body that remain at least 2 degrees colder than the maximum temperature of the surrounding flow of the adjacent water body.
Ectotherm / Ectothermic	A cold-blooded animal that depends on external sources to regulate its body temperature sufficiently.
Feedback Loop	A feedback loop is a biological occurrence where the output of a system amplifies the system (positive feedback) or inhibits the system (negative feedback).
Freshet	Annual high-water events caused by snow melts.
Genotype	The genetic constitution of an individual organism.
Glochidia	Microscopic larval stage of some freshwater mussels and aquatic bivalve mollusks that disperse by attaching to host species (e.g., fish) with hooks or suckers.
Habitat Generalist	A species that can survive in a many different types of environments and conditions and can eat a variety of diets.
Habitat Patch	An area with a distinct shape or spatial configuration that is used by one or more species for breeding or to obtain other resources.
Headwater Stream	The smallest parts of a river or stream network. They are typically at the furthest point away from the stream's endpoint or confluence with another stream or waterbody.
Herptile	A reptile or amphibian.
Heterogeneous	The uneven, or diversity in distribution of biological or geological components throughout a landscape.
Hydrologic Cycle	The sequence of conditions through which water passes from vapor in the atmosphere through precipitation upon land or water surfaces and ultimately back into the atmosphere as a result of evaporation and transpiration.

Term	Definition
Hydroperiod	The number of days per year that a section of land contains standing water or remains wet.
Leaf out	The plant function that causes leaf emergence and growth.
Lentic Systems	Includes all non-flowing (still waters) such as ponds, wetlands, and lakes.
Mitigation	The reduction of harmful impacts on the environment that minimizes but does not eliminate risk. Example: the creation of habitat on or offsite to decrease the degree of damage caused.
Monoculture	The existence (or cultivation) of a single species within an area.
Novel Ecosystem	A system of components that originates from human influence and differs from ones that have existed historically. Once created, they organize and react independent of human involvement.
Online Pond	A pond connected directly to a natural surface waterway such as a creek, stream, river, etc.
Phenology	The study of seasonally dependent events and recurring cycles, especially in relation to climate and plant life.
Photoperiod	Length of daylight, or the recurring time frame within which an organism is exposed to light.
Propagule	A vegetative structure that can become detached from a plant and give rise to a new plant, e.g., a bud, cutting, sucker, or spore.
Warmwater Refugia	Sections of a water body that remains warmer than the temperature of the surrounding body of mixed water, creating preferred conditions for specific species.
Salmonids	Belonging or pertaining to the family Salmonidae, including the salmons, trouts, chars, and whitefishes.
Spring Ephemerals	Perennial woodland plants that quickly grow and reproduce during the early spring, dying back to their underground parts once the surrounding vegetation is fully grown and blocks the light they were exposed to previously.
Synergistic	An ecological association in which the physiological processes of behaviour of an individual are enhanced by the nearby presence of another organism.[1]
Thermal Regime	The temporal and spatial distribution of temperature across a landscape.
Vernal Pool	A seasonal pool of water that provides habitat for distinctive plants and animals.
Xylem	The vascular tissue of plants that conducts water and nutrients up from the roots and aids in the formation of woody materials within the stem.

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Appendix 1: NatureServe Climate Change Vulnerability Index for Canada

NatureServe's Climate Change Vulnerability Index is a Microsoft Excel-based tool that uses a scoring system to assess the vulnerability of a plant, animal, or lichen to climate change in a defined geographic area (Canadian Version v.3.0, Young and Hammerson 2015). Factors considered include the following:

Section A: Exposure to Local Climate Change

1) Temperature
2) Climate moisture deficit
3) Migratory exposure- climate change exposure index

Section B: Indirect Exposure to Climate Change

1) Exposure to sea level rise
2) Distribution relative to barriers
    a) Natural barriers
    b) Anthropogenic barriers
3) Predicted impact of land use changes resulting from human responses to climate change

Section C: Sensitivity and Adaptive Capacity

1) Dispersal and movements
2) Predicted sensitivity to temperature and moisture changes
    a) Predicted sensitivity to changes in temperature
        i. historical thermal niche
        ii. physiological thermal niche
    b) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime
        i. historical hydrological niche
        ii. physiological hydrological niche
    c) Dependence on a specific disturbance regime likely to be impacted by climate change
    d) Dependence on ice, ice-edge, permafrost, or snow-cover habitats
4) Restriction to uncommon landscape/geological features or derivatives
5) Interspecific interactions
    a) Dependence on other species to generate required habitat
    b) Dietary versatility (animals only)
    c) Pollinator versatility (plants only)
    d) Dependence on other species for propagule dispersal
    e) Sensitivity to pathogens or natural enemies
    f) Sensitivity to competition from native or non-native species
    g) Forms part of an interspecific interaction not covered by 4a-f
6) Genetic factors
    a) Measured genetic variation
    b) Occurrence of bottlenecks in recent evolutionary history (use only if 5a is "unknown")
    c) Reproductive system (plants only; use only if C5a and C5b are "unknown")
7) Phenological response to changing seasonal temperature and precipitation dynamics

Section D: Documented or Modeled Response to Climate Change (optional)

1) Documented response to recent climate change
2) Modeled future (2050) change in population or range size
3) Overlap of modeled future (2050) range with current range
4) Occurrence of protected areas in modeled future (2050) distribution

Appendix 2: Climate Vulnerable Species in the Conservation Halton Watersheds

Climate vulnerable species in the CH watershed

A Climate Change Vulnerability Index (CCVI) (Canadian Version v.3.0, Young and Hammerson 2015) was completed for numerous species within the Ontario Great Lakes basin (Brinker et al. 2018). These scores were based on the evaluation of 20 sensitivity and indirect exposure factors which when scored and combined, created a final vulnerability score and qualitative category. The exposure score was developed by evaluating modelled climate data that predicted temperature and moisture changes throughout each species ranges in the Ontario Great lakes basin using both recent historical data (1960-1990) and data from the "2050's period" (2041-2071). Sensitivity scores, where sensitivity is defined as how closely a species is linked to ecological conditions and microclimates that might be impacted by climate change, were then developed based on historical climate analyses, literature reviews, species distribution mapping and expert opinions (Brinker et al. 2018). Overall, the focus was on a species' intrinsic traits, physiological characteristics, and ecological relationships without consideration of geographic range size and anthropogenic threats. This allowed for comparison amongst species with different conservation statuses or range sizes. The resulting combination of exposure and sensitivity scores resulted in an overall vulnerability score, which was categorized into five categories: extremely vulnerable, highly vulnerable, moderately vulnerable, less vulnerable, and insufficient evidence and assigned a confidence level to the rank.

Due to the number of species assessed, a single climate scenario was used incorporating climate data spanning the Ontario Great Lakes Basin, an area of approximately 230,000km^2 (Brinker et al. 2018). The dataset covered two terrestrial ecozones, resulting in significant variability in climate, elevation, topography, and landuse. As a result, the generic projections across the basin do not necessarily reflect specific conditions expected within the Conservation Halton watersheds. It does however provide insight into potential threats and species expected to be vulnerable to climate change. Table A-1, lists species assessed for climate change vulnerability that occur in the Conservation Halton watersheds, along with the expected vulnerability ranking and status in the watershed.

TABLE A-1: MODIFIED FROM BRINKER ET AL. 2018

Common Name	Scientific Name	Vulnerability	Status in Watershed*
Louisiana Waterthrush	*Parkesia motacilla*	Highly vulnerable	THR, rare
American Hart's-tongue Fern	*Asplenium scolopendrium var. americanum*	Highly vulnerable	SC, rare
Chinese Hemlock Parsley	*Conioselinum chinense*	Highly vulnerable	No status in NAI
Spotted Salamander	*Ambystoma maculata*	Moderately vulnerable	Uncommon
Four-toed Salamander	*Hemidactylium scutatum*	Moderately vulnerable	Rare
Pickerel Frog	*Lithobates palustris*	Moderately vulnerable	Uncommon
Spring Peeper	*Pseudacris crucifer*	Moderately vulnerable	Abundant

Common Name	Scientific Name	Vulnerability	Status in Watershed*
Western Chorus Frog	*Pseudacris triseriata*	Moderately vulnerable	Common, THR (COSEWIC)
Prothonotary Warbler	*Protonotaria citrea*	Moderately vulnerable	Casual, END
Cerulean Warbler (poss)	*Setophaga cerulea*	Moderately vulnerable	Casual, THR
Mottled Duskywing	*Erynnis martialis*	Moderately vulnerable	Rare, END
Harlequin Darner	*Gomphaeschna furcillata*	Moderately vulnerable	Rare
Common Mudpuppy	*Necturus maculosus*	Less vulnerable	Rare
Red-spotted Newt	*Notophthalmis viridescens*	Less vulnerable	Common
Wood Duck	*Anax sponsa*	Less vulnerable	Common
Blue-winged Teal	*Anas discors*	Less vulnerable	Uncommon
American Black Duck	*Anas rubripes*	Less vulnerable	Uncommon
Short-eared Owl	*Asio flammeus*	Less vulnerable	Uncommon winter resident, SC
Red-shouldered Hawk	*Buteo lineatus*	Less vulnerable	Rare
Green Heron	*Butorides virescens*	Less vulnerable	Uncommon
Turkey Vulture	*Cathartes aura*	Less vulnerable	Common
Chimney Swift	*Chaetura pelagica*	Less vulnerable	Uncommon, THR
Bobolink	*Dolichonyx oryzivorus*	Less vulnerable	Common, THR
Hooded Warbler	*Setophaga citrina*	Less vulnerable	Rare
Acadian Flycatcher	*Empidonax virescens*	Less vulnerable	Casual, END
Peregrine Falcon	*Falco peregrinus*	Less vulnerable	Casual (release program), SC
Barn Swallow	*Hirundo rustica*	Less vulnerable	Common, THR
Least Bittern	*Ixobrychus exilis*	Less vulnerable	Rare, THR
Red-headed Woodpecker	*Melanerpes erythrocephalus*	Less vulnerable	Rare, END
Wild Turkey	*Meleagris gallopavo*	Less vulnerable	Uncommon
Pied-billed Grebe	*Podilymbus podiceps*	Less vulnerable	Uncommon
Eastern Meadowlark	*Sturnella vulgaris*	Less vulnerable	Common, THR
Golden-winged Warbler	*Vermivora chrysoptera*	Less vulnerable	Rare, SC

Common Name	Scientific Name	Vulnerability	Status in Watershed*
Eastern Red Damsel	*Amphiagrion saucium*	Less vulnerable	Rare
Amber-winged Spreadwing	*Lestes eurinus*	Less vulnerable	Rare
West Virginia White	*Pieris virginiensis*	Moderately vulnerable	Common, SC
Virginia Opposum	*Didelphis virginiana*	Less vulnerable	Common
Woodland Vole	*Microtus pinetorum*	Less vulnerable	Rare, SC
Northern myotis	*Myotis septentrionalis*	Moderately vulnerable	Common, END
Tricolored Bat	*Perimyotis subflavus*	Less vulnerable	No status in NAI, END
Snapping Turtle	*Chelydra serpentine*	Less vulnerable	Common, SC
Blanding's Turtle	*Emydoidea blandingii*	Moderately vulnerable	Rare, THR
Northern map turtle	*Graptemys geographica*	Less vulnerable	Rare, SC
Sugar Maple	*Acer saccharum*	Less vulnerable	Common
Puttyroot	*Aplectrum hyemale*	Moderately vulnerable	Rare
Fern-leaved Yellow False Foxglove	*Aureolaria pedicularia*	Moderately vulnerable	Rare, THR
Eastern Mosquito Fern	*Azolla cristata*	Less vulnerable	Rare
American Chestnut	*Castanea dentata*	Moderately vulnerable	Uncommon, END
Eastern Flowering Dogwood	*Cornus florida*	Moderately vulnerable	Uncommon, END
Black Ash	*Fraxinus nigra*	Moderately vulnerable	Common, END
Goldenseal	*Hydrastis canadensis*	Moderately vulnerable	Rare, SC
Butternut	*Juglans cinerea*	Moderately vulnerable	Common, END
Redside Dace	*Clinostomus elongatus*	Extremely Vulnerable	Rare, END
Silver Shiner	*Notropis photogensis*	Moderately vulnerable	Rare, THR
Eastern Pondmussel	*Ligumia nasuta*	Moderately vulnerable	SC

* END, THR, SC are COSSARO unless otherwise stated. Watershed status based on local status in 2006 Halton Natural Areas Inventory (Dwyer 2006b). Underlined species' local status may need to be re-evaluated as their populations are suspected to have increased or declined since 2006.