ADAPTING FORESTRY PROGRAMS FOR CLIMATE CHANGE

2018

Lake Simcoe Region
conservation authority

Executive Summary

The Lake Simcoe Protection Plan (LSPP) recognizes that stewardship is an essential tool in achieving the LSPP's objectives related to natural heritage, water quality and climate adaptation, and that stewardship approaches will need to evolve over time as more is learned, accomplishments are made and new priorities emerge. Maintaining, expanding and enhancing tree canopy cover across the watershed is critical for protecting and restoring water quality in the Lake Simcoe watershed, especially in the face of increased development and projected changes in local and regional climatic conditions. The species recommended for afforestation and reforestation projects, and the timing of planting, may need to be revised to account for future climate changes.

LSPP Policy 8.9-SA directs those involved in stewardship to assess stewardship programming, and modify as necessary, to address priority needs in the watershed. The Lake Simcoe Climate Change Adaptation Strategy calls for the planting of climate resilient tree species. Furthermore, Lake Simcoe Region Conservation Authority's (LSRCA) 2016-2020 Strategic Plan, *Vision to action, action to results* (LSRCA, 2016), Goal 2 sets out to "improve knowledge and increase certainty through excellence in research and scientific knowledge", with a Priority Action of developing a Lake Simcoe Watershed Climate Adaptation Strategy. This project was initiated to facilitate such efforts.

To address these needs, LSRCA has undertaken a comprehensive study into the impacts of climate change on tree planting and forest management, and the ways in which these programs might be adapted for climate change. Funding support was provided by the Ontario Ministry of the Environment and Climate Change (MOECC). This project is intended to provide knowledge transfer to LSRCA staff, municipal staff and members of environmental non-governmental organizations (ENGOs) active in the Lake Simcoe watershed, on how to include climate change considerations in planning for afforestation, natural area enhancement and restoration and urban tree planting.

The objectives of this project were to:

1) Develop a revised list of tree species that may be used to improve the effectiveness and success of restoration, afforestation, LID and stormwater management plans in the watershed;
2) Incorporate recommended changes into LSRCA programming; and
3) Transfer that knowledge to municipalities, Conservation Authorities and ENGOs within the Lake Simcoe watershed and beyond.

It was also recognized that improving the effectiveness and success of forestry programs will require more than an updated planting list, and the project was expanded to consider how forest management practices can be adapted for a changing climate.

Project Approach

A state-pressure-response approach was applied and involved three phases:

- Building an understanding of how the LSRCA currently delivers forestry programming;
- Researching the range of pressures climate change will place on forests in the watershed; and
- Recommending response options in order to adapt current program delivery methods to the expected pressures.

Internal consultation was held with LSRCA departments engaged in work connected to climate change and forestry. External stakeholder consultation was also conducted with forestry practitioners at municipalities, conservation authorities and environmental non-governmental organizations in and around the Lake Simcoe watershed, as well as with nursery suppliers and academia. Stakeholder input shaped the direction of the research project and ensured that research results would be of value to the participants. To address the issues raised through stakeholder engagement, a literature review and jurisdictional scan was undertaken, encompassing research focused on climate change impacts, projected species distributions and proposed adaptation measures for the forestry sector.

Lake Simcoe Watershed Forest Canopy Cover Status and Targets

The Lake Simcoe watershed is located within Canada's Great Lakes-St. Lawrence forest region, a transitional zone between the deciduous-dominated forests to the south and predominantly coniferous boreal forest to the north. Forest cover is unequally distributed throughout Lake Simcoe's many subwatersheds, with the lowest degree of forest cover tending to be associated with heavy agricultural use or urban development. Forest ownership is complex and includes public and private lands.

As stated in the LSPP, natural heritage features are a vital component of the ecosystem and closely linked to elements such as water quality and quantity. They provide many cultural, social and economic benefits through recreation and tourism, and the sustainable harvest of natural products. The threshold amount of total woodland cover for maintaining woodland-dependent biodiversity is believed to be approximately 30% as the ecological function of woodlands tends to be influenced by factors relating to fragmentation, patch size, woodland quality and total woodland cover. The LSPP recommends a target of 40% high quality natural vegetation in the watershed, including woodlands and wetlands.

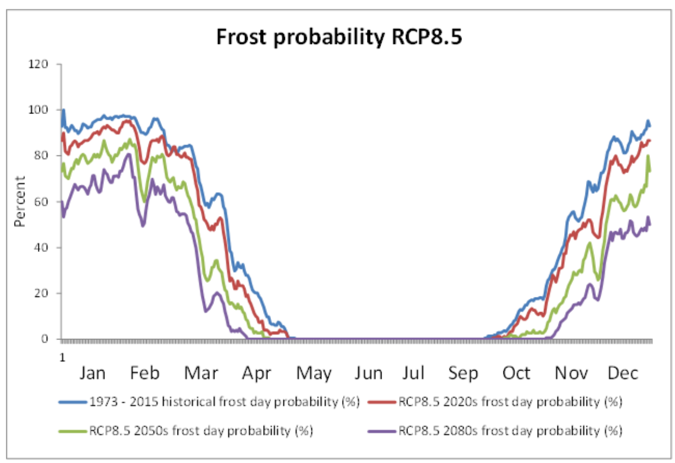
Currently, approximately 35% of the Lake Simcoe watershed is under canopy cover, though much of it is fragmented state and not all considered to be of "high quality". LSRCA's Integrated Watershed Management Plan recommends a target of 25% woodland cover in each subwatershed and 14 of the 19 currently meet this target. LSRCA's *Natural Heritage System and Restoration Strategy* establishes a 40% target for forest cover at the watershed scale and regional municipalities in the watershed have set canopy cover targets of 25% and 30%. Significant afforestation activities will be required to meet these canopy and woodland cover targets, particularly in subwatersheds with currently low levels.

LSRCA works towards its goal of protecting forests and increasing canopy cover through the activities of several internal departments including Forestry, Urban Restoration, Planning, Integrated Watershed Management, and Environment Science and Monitoring. The activities of each are described in the report in order to inform the development of adaptation strategies to support them.

Climate Change Projections

Human emissions of greenhouse gases are driving global climate change and changes in historical climate patterns have already been observed at long-term monitoring stations throughout the watershed, with the decadal average temperature increasing from 5.7°C early in the 20th century to 7.5°C in the 2010s. The long-term dataset clearly shows a gradual warming trend which has been accelerating more recently, in line with global data. Greenhouse gases like carbon dioxide remain in the atmosphere for many decades, meaning that we have committed to substantially more climatic change this century. Climate change projections indicate that average annual temperatures will increase 2-3°C over historical levels by the 2050s and temperatures may increase 5°C by 2100 if current emission levels are not significantly reduced. With this magnitude of temperature increase, maximum summer temperatures will rise to an average of over 30°C by 2100, with average winter maximum temperatures increasing to over the freezing mark of 0°C. While we are locked into much of the change expected by 2050, the magnitude of further change by 2100 will be determined by how rapidly countries around the world are able to drastically reduce greenhouse gas emissions.

Rising temperature trends are consistent with an extended growing season and the growing season in the watershed has already lengthened by approximately one week compared to historical data. Model projections show a continued increase in growing season length, as frosts may occur up to 1 month earlier in spring and 1.5 months later in autumn under a high emissions scenario.



Probability of the occurrence of frost expressed as the percentage number of days when minimum temperature is greater than 0°C, over a 5-day running mean.

Precipitation patterns are becoming more variable and rainfall intensity is increasing. Total annual precipitation in the watershed is projected to increase slightly, with winters becoming wetter and summers becoming drier on average. Higher temperatures will drive increased evapotranspiration and result in less available water. More winter precipitation will fall as rain rather than snow, and extreme weather events such as droughts, heat waves, floods, high wind events and ice storms are increasing in frequency, duration and intensity.

Climate change is projected to have significant impacts on the health and composition of forests across the country. These climatic changes are profoundly problematic for vegetation, which is finely adapted to local conditions and unable to migrate to keep pace with suitable climatic habitat. Effects on forests will occur on scales from gene to ecosystem, with impacts on physiological processes, site conditions, disturbance patterns, species interactions, regeneration, productivity, distribution and forest composition. Of particular concern is the rapid rate at which this will occur, with significant changes expected over the lifespan of any individual tree. A changing climate drastically increases the likelihood of tree stress and mortality, requiring the need for new and adaptive approaches to tree planting and forest management now and in the future.

Climate envelopes have already begun to shift at unprecedented rates due to the warming climate, with those for many common tree species having shifted northward by an average of 57 km since the early 1960s. Significantly more substantial northward shifts are expected in the future. Across 130 North American tree species, the mean centres of future climate envelopes are projected to shift northward by an average of 6-7 degrees latitude and decrease by 6-12% in overall size. Climate envelopes for most species are moving at a rate that considerably outpaces migration ability. Tree species have three possible fates in this rapidly changing environment: persistence in current locations through adaptation to new conditions, migration to track changing habitats, or extirpation. The factors influencing these fates are discussed in sections on adaptation, migration and disturbance.

Impacts and Adaptation Strategies

Adaptation Strategies have been developed to address the stresses on trees and forest cover that are forecasted to result from climate change. There are 44 Adaptation Strategies to address impacts in 15 categories including:

- Forest Composition
- Extreme Weather
- Biotic Disturbances
- Forest Growth and Productivity
- Seed Zones
- Carbon Sequestration and Storage
- Silviculture
- Tourism
- Urban Stressors
- Watershed Planning
- Resources
- Education and Awareness
- Planning for the Future
- Species Selection
- Tree Planting Logistics

As a primary objective of the research project, an initial list of climatically-suitable species options for the Lake Simcoe watershed has been prepared to guide delivery of the LSRCA planting program. The species list has been divided into three groups of trees that each display similar climatic envelope shifts:

- Retreating species – Those currently present in the Lake Simcoe watershed but are projected to retreat northward in the future;
- Enduring species – Those currently present and will continue to persist; and
- Advancing species – Those not currently present in the watershed but will expand northwards and become a new planting possibility.

These species lists are not intended to be comprehensive, as they include only the most common species used in afforestation and restoration programs. Additionally, the need for professional judgement to interpret and apply this list based on site conditions and project objectives must be emphasized. One mapped example for each category is given within the report with three maps presented for each species to allow visualization of ranges across a variety of time periods and scenarios.

Next Steps

The results of this report are being incorporated into LSRCA forestry programming. Beginning in spring 2018, trees from the updated planting list will be planted on a variety of sites and monitored on an ongoing basis. A review and prioritization of the Adaptation Strategies will be undertaken to inform LSRCA Forestry Programming going forward. Presentations are proposed to be made at conferences or symposia beginning in 2018 to discuss research findings and how LSRCA will be implementing these adaptation recommendations.

Contents

Acknowledgements

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Reference: Lake Simcoe Region Conservation Authority, 2018. Adapting Forestry Programs to Climate Change.

I. Project Background & Objectives

The Lake Simcoe Protection Plan (LSPP) recognizes that stewardship is an essential tool in achieving the LSPP's objectives related to natural heritage, water quality and climate adaptation. Maintaining, expanding and enhancing tree canopy cover across the watershed is critical for protecting and restoring water quality in the Lake Simcoe watershed, especially in the face of increased development and projected changes in local and regional climatic conditions. The LSPP also recognizes that stewardship approaches will need to evolve over time as more is learned, accomplishments are made and new priorities emerge. Specifically, LSPP Policy 8.9-SA directs those involved in stewardship to assess stewardship programming, and modify it as necessary, to address priority needs in the watershed.

The Lake Simcoe Climate Change Adaptation Strategy, released in accordance with Policy 7.11-SA lists Strategic Action 1.2, which calls for the planting of climate resilient tree species. With climate change projected to lead to hotter and drier summers, longer growing seasons, less snow cover in winter and more frequent extreme weather events, the approach to afforestation may need to change. Both the species recommended for selection in afforestation and reforestation projects, and the timing of planting may need to be revised to account for future climate changes. This project was initiated to facilitate such efforts. In addition, an increasing focus on Low Impact Development (LID) approaches to stormwater management requires consideration and understanding of the most appropriate tree species to be planted in the urban forest as part of installed features such as bioswales and vegetative buffers.

The LSRCA 2016-2020 Strategic Plan, *Vision to action, action to results* (LSRCA, 2016), Goal 2 sets out to "improve knowledge and increase certainty through excellence in research and scientific knowledge", with a Priority Action of developing a Lake Simcoe Watershed Climate Adaptation Strategy.

To address these needs, the Lake Simcoe Region Conservation Authority (LSRCA) undertook a comprehensive study into the impacts of climate change on tree planting and forest management, and the ways in which these programs might be adapted for climate change. Funding support for this research was provided by the Ontario Ministry of the Environment and Climate Change (MOECC). This project is intended to provide knowledge transfer to LSRCA staff, municipal staff and members of environmental non-governmental organizations (ENGOs) active in the Lake Simcoe watershed, on how to include climate change considerations in planning for afforestation, natural area enhancement and restoration and urban tree planting.

The objectives of this project were to:

1) Develop a revised list of tree and shrub species that may be used to improve the effectiveness and success of restoration, afforestation, LID and stormwater management plans in the watershed;
2) Incorporate the changes into LSRCA programming; and

3) Transfer that knowledge to municipalities, Conservation Authorities and ENGOs within the Lake Simcoe watershed and beyond.

After these objectives were initially developed, it was recognized that improving the effectiveness and success of forestry programs will require more than an updated planting list. The focus of this project was thus expanded to also consider all aspects of the entire tree planting process, as well as how forest management practices can be adapted for a changing climate.

II. Project Approach

The LSRCA has previously used a state-pressure-response framework in the subwatershed planning process to examine the anticipated impacts of stressors on the watershed. That approach was determined to be appropriate for this project as well and involved three phases: first, building an understanding of how the LSRCA currently delivers its forestry programming; second, researching the range of pressures climate change will place on forests in the Lake Simcoe watershed; and third, recommending response options in order to adapt current program delivery methods to the expected pressures.

To ensure that this project considered the full range of programs that would be impacted by an updated tree planting list and to ensure alignment with other ongoing projects, a series of internal consultation meetings were held with several LSRCA departments engaged in work connected to climate change and forestry, including Forestry and Stewardship, Integrated Watershed Management, Urban Restoration, Planning and Development, and Environmental Science and Monitoring.

An initial external stakeholder consultation workshop was held in August 2017 for forestry practitioners at municipalities, conservation authorities and environmental non-governmental organizations involved in planting trees in and around the Lake Simcoe watershed. The discussions at this workshop centred around three themes:

- In consideration of the impacts that climate change will have, what concerns do you have with respect to your ongoing forest management and/or tree planting programs?
- What actions has your organization taken (or plan to take) to address these concerns?
- What additional information would you find helpful in assisting you to make your decisions/recommendations?

The views shared at this workshop helped to shape the direction of the research project and stakeholder involvement in the discussion ensured that our research would also be of value to the participating organizations. A follow-up workshop for forestry practitioners was held in November 2017 in order to share our results and management recommendations, and discuss how these will be implemented. Additional one-on-one interviews were conducted with stakeholders in the Ministry of Environment and Climate Change, the Ministry of Natural Resources and Forestry, academia and the nursery industry in order to obtain the perspectives of these forestry researchers, advisors and suppliers.

To address the extensive list of questions raised through the internal and external stakeholder engagement processes, a literature review and jurisdictional scan was undertaken. This review encompassed research focused on climate change impacts, projected species distributions and proposed adaptation measures for the forestry sector. It was important to consult the full depth and breadth of relevant literature to ensure that our conclusions were well-informed, based on recent and accurate data, supported by expert recommendations and robust over a variety of potential future climate conditions.

The completion of this report does not mark the end of the LSRCA's forestry adaptation activities. Beginning in spring 2018, several specimen trees from the updated tree planting list will be installed in high-visibility locations and LIDs, and will be monitored on an ongoing basis to track their growth and vigour. Funding has also been set aside for planting new species in afforestation block plantings. Through 2018 a review and prioritization of the Adaptation Strategies presented in this research will be undertaken to inform LSRCA Forestry Programming going forward. Additionally, the process of sharing our results will continue. Presentations are proposed to be made at conferences or symposia beginning in 2018 to discuss how the LSRCA will be implementing these adaptation recommendations, with the goal of coordinating stakeholder efforts to collectively prepare for the impacts of climate change through the forests in and around the Lake Simcoe watershed.

III. Current Status of Lake Simcoe Forests

The Lake Simcoe watershed is located within Canada's Great Lakes-St. Lawrence forest region, a transitional zone between the deciduous-dominated forests to the south and the predominantly coniferous boreal forest to the north. This transition is well reflected in the woodland cover classifications of the watershed. Deciduous forest and mixed forest collectively account for just over 50% of the watershed's forest cover, with conifer forests accounting for an additional 6.5%. Deciduous forest habitats are characterized by red maple (*Acer rubrum*), sugar maple (*Acer saccharum*), speckled alder (*Alnus incana*), yellow birch (*Betula alleghaniensis*), white ash (*Fraxinus americana*), black ash (*Fraxinus nigra*), green ash (*Fraxinus pennsylvanica*), bur oak (*Quercus macrocarpa*), white cedar (*Thuja occidentalis*) and American elm (*Ulmus americana*). Mixed forests are characterized by white cedar, sugar maple, yellow birch, white ash and white birch (*Betula papyrifera*). While the Lake Simcoe watershed is north of the Carolinian forest boundary, some species such as black walnut (*Juglans nigra*), ironwood (*Ostrya virginiana*) and American beech (*Fagus grandifolia*) are also present (LSRCA, 2016b). Wooded swamps form the next largest portion of the watershed's forest cover, with conifer swamps, mixed swamps and deciduous swamps comprising over 30% of the total forested area. Deciduous swamps are dominated by green ash, black ash, poplar (*Populus spp*.) and silver maple (*Acer saccharinum*), with some bur oak and black walnut (*Juglans nigra*). Mixed wood swamps are characterized by white cedar, white pine (*Pinus strobus*), balsam fir (*Abies balsamea*), white spruce (*Picea glauca*), eastern hemlock (*Tsuga canadensis*), willow (*Salix spp*.), poplar and silver maple. The remaining 13% of forest cover is comprised of cultural plantations and woodlands, often planted with pioneer conifer species such as white spruce (*Picea glauca*) or red pine (*Pinus resinosa*). A detailed breakdown of these classifications can be found in Table 3.1.

Woodland Type	**Forest Cover**	
	ha	%
Cultural Plantation (CUP)	5,663	7.1%
Cultural Woodland (CUW)	3,224	4.1%
Conifer Forest (FOC)	6,103	7.7%
Deciduous Forest (FOD)	17,187	21.7%
Mixed Forest (FOM)	12,751	16.1%
Conifer Swamp (SWC)	6,629	8.4%
Deciduous Swamp (SWD)	13,939	17.6%
Mixed Swamp (SWM)	13,742	17.3%
Total	79,238	100%
Approximate Area of Watershed (excl. lake)	261,887	30.3%

Table 3.1: Woodland cover by type in the watershed (LSRCA, 2018)

Forest cover is unequally distributed throughout Lake Simcoe's many subwatersheds, from a high of 68.5% on the Lake Simcoe Islands to a low of 11.7% in the Maskinonge River subwatershed (Figure 3.1, Table 3.2). The lowest degree of forest cover tends to be associated with heavy agricultural use or urban development. The ownership of these forests is complex, with forests contained within LSRCA,

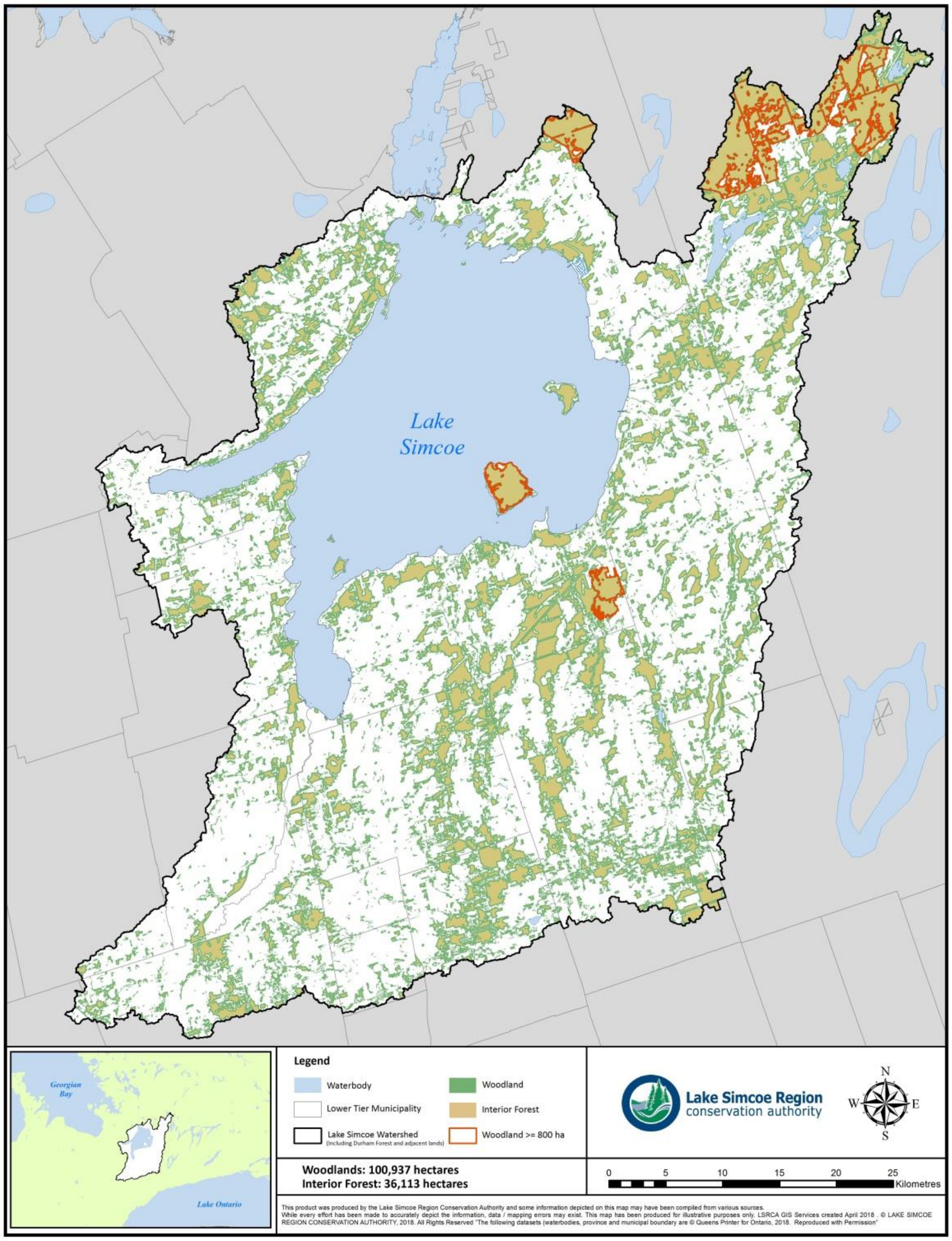


Figure 3.1: LSRCA woodland distribution.

provincial, or municipal conservation areas, protected areas and on private land. The LSRCA owns or manages 24 conservation properties and nature reserves within the watershed, comprising 2,407ha of conservation landholdings. The watershed also contains important portions of the 12,950ha Simcoe County Forest, 2,300ha York Regional Forest and the 596ha Durham Regional Forest. Five provincial parks and nature reserves – Sibbald Point, Mara, McRae Point, Holland Landing and Duclos Point – have been established within the watershed (Douglas *et al*, 2014). In total, 22,614ha of the watershed (6.85% of total land area) in 137 different protected areas are managed by authorities including the LSRCA, Ontario Parks, OMNRF, various NGOs (e.g. the Nature Conservancy of Canada), land trusts and private landowners (Lemieux *et al*, 2012).

Subwatershed	Area (ha)	Woodland Cover (%)
Barrie Creeks	3,753	13.6
Beaver River	32,725	25.3
Black River	37,536	43.2
East Holland River	24,715	22.8
Georgina Creeks	4,933	38.1
Hawkestone Creek	4,487	49.7
Hewitt's Creek	1,752	15.1
Innisfil Creeks	10,715	28.2
Lover's Creek	5,995	28.1
Maskinonge River	6,346	15.5
Oro Creeks North	7,526	37.9
Oro Creeks South	5,739	41.2
Pefferlaw Brook	28,490	40.1
Ramara Creeks	13,731	34.6
Talbot River	7,014	32.7
Upper Talbot River	29,456	63.4
Uxbridge Brook	16,134	32.5
West Holland River	35,193	22.2
White's Creek	10,540	33.2
Islands in Lake Simcoe combined	1,887	68.5%

Table 3.2: Woodland cover by subwatershed areas (LSRCA, 2015)

The most detailed information on canopy cover distribution comes from analysis completed using i-Tree Eco and i-Tree Canopy, web-based aerial photo interpretation software created by United States Department of Agriculture (USDA) Forest Service. Canopy cover assessments have been completed using i-Tree for the municipalities of Aurora, Newmarket, Upper York Region (East Gwillibury, Georgina, King and Whitchurch-Stouffville) and later for the remainder of watershed municipalities in Durham Region, Simcoe County, Kawartha Lakes and Barrie. The majority of the Lake Simcoe watershed's urban forest is located on private property. Thus, residents and businesses are the most influential stewards of the urban forest and their cooperation is essential to achieving all future urban forest targets. Recognizing that a lack of tree care is a significant threat to tree health and that municipal resources are finite, it is clear that the public must share the responsibility for tree care and preservation. While by-laws designed to prevent the damage and destruction of trees can serve as a critical safety net, it is ultimately a strong collective stewardship ethic that will ensure the growth and long-term health of the urban forest on both public and private property (LSRCA, 2016b; LSRCA 2016c).

IV. Canopy and Cover Targets

There are numerous reasons why municipalities in the watershed are aggressively pursuing their canopy cover targets. As stated in the Lake Simcoe Protection Plan, natural heritage features are a vital component of the ecosystem and are also closely linked to other elements such as water quality and quantity by preventing erosion, stabilizing shorelines, filtering contaminants and retaining carbon, nutrients and sediments. They also provide many cultural, social and economic benefits through recreation and tourism, and the sustainable harvest of natural products. The Natural Heritage Reference Manual (OMNR, 2010) lists a variety of important functions associated with woodlands and Larson *et al* (1999) summarize the importance of woodlots. These important functions can generally be described as follows:

- Economic Services and Values: oxygen production, carbon sequestration, climate moderation, water quality and quantity improvements, woodland products, economic activity associated with cultural values
- Cultural/Social Values: education, recreation, tourism, research, spiritual and aesthetic worth
- Ecological Values: diversity of species, structural heterogeneity, nutrient and energy cycling
- Hydrological Values: interception of precipitation, reduction of intensity of rainfall runoff, slower release of melt water from snowpack, shade to watercourses

The threshold amount of total woodland cover for maintaining woodland-dependent biodiversity is believed to be approximately 30% (Fahrig, 2003; Environment Canada, 2013). This is because the ecological function of woodlands tends to be influenced by factors relating to fragmentation (the splitting of larger woodlands into ever smaller pieces), patch size (the requirement of woodland pieces to be of a certain area for the maintenance of some functions), woodland quality (such as shape, interior habitat, age, composition, structure and the presence of native or invasive species that impact forest health) and total woodland cover (i.e., the woodland area within a jurisdiction or watershed).

The Lake Simcoe Protection Plan recommends a target of 40% high quality natural vegetation in the watershed, which includes both woodlands and wetlands. Currently, approximately 35% of the Lake Simcoe watershed is under canopy cover, though much of it is in a fragmented state and would not all be considered to be of “high quality”. The LSRCA’s Integrated Watershed Management Plan (LSRCA, 2008) recommends a target of 25% woodland cover in each subwatershed, with the progress towards this goal shown in Table 3.2 above. Fourteen of the nineteen Lake Simcoe subwatersheds currently meet this target. The LSRCA’s new *Natural Heritage System and Restoration Strategy* (LSRCA, 2018) also establishes a 40% target for forest cover at the watershed scale. The regional governments of York and Durham also have canopy cover targets they are working towards within their municipal boundaries. The forest cover target for York Region is 25% by 2031, with current woodland cover estimated at 23% (York Region, 2016). The forest cover target in Durham Region is 30%. Significant afforestation in the Lake Simcoe watershed will be required to meet these targets, particularly in subwatersheds with the least total forest cover.

V. Watershed Forestry Programming

The LSRCA works towards its goal of protecting forests and increasing canopy cover through the activities of several internal departments. The Forestry group is responsible for implementing large-scale afforestation projects and for practicing forest management on conservation lands, the Urban Restoration Department encourages the planting of trees and woody vegetation within LID features to increase green infrastructure and improve stormwater management in urban regions, and the Planning Department oversees natural heritage reviews as part of planning and regulatory processes. Additionally, a number of projects under the Integrated Watershed Management and Environment Science and Monitoring Departments examine the interactions between trees and watershed functions, reinforcing the importance of healthy forests and often recommending increased tree planting in sensitive regions in order to meet watershed objectives. This section will describe each of these programs in greater detail in order to explore all the ways in which forestry programming is currently delivered by the LSRCA.

5.1 Afforestation Programs

Large-Scale Afforestation

The primary goal of the LSRCA's afforestation program is to establish new large block plantings within the watershed, preferably with a focus on forest connectivity or riparian buffer enhancements in order to maximize the environmental benefits and associated ecosystem services. This process involves engaging with landowners to identify appropriate sites for afforestation, conducting a site visit to determine a planting plan, carrying out the block planting and ensuring that the new trees are set up for success. Each of these steps will be described here in further detail.

Site Selection

As the majority of its afforestation projects occur on private rather than public lands, the LSRCA strongly relies on engaging with interested landowners to implement its planting programs. Communications staff are instrumental partners in promoting afforestation programs to landowners within the watershed through media releases, mail-outs and other forms of advertising. Once a landowner expresses interest, the LSRCA will attempt to match funding criteria from available programs to the potential site. While the minimum land area required to be eligible for funding and support is dependent on the municipality, the majority of suitable large sites are former agricultural fields. Another common reason a landowner may wish to pursue a tree planting project is to ensure their property qualifies for a MFTIP (Managed Forest Tax Incentive Program), which requires a minimum of 4 hectares (approximately 10 acres) of forested area. If a property qualifies for the necessary funding and the LSRCA, the landowner and any other partners collaboratively decide to pursue afforestation, the project will move forward and a detailed plan will be developed for implementation.

An emerging challenge noted by forestry staff is the increasing difficulty in identifying new afforestation sites, particularly with growing land use pressures in the Lake Simcoe watershed, which may include urban development, farming and other activities (e.g. green energy). Afforestation is a long-term land use decision, as establishing a woodland renders it difficult to revert to another type of land use.

However, landowner decision-making and commitment often tends to be more focused on the short-term. Clients with the resources to own a sizeable property and implement a large-scale tree planting project tend to be older, meaning that the landowner at the time of planting will not necessarily be present to manage the forest in the following decades. Landowners who worked with the LSRCA to plant trees 10 to 20 years ago often no longer own the same property. Adopting new communications strategies to identify interested landowners and maintain contact over the longer-term will play an important role in addressing this challenge.

Site Conditions & Species Selection

The goal of a site visit is to develop an understanding of the landowner's objectives, determine the plantable area of the property, identify any challenging site conditions that might impact afforestation and tree survival, and to try to best match the soil conditions to an appropriate tree species. In general, afforestation sites are most often classified as an early successional environment with disturbed soils due to the former agricultural nature of these locations. Consequently, shade-intolerant conifers make excellent pioneer species considering the prevailing soil and ecological conditions in these open, exposed sites. Selecting species for soil conditions is becoming an additional challenge as the soil itself has the potential to change with climate. While any transformational changes in soil structure will occur over longer time spans than are relevant for afforestation projects in the coming decades, climate change does have the potential to impact the water and organic matter content in the surface layer, which is important for the successful growth and establishment of newly planted seedlings.

The amount and variety of tree species available for LSRCA programming is currently determined by the annual allocation from the growers. While the specifics of this allocation are determined largely at the discretion of the nursery, every few years there may be an opportunity for the LSRCA to consult with the nursery regarding upcoming species allocations. The majority of the annual allocation comprises a variety of versatile conifer species, approximately 25% of which is typically eastern white pine (*Pinus strobus*). White spruce (*Picea glauca*), Norway spruce (*Picea abies*), red pine (*Pinus resinosa*) and eastern white cedar (*Thuja occidentalis*) are also commonly allocated species. While small numbers of hardwoods are occasionally planted, these species are not preferred as they are at greater risk of mortality after planting due to animal predation, competition from weeds, and other factors.

An additional complicating factor in selecting which species to plant at a given site can be landowner preferences. Landowner biases have occasionally been noted against species such as spruce, which may be viewed as less remarkable, slow-growing trees. More prominently, many landowners are particularly opposed to planting non-native species. For this reason, operational issues may be encountered in any potential assisted migration projects of southern species due to landowner preferences to only plant native trees. If climate change necessitates increased planting of non-native species, it may be crucial to increase educational opportunities for landowners in order to properly communicate the reasons for proposing to plant non-native trees. Conversely, landowners often show a preference for planting hardwoods, which have traditionally been more difficult to establish due to site conditions and predation. Future species projections appear to favour many hardwood species, which may improve landowner enthusiasm for these planting projects.

Afforestation Process

Large-scale afforestation work occurs solely in the spring due to stock availability, with the prime planting period lasting from when the ground dries up after the spring melt until weed emergence and rising temperatures become an issue, and the trees break from their winter dormancy. To align with this timeframe, the nursery suppliers typically start lifting seedlings in early April. Seedlings are then shipped to the LSRCA and kept in cold storage, with the aim of having all of them planted by the May long weekend. Nurseries source their stock from seed orchards across the province and the afforestation stock they supply to the LSRCA is comprised of 2-3 year old bare root seedlings or plugs.

Depending on the terrain and site conditions, trees are planted either by tractor or by hand at a typical spacing of 1.8m (6 ft.) between trees and 2.4m (8 ft.) between rows. This arrangement is used in order to promote growth of higher-quality stems through competition for growing space and facilitate future management activities, such as mowing between tree rows and eventual thinning to promote forest succession. This standardized approach is employed to provide efficiencies for planning, planting, maintenance and future management. However, some landowners have indicated that they dislike tree plantations comprised of long, repeating, straight rows as they are not aesthetically pleasing. Direct seeding by hand to obtain a more natural-looking forest is a viable alternative, however sites planted in this way are significantly more complicated to maintain and manage. This method is more frequently used to plant hardwood species and thus is a more common approach in Southwestern Ontario where hardwood species represent a greater component of the forested landscape. Direct seeding allows for higher stock numbers per area at a reduced per tree cost, helping to alleviate the concerns of predation and competition that are inherent in planting hardwood seedlings. Site preparation requirements are different for direct seeding however and an approach known as "pit and mound" is often utilized. This method of disturbing the soil to form shallow pits and associated mounds has the advantage of better emulating the microtopography of a natural forest floor, which has been found to improve seedling establishment.

Anticipated Afforestation Program Challenges

Several concerns have already been raised relating to how climate change will impact the implementation and timing of the afforestation program. Climatic warming is expected to result in an earlier start to the spring season, which has important implications for labour availability. Local tree nurseries rely heavily on migrant workers for lifting tree seedlings in the spring and in one year already the nursery needed to start this process before workers had arrived. This problem cannot easily be solved by bringing workers in earlier in the year, as strict visa regulations dictate the total amount of time migrant workers are entitled to work in Canada each year, and starting work earlier in the spring only results in moving the labour deficit to the fall season. In the case of an early spring, all afforestation projects are thus at the mercy of the nursery and their ability to lift seedlings with a limited labour force, which may become an increasingly common occurrence with climate change. Earlier springs may also impact labour availability at the LSRCA. Summer students typically finish their university or college semesters in late April and are available to start work at the LSRCA by early May. With the possibility of earlier springs, students may no longer be available to provide planting labour for the majority of afforestation projects.

Post-planting

The landowner is responsible for the care and maintenance of trees and shrubs after planting. The LSRCA approach is relatively hands-off once trees are in the ground, with an organizational focus on providing advice, recommendations and encouragement for landowners on how to manage their new trees. The LSRCA's efforts are focused on selecting high quality plant material of an appropriate species for the site and ensuring that the trees are properly installed, after which the participants must do their part to tend the trees and hope that temperature, precipitation and predation conditions cooperate to allow the new trees to establish. Reasonable measures to protect the new plantation from livestock, fire, insects, rodents and disease are expected, such as mowing grass between tree rows to reduce competition. Another frequent recommendation is to apply simazine following planting. This pre-emergent grass control agent is another means of reducing problematic competition. No watering or replacement planting programs are currently in place and the LSRCA is not responsible for the failure of trees to become established. Exceptions do exist and the LSRCA may continue to have more direct involvement on certain problematic planting sites, such as those where significant predation pressures necessitate ongoing management measures and possibly additional planting. The LSRCA is responsible for conducting various monitoring programs at year 1, 3 and 5 following planting on certain projects, depending on the funder. In the past, partnerships have been established with other organizations for survival assessments and monitoring activities.

Large Stock Planting

While the spring planting program is concentrated on afforestation projects, which may include the use of large stock in riparian and community planting projects, the fall season in particular is strongly focused on riparian buffer planting. This usually occurs over a two-week period in November once plants have become dormant. The stock planted as part of this program includes larger potted trees and shrubs. These more sizeable plants are advantageous in that they have fewer issues with competition and predation than their seedling counterparts. While more expensive than seedlings, the cost of utilizing large stock for riparian planting is less prohibitive than would be the case for afforestation projects due to the more limited amount planted (typically less than 500 trees). More diverse tree options are also available, as growers are readily able to obtain potted stock for nearly any species. Occasional larger-caliper planting projects may also occur through the memorial tree program or along boulevards, although this is more often handled by municipalities.

5.2 Forest Management

Silvicultural Practices

The LSRCA manages several forest tracts and conservation areas, most significantly the 596ha Durham Regional Forest (DRF). The principal goal of its management activities is to encourage the natural regeneration of diverse native tree species in mature plantation forests. This is accomplished primarily through regular thinning operations which are guided by a silvicultural prescription, prepared by a Registered Professional Forester (RPF). The prescription generally aims to remove a certain portion of the basal stand area (for example, removing every third row) in order to create more space for the remaining trees to expand due to the increased availability of light and reduced competition, promoting natural forest succession. The prescription is implemented in the field by Certified Tree Markers. The thinning process also results in some intentional disturbance of the mineral soil surface, which provides opportunities for seeds to become established and begin the process of natural regeneration. Although the intent is the regeneration of native tree species, the newly favourable growing conditions do unavoidably increase the potential for invasive species to establish. The conversion from a plantation to a more natural forest will typically occur naturally over time, as long as local seed sources are available. For certain properties where there are no nearby woodlands to provide a source of seed there is the possibility of completing underplanting if necessary, though this is not commonly done.

Two potential windows of time are available each year for forest harvesting activities. Harvesting in winter occurs over snow and ice cover in order to minimize excessive soil disturbance and rutting. Harvesting in late summer or early fall is also possible while soil conditions remain very dry, however it can be challenging to implement harvesting operations during this time period due to a high levels of recreational trail use. Both the winter and late summer/fall periods also ensure that activities are carried out outside of breeding bird season restrictions. The ideal harvesting window for the LSRCA occurs from January through early March, when property use levels are lower and sufficient staff resources are available. All harvesting is carried out while LSRCA staff are available to monitor activities and respond to user concerns that may arise, which rules out the possibility of harvesting in late December and on all weekends. Additionally, most municipalities implement half-load weight limitations for trucks on March 1 as the frost comes out of the ground and roads are at greater risk of damage, which significantly increases hauling costs for the wood buyer. This leaves about 50 days of prime operational harvesting time in January and February, although it is certainly possible to harvest during other times of year if circumstances allow. For example, Simcoe County has developed a system that allows them to undertake harvesting operations throughout the year.

The LSRCA typically expects that each harvesting operation will take approximately one month to complete, although the precise time required will depend on the equipment and manpower a logging contractor has available. Weather conditions can also create substantial difficulties, as evidenced by the harvesting operation in winter 2017. This program was only two weeks in duration, with the contractor rushing to rapidly finish the project due firstly to strong winter weather creating challenges in opening the logging roads, and secondly to unseasonably warm February conditions (rising to 17^{o}C) necessitating that operations conclude as quickly as possible in order to minimize damage to the stand and access roads.

Risk Tree Management

All trees present a certain level of risk, as even healthy defect-free trees have the potential to fully or partially fail during high winds or ice storms if the force applied exceeds the strength of the tree. Within forests managed by the LSRCA, a tree is seen to represent a risk when it has the imminent potential to fall and strike a target (e.g. person or infrastructure). With the use of greenspaces for passive recreational activities increasing, the LSRCA is seeing significantly more people on more trails than has occurred in the past. The intent of the risk tree management program is thus to regularly examine the trails and gathering areas at all conservation properties to assess and remove risk trees in order to create a safer environment for trail users and infrastructure. Properties where public recreational use is sanctioned are examined at minimum every two years depending on their frequency of use, with crews also sent out to clear trails and dead limbs following a known weather event on a property or upon notification from the public of a problem. Staff have noted that this method of proactively dealing with risk trees has become more difficult in recent years as more localized precipitation and wind events can make it more difficult to quickly determine which areas of the watershed have been impacted by a storm. With more frequent and intense extreme weather events, there are also more instances of trees that did not previously exhibit any characteristics of weakness or defect failing. One further method of risk tree removal is through silvicultural management practices, as harvesting operations preferentially remove weakened or defective trees from thinned stands.

With prevailing weather patterns changing, isolated severe damage to individual trees or stands is also becoming more common. In particular, changes to disturbance regimes such as more frequent ice storms and the spread of problematic insects such as emerald ash borer (*Agrilus planipennis*) are creating more potential hazards across the watershed. In terms of impacted species, risk trees tend to comprise a diverse mix. Many different causes of risk trees are possible, from saturated soil and high winds to disease or ice storms. Certain problematic diseases and pests in the watershed such as red pine pocket decline or emerald ash borer can result in proportionally more hazard trees among the effected species in certain areas. Prior research has shown that long-lived native trees such as oaks (*Quercus* spp.) and maples (*Acer* spp.) seem to fare much better in weathering ice storms than introduced or nursery-bred species (Hauer *et al*, 2006).

5.3 Urban Restoration

The Urban Restoration department explores opportunities for integrating stormwater management into sustainable urban landscapes. This may take the form of implementing low-impact development (LID) projects, stormwater retrofits, or online pond restoration, including any offline or adjacent natural features. Green infrastructure and LID projects in particular have a strong intersection with forestry programs and the trees in these installations are subject to the pressures of growing in challenging urban conditions in addition to the impacts of climate change.

The primary goal of LIDs is to manage stormwater at the source using a combination of natural and engineered features, which can result in reduced peak flow amounts as well as improved water quality and groundwater recharge via promoting filtration and infiltration. Municipal water use in landscaped roadside areas can also be reduced, as stormwater can instead be used to irrigate vegetation. Selecting appropriate vegetation for an LID requires consideration of the type of soil at the site as well as current groundwater levels, as native or non-native grasses, vascular plants and woody plants all have the potential to function effectively. As a high-visibility boulevard feature, it is also important for the vegetation to be aesthetically pleasing. The desires of adjacent landowners should also be taken into consideration, as any vegetation will be better maintained by municipal landowners if they feel a sense of ownership over their LID.

Planting trees in LIDs comes with its own unique set of challenges. While trees can provide the greatest benefit in increasing the evapotranspiration of the feature, most species have a very limited tolerance to salt. As research on the survival of trees exposed to stormwater progresses, an interim approach has seen trees installed adjacent to the LID stormwater system, rather than as a component of it. At two recent LIDs in Newmarket (on Davis Drive and at the Ray Twinney Recreation Complex), trees were planted on the higher parts of the site – adjacent to, but not connected to the LID – in order to provide shade and to protect the trees from salt damage. In contrast, a study at an LID on St. Clair Avenue, Toronto compared the performance of trees in Soil Cell Systems which were either exposed to or isolated from winter runoff. Against expectations, the tree open to water year-round was noticeably healthier, perhaps as a result of the more regular flow flushing the soil of excess salt. This successful demonstration indicates that perhaps trees have the potential to be more successful as components of an LID system than previously thought.

The high evapotranspiration potential of trees may also open up new design possibilities, as LIDs containing trees could promote evapotranspiration rather than infiltration of stormwater. One possible downside of trees compared to smaller vegetation is the concern that the roots of rapidly growing tree species may approach vulnerable infrastructure more quickly. Additionally, current LID designs may cause the growing environment to be drier between rain events as the media is designed to move the water through the soils, which may necessitate a different maintenance program for treed LIDs.

While LIDs are slowly gaining traction, many jurisdictions still have reservations about implementing such an unfamiliar approach to stormwater management. One difficulty lies in confronting the misconception that the purpose of an LID is to store water adjacent to the roadway. This would contrast with the typical engineering approach of moving water away from the road as quickly as possible, since stormwater and the road salt it carries are known to cause corrosion issues for concrete and other infrastructure such as roads, pipes and sewers. LIDs are in fact designed to achieve this same goal of moving water and protecting infrastructure through different means and a properly designed LID will not hold water by the roadway but instead act as a conduit to promote water infiltration. This can result in additional benefits for adjacent roads, including a reduction in frost heaving due to moisture infiltrating the soil rather than remaining near the surface. It is also likely that LID features may become more popular and necessary as the risk of flooding heightens under future climate change. Addressing municipal concerns will require further education to build an understanding of LID design, maintenance and monitoring requirements, along with the promotion and demonstration of successful projects in order to increase the adoption of LIDs in municipal planning.

5.4 Watershed Planning

The Planning and Development Department has several responsibilities related to identifying, protecting and restoring important natural heritage features through legislative instruments. As recommended through the *Conservation Authorities Act*, municipalities in the watershed have a memorandum of understanding in place with the LSRCA to provide natural heritage review on their behalf with respect to governing policies such as the Oak Ridges Moraine Conservation Plan, Lake Simcoe Protection Plan, Greenbelt Plan, Growth Plan, Provincial Policy Statement and the *Environmental Assessment Act*. This review includes the identification and protection of natural heritage features as well as mitigation and offsetting based upon land use impacts such as development and infrastructure. Offsetting can include creation of new habitat resulting from a loss where no other alternative is available while mitigation can include edge management plans, stormwater management landscape plans, sediment and erosion controls, or other measures as appropriate. The LSRCA also provides natural heritage review under the regulatory process, as under the *Conservation Authorities Act* it is the LSRCA's role to uphold Section 28 of the *Act* and enforce watershed development policies, which can include protecting treed habitat in regulated areas.

In addition to planning and regulatory review, Planning and Development also engages in partnerships with watershed stakeholders to assist in Official Plan reviews through protection of woodlands and consideration of climate change impacts, reviews and comments on circulated bylaws such as the tree protection and removal bylaws, and support partner committees of the watershed in climate change related plans, for example providing natural heritage expertise for the *Durham Region Climate Change Adaptation Plan*. Internal projects within the department including the Natural Heritage System Restoration Strategy also relate to the identification of natural heritage features (including significant or interior woodlands for protection), targeted areas that will enhance the Natural Heritage System and align with the LSRCA Climate Change Adaptation Strategy.

5.5 Other LSRCA Projects

In an effort to ensure that this forestry study aligned with other climate change work underway at the LSRCA, several internal working groups were consulted in order to share knowledge and coordinate a unified approach. The Integrated Watershed Management (IWM) Department administers several major projects related to climate change, including the development of the *LSRCA Climate Adaptation Strategy*. This strategy has also adopted a State-Pressure-Response approach and will apply this framework to thematic chapters covering the different aspects of the Conservation Authority's business, including surface water, groundwater and natural heritage. Considering their similar goals, the structure of this forestry study has been specifically tailored to integrate with the Adaptation Strategy's terrestrial natural heritage chapter. A *Climate Mitigation Strategy* is also in the early stages of development, with the goal of constructing a carbon budget for the watershed. Research has commenced on building a model to forecast carbon storage in forests in the watershed. A second study is underway to determine the amount of carbon stored in the watershed's wetlands, including forested wetlands. Developing a greater understanding of the role Lake Simcoe's forests play in storing carbon and mitigating climate change will undoubtedly reinforce the need to protect the structure and function of these vital ecosystems through adaptation.

Several additional IWM studies are already underway that will inform how forests in the Lake Simcoe watershed are managed with regard to both adaptation and mitigation. These will each be briefly described, as their outcomes may impact the delivery of forestry programs. The Subwatershed Planning program is currently under redevelopment, with the new path forward potentially incorporating directions for mitigating the impacts of development activities in the watershed. The ultimate goal of this approach may be to encourage new developments to strive for net-zero carbon emissions, which could include offsetting carbon through afforestation within the watershed. Source water protection work is not as directly related to climate change, however there is interest in developing a greater understanding of how climate change will impact groundwater recharge, particularly in relation to shallow groundwater within the first 10m of surface. Assessing the resiliency of this groundwater layer may produce mapping details that could inform afforestation. The LSRCA is also examining the link between forests and baseflow in rivers. Preliminary results may be suggesting that the loss of forest cover in the watershed has increased baseflow in rivers due to reduced evapotranspiration capabilities, resulting in rivers having more water than they used to. Reversing this trend may necessitate more intensive and focused riparian afforestation, particularly for species with high evapotranspiration rates.

VI. Climate Projections

Human emissions of greenhouse gases are driving global climate change (Intergovernmental Panel on Climate Change [IPCC], 2014). Changes in historical climate patterns have already been observed at long-term monitoring stations throughout the Lake Simcoe watershed, with the decadal average temperature increasing from 5.7°C early in the 20th century to 7.5°C in the 2010s (*Figure 6.1*). This long-term dataset clearly shows a gradual warming trend which has been accelerating more recently, in line with global data. Greenhouse gases like carbon dioxide remain in the atmosphere for many decades, meaning that we have committed to substantially more climatic change this century. While we are locked into much of the change expected by 2050, the magnitude of further change by 2100 will be determined by how rapidly countries around the world are able to drastically reduce greenhouse gas emissions.

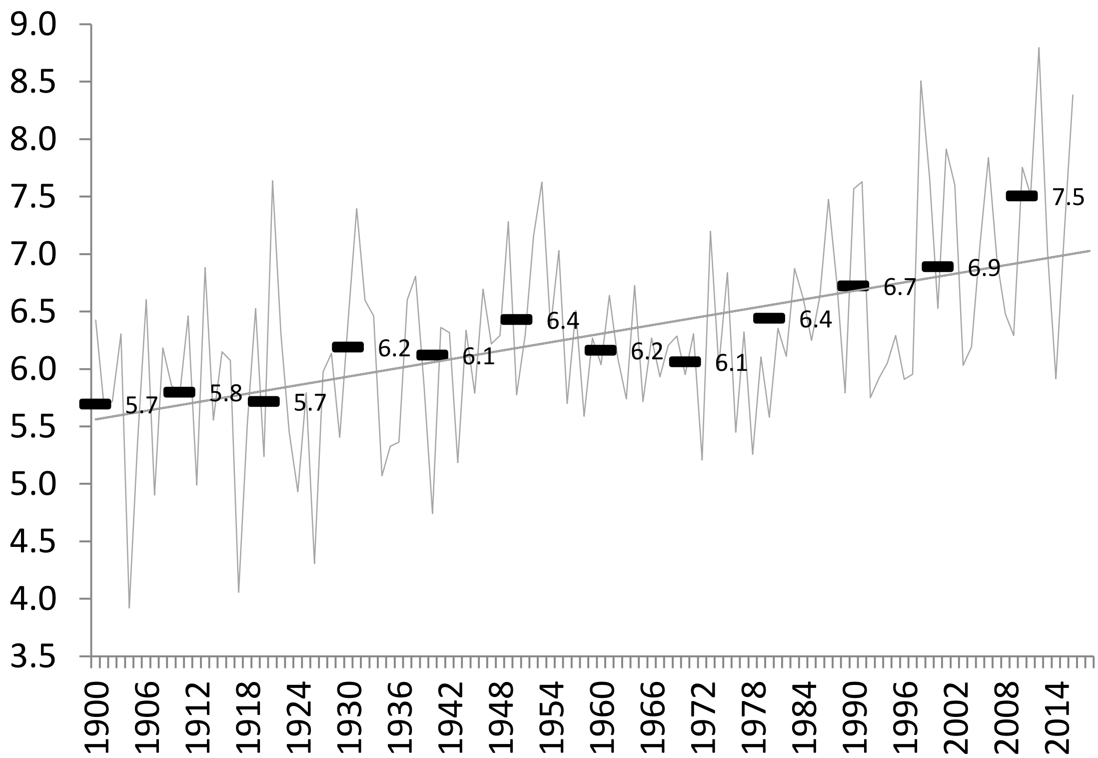


Figure 6.1: Annual and decadal average temperatures in the Lake Simcoe watershed, 1900-2015 (LSRCA [internal dataset])

While further detail on localized climate projections in the Lake Simcoe watershed will be reviewed in the forthcoming *LSRCA Climate Adaptation Strategy*, a brief overview of climate data relevant to forestry programing will be provided here. Projections across all scenarios indicate that average annual temperatures will increase 2-3°C over historical levels by the 2050s (Figure 6.2). Temperatures may increase 5°C by 2100 if current emission levels are not significantly reduced. With this magnitude of temperature increase, maximum summer temperatures will rise to an average of over 30°C by 2100, with average winter maximum temperatures increasing to over the freezing mark of 0°C (Figure 6.2).

Figure 6.2: Downscaled annual and seasonal temperature projections for the Lake Simcoe watershed (LSRCA Climate Adaptation Strategy, forthcoming)

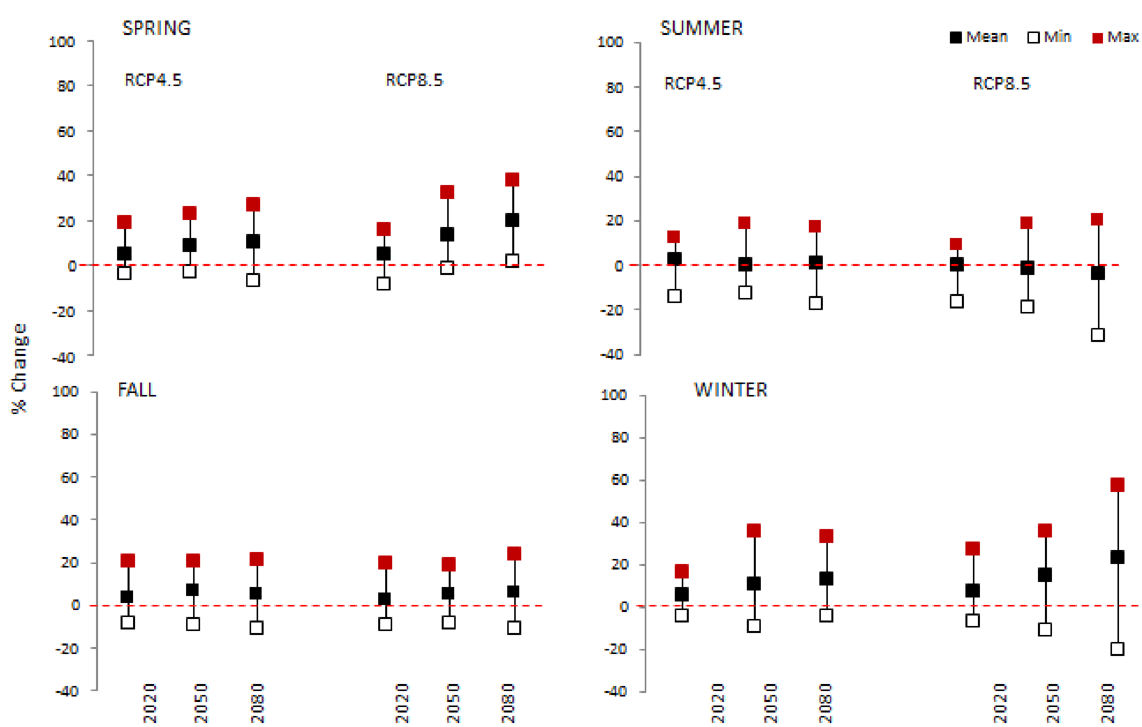


Figure 6.3: Downscaled seasonal precipitation projections for the Lake Simcoe watershed (LSRCA Climate Adaptation Strategy, forthcoming)

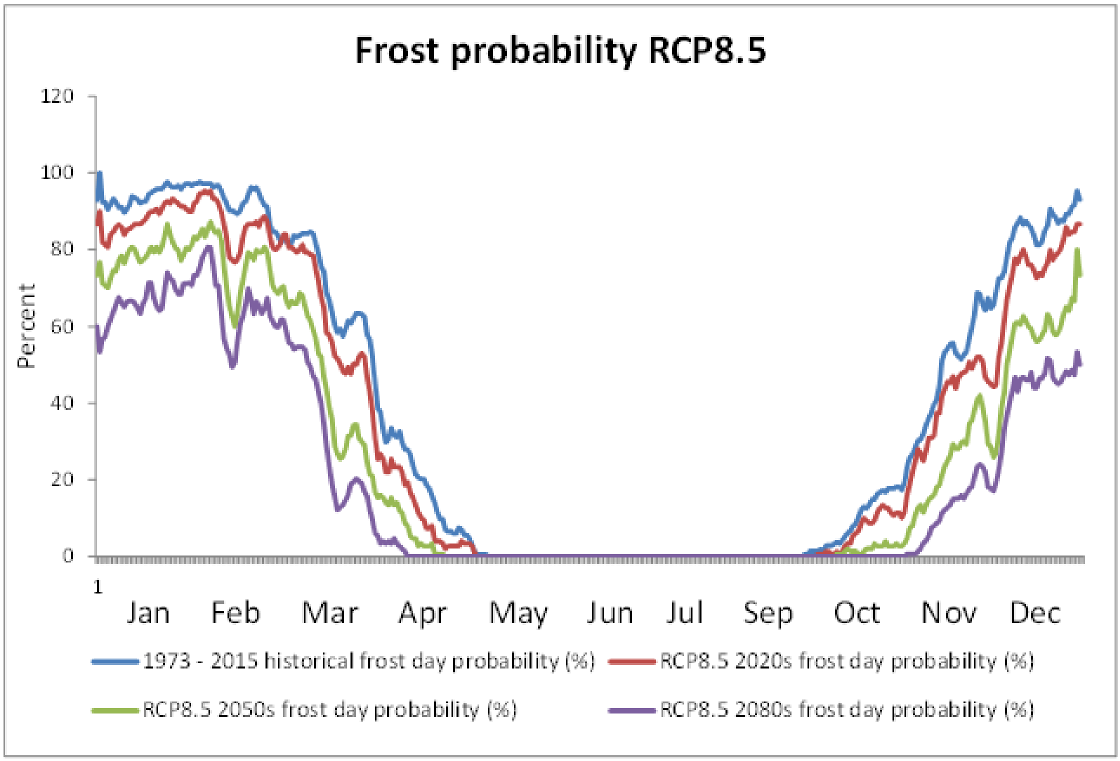


Figure 6.4: The probability of the occurrence of frost is expressed as the percentage number of days when minimum temperature is greater than 0°C, over a 5-day running mean. Length of growing season is expressed as the period when daily mean temperature is less than 0°C. RPC8.5 (high emissions) projections are obtained by comparing to the historical data between 1970 – 2015.

Rising temperature trends are consistent with an extended growing season. The growing season in the Lake Simcoe watershed has already lengthened by approximately one week compared to historical data, primarily as a result of the last spring frost occurring earlier in the year (LSRCA Climate Adaptation Strategy, forthcoming). Model projections show a continued increase in growing season length, as frosts may occur up to 1 month earlier in spring and 1.5 months later in autumn under a high emissions scenario (Figure 6.4).

Precipitation patterns are becoming more variable and rainfall intensity is increasing (IPCC, 2014). Total annual precipitation in the Lake Simcoe watershed is projected to increase slightly, with winters becoming wetter and summers becoming drier on average (Figure 6.3). Even under similar average precipitation amounts, higher temperatures will drive increased evapotranspiration and result in less available water. More winter precipitation will fall as rain rather than snow. Extreme weather events such as droughts, heat waves, floods, high wind events and ice storms are increasing in frequency, duration and intensity.

VII. Impacts and Adaptation Strategies

Climate change is projected to have significant impacts on the health and composition of forests across the country. Average temperatures in southern Ontario have already risen by 0.9^{o}C (Douglas *et al*, 2014) and further warming will cause future conditions to be similar to the current climate in locations 400-500km south well before the end of the century (Galatowitsch *et al*, 2009). These climatic changes are profoundly problematic for vegetation, which is finely adapted to local conditions such as rainfall, temperatures and growing season length and is unable to migrate to keep pace with its suitable climatic habitat. Effects on forests will occur on scales from gene to ecosystem, with impacts on physiological processes, site conditions, disturbance patterns, species interactions, regeneration, productivity, distribution and forest composition (Johnston *et al*, 2009; Aubin *et al*, 2011; Douglas *et al*, 2014). Of particular concern is the rapid rate at which this will occur, with significant changes expected over the lifespan of any individual tree (Spittlehouse and Stewart, 2003; Johnston *et al*, 2009).
A changing climate drastically increases the likelihood of tree stress and mortality, making it clear that new and adaptive approaches to tree planting and forest management are needed now and in the future.

7.1 Forest Composition

How does climate influence tree distribution?

The geographic distribution of vegetation is determined by a variety of factors. Climate is the dominant control on the broad-scale distribution limits of tree species, as temperature, precipitation, wind and radiation patterns must be within a plant's physiological tolerances in order for it to survive, grow and reproduce (Pearson and Dawson, 2003; Williamson *et al*, 2009). Local-scale species distribution is more strongly influenced by soil characteristics, topography and biotic interactions (Pearson and Dawson, 2003), with the relative importance of these different factors varying during the life cycle of an individual plant (Lafleur *et al*, 2010). Climatic factors do still play a role at the local level as well, as climate has a direct influence on regeneration, phenology, synchrony with interacting species, photosynthesis, respiration, water uptake, transpiration, disturbances and competitive success (Williamson *et al*, 2009).

Due to their long life cycles trees are expected to become increasingly maladapted to their environment, which will likely lead to vegetation redistribution in response to climate change (McKenney *et al*, 2007). Climate change may also alter competitive interactions, pest disturbances and soil characteristics, with these factors potentially being as important as changes in temperature and precipitation for assessing changes in forest composition (Goldblum and Rigg, 2005). The future distribution of forest ecosystems will ultimately depend on the responses of individual tree species to these multiple interacting factors (Scheller and Mladenoff, 2008). Tree species responding individually is a key concept and it is important to recognize that modern forest communities in Canada are transitory combinations of species that have only co-occurred over the last 6,000-8,000 years (Mohan *et al*, 2009).

Scientists are able to model the effects of climate on a species' distribution using bioclimatic envelope models, which capture the range of climatic conditions a species can tolerate well enough to grow to maturity. A small number of climatic variables are highly correlated with North American tree distribution, including annual mean temperature, minimum temperature of the coldest month, maximum temperature of the warmest month, total annual precipitation, precipitation in the warmest quarter and precipitation in the coldest quarter (McKenney *et al*, 2007). Since climate envelope models can be produced for individual species, they can be thought of as a customized species-specific hardiness map (McKenney *et al*, 2015). Bioclimatic envelopes do have limitations, as they do not account for biotic interactions like competition, evolutionary changes, or limitations to species dispersal (Pearson and Dawson, 2003). These simple models have however been shown to be effective at representing tree distributions at macro-scales and results are in overall agreement with more complex process-based distribution models (Pearson and Dawson, 2003; Iverson *et al*, 2017).

Climate envelopes have already begun to shift at unprecedented rates due to the warming climate (Williamson *et al*, 2009). Climate envelopes for many common tree species have shifted northward by an average of 57 km since Canada's original plant hardiness zone calculations were made in the early 1960s (McKenney *et al*, 2014). Significantly more substantial northward shifts are expected in the future. Across 130 North American tree species, the mean centres of future climate envelopes are projected to shift northward by an average of 6-7 degrees latitude (approximately 660-770 km) and decrease by 6-12% in overall size (McKenney *et al*, 2007; McKenney *et al*, 2011). This decrease in size is related to the spatial complexity of future climate patterns. Temperature and precipitation patterns will not simply shift northward in synchrony, but rather certain climate combinations will be lost and novel climates may arise that have no current analogue (McKenney *et al*, 2015).

Dramatic range shifts would occur if species could perfectly track their shifting climatic envelope (Rustad *et al*, 2012). However, climate envelopes for most species are moving at a rate that considerably outpaces migration ability (Aitken *et al*, 2008; Williamson *et al*, 2009). At the other extreme, if no species migration occurs there is surprisingly little overlap between current and future climate envelopes for most species – in this case species ranges would decrease sharply by an average of 58% by 2100 (McKenney *et al*, 2007). Tree species have three possible fates in this rapidly changing environment: persistence in current locations through adaptation to new conditions, migration to track changing habitats, or extirpation (Aitken *et al*, 2008). The factors influencing these fates will be discussed in the following sections on adaptation, migration and disturbance.

Can trees adapt to a changing climate?

Environmental conditions will be rapidly altered by climate change and locally adapted populations will quickly experience climates to which they are not well adapted (Wang *et al*, 2010)**.** A species' vulnerability to these climatic changes depends on its degree of exposure to environmental change, its individual sensitivity to altered growing conditions and its capacity to accommodate or cope with those environmental changes (Aubin, 2014). Short-term tolerance of new environmental conditions is referred to as acclimation, while longer-term evolution is called adaptation (Aubin, 2014). Widespread species with large populations, high levels of genetic diversity and high fecundity are more likely to persist and adapt to climate change, while low-diversity species in fragmented ecosystems are particularly vulnerable to severe declines in abundance (Aitken *et al*, 2008; Swanston and Janowiak, 2012; Aubin, 2014). The availability of better-adapted genetic material to draw on will also be advantageous for enabling successful growth in a warming climate. Species near their northern range limit may receive genes from populations in warmer climates that will aid in adaptation, while species near their southern range limit do not have more southerly populations to rely on and are at higher risk (Reich *et al*, 2015). Most tree species in eastern North America are considered vulnerable due to an inability to cope with the rapid rate of climate change and increased risks of disturbance, although overall vulnerability in the Mixedwood Plains will be lower than that of the boreal forest (Johnston *et al*, 2009; Rogers *et al*, 2017). Given the inability of many tree species to rapidly adapt to new conditions, persistence will largely depend on the ability to shift geographic ranges (Rehm *et al*, 2015).

Can trees migrate to keep pace with climate change?

Tree migration is a function of reproduction and colonization ability, with migration rate determined by total seed production, the frequency of good seed years, time to reach sexual maturity, seed dispersal mode and the capacity to tolerate inbreeding and grow in small populations once new habitat is reached (Aubin, 2014). Migration will also be highly dependent on how climate change impacts flowering, pollination, seed formation, germination and seedling survival, as trees are most vulnerable to climatic stresses during regeneration (Johnston *et al*, 2009). In many cases additional species are involved in the reproduction and migration process, such as fungal symbionts, pollinators and animal seed dispersers. These species will each respond independently to climate change, which may decouple traditional pollination and dispersal systems and reduce tree migration capabilities (Mohan *et al*, 2009; Aubin, 2014). Generalist species that reach maturity quickly, produce large amounts of easily-dispersed seeds that are able to survive and grow in significantly different climate conditions than the parent plant and are able to spread asexually in new habitat have the best potential to keep pace with their rapidly shifting climate envelope (Johnston *et al*, 2009; Aubin, 2014), while long-lived species with low dispersal potential and low genetic variation will be particularly threatened (Kilkenny *et al*, 2013).

As transition zones between different forest types, ecotones are ideal regions to examine the impacts of climate change on tree migration and the composition, structure and productivity of forests (Williamson *et al*, 2009). Range-edge climates are more exposed to extreme weather events and more intense competition than a species' core range and these range-edge populations will be critical in climate-driven range shifts (Rehm *et al*, 2015). Species distributions are controlled by different factors in different parts of their range, with northern range edges typically being determined by climatic tolerances and southern range edges dependent on both competition and temperature limitations (Scheller and Mladenoff, 2008). Leading-edge populations are most genetically suited for colonization survival in harsh conditions and will be crucial for migratory dispersal, while trailing-edge populations are best suited to persistence in warmer climates but are most threatened with extirpation (Aitken *et al*, 2008; Murphy *et al*, 2010; Rehm *et al*, 2015). These differences highlight the importance of considering not only the shift in a species' overall range, but the adaptive advantages present in both leading-edge and trailing-edge genotypes.

Tree migration rates in a rapidly warming world can be inferred by studying range expansions following the most recent glaciation. Although it was originally thought that temperate tree species may have expanded at rates of 100-1,000m/year as the ice sheets receded, which is substantially higher than observations in modern forests, this has been re-evaluated in light of new molecular evidence from fossil pollen (McLachlan *et al*, 2005). Rather than expanding from refugia in the far southern United States, it was found that low-density outlier populations of temperate tree species persisted much closer to the edge of the Laurentide Ice Sheet than previously thought. Taking these isolated populations into account, post-glacial migration rates were revised to less than 100m per year (McLachlan *et al*, 2005). Keeping pace with current rates of climate change would require migration rates of 3,000-5,000m per year, pointing to an inability for tree species to track a rapidly warming climate through range expansion (McLachlan *et al*, 2005; Feurdean *et al*, 2013; Kilkenny *et al*, 2013).

The temperate-boreal forest transition may be particularly sensitive to climate change and species composition may shift dramatically as the boreal forest recedes and temperate species migrate northwards (Parker *et al*, 2000; Boulanger *et al*, 2016b). Indications of these changes have recently been noted across the temperate-boreal ecotone in the northern United States, with increased temperate species regeneration and reduced boreal species regeneration suggesting that the current boreal overstory will fail to be replaced (Fisichelli *et al*, 2014a). Numerous other studies have found only limited evidence of species' ranges expanding northward to date (Zhu *et al*, 2012; Rustad *et al*, 2012; Fei *et al*, 2017). Longer growing seasons and higher temperatures are instead driving an overall tendency toward faster population turnover through increased growth rates, mortality and recruitment (Zhu *et al*, 2014). Limited northward range expansion combined with lack of replacement along southern range edges may result in an overall range contraction being the most common tree species response to climate change (Murphy *et al*, 2010). This lack of evidence for climate-mediated migration should increase concern for the risks posed by climate change (Zhu *et al*, 2012).

Actual movement of tree species into newly suitable habitat is expected to be limited, at least in the short-term, since migrating species face the challenge of colonizing already-occupied sites and will have to compete for limited resources (Lafleur *et al*, 2010). This lag between a change in climate and a change in species composition is termed vegetational inertia and results in current species persisting on a site in non-optimal conditions even when new species may be favoured (Colombo, 2008; Williamson *et al*, 2009). Eventual replacement will occur when occupying species fail to regenerate in the altered climate or are removed via disturbance (Colombo, 2008), though this process may take many decades. As long-lived organisms, trees are quite resilient to periods of unfavourable climatic conditions and major range shifts are unlikely to be realized in the near future (Spittlehouse and Stewart, 2003; Keenan, 2015; Wang *et al*, 2017). Most forests in southern Ontario are still quite young and will not reach the end of their natural lifespans for many decades, with modeling studies suggesting there will only be minimal changes in tree species distribution by 2100 when accounting for tree demographics (Wang *et al*, 2017). Significant range shifts and species extirpations will be more apparent in subsequent generations due to failed regeneration of climatically-unsuitable species (Spittlehouse and Stewart, 2003; Wang *et al*, 2017).

If unable to migrate to more suitable habitat or adapt to rapidly changing conditions, trees are likely to experience decline and reduced regeneration, eventually leading to extirpation from climatically-unsuitable regions (Aitken *et al*, 2008). Natural migration of southerly species into southern Ontario will be particularly challenging given physical barriers like the Great Lakes, large regions dominated by farms or cities, a fragmented forest landscape and expanding urbanization, and the small and isolated nature of most Carolinian species in Ontario (Colombo, 2008; Puric-Mladenovic *et al*, 2011; Douglas *et al*, 2014).

It is uncertain whether southern tree species will be able to effectively spread to the Lake Simcoe watershed without assisted migration (Puric-Mladenovic *et al*, 2011).

Assisted Migration

Assisted migration is the concept of humans deliberately moving species or genotypes to new locations that should better match their climatic suitability in the future (Aubin *et al*, 2011; Ste-Marie, 2014). Assisted migration is a broad term that covers several specific strategies, including moving populations to different regions within a species' current range, extending a species' range to adjacent areas, or moving a species to areas beyond where it would naturally spread (Ste-Marie, 2014). These different migration concepts are illustrated in Figure 7.1 below (Williams and Dumroese, 2014). The objectives of an assisted migration project may include conserving threatened species or populations, maintaining or improving the resilience of ecosystem services, or enhancing potential productivity gains in economically-important forests (Williamson *et al*, 2009; Pedlar, 2011; Ste-Marie, 2014; Williams and Dumroese, 2014). Deliberate species introductions are not without risks, and farther species movements are associated with increased risks of failed translocations and unintended damage to the recipient ecosystem due to new pests, diseases, or invasive characteristics (Aubin *et al*, 2011; Ste-Marie, 2014).

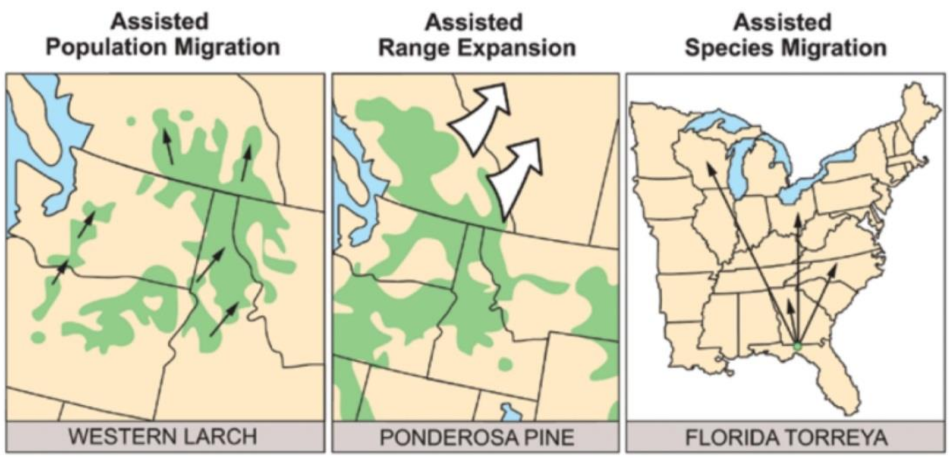


Figure 7.1: Different types of assisted migration (Williams and Dumroese, 2014).

The role of assisted migration in climate change adaptation is currently a hotly debated topic, as in many ways it runs counter to historical conservation paradigms (Williams and Dumroese, 2014). Proponents of assisted migration tend to believe that the unprecedented ecological consequences of climate change call for urgent and unprecedented actions, with the potential benefits outweighing the risks. Opponents feel that the considerable uncertainty and potential negative ecological consequences associated with assisted migration present too great a risk to ignore, and that introducing new species to stressed ecosystems is too much of an ecological gamble (Aubin *et al*, 2011). It is important to recognize that determining whether to pursue assisted migration is not solely a scientific question – there are also environmental, cultural and political aspects engrained in personal values and perceptions of ecological risks, meaning that consensus in not likely to be reached through research and risk assessment alone (Aubin *et al*, 2011).

Assisted migration tends to be regarded favourably within the forestry community, due to recognition of the magnitude of the migration issue for tree species and considerable industry experience with properly collecting and transferring plant material. Numerous sources advocate that assisted migration must play a role in conservation policies given the likely possibility of numerous and imminent extinctions and the insurmountable challenge of conserving forest biodiversity in Ontario without drastic action (McLachlan *et al*, 2007; Crowe and Parker, 2011). Delaying action also carries the risk of southern seed sources being too maladapted to their altered climate to produce seed (FGCA, 2013). While the potential benefits of assisted migration are clear, many operational challenges have yet to be resolved. Chief among these is selecting a suitable migration distance – moving seed too far may result in poor survival, while not moving seed far enough may still result in significant maladaptation (Pedlar *et al*, 2011). Provenance tests provide the best species-specific data sources if available, otherwise targeting the climate anticipated at approximately one-quarter to one-third of the rotation length is recommended to achieve a reasonable climatic match during the vulnerable establishment period and a balance of adaptation over a tree's lifespan (Pedlar *et al*, 2011; Ste-Marie, 2014; O'Neill *et al*, 2017). It is also important to source seed from multiple healthy trees in order to improve genetic diversity and ensure that adequate planning and monitoring are part of any assisted migration plantings (FGCA, 2013).

Adaptation Strategies:

7.1.1: Shorten rotation ages.

Anticipate and respond to species declines by shortening rotations to reduce the period of disequilibrium and vulnerability, which also allows for more generations and increases the likelihood of genetic adaptation to new conditions. Harvesting prior to stand decline followed by planting can be used to speed the establishment of better-adapted forest types (Colombo, 2008; Swanston and Janowiak, 2012; Duveneck and Scheller, 2016).

7.1.2: Promote better-adapted species.

Favour species that are expected to be better adapted to future conditions. Reduce reliance on natural regeneration in forests that are anticipated to be significantly maladapted to future climates. Underplanting with climate-adapted species prior to harvest can increase species turnover and provide protection for sensitive seedlings (Parker *et al*, 2000; Spittlehouse and Stewart, 2003; Gunn *et al*, 2009; Johnston *et al*, 2009; Swanston and Janowiak, 2012; Duveneck and Scheller, 2016).

7.1.3: Facilitate community adjustments through assisted migration.

Conduct assisted migration plantings to help species accomplish range shifts. The focus should be on species and populations that would naturally migrate into the watershed given adequate time, rather than planting exotic species. Species with small populations, fragmented ranges and which are threatened with decline should also be candidates for assisted migration. Ensure appropriate risk management planning takes place for any species introductions, including the risks of introducing new pests or diseases with imported plant material (Spittlehouse and Stewart, 2003; Aitken *et al*, 2008; Lawler, 2009; Pedlar *et al*, 2011).

7.2 Extreme Weather

Climate change is expected to alter the frequency, intensity, duration and timing of a variety of extreme weather events, including drought, heat waves, fire, hurricanes, thunderstorms, windstorms and ice storms (Dale *et al*, 2001), with this extreme weather resulting in substantially increased risks as early as 2030 as the atmosphere exceeds the 2^{o}C threshold for dangerous climatic warming (Williamson *et al*, 2009). Changing disturbance regimes will have significant impacts on forests, determining which species are able to establish, mature and regenerate (Gunn *et al*, 2009). More intense extreme weather certainly has the capability to drive large-scale mortality and widespread forest change (Galatowitsch *et al*, 2009), potentially favouring early successional species and decreasing the average age of forests (Williamson *et al*, 2009). Perhaps even more importantly than individual extreme events, climate change may also reduce the long-term resilience of forests to acute disturbance events (Duveneck and Scheller, 2016), setting the stage for more dramatic ecosystem impacts over time.

Adaptation Strategies:

7.2.1: Increase resilience to disturbance.

Enhance and maintain species, structural and genetic diversity, as diverse forests will exhibit variability in resistance to pests, drought and wind events, and will be better able to recover from disturbance. More aggressive forest thinning will reduce competition, improving resilience to heat and drought stress. Favour existing genotypes that are better adapted to future conditions, incorporate genetic material from a greater range of southern sources and include pest- or drought-resistant varieties where appropriate (Parker *et al*, 2000; Spittlehouse and Stewart, 2003; Johnston *et al*, 2009; Brandt *et al*, 2016; Clark *et al*, 2016).

7.2.2: Plan for and respond to disturbance.

Develop response options to prepare for more frequent and severe disturbances (Brandt *et al*, 2012; Swanston and Janowiak, 2012). Use large scale disturbances as windows of opportunity to re-establish forests that are less vulnerable to future climate change (Johnston *et al*, 2009). Promptly revegetate sites following disturbance and allow for some areas of natural regeneration to identify well-adapted species (Swanston and Janowiak, 2012). Disturbed areas can also provide a perfect opportunity to test assisted migration genotypes, seed mixes and age classes (Williams and Dumroese, 2014). Examples of specific actions for different types of disturbance are provided in the subsections below.

Temperature and drought stress

Background rates of tree mortality have been increasing worldwide due to elevated temperatures and more severe drought stress, even in forests where precipitation and water availability have increased (Allen *et al*, 2010; Luo and Chen, 2015). Rising average temperatures are projected to further raise drought stress and mortality risk due to increases in evaporative demand (Dale *et al*, 2001; Allen *et al*, 2010). A warming world also substantially increases the frequency of extreme events such as severe droughts and heat waves (Allen *et al*, 2010). Droughts are a particular concern since they will be hotter with climatic warming, with the resulting increase in vapour pressure demand leading to a non-linear increase in tree mortality even in shorter droughts (Allen *et al*, 2015). The more frequent occurrence of these “hotter droughts” or “global-change-type droughts” could be capable of driving abrupt tree mortality at an unprecedented scale (Millar and Stephenson, 2015). While drought-resistant species with a high capacity for population recovery will be more likely to persist in their current range (Aubin, 2014), an increase in drought- and heat-induced mortality are expected to drive major changes in forest health, composition and distribution (Allen *et al*, 2015; Clark *et al*, 2016). Increased temperatures will not necessarily result in catastrophic dieback, but will drive species transitions due to an altered competitive balance for understory regeneration or following disturbance (Colombo, 2008).

In addition to the impacts of climate change on the mortality of mature trees, the effect of extreme climatic events on seedling recruitment and survival is a significant concern (Dietze and Moorcroft, 2011). Heat stress disproportionately impacts seedlings due to their small size as buds and foliage remain within the zone of highest temperatures directly above the soil surface, and small trees also have shallower root systems which reduces access to soil water reserves (Colombo, 2008; Fisichelli *et al*, 2014b) resulting in significantly higher sensitivity of young forests to warming and drought (Luo and Chen, 2013). Warmer temperatures tend to increase emergence, development and growth of first-year seedlings but the additional heat stress results in reduced seedling survival, which could potentially cause seedling establishment to become more episodic with climate change (Fisichelli *et al*, 2014b). Changing climatic conditions are also expected to exacerbate competition-induced mortality. Forest dynamics are driven by competition for light, water and nutrients, and where climate change results in more variable resource availability it is certain to intensify that competition (Zhang *et al*, 2015). Competition disproportionately amplifies tree stress during drought conditions, with the highest mortality rates observed at high competition levels (Ruiz-Benito *et al*, 2013; Young *et al*, 2017). More variable precipitation patterns also increase the risk of increased mortality from both damping off and desiccation within the same year, extending the time required for forest compositional shifts in response to climate change (Fisichelli *et al*, 2014b).

Adaptation Strategies:

7.2.3: Improve resilience to heat and drought stress.

Improve the resilience of forests to heat and drought stress. Healthy trees with adequate access to necessary resources will be better able to cope with environmental stresses (Brandt *et al*, 2012). Reducing stand density will reduce competition, lowering the probability of drought-related tree mortality (Galatowitsch *et al*, 2009; Gunn *et al*, 2009; Johnston *et al*, 2009; Williamson *et al*, 2009; Joyce and Rehfeldt, 2013; Clark *et al*, 2016). More aggressive thinning practices may be required to improve drought resistance, increase growth and improve resilience to future stress (Ruiz-Benito *et al*, 2013; Young *et al*, 2017; Spittlehouse and Stewart, 2003; Keenan, 2015; Duveneck and Scheller, 2016).

Fire risk

While the managed forests of southern Ontario have traditionally not been significantly impacted by forest fires, climate change will amplify certain risks. Weather is the most important factor in forest fire development, with prevailing hot, dry and windy conditions being most problematic – all conditions that will become more prevalent with climate change (Flannigan, 2017). Higher temperatures also result in drier understory fuels and more frequent lightning strikes (Flannigan, 2017), providing a dangerous combination of larger fuel loads and more opportunities for ignition. Additionally, climate change increases the likelihood of cascading disturbances since a higher frequency of drought and insect infestations can result in more widespread stand decline, promoting future fires (Parker *et al*, 2000; Dale *et al*, 2001). Warmer and drier conditions are projected to increase fire season length, hazard level, intensity and annual area burned across Canada (Colombo, 2008; Williamson *et al*, 2009). Overall the Atlantic-Mixedwood forest region is projected to have a slight increase in fire risk, but this is still substantially less of an increased risk than other regions in Canada (Lemprière *et al*, 2008). Currently there is no expectation for the development of large forest fires in southern Ontario due to the lack of a large, continuous forest and the more deciduous-dominated landscape (Flannigan, 2017).

Adaptation Strategies:

7.2.4: Protect forests from severe fire.

Where necessary, protect forests from severe fire. A fire-smart landscape may include targeted harvesting to alter forest structure or composition to reduce fire risk, prescribed burning to minimize fuel loads and reduce wildfire spread, establishing fuel breaks around high-risk areas, density reduction in fire-suppressed stands, or increasing the focus on more fire-resistant species (Johnston *et al*, 2009; Williamson *et al*, 2009; Millar *et al*, 2007; Swanston and Janowiak, 2012; Spittlehouse and Stewart, 2003; Young *et al*, 2017). Most forests across Southern Ontario will not need to pursue these strategies given the minimal overall fire risk, but in certain situations it may be prudent to anticipate and plan for surprises such as atypical fires (Millar *et al*, 2007).

Ice storms & frost damage

Climate change will influence the characteristics of cold-weather tree damage including ice storms, spring frosts and winter browning. Ice storms, which are caused by super-cooled rain freezing on contact with cold surfaces, are one of the most frequent and damaging forest disturbances in eastern North America (Hauer *et al*, 2006). While light ice storms can benefit forests as they thin out branches and make way for new growth, severe or repeated icing events can be devastating (American Society of Agronomy [ASA], 2017). Ice accumulations on tree limbs can increase branch weight by 10-100 times, with these heavy ice loads capable of causing broken branches, stems bending to the ground, or outright breakage of the trunk (Irland, 2000; Hauer *et al*, 2006). Damage potential increases with ice amounts, wind exposure and storm duration, and unfrozen ground increases the chance of trees uprooting entirely (Hauer *et al*, 2016). Any damage caused by an ice storm may also be exacerbated by pests and pathogens, as broken limbs provide easy infection sites (ASA, 2017). Ice storm frequency and severity is projected to increase in the northeastern United States and eastern Canada, as short term weather patterns will continue to bring blasts of arctic air into the region even as average winter temperatures increase (ASA, 2017).

Certain characteristics affect tree susceptibility to ice storms. Trees with weak branch junctures, large lateral branches, broad or unbalanced crowns, and root systems that are shallow, unbalanced, damaged, or diseased are at higher risk (Hauer *et al*, 2006). Features that increase ice storm resistance include conical or coarse branching patterns (typical of many conifers, Kentucky coffeetree, or black walnut), strong branch attachments, narrow crowns and selecting seed sources from areas subjected to regular ice storms (Hauer *et al*, 2006). Softwoods generally suffer less severe damage under the same degree of ice loading than hardwoods, and native species fare far better in ice storms than exotic species (Irland, 2000). Species with strong resistance to ice storm damage include spruces, hemlock, white and bur oak, black walnut and ironwood (*Ostrya virginiana*). Beech, sugar maple, white pine, ash and hickories exhibit average resistance, while silver maple, cherry, white birch and cedar are more susceptible to ice storm damage (Irland, 2000).

Frost damage also remains a concern in a changing climate, as extreme minimum temperatures are not increasing as quickly as average monthly temperatures, and an earlier start to the growing season results in earlier spring bud burst while there is still a risk of late spring frosts (McKenney *et al*, 2014). These factors result in a continued risk of frost damage in a warming world, particularly when using more southerly seed sources and planting earlier in the year (Gu *et al*, 2008). Additionally, more frequent winter freeze /thaw cycles may present several problems for plant growth, including delayed hardening and reduced freeze tolerance (Gu *et al*, 2008). Adequate cold hardiness will continue to be an important trait in the coming decades, since ongoing extreme cold events present considerable risk to less hardy plant species (McKenney *et al*, 2014). Winter browning of conifers may become more common as rising winter temperatures increase the rates of water loss and the earlier onset of spring increases the risk of intermittent cold periods as the seasons transition.

Adaptation Strategies:

7.2.5: Develop contingency plans for ice storm damage.

Incorporate ice storm prevention, response and recovery actions into management plans. Prepare contingency plans for prompt assessment and post-storm response, increase landowner education for ice storm response, and improve documentation of ice storm damages to inform future decision-making. Consider ice storm susceptibility as a factor in species selection. Avoid planting significant numbers of highly vulnerable species in high-risk areas in order to reduce potential property damage. Proper tree placement and regular pruning will also reduce the severity or extent of ice damage (Irland, 2000; Hauer *et al*, 2006; Swanston and Janowiak, 2012).

7.3 Biotic Disturbance

Forests are home to a diverse variety of native herbivorous insects, pathogens and parasites that impact tree vitality, and while these species have the potential to cause acute or widespread forest mortality, they are integral components of the forest ecosystem (Lemprière *et al*, 2008; Dukes *et al*, 2009). Forests are also impacted by introduced pest species and invasive plants, which can be more disruptive to the native ecosystem. The cumulative impact of these native and invasive biotic disturbance agents is massive, annually impacting around 20 million hectares of Canadian forest – an area of magnitude greater than the area affected by wildfire (Boulanger *et al*, 2016a). Herbivore browsing is also a growing threat, with white-tailed deer populations impacting the regeneration of tree species like eastern white cedar, white pine, yellow birch, red oak (Galatowitsch *et al*, 2009).

Climate change is projected to alter biotic disturbance patterns in a number of important ways. These include changes in the frequency, severity, duration and timing of pest species outbreaks, population dynamics, shifting species ranges, an increased probability of introduced species surviving and spreading, the degree of synchrony between the pest and host species, host species distribution, defense compounds in host species, and related effects on other predators, pathogens and mutualists (Dale *et al*, 2001; Lemprière *et al*, 2008; Dukes *et al*, 2009; Régnière *et al*, 2010). It is also important to recognize that these increasing pest risks are occurring in conjunction with climate change causing amplified tree stress, further increasing susceptibility to insects and diseases (Johnston *et al*, 2009; Aubin, 2014). This combination of higher risks and increased susceptibility means that it is very likely that there will a short- to medium-term increase in the likelihood of biotic disturbance impacts (Lemprière *et al*, 2008).

Modeling the impacts of climate change on individual pest species is complex, making predictions difficult. While acknowledging this uncertainty is important, there is a general consensus in published research that forest pests, pathogens and invasive plants are likely to become more problematic in the future. Case studies conducted for two insects (hemlock woolly adelgid [*Adelges tsugae*] and forest tent caterpillar [*Malacosoma disstria*]), two pathogens (Armillaria root rot [*Armillaria spp.*] and beech bark disease [*Neonectria spp.*]), and two invasive plants (glossy buckthorn [*Frangula alnus*] and oriental bittersweet [*Celastrus orbiculatus*]) suggest an increased range and/or heightened impact for these species in response to climate change (Dukes *et al*, 2009). None of these species was projected to be less problematic in the future, although that possibility could not be ruled out (Dukes *et al*, 2009). Some further detail on these different categories of pest species will be provided in the following paragraphs.

Insects

Climate change will impact the activity levels, life cycles, survival rates, dispersal rates and outbreak patterns of insects (Boulanger *et al*, 2016a). Higher temperatures tend to increase insect metabolic rates, accelerating insect growth, development, movement, consumption and reproduction (Colombo, 2008; Dukes *et al*, 2009). Enhanced reproductive rates also increase the potential for additional generations to occur in a single season (Colombo, 2008). These changing life cycle characteristics in combination with shifting ranges mean it is likely that some relatively innocuous insect species may become severely disruptive in the future (Williamson *et al*, 2009), as has been the case with the mountain pine beetle (*Dendroctonus ponderosae*) outbreak in western Canada. The timing and severity of major insect outbreaks may change substantially, particularly at range margins (Candau and Fleming, 2008; Williamson *et al*, 2009).

Range limits for many species are likely to expand northwards, with many temperate-zone insects already having begun to shift their distributions in response to climate change (Colombo, 2008; Régnière, 2009). Rapidly changing climate conditions favour adaptable generalist species, with an individual species' ability to realize a range shift being dependent upon its mobility and any factors constraining its distribution (Régnière, 2009). Indirect effects of climate include altered predator behaviour and host plant phenology, which can be important for defoliating insects that feed on new leaves as even a few days of asynchrony between insect emergence and budburst can cause insects to starve (Colombo, 2008). Many noteworthy forest insects have the potential to benefit from climate change, with an increase in the area, duration and intensity of infestations expected for spruce budworm, spruce bark beetle, forest tent caterpillar and large aspen tortrix (Williamson *et al*, 2009). Three case studies follow for several high-impact insects that have been the subject of detailed studies.

Spruce Budworm

The spruce budworm (*Choristoneura fumiferana*) is the most important insect disturbance in the boreal forest, and its defoliation patterns are strongly related to temperature and precipitation cues (Candau and Fleming, 2008). Climate change is predicted to increase spruce budworm growth rate, survival and fecundity, although competition may limit population expansion (Candau and Fleming, 2008). A pronounced northward range expansion is expected (Candau and Fleming, 2008; Régnière *et al*, 2010; Boulander *et al*, 2016a). Projections of outbreaks at the southern edge of the boreal are variable and highly uncertain at this point (Boulanger *et al*, 2016a), with studies suggesting this region will either experience little change in total defoliated area (Candau and Fleming, 2008) or a reduction in budworm outbreaks due to warmer temperatures causing increased overwinter mortality (Régnière *et al*, 2010). The distribution of host plants will also play a role as the southern edge of the boreal forest gradually retreats to higher latitudes (Régnière *et al*, 2010).

Emerald Ash Borer

Forestry practitioners in Southern Ontario are particularly concerned about the potential for new or exacerbated infestations of pests and diseases due to recent experiences with the devastation caused by emerald ash borer (EAB, *Agrilus planipennis*). EAB has spread rapidly since its introduction to North America in the 1990s, killing tens of millions of native ash trees across Canada and the United States with mortality rates reaching up to 99% (Poland *et al*, 2015). EAB emergence, activity and reproduction are driven by temperature cues, and they have been noted to be most active on sunny days with temperatures above 25°C (Poland *et al*, 2015). With climbing summer temperatures it is likely that EAB may emerge earlier and be more active over a longer period of the year, meaning climate change is not likely to bring any respite for the province's ravaged ash tree population.

Gypsy Moth

Gypsy moth (*Lymantria dispar dispar*) fitness and distribution is strongly affected by climate cues. Exposure to temperatures below -9°C will kill eggs and temperatures of -23°C for even short periods of time are lethal, though survival can be facilitated through behavioural modifications such as females laying eggs on the lower parts of trees where they will be insulated by snow cover (Doane and McManus, 1982). Rising winter temperatures are thus likely to result in greater overwinter survival and a northward range expansion. Temperatures above 32°C greatly accelerate growth and development, with large scale gypsy moth outbreaks having been correlated with successive years of hot, dry weather in June (Doane and McManus, 1982). The proportion of Canada's deciduous forests at risk of damage by gypsy moth will grow from the current 15% to more than 75% by 2050 as changing climatic conditions will allow for further expansion of the gypsy moth into Canada (Régnière, 2009).

Pathogens

Climate change will affect host species, pathogens, and their interactions (Sturrock *et al*, 2011). Three elements are required for pathogenic infection: a susceptible host, a pathogen species producing infective propagules, and suitable environmental conditions for infection, all of which will be impacted by climate (Ramsfield, 2018). Diseases will typically become a problem when climate conditions are more stressful for the host plant than for the pathogen, and disease impacts will increase as host defences are compromised (Boland *et al*, 2004; Ramsfield, 2018). Climate change will result in forest pathogens experiencing increased growth and reproduction, rate of disease progress, dispersal and transmission rates, overwinter survival, expanding ranges, more days favourable for spore production, more days where hosts will be susceptible to infection, and overall greater expected impacts from disease (Boland *et al*, 2004; Dukes *et al*, 2009; Ramsfield, 2018). Increased infection opportunities are also likely due either to mechanical damage from wind or ice storms providing new infection sites, or from environmental extremes such as drought, flooding and higher temperatures increasing the vulnerability of trees to pathogen attacks (Dukes *et al*, 2009; McLaughlin, 2017).

In Ontario, climate change is expected to increase the incidence, progress, or duration of pathogenic diseases such as beech bark disease (*Nectria coccinea*), oak wilt (*Ceratocystis fagacearum*), Armillaria root rot (*Armillaria* spp.), blue stains (*Ophiostoma* spp.), Diplodia canker (*Sphaeropsis sapinea*), Fomes root rot (*Heterobasidion annosum*), Hypoxylon canker (*Hypoxylon mammatum*) and Tomentosus root rot (*Inonotus tomentosus*), with no indication that any tree disease in Ontario will decline with climate change (Boland *et al*, 2004). Currently insignificant pathogens may become more problematic due to increased host stress (Ramsfield, 2018). Particular care must be taken in assisted migration plantings, as moving plant material risks the accidental transport of pathogens as well (Ramsfield, 2018). Movement of host material into a new area may also subject it to impacts from native pathogens for which it is unprepared, and it is also possible that bringing together pathogen genotypes from different areas may increase pathogen virulence (Ramsfield, 2018). Pathogens are also better able to adapt to changing climatic conditions better than their long-lived host species (Sturrock *et al*, 2011).

Invasive plants & other biotic stressors

While insects and pathogens are regarded as stressors for their ability to cause tree damage and mortality, other stressors like invasive plants are problematic for the disruption they cause in native ecosystems. Climate change is likely to benefit invasive plants due to several common traits they possess, including high phenotypic plasticity, broad environmental tolerances and long-range dispersal mechanisms (Dukes *et al*, 2009). A warmer climate is expected to contribute to more rapid spread of invasive plants and earthworms, hindering the growth and establishment of native tree seedlings (Gatatowitsch *et al*, 2009). Other major concerns include the northward expansion of cold-limited invasive species, the greater potential for new invasive species to establish and spread once introduced, and the competitive advantage that invasive species will have over native species in stressed ecosystems. With climate change already driving range shifts for a large percentage of all species on that planet, current definitions of native and non-native species in the Lake Simcoe watershed may require revision as new collections of species form (Lemieux *et al*, 2012).

Adaptation Strategies:

7.3.1: Reduce the impact of existing stressors.

Continue emphasizing restoration programming to alleviate existing non-climatic stressors such as habitat fragmentation and loss, pollution, over-exploitation and invasive species in order to increase forest resilience and allow ecosystems to more effectively respond to climate change (Lawler, 2009; Reyer *et al*, 2009; Brandt *et al*, 2012; Rustad *et al*, 2012; Rogers *et al*, 2017).

7.3.2: Improve stand vigour to increase pest resilience.

Reduce the risks of catastrophic forest losses to pests and pathogens through thinning to reduce density and improve stand vigour, sanitation cuts to remove infected trees, and shorter rotation lengths (Parker *et al*, 2000; Spittlehouse and Stewart, 2003; Gunn *et al*, 2009; Johnston *et al*, 2009; Swanston and Janowiak, 2012). Reduced stand densities also lower relative humidity and this decrease in available moisture can reduce disease prevalence (Ramsfield, 2018). Efforts to maintain and restore soil quality, nutrient cycling, hydrology, habitat and biodiversity will also improve ecosystem resilience (Lawler, 2009; Swanston and Janowiak, 2012; Schmitz *et al*, 2015; Brandt *et al*, 2016).

7.3.3: Protect regenerating vegetation from herbivory.

Manage herbivory and deer browsing of vulnerable species using fencing or other barriers, strategically-located deer exclosures, intensive hunting zones, or "hiding" desirable species in a mixture of less palatable plants. Regeneration can also be promoted by controlling light availability and altering harvest gap sizes. Actions taken to protect regenerating vegetation may allow existing plant communities to persist for decades longer, or favour the establishment of better-adapted tree species (Galatowitsch *et al*, 2009; Swanston and Janowiak, 2012; Fisichelli *et al*, 2014a).

7.3.4: Prevent the establishment of invasive species.

Increase monitoring programs for invasive pests, diseases and plants. Quality monitoring data will be crucial for early detection, rapid response and intensive removal of invasive species, and will contribute to informing adaptive management (Gunn *et al*, 2009; Sturrock *et al*, 2011; Swanston and Janowiak, 2012; Douglas *et al*, 2014). Consider insecticide, fungicide or herbicide use to protect high-value trees or natural areas, or to retain desired species on the landscape (Parker *et al*, 2000; Spittlehouse and Stewart, 2003; Millar *et al*, 2007; Brandt *et al*, 2016). Naturally migrating species will also be moving into the watershed and forest managers should determine if these natural species migrations should be classified as invasive and removed within a given management area (Galatowitsch *et al*, 2009). Due to the difficulty in predicting future pest dynamics, encourage policies that allow the flexibility to address surprises (Dukes *et al*, 2009).

7.4 Forest Growth & Productivity

Elevated annual temperatures result in an earlier onset of spring warming and a delay in fall cooling, which will lengthen the growing season of temperate and boreal forests (Parker *et al*, 2000). The growing season in the Lake Simcoe watershed (seed zone 34) has already extended by nearly 5 days between 1950 and 2005, with a further expected increase of 25 days in 2041-2070 up to 40 days in 2071-2100 under a business-as-usual emissions scenario (McKenney *et al*, 2009). This longer growing season has the potential to improve plant growth, with models indicating that a 1% increase in growing season length may result in a 1.6% increase in net ecosystem productivity (Mohan *et al*, 2009). Simulations for the northeastern United States have predicted up to a 10% increase in total forest biomass with climate change (Wang *et al*, 2017). Longer growing seasons are not the only product of higher temperatures however and more variable precipitation patterns combined with increased evaporation and respiration rates may render it difficult to take advantage of the extended growing season. The overall effect of growing season changes on productivity remains uncertain. A longer growing season provides an opportunity for improved productivity if conditions remain favourable, but it is possible that these gains will be balanced or even outweighed by exponentially-increasing respiratory losses with rising temperatures, which would result in a longer growing season causing a decline in net productivity (Parker *et al*, 2000; Johnston *et al*, 2009; Mohan *et al*, 2009). An extended growing season also poses challenges for native vegetation, which tends to be finely adapted to the current local climate and may be unable to acclimatize or adapt rapidly enough to take advantage of the changing growth period (Williamson *et al*, 2009). Trees that cannot adequately adjust to longer growing seasons will not have competitive growth rates, with this maladaptation potentially leading to eventual extirpation if populations fail to compete (Aitken *et al*, 2008).

While climate change is known to be caused by anthropogenic greenhouse gas emissions, the increasing concentrations of atmospheric carbon dioxide (CO_2) do have some benefits for plant life through a process known as carbon enrichment or carbon fertilization. Higher levels of CO_2 enhance photosynthesis and water use efficiency, since plants are able to more efficiently take up CO_2 through stomata in their leaves while losing less water to transpiration (Johnston *et al*, 2009). Higher CO_2 can result in increased growth rates and productivity if plants have plentiful access to light, water and nutrients (Parker *et al*, 2000). Trees benefit from increased CO_2 concentrations more than many other plants, with physiological responses tending to be larger in younger trees and more pronounced in deciduous species (Parker *et al*, 2000; Williamson *et al*, 2009). Seeds also exhibit higher germination rates in higher CO_2 concentrations, though these may develop into smaller, slower-growing seedlings (Mohan *et al*, 2009). The benefits of higher CO_2 concentrations may be only temporary however, as research indicates that increased growth only lasts a few years as plants acclimate to the new conditions (Johnston *et al*, 2009; Williamson *et al*, 2009). Benefiting from higher CO_2 will be further challenged by increased warming-induced stress, with the balance between these two factors thus far resulting in an overall growth decline in Ontario, rather than an increase (Silva *et al*, 2010). Higher temperatures are also expected to increase tropospheric ozone (O_3) production, which can damage vegetative tissue and significantly reduce reproductive success, with these negative effects being another process to offset any production gains from CO_2 enrichment (Mohan *et al*, 2009).

A longer growing season and a higher atmospheric concentration of carbon dioxide will occur in the future, both of which have the potential to increase plant productivity. However, research indicates that the positive effects of climate change on productivity may be offset by growth losses and mortality related to heat stress and drought, more frequent disturbance, pests and diseases, changes in suitable habitat, and continued problems with air pollution (Parker *et al*, 2000; Rustad *et al*, 2012). While productivity improvements may increase timber supply in some areas, the impact of increased disturbances will dominate in most locations (Lemprière *et al*, 2008). Overall changes in timber supply may be positive or negative depending on location, time frame and adaptation actions taken (Williamson *et al*, 2009), but climate change will certainly have implications for timber cost, quality, quantity and timing of access (Lemprière *et al*, 2008).

Adaptation Strategies:

7.4.1: Include climate change variables in growth and yield models.

Climate change has diverse implications for forest productivity and forest growth models should account for these factors so that forest management and timber supply planning can proceed accordingly (Gunn *et al*, 2009; Williamson *et al*, 2009). Longer growing seasons and CO_2 fertilization have the potential to increase productivity, but these gains may be offset by productivity losses due to extreme weather events, heat stress, pest outbreaks and shifting species ranges.

7.5 Seed Zones

Impacts of climate change on seed zones

The province of Ontario is divided into 38 discrete seed zones (Figure 7.5), which have been developed to ensure that tree seed is planted where it is genetically adapted to the local environment (Ministry of Natural Resources [MNR], 2010). Movement across seed zone boundaries is restricted, which is intended to conserve genetic diversity and reduce the risk of poorly adapted stands that would be at increased risk of damage due to cold, drought, insects and disease (MNR, 2010). Through ensuring the use of locally-adapted plant material, seed zones are important for the long-term resilience of native plant populations (Kilkenny *et al*, 2013). However, climate change will alter the temperature and soil moisture conditions to which forests are currently adapted. Plantations established using local seed sources will become increasingly maladapted to changing climate conditions, resulting in increased pest susceptibility, reduced growth and reduced carbon sequestration (O'Neill *et al*, 2017). With rapid climate change, the use of local seed sources may no longer be the best approach for generating productive, healthy and resilient forest plantations (McKenney *et al*, 2014).

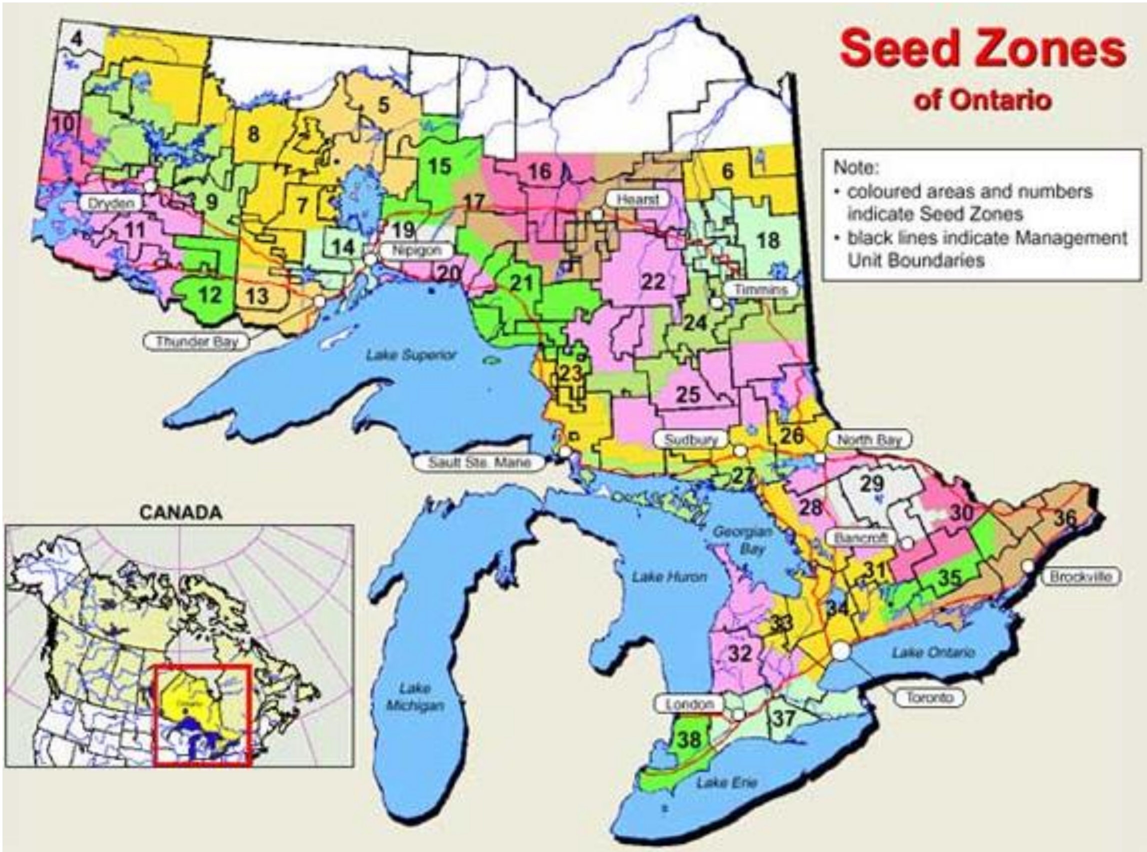


Figure 7.5: Seed zones of Ontario (MNRF, 2010)

Selecting appropriate stock for a given site is particularly challenging given the extended lifespan of trees, as a seedling's climatic microsite may change significantly over the course of its growth (Cherry, 2001). Matching seed sources to the current climate may improve survival and productivity during establishment, at the risk of maladaptation to future conditions and resulting decline; conversely, there is also risk in prematurely transferring stock into regions that are projected to become suitable habitat in the future (McKenney *et al*, 2009; Joyce and Rehfeldt, 2013). While climate change introduces numerous complications into traditional seed source deployment, the decisions made today will affect forests health and composition for decades. Forest managers must learn to consider the effects of climate change on their seed selection policies and practices (Colombo *et al*, 2008).

Seed transfer guidelines

Given the impacts of climate change on tree seed it is clear that stock deployment based on current seed zones is no longer the best option (Cherry, 2001), and that strict adherence to seed zones as the climate warms will have potentially disastrous consequences for forest health and productivity (Joyce and Rehfeldt, 2013). Instead, seed collection areas and seed deployment areas will become spatially disjunct under projected climate conditions (Thomson *et al*, 2010), with seed transfer guidelines providing a means of addressing the necessary geographic movement of forest genetic material. Developed through reciprocal transplant experiments or genealogical studies, seed transfer guidelines can be used to estimate the impact of future climate change on a species and help forest managers select vegetation adapted to future climates (Kilkenny *et al*, 2013). Canada is already beginning to move in this direction, as the province of British Columbia has recently proposed shifting from a system of seed transfer based primarily on geography to one based on climate, which will allow seedlots to be better matched to planting sites and facilitate assisted migration (O'Neill *et al*, 2017). It should be noted that designating seed procurement zones under climate change is a moving target, and zone boundaries must be re-evaluated as new information become available (Thomson *et al*, 2010).

While the need to begin procuring seed from warmer climates is obvious, the question of how exactly to identify and transfer climate-appropriate stock from other regions remains challenging. Early predictions indicate that a 3^{o}C increase in mean temperature and the corresponding changes in soil moisture might be interpreted as a shift of approximately three seed zones (Cherry, 2001). Transferring seed based solely on average temperature projections is problematic, however. Since the climate has already undergone change in the past several decades, it may be necessary to account for both past and future climate conditions when determining seed migration distances (Pedlar *et al*, 2011). Additionally, planting stock in more northerly latitudes exposes plants to longer photoperiods, causing trees to remain active later in the year and increasing the risk of freezing damage (Colombo, 2008). Examining multiple climate scenarios is a crucial step in addressing the risks of moving tree seed, as ideally the seed selected should be adapted to multiple future climates in order to provide the best chance of successful growth in an uncertain future (Pedlar *et al*, 2011). If a high degree of uncertainty exists, it may be prudent to instead plant a mix of local stock and seed from multiple procurement zones as a diversified bet-hedging approach (Colombo, 2008; Pedlar *et al*, 2011), hoping that the best-adapted seed source will thrive.

Conservation of genetic material

Moving away from the current practice of using local seed for environmental restoration also raises the issue of how to best conserve the genetic diversity of native tree populations. In a survey of thirty expert respondents, genetic conservation was recommended for 52% of Canada's 124 native tree species, either via preservation in protected areas or through seed collection (Beardmore *et al*, 2006). Not all of these species are in danger of extinction or extirpation, but climate change could result in the loss of genetically-diverse local populations (Beardmore *et al*, 2006). For this reason, preserving genetic material from different parts of a species' range should be considered. While northern populations of many temperate species may prove to be the most successful colonists, as these were the populations that successfully migrated northwards following the last ice age, the southern populations of many species are the most likely to be lost and should also be candidates for genetic conservation (McLachlan *et al*, 2007). With increased pressures for natural regeneration, even widely distributed species may require increased planting with better-adapted genetic sources (Colombo, 2008). The impact of climate change on seed production volumes is still uncertain, so it is unclear whether the current system of seed collection from orchards and wild stands will continue to function adequately (Pedlar *et al*, 2011).

Adaptation Strategies:

7.5.1: Support responsible forest genetic management.

In collaboration with nurseries, provincial agencies and other stakeholder organizations, support genetic conservation efforts and the development of climatically-appropriate seed zone designations, seed transfer policies and seed orchards to allow for the availability of necessary genetic material for afforestation (Spittlehouse and Stewart, 2003; Johnston *et al*, 2009; McKenney *et al*, 2009; Williamson *et al*, 2009; Thomson *et al*, 2010; Pedlar *et al*, 2011; Lu *et al*, 2014; Williams and Dumroese, 2014; FGCA, 2017). Support increased seed collection efforts, which may be needed to support climate-suitable planting efforts (Colombo, 2008).

7.6 Carbon Sequestration and Storage

Forests play an important global role in sequestering and storing atmospheric carbon dioxide. Carbon uptake rate is dependent on species, stand density and tree age, but large trees consistently provide a considerably greater benefit than smaller trees (Stephenson *et al*, 2014). In extreme cases a single large tree can sequester the same amount of carbon in one year as is contained in an entire mid-sized tree (Stephenson *et al*, 2014), emphasizing the importance of maintaining large healthy trees in the landscape. Global efforts to combat climate change will require these substantial forest sequestration and storage contributions to continue, but the increasing frequency, severity and extent of disturbance events threatens the overall carbon storage and carbon sequestration ability of temperate-latitude forests (Millard *et al*, 2007; Lemprière *et al*, 2008; Lines *et al*, 2010; Michaelian *et al*, 2011; Millar and Stephenson, 2015). Any action that can be taken to mitigate climate change through forest carbon management will be beneficial (Spittlehouse and Stewart, 2003).

Adaptation Strategies

7.6.1: Prioritize forest adaptation to climate change.

Maintain or improve the vigour and diversity of current forests. As climate change imposes various threats to forest health, addressing these issues through adaptation is the most effective method for continued forest carbon sequestration and should remain the top priority (Keenan, 2015).

7.6.2: Where mitigation complements adaptation, manage forests for increased carbon sequestration.

Prevent deforestation and create new canopy cover as these remain the best methods for enhancing carbon sequestration (Parker *et al*, 2000; Millar *et al*, 2007; Rustad *et al*, 2012). There may be trade-offs involved between other mitigation and adaptation strategies, and managers should approach these decisions carefully; for example, shorter rotation lengths enhance forest adaptation but result in less carbon storage, while conversely carbon sequestration can be increased with longer rotation lengths (Reyer, 2009; Brandt *et al*, 2012; Keenan, 2015). Mitigation options that can be considered on a case-by-case basis include (Parker *et al*, 2000; Millar *et al*, 2007; Gunn *et al*, 2009; Brandt *et al*, 2012; Rustad *et al*, 2012):

- Choosing forest management practices and equipment that reduce GHG emissions;
- Favouring rapidly-growing or long-lived species to improve carbon sequestration; or
- Increasing carbon storage via lengthening harvest intervals, reducing removals, or opting to use higher stocking levels. These practices may increase climate risks and slow adaptive responses, and are listed here more for completeness than as a recommendation for the LSRCA's programs.

7.6.3: Encourage the use of local forest products for construction.

Where possible and practical, the use of local wood products in LSRCA building projects should be encouraged. In addition to sustainably using our own resources, using wood for construction allows for the long-term storage of forest carbon (Parker *et al*, 2000; Millar *et al*, 2007). The criteria developed for sustainable construction and design programs such as LEED or the Living Building Challenge should be considered as guidelines for projects.

7.6.4: Stay informed on trends in global carbon markets.

Carbon credits are an intriguing option for mitigating climate change while generating revenue for afforestation programs, so forest managers should stay informed on carbon market trends (Cherry, 2001). Ensure that forest management with the primary goal of carbon sequestration aligns with any specified program requirements.

7.7 Silviculture

Climate change is causing winters to be shorter and warmer with increased freeze-thaw activity, more frost-free days, and extended periods of rain instead of snow. Since frozen ground and snow cover is required to minimize soil rutting and stand damage during winter harvesting operations, these conditions will be problematic (Colombo, 2008; Lemprière *et al*, 2008; Gunn *et al*, 2009). Forests will become more difficult to access, the inoperable season will be extended, winter harvests will need to occur during a shorter timeframe, and previously accessible areas under frozen conditions may become inoperable ground (Gunn *et al*, 2009). Winter harvest roads will be less useful and have reduced lifespans (Lemprière *et al*, 2008). Achieving forest management objectives will become more challenging with climate change and altered site access patterns (Williamson *et al*, 2009), and adaptation will be crucial for well-planned and successful operations.

Adaptation Strategies:

7.7.1: Prepare for seasonal operational limitations and reduced winter harvest.

Plan for a reduced winter harvesting window involving warmer temperatures, more frequent freeze-thaw cycles and reduced snow cover, which will create increasingly variable and difficult conditions for safe winter harvesting practices (Gunn *et al*, 2009). One option is to adjust to the shorter, warmer winters by reducing the length of winter harvest operations, or potentially allowing for greater operational flexibility to account for unseasonably warm temperatures (Colombo, 2008). Alternative harvesting practices are another possibility, which may involve constructing more all-weather logging roads or utilizing different types of equipment on sensitive sites (Colombo, 2008; Williamson *et al*, 2009). These practices could allow winter harvests to continue, but will likely increase costs (Williamson *et al*, 2009). In particularly challenging winters it may be necessary to shut down or postpone all logging and hauling operations to prevent excessive stand damage (Colombo, 2008).

7.8 Tourism

Extreme weather events, pest outbreaks and shifting species ranges have the potential to dramatically increase forest stress, dieback and mortality, resulting in a more frequent incidence of hazard trees on conservation properties. This concern is compounded by a rise in conservation area use due to a growing population, increasing use of green spaces and warmer temperatures. While the duration of recreational seasons will be impacted, climate change is expected to have a net positive effect on nature-based tourism and outdoor recreation in Ontario (Lemprière *et al*, 2008; Williamson *et al*, 2009). Warmer winters will result in substantially shorter seasons and reduced participation, safety and economic viability for activities like ice fishing, Nordic skiing and snowmobiling, but longer seasons for warm-weather recreation activities should result in an overall increase in park use (Lemieux *et al*, 2012). Moreover, the evolution of existing technologies or the development of new activities may increase activities in non-traditional seasons. Visitation levels to conservation areas could increase by over 25% in the 2020s and over 50% in the 2050s due solely to climate-induced changes in recreation patterns, which will be further compounded by continued population growth in the Lake Simcoe watershed (Lemieux *et al*, 2012). This will place additional stress on park ecosystems and alter maintenance, revenue and management requirements (Lemieux *et al*, 2012; Douglas *et al*, 2014).

Adaptation Strategies:

7.8.1: Be more active in risk mitigation for hazard trees.

Increase focus on the hazard tree program, including more frequent hazard tree assessment and removal to identify and mitigate risks. Major hazards should be promptly removed, including hazard trees and broken limbs near trails and roadways (Brandt *et al*, 2016). If certain stands or forest structures are identified as being particularly vulnerable to large disturbances, forest management should favour less vulnerable species or structures (Spittlehouse and Stewart, 2003; Johnston *et al*, 2009).

7.9 Urban Stressors

Trees in urban environments are already subject to challenging growing conditions, including extreme heat, large temperature fluctuations, flooding events, low water supplies, restricted rooting space, air pollution, road salt, vandalism, vehicle impacts, and poor quality compacted soils, resulting in high environmental stress and short life spans for urban trees. Many of these stresses will be further exacerbated by climate change (Ligeti *et al*, 2007; Roloff *et al*, 2009; Brandt *et al*, 2016). Urban forest stressors also include management challenges, including inadequate tree monitoring and maintenance, a lack of biodiversity in the urban forest, insufficient policy protection for trees, most urban trees being located on private property, and inadequate appreciation for the value of urban trees (Ligeti *et al*, 2007).

Adaptation Strategies

7.9.1: Select suitable tree and shrub species for urban environments.

While long-term climatic change will not typically be a high-priority stressor due to the relatively short expected lifespans of street trees, species selection for urban parks and open spaces should consider a species' current and future climate suitability. Urban forestry programs already have considerable experience planting more southerly species within the Lake Simcoe watershed (e.g. Kentucky coffeetree, tulip tree, honey locust) due to the relatively high urban tolerances of these species. Adaptation approaches in urban areas are more likely to incorporate novel species or cultivars (Brandt *et al*, 2016).

Larger stature tree species (eg. oaks, maples) with larger leaf surface areas should be planted where space allows, such as within municipal parks, to capitalize on the greater benefits provided by bigger, longer-lived trees.

7.9.2: Continue research and trials for LID-appropriate tree species.

Continue investigating the unique set of challenges inherent in installing trees in LIDs, most of which relate to the tree's ability to survive and thrive in this challenging growing environment. The species selection process for trees in LIDs already includes numerous factors, including soil type, moisture, exposure, tolerance for drought, salt and pollution, growth rate, and size considerations. It is recommended that this selection process also consider a species' current and future climate suitability (Roloff *et al*, 2009).

7.9.3: Enhance site preparation and maintenance practices.

Increase emphasis on tree care, including watering, mulching and pruning in the critical first three to five years following planting. Protection of root zones during construction activities can partially safeguard trees against root damage caused by soil compaction or trenching (LSRCA Forest Study, 2017). Increased site preparation, monitoring and maintenance programs for urban trees will be beneficial for improving tree vigour and survival in response to all stressors, including climate change. These practices may include experimenting with ground stabilizers or permeable paving, more frequent monitoring of tree health to identify biotic stressors, expanded watering and pruning programs, supporting and providing incentives for expanded community involvement in tree maintenance and monitoring programs, and developing extreme weather response plans for the urban forest (Ligeti *et al*, 2007).

7.10 Watershed Planning

Forests provide a multitude of essential ecosystem services that may become more vulnerable with climate change, including ecological, aesthetic, cultural, recreational and heritage values (Lemprière *et al*, 2008). Protected areas that have been established to conserve these values may become inadequate with climate change, and preserving the ecological integrity, biodiversity and habitat composition of forest ecosystems will be challenging (Lemprière *et al*, 2008). Climate change also threatens culturally significant tree species, compromising the collection of foods and medicines, as well as traditional First Nations practices.

Adaptation Strategies:

7.10.1: Maintain or create refugia.

Climate refugia should be identified and maintained in order to promote habitat persistence and allow for the long-term retention of sensitive or culturally-valuable species and ecosystems (Millar *et al*, 2007; Brandt *et al*, 2012; Swanston and Janowiak, 2012; Schmitz *et al*, 2015; Rogers *et al*, 2017). Refugia are favourable geographic locations that should maintain relatively stable climatic and biophysical conditions, such as sheltered spring-fed stands or cold valleys. For certain highly vulnerable species, artificial reserves such as nurseries or arboreta may be the best option to maintain species until a viable long-term solution can be identified, such as translocation to new habitat (Swanston and Janowiak, 2012). Rare plant species often have specialized environmental requirements and low genetic diversity, so conservation and recovery programs for these species may need to be re-evaluated to consider climate impacts (Spittlehouse and Stewart, 2003).

7.10.2: Increase landscape connectivity and ecosystem redundancy.

Habitat connectivity should be enhanced through restoring forest corridors along important dispersal pathways, which will allow for improved movement of species across the landscape, fostering migration and sustaining genetic flow to improve resilience (Spittlehouse and Stewart, 2003; Millar *et al*, 2007; Gunn *et al*, 2009; Lawler, 2009; Williamson *et al*, 2009; Brandt *et al*, 2012; Rustad *et al*, 2012; Swanston and Janowiak, 2012; Schmitz *et al*, 2015; Rogers *et al*, 2017). Ecosystem redundancy is the practice of maintaining similar habitats at multiple sites in order to spread risks, improve the likelihood of adaptation and increase monitoring information. Redundancy should be increased to improve resilience (Spittlehouse and Stewart, 2003; Millar *et al*, 2007; Rustad *et al*, 2012; Swanston and Janowiak, 2012).

7.10.3: Increase support for woodland protection, restoration and creation.

Woodland protection in governing policies for the watershed is a crucial component of sustainable land management and forest ecosystem conservation. Natural heritage systems planning framework should protect woodlands in their entirety, identify adequate buffers and support expanding them through linkages to further economic, social and environmental benefits. Policies should be directed to restore degraded woodlands and improve resiliency against threats.

7.10.4: Support enhancement of high quality canopy cover.

Ensure that climate change adaptation measures result in high quality habitat and support canopy cover targets in the watershed. High-quality reserves and other natural heritage areas preserve important physiographic diversity and environmental heterogeneity, improving the chances of biodiversity protection, species migrations and ecological adaptation to climate change (Galatowitsch *et al*, 2009; Lawler, 2009; Lemieux *et al*, 2012; Schmitz *et al*, 2015). In many situations, climate change adaptation will involve continuing programs and projects already established in support of maintaining healthy ecosystems, healthy people and a healthy economy, which is already a key focus of the Lake Simcoe Protection Plan (Douglas *et al*, 2014).

7.10.5: Connect with organizations that have experience planting southern species.

Seek out first-hand technical knowledge of new species' characteristics, planting requirements and growth potential. Forestry practitioners from conservation authorities and other organizations in more southerly seed zones, such as seed zones 32, 37 and 38, may provide their knowledge and experience with both enduring and advancing species, as described in *Adaptation Strategy 9.2.1*.Knowledge transfers should also include the ecological, economic, social and cultural aspects of how these species are valued and utilized. Coordinate with more northerly organizations to share this information for species that will be new to those regions.

VIII. Adapting Management Practices

8.1 Resources

Addressing climate change will require a variety of resources to respond to impacts and adapt programs. Management practices have an important influence on forest composition and health, and many current management objectives and practices will face substantial challenges as forests respond to climate change (Swanston and Janowiak, 2012). Adequate funding, time, staffing, nursery stock and knowledge will be required to implement changes, provide enhanced tree maintenance and rapidly adapt to unexpected conditions.

8.1.1: Increase resources for adaptation initiatives.

Allocate additional human and capital resources to sustain healthy ecosystems, assist species regeneration, respond to extreme weather events, cope with biotic disturbances, aid monitoring programs and otherwise support climate change adaptation initiatives (Puric-Mladenovic *et al*, 2011; Sturrock *et al*, 2011; Swanston and Janowiak, 2012; Johnston and Edwards, 2013). Forest management will need to be more active than current practices and should be supported with increased investments.

8.1.2: Allocate limited resources to where they will be most useful.

Adopt a triage approach to prioritizing scarce resources (Lawler, 2009; Reyer *et al*, 2009; Williamson *et al*, 2009). Action on low priority impacts (e.g. species or ecosystems that are not immediately threatened) can be postponed until resources become available, whereas other adaptation actions should be emphasized as high-priority items (e.g. species or ecosystems that will require immediate and constant management to avoid extirpation). Some impacts may even be unmanageable with current resources, in which case it can still be valuable to observe and learn (Lawler, 2009). Low-cost practices with known benefits (e.g. increasing species and structural diversity) should be emphasized over projects with higher upfront costs and greater uncertainty (Gunn *et al*, 2009).

8.2 Education & Awareness

There is an integral need for education to support adaptation initiatives in the forestry sector. Whether engaging the public to support citizen science and gather observations, encouraging landowners to consider the impacts of climate change on their plantations or woodlots, or discussing desired tree species with commercial tree nurseries, implementing adaptation actions will not be nearly as effective without increased public awareness.

8.2.1: Maintain an engaged network of stakeholders.

Continue active interagency collaboration with forestry practitioners and the research community to share knowledge, resources and best practices in order to improve adaptation planning and management (Edwards and Hirsch, 2012; Douglas *et al*, 2014; Brandt *et al*, 2016).

8.2.2: Increase public awareness and appreciation for forestry adaptation initiatives.

Build capacity to monitor and respond to impacts, and secure political buy-in and financial support for adaptation from local communities. Since many factors contributing to climate change vulnerability are social in nature, it is crucial to engage with the public via educational outreach, planting events and communications campaigns in order to raise awareness of climate change risks and the need for adaptation (Lemprière *et al*, 2008; Johnston and Edwards, 2013; Douglas *et al*, 2014; Brandt *et al*, 2016).

8.2.3: Transfer knowledge.

Pursue opportunities for knowledge transfer to community stakeholders, private landowners and forestry practitioners in other organizations (Lemprière *et al*, 2008; Johnston *et al*, 2009; Brandt *et al*, 2012). This process may include venues such as workshops, conference presentations, website content and distribution of this report.

8.2.4: Initiate climate change training for forestry staff members.

Ensure current scientific knowledge on climate change is understood by forestry staff and used to inform forest management decisions, as understanding climate change impacts and available adaptation strategies will be crucial for effective on-the-ground implementation (Lemprière *et al*, 2008; Reyer *et al*, 2009). This may include training on up-to-date climate projections for species ranges, adaptation strategy selection, or invasive species identification and safety considerations.

8.3 Planning for the Future

Climate change adds complexity and uncertainty to traditional forest management (Janowiak *et al*, 2014). While the need for adaptation in forest management is clear, transitioning from this recognition to implementing on-the-ground actions can be a major challenge. Uncertainty around key factors such as international climate change mitigation efforts, the accuracy of climate model results, plant responses to climate change, and unforeseen disturbance agents can make it difficult to identify specific adaptation strategies that will allow for rapid responses to new challenges and new information (McKenney *et al*, 2009). This uncertainty combined with a lack of guidance on selecting adaptation strategies that align with existing management goals and values can be paralyzing, and result in necessary action being delayed (Janowiak *et al*, 2014; Keenan, 2015; Schmitz *et al*, 2015). While there is no single answer as to how to address climate change, a toolbox approach that includes both short-term strategies to strengthen current conservation efforts and enhance ecosystem resilience as well as long-term guidance on transitioning forests to a better-adapted state will be useful to build the capacity for forest managers to proactively anticipate and plan rather than react and cope (Millar *et al*, 2007; Schmitz *et al*, 2015; FGCA, 2017).

Organizations will need to determine whether they are trying to manage ecosystems to resist change, become more resilient to impacts, or transition to a better-adapted state (Spittlehouse and Stewart, 2003; Keenan, 2015). Resistance, resilience and facilitation strategies allow adaptation to small, medium and large magnitudes of climate change, respectively, and it may be necessary to switch from one strategy to another as the climate continues to warm (Galatowitsch *et al*, 2009). Resistance strategies are designed to deal with small magnitudes of climate change by maintaining the status quo for high-value species or ecosystems until viable long-term adaptation options can be identified. Resilience strategies allow forests to accommodate gradual changes while aiming for eventual recovery from climate change impacts. Response strategies aim to help ecosystems transition and adapt to a new climate paradigm (Millar *et al*, 2007; Galatowitsch *et al*, 2009). While maintaining forests within historical ranges may initially be successful, crossing climate thresholds could result in substantial and abrupt forest changes that should be anticipated and planned for (Millar and Stephenson, 2015).

Once an objective has been developed for a particular management area, adaptation options can be prioritized by risk level, geographic scale and expectations for monitoring and evaluation (Colombo *et al* 2008; Brandt *et al*, 2012). All adaptation strategies that involve manipulating ecosystems have inherent risks, but the risks of inaction are believed to be much higher. Employing a judicious approach to adaptation is warranted, wherein actions are designed to reduce risks through carefully planned implementation and closely monitored results (Colombo, 2008). Implementing adaptation should commence with "no regrets" strategies, such as improving genetic diversity, which are low-barrier options with known benefits across all possible future scenarios (Swanston and Janowiak, 2012). Higher-risk proposals must demonstrate strong evidence of benefit and the need to act promptly to avoid an imminent threat (Colombo, 2008). Purposeful procrastination may even be justified in certain cases where costs or uncertainty are high relative to expected impacts, and waiting to implement adaptation until after a significant disturbance may be a more effective use of resources (Keenan, 2015).

Adaptation Strategies:

8.3.1: Incorporate climate change adaptation into forest management planning.

Increasing the climate-sensitivity of forest management objectives should be integrated into all management activities (Johnston *et al*, 2009; Williamson *et al*, 2009; Edwards and Hirsch, 2012; Swanston and Janowiak, 2012; Douglas *et al*, 2014), and climate change should be identified as a priority or guiding theme in strategic planning documents in order to lay the groundwork for undertaking more focused adaptation actions. Managing forests in an increasingly complex, dynamic and uncertain environment is a substantial challenge, but early action is the economically-efficient approach to reducing potential risks and benefitting from new opportunities (Lemprière *et al*, 2008; Williamson *et al*, 2009). Adaptation is the process of recognizing and understanding climate change impacts, planning for their consequences, and undertaking deliberate management efforts to maintain ecosystem integrity (Johnston *et al*, 2009; Swanston and Janowiak, 2012; Keenan, 2015). Climate adaptation measures such as facilitated migration, better genetic management and improved forest resilience have been recognized as a necessity (Johnston *et al*, 2009; Williamson *et al*, 2009). Climate change adaptation actions are consistent with the principles of sustainable forest management, as both share the goal of increasing forest health and resilience in response to external pressures.

8.3.2: Ensure that every project has a well-defined objective.

The LSRCA should be purposeful in ensuring that all forestry projects have well-defined objectives, which will be crucial to selecting appropriate adaptation strategies. The crucial first step for effective adaptation is to set a clear management objective (Keenan, 2015). It is unlikely that adaptation can address all the impacts of climate change or that all present forest values will be preserved, so forest managers will need to make difficult decisions on where to focus efforts and limited resources (Lemprière *et al*, 2008; Keenan, 2015). Selecting adaptation strategies that are robust across multiple future climate scenarios will help to minimize the risks of maladaptation (Lawler, 2009; Keenan, 2015). Swanston and Janowiak (2012) outline the following process for planning adaptation:

1) Define area of interest, management goals and objectives, and time frames.
2) Assess climate change impacts and vulnerabilities for the area of interest.
3) Evaluate management objectives, given projected impacts and vulnerabilities.
4) Identify adaptation approaches and tactics for implementation.
5) Monitor and evaluate effectiveness of implemented actions.

8.3.3: Conduct more frequent and intentional reviews of 20-year management plans.

Long-term management plans should be reviewed regularly to revise objectives and account for new information, as weather patterns, species ranges and pest outbreaks have the potential to change quickly and unpredictably in unprecedented ways, making it difficult to achieve stated forest management objectives.

8.3.4: Adopt adaptive management practices.

The substantial uncertainty associated with climate change impacts and adaptation strategies challenges the inflexibility inherent in traditional long-term management methods. Adaptive management is an alternative approach that emphasizes monitoring and regular review of management actions in order to strive for continuous improvement (Pedlar *et al*, 2011). With the substantial complexity inherent in addressing climate change, adaptive management practices are one of the best tools available to resource managers and should be adopted (Spittlehouse and Stewart, 2003; Galatowitsch *et al*, 2009; Johnston *et al*, 2009; Lawler, 2009; Williamson *et al*, 2009; Pedlar *et al*, 2011; Brandt *et al*, 2012; Douglas *et al*, 2014; Rogers *et al*, 2017).

Implementing adaptive management begins with committing to a heightened focus on monitoring. A strategic, coordinated climate monitoring program for terrestrial vegetation should include monitoring of species composition and abundance, tree growth measurements, and phenological events (Williamson *et al*, 2009; Puric-Mladenovic *et al*, 2011). This enhanced species-level monitoring will ensure the early detection of climate change impacts and allow for the assessment and modification of management actions and institutional behaviours (Johnston *et al*, 2009; Brandt *et al*, 2012). Given the geographic extent of climate change impacts it is also important to emphasize that adaptive planning and monitoring must not be confined by traditional jurisdictional and political boundaries. Collaborative interagency coordination and continuous knowledge sharing will be essential for successful regional-scale adaptation (Galatowitsch *et al*, 2009; Lawler, 2009; Puric-Mladenovic *et al*, 2011; Brandt *et al*, 2012; Janowiak *et al*, 2014; Keenan, 2015).

IX. Tree Planting in a Changing Climate

9.1 Species Selection

Suitable climate conditions for many tree species are shifting northwards at a much faster rate than trees are able to naturally migrate. The rapid pace of climatic change and uncertainty over future conditions is making it increasingly difficult to determine appropriate tree species to plant. Tree species richness in the Lake Simcoe watershed is also projected to change substantially. Richness will increase in the near-term due to new species options becoming available while retreating species will still be present, however species retreats over the long-term will result in a decline in total richness (Lemieux *et al*, 2012). Differences between emissions scenarios are important to recognize. While large changes in forest habitat will occur even under a low-emission future, forest disruption and species migration pressure over the long-term will be much more severe if greenhouse gas emissions are not significantly reduced (Iverson *et al*, 2008). Selecting climatically-suitable tree and shrub species to plant in the Lake Simcoe watershed is thus a crucial practical application of the impacts and adaptation concepts discussed throughout this report.

Adaptation Strategies:

9.1.1: Select climatically-appropriate tree species.

To increase the chance of survival, species selection should consider climatic range projections in addition to more traditional factors such as soil type and site tolerances. Favouring climate-suitable species has been identified as a key adaptation strategy for improving ecosystem resilience (Spittlehouse and Stewart, 2003; Johnston *et al*, 2009; McKenney *et al*, 2009; Reyer *et al*, 2009; Williamson *et al*, 2009; Brandt *et al*, 2016; Clark *et al*, 2016; Duveneck and Scheller, 2016; Rogers *et al*, 2017). Project objectives should inform species selection, and even retreating species should see some continued use for meeting particular goals. A climate-suitable planting list for LSRCA projects has been developed and will be elaborated on in the following sections.

Canada's Plant Hardiness Website

The LSRCA's climate-suitable tree planting list has been informed by literature review and supported by species-specific climate change maps and models available through Natural Resources Canada's Plant Hardiness website (Natural Resources Canada, 2017). This online resource is built on approximately 3 million plant occurrence observations, which have been used to generate climate profiles for nearly 3,000 North American plant species (McKenney *et al*, 2015). Present climate at each of these occurrence locations provide the basis for each species' climatic tolerance limits, and future climate envelopes can be determined by using climate models to project where these climate conditions will exist in the future. It should be noted that these maps only show suitable climate envelopes and do not account for other factors like soils or migration ability that will constrain tree species distributions. The maps must be interpreted as depicting the climatically-suitable regions to plant each species, rather than projections for actual tree species distributions in the time period given. However, through comparing a species' historical range to where its suitable climatic habitat will exist under multiple future scenarios, we can identify species that have a greater or lower suitability to the changing climate. Aside from the species listed here, projections for thousands of other plant species are available through Canada's Plant

Hardiness website. Users can explore species-specific maps and models across multiple time periods and climate scenarios, and access more detailed information on the modeling process.

Climate-Suitable Species Lists

An initial list of climatically-suitable species options for the Lake Simcoe watershed has been prepared to guide delivery of the LSRCA planting program. The species list has been divided into three groups of trees that each display similar climatic envelope shifts:

> Retreating species: Currently present in the Lake Simcoe watershed but are projected to retreat northward in the future;
>
> Enduring species: Currently present and will continue to persist; and
>
> Advancing species: Not currently present in the watershed but will expand northwards and become a new planting possibility.

These species lists are not intended to be comprehensive, as they include only the most common species used in afforestation and restoration programs. Additionally, the need for professional judgement to interpret and apply this list based on site conditions and project objectives must be emphasized.

One mapped example for each category is given. Three maps are presented for each species to allow visualization of ranges across a variety of time periods and scenarios. On the left is the historical distribution (1971-2000), which is built on actual plant occurrence observations. In the middle is the projected climate envelope distribution for 2011-2040. Climatic change for this period is largely based on committed warming from already-emitted greenhouse gases, so distribution projections are quite consistent across low and high scenarios. The map on the right displays projections for 2041-2070 under the high emissions scenario RCP 8.5, which is the path our society is currently following. Species distribution patterns under a high emissions scenario in the 2071-2100 time period illustrate even more dramatic trends, but are not shown here due to the difficulty of making species selection decisions that will remain appropriate given the uncertainty over this longer timeframe.

Retreating

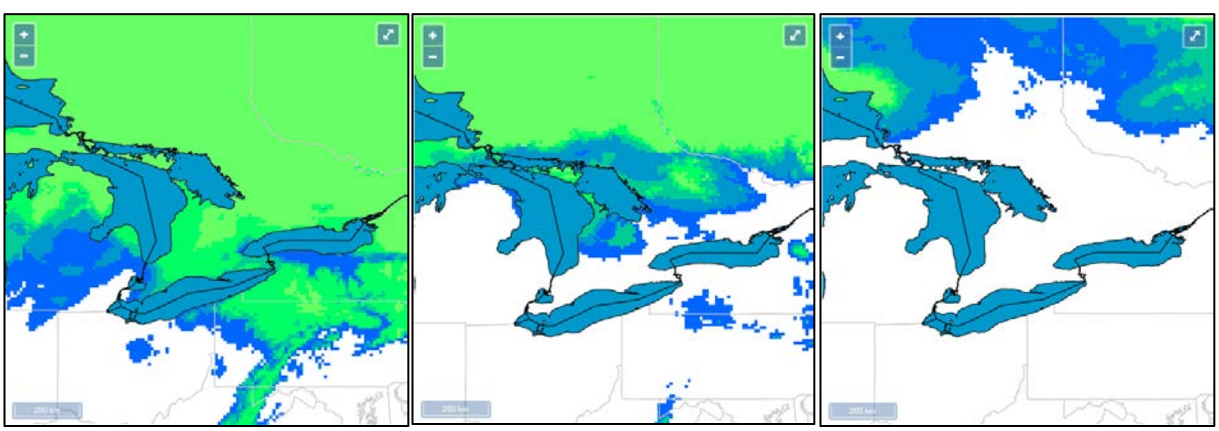
Numerous observations, experiments and model projections indicate that warmer and drier climate conditions will impose strong constraints on the growth, survival, reproduction and competitive ability of boreal species in the southern parts of their range, leading to a high probability of dramatic declines in habitat quality and extent, a northward retreat for species such as white spruce, black spruce, balsam fir, hemlock, trembling aspen, tamarack and paper birch, and eventually the possible loss of the boreal forest biome from the northern United States and southeastern Canada (Parker *et al*, 2000; Cherry, 2001; Iverson and Prasad, 2002; Goldblum and Rigg, 2005; Galatowitsch *et al*, 2009; Iverson *et al*, 2008; Williamson *et al*, 2009; Thomson *et al*, 2010; Dietze and Moorcroft, 2011; Puric-Mladenovic *et al*, 2011; Lemieux *et al*, 2012; Rustad *et al*, 2012; Swanston and Janowiak, 2012; Huang *et al*, 2013; Luo and Chen, 2013; Reich *et al*, 2015; Boulanger *et al*, 2016b; Iverson *et al*, 2017; Rogers *et al*, 2017). Remnant populations of boreal species may persist on cooler, wetter refuges such as lowlands and north-facing slopes as well as at higher elevations in locations like Algonquin Park, but the overall abundance of boreal species will be substantially reduced in south-central Ontario with even moderate warming (Cherry, 2001; Galatowitsch *et al*, 2009). Many of these species have important ecological, commercial, afforestation and tourism values, and their loss from more densely-populated southern regions will be impactful (Cherry, 2001; Iverson *et al*, 2008; Rustad *et al*, 2012; Reich *et al*, 2015).

Retreating species are those projected to no longer be climatically-suitable for our watershed in the coming decades. These species tend to be associated with the boreal forest and are already at the southern edge of their range. While these species' climate envelopes retreating from our watershed within decades is inevitable, continuing to plant these trees may be appropriate depending on project objectives. For example, white spruce is a valuable tree in afforestation projects and should continue to be planted as long as it is able to survive for an adequate period of time. Determining what constitutes "adequate" time will vary, but may be as little as 30 years of growth and survival until the first thinning operation when transition to a mixed hardwood forest can begin. Increased tending will likely be required to improve seedling survival and establishment. However, land managers should be prepared for the potential of reduced growth, shorter lifespans and a lack of natural regeneration when planting the following species.

- White spruce
- Balsam fir
- Eastern white cedar
- Paper birch
- Tamarack
- Trembling aspen

Example: White spruce

The following maps are an example of expected trends for white spruce (*Picea glauca*) under a high-emissions scenario, showing the complete loss of suitable habitat in Southern Ontario in the coming decades. Healthy, mature trees should be able to persist despite the increased stress, but they are unlikely to be replaced by a new generation. This species will gradually retreat from our watershed.



1971-2000 2011-2040 2041-2070

Enduring

As the boreal forest retreats northward, many temperate forest species may benefit and become more dominant in the northern portions of their range. Species like white pine, red maple, red oak, white oak, bur oak, American basswood and American beech are quite resilient and adaptable to climatic warming and may respond positively with increased growth rates and northward expansion, meaning that these species should continue to be reliable planting choices in the Lake Simcoe watershed for decades to come (Cherry, 2001; Goldblum and Rigg, 2005; Galatowitsch *et al*, 2009; Williamson *et al*, 2009; Huang *et al*, 2013; Reich *et al*, 2015; Boulanger *et al*, 2016b; FGCA, 2017; Iverson *et al*, 2017). With ranges for these species extending south well into the United States, substantial reserves of better-adapted seed is available and should be integrated into local planting projects.

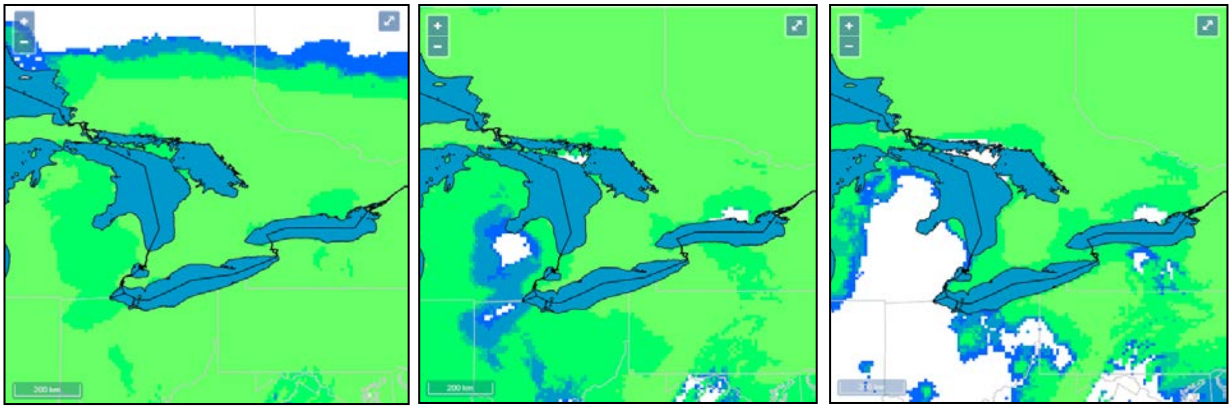
Currently threatened species such as ash and elm trees will also continue to be climatically suitable in the future and have been recommended for continued use in afforestation if viable solutions for preserving these species are identified (Cherry, 2001; Galatowitsch *et al*, 2009; Puric-Mladenovic *et al*, 2011). Non-native species like common buckthorn are also in this group (Reich *et al*, 2015), which will likely complicate control programs. Some species such as sugar maple and white pine are not as well adapted to warm conditions, and high emissions scenarios project habitat deterioration and eventual extirpation from southern Ontario towards the end of the century due to significantly warmer and drier conditions (Cherry, 2001; Joyce and Rehfeldt, 2013; Boulanger *et al*, 2016b; Iverson *et al*, 2017). While these species are classified in the "enduring" category for a mid-century timeframe, this long-term perspective should be acknowledged as a reminder of the more dramatic changes that will occur under a high-emissions future.

Enduring species are currently prevalent in our watershed and will continue to be climatically-suitable in the future. These species tend to be associated with the temperate forest, with southern Ontario being towards the northern edge of their range. They have been viable planting choices in the watershed in the past and will be appropriate for decades to come, though southern seed sources will likely prove to be better adapted than native seed over longer time horizons.

- Beech
- Black cherry
- Maple (red, sugar, silver)
- Oak (red, white, bur)
- White pine
- *White, green and black ash; white and slippery elm (**significant pest concerns*)

<u>Example: Sugar maple</u>

The following maps are an example of expected trends for sugar maple (*Acer saccharum*) under a high-emissions scenario, showing that Southern Ontario continues to be core habitat for this species. Range erosion can be seen in the northern United States by mid-century. Healthy trees should persist and regeneration should continue as normal, though southern seed sources may be better-adapted to the hotter climate and longer growing season. This species is expected to endure in our watershed.



1971-2000 2011-2040 2041-2070

Advancing

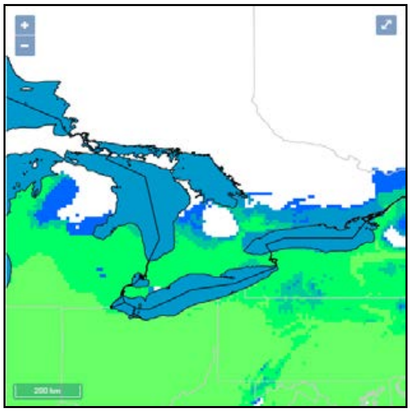
The Lake Simcoe watershed is located north of the remnant Carolinian forest zone in extreme southern Ontario, a region with a diverse abundance of deciduous trees not found elsewhere in Canada. Climate change is resulting in the characteristic Carolinian climate advancing northwards, bringing the possibility of new species options to Lake Simcoe such as tulip tree, shagbark hickory, cottonwood, hackberry and willow oak (Cherry, 2001; Galatowitsch *et al*, 2009; Puric-Mladenovic *et al*, 2011; Lemieux *et al*, 2012). Several nearby organizations have recently begun limited plantings of Carolinian species and consultation with forestry practitioners in these organizations has been helpful in refining a list of these species that are already performing well in our region. Warmer and drier climatic conditions are also projected to favour oak and hickory species, which should gain substantial habitat and grow well in more northern regions (Iverson *et al*, 2008; Rustad *et al*, 2012; Fisichelli *et al*, 2014b; Clark *et al*, 2016; Iverson *et al*, 2017).

Advancing species present new options for planting that will become suitable for our watershed as the climate continues to warm. Forest managers should seek out information on a new species' characteristics, planting requirements, growth potential and how these trees are performing in nearby areas. Consultation with practitioners at more southerly conservation authorities and other agencies will lend practical advice to promote outplanting success.

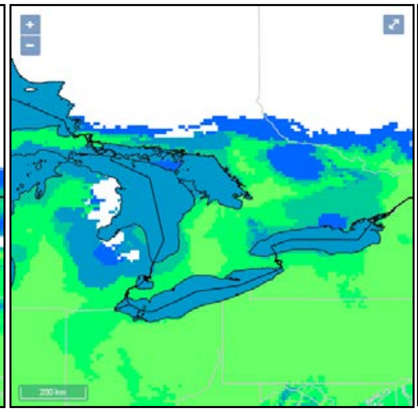
- Hickories (e.g. Shagbark hickory (*Carya ovata*), bitternut hickory (*C. cordiformis*), pignut hickory (*C. glabra*)
- Southern oaks (e.g. swamp white oak (*Quercus bicolor*), eastern black oak (*Q. velutina*), Chinquapin oak (*Q. muehlenbergii*), scarlet oak (*Q. coccinea*)
- Sycamore (*Platanus occindentalis*)
- Hackberry (*Celtis occidentalis*)
- Tulip tree (*Liriodendron tulipifera*)
- Blackgum (*Nyssa sylvatica*)
- Various other Carolinian species (there are a diverse array of less common but possible species options other than those listed here).

<u>*Example: Shagbark Hickory*</u>

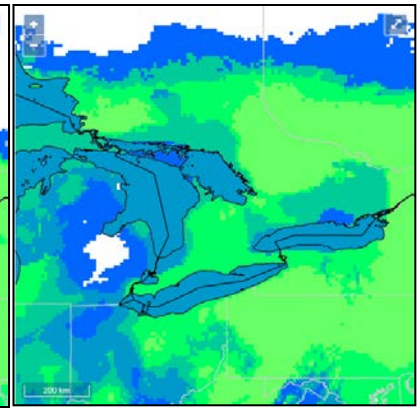
The following maps are an example of expected trends for shagbark hickory (*Carya ovata*) under a high-emissions scenario, showing significant new available habitat in Southern Ontario in the coming decades. Starting to plant these trees in limited numbers should be possible immediately and more widespread plantings can be pursued once reasonable survival and growth rates are confirmed locally. This species will gradually advance into our watershed.



1971-2000



2011-2040



2041-2070

9.2: Tree Planting Logistics

Unpredictability in the spring planting season has always been a concern, but climate change will introduce further operational issues including more difficult site access, a longer growing season necessitating an earlier start and later end to the planting season, and potential for reduced access to traditional seasonal labour (ie. Students who join planting crews at the end of their post-secondary school year). Trees will also be under greater environmental stress and be at a higher risk of mortality during establishment due to higher temperatures, extreme weather events, pest outbreaks and intensified competition. Addressing these factors will necessitate increased post-planting maintenance activities.

Adaptation Strategies:

9.2.1: Increase the species, genetic and structural diversity of planted stock.

The LSRCA should consider increasing diversity for all planting projects. Trees have different vulnerabilities to a variety of environmental stressors depending on species, genetic composition and age. Overall site resilience will be improved by with a greater emphasis on diversity (Parker *et al*, 2000; Spittlehouse and Stewart, 2003; Millar *et al*, 2007; Johnston *et al*, 2009; Galatowitsch *et al*, 2009; Gunn *et al*, 2009; Reyer *et al*, 2009; Brandt *et al*, 2012; Swanston and Janowiak, 2012; Brandt *et al*, 2016; Clark *et al*, 2016; Iverson *et al*, 2017). To improve a species' genetic resilience at a planting site, local and southerly plants from at least two different southern seed sources should be mixed in the ratio of approximately 50% local, 25% from one seed zone to the south, and 25% from two seed zones to the south (Colombo, 2008; Galatowitsch *et al*, 2009; FGCA, 2013; FGCA, 2017).

Increasing species diversity has also been identified as a critical for maintaining urban canopy cover and protecting it from the impacts of future pest or disease infestations. It is recommended that no species represents more than 5% of the tree population, no genus represents more than 10% of the tree population, and no family represents more than 20% of the intensively managed tree population both municipal-wide and at the neighbourhood level (LSRCA, 2016a).

9.2.2: Consult and collaborate with nursery growers.

Actively engage and collaborate with tree nursery growers to ensure that sufficient site and genetically appropriate stock are available for afforestation projects. Consultation should begin 3 or more years in advance of planting projects to ensure that nurseries are able to collect and propagate the tree seeds required to growing seedling stock for outplanting. Active engagement with nurseries will also facilitate the exchange of information necessary to ensure that afforestation programming continues to be adaptive to climate change.

9.2.3: Modify planting programs to increase flexibility and spread risk.

Projects should allow for greater flexibility in timing and delivery. Spring variability has always been a challenge and industry shifts to accommodate a longer growing season will be gradual, but organizations should begin preparing for the implications. It may be beneficial to conduct large projects over multiple years, bet-hedging against years with unfavourable conditions for establishment (Galatowitsch *et al*, 2009; Brandt *et al*, 2016). Experimentation and monitoring of different stock types (i.e. seeds, seedlings, or caliper stock), planting timeframes (spring or fall), and site preparation strategies (mechanical, cover cropping, companion plantings) will provide insight on what combination of options results in the best performance (Johnston *et al*, 2009; Ste-Marie, 2014).

9.2.4: Prepare for earlier planting timeframe.

While industry shifts to accommodate a longer growing season will likely be gradual, organizations should begin preparing for the implications on labour, program timelines, seedling storage and planting equipment. Variable spring weather has always been a challenge, but an earlier spring thaw and longer growing season has additional implications for nursery stock distribution and labour availability for planting.

9.2.5: Increase post-planting tending activities.

Watering, weeding, mulching, pruning, predator/pest control and vegetation management all have the potential to substantially improve seedling survival and establishment, and while financial and logistical constraints will inevitably limit tending, these activities should be considered based on site conditions and environmental pressures (Pedlar *et al*, 2011; FGCA, 2013; Ste-Marie, 2014; LSRCA Forest Study, 2017). Monitoring and experimentation can help determine whether such measures will be more or less necessary for particular species (Pedlar *et al*, 2011; Ste-Marie, 2014). In order to allow tending to occur in the first 3-5 years following planting, programs should be modified to require longer-term commitments from landowners, and secure resources at the time of planting that will support the ability of LSRCA staff to monitor and maintain planted sites (eg. building future management costs into per seedling planting costs).

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Appendix I: Adaptation Strategies Overview

This section summarizes the Adaptation Strategies found within the main body of the Adapting Forestry Programs for Climate Change report. Acknowledgement of the materials and research referenced are included within the main body of the report.

7.1 Forest Composition

Suitable climate conditions for many tree species are shifting northwards at a much faster rate than trees are able to naturally migrate. The growing geographic distance between a species' current and future climatic envelope will leave forests in a state of disequilibrium, increasing their vulnerability to environmental stresses and disturbances.

7.1.1: Shorten rotation ages.

Anticipate and respond to species declines by shortening rotations to reduce the period of disequilibrium and vulnerability, which also allows for more generations and increases the likelihood of genetic adaptation to new conditions. Harvesting prior to stand decline followed by planting can be used to speed the establishment of better-adapted forest types.

7.1.2: Promote better-adapted species.

Favour species that are expected to be better adapted to future conditions. Reduce reliance on natural regeneration in forests that are anticipated to be significantly maladapted to future climates. Underplanting with climate-adapted species prior to harvest can increase species turnover and provide protection for sensitive seedlings.

7.1.3: Facilitate community adjustments through assisted migration.

Conduct assisted migration plantings to help species accomplish range shifts. The focus should remain on species and populations that would naturally migrate into the watershed given adequate time, rather than planting exotic species. Ensure appropriate risk management planning takes place for any species introductions, including the risks of introducing new pests or diseases with imported plant material.

7.2 Extreme Weather

Climate change is expected to alter the frequency, intensity, duration and timing of a variety of extreme weather events, including drought, fire, hurricanes, windstorms, ice storms, and landslides.

7.2.1: Increase resilience to disturbance.

Enhance and maintain species, structural, and genetic diversity, as diverse forests will exhibit variability in resistance to pests, drought, and wind events, and will be better able to recover from disturbance. More aggressive forest thinning will reduce competition, improving resilience to heat and drought stress. Favour existing genotypes that are better adapted to future conditions, incorporate genetic material from a greater range of southern sources, and include pest- or drought-resistant varieties where appropriate.

7.2.2: Plan for and respond to disturbance.

Develop response options to prepare for more frequent and severe disturbances. Use large scale disturbances as windows of opportunity to re-establish forests that are less vulnerable to future climate change. Promptly revegetate sites following disturbance, and allow for some areas of natural regeneration to identify well-adapted species.

7.2.3: Improve resilience to heat and drought stress.

Improve the resilience of forests to heat and drought stress. Healthy trees with adequate access to necessary resources will be better able to cope with environmental stresses. Reducing stand density will reduce competition, lowering the probability of drought-related tree mortality. More aggressive thinning practices may be required to improve drought resistance, increase growth and improve resilience to future stress.

7.2.4: Protect forests from severe fire.

Where necessary, protect forests from severe fire. A fire-smart landscape may include targeted harvesting to alter forest structure or composition to reduce fire risk, prescribed burning to minimize fuel loads and reduce wildfire spread, establishing fuel breaks around high-risk areas, density reduction in fire-suppressed stands, or increasing the focus on more fire-resistant species. Most forests across Southern Ontario will not need to pursue these strategies given the minimal overall fire risk, but in certain situations it may be prudent to anticipate and plan for surprises such as atypical fires.

7.2.5: Develop contingency plans for ice storm damage.

Incorporate ice storm prevention, response and recovery actions into management plans. Prepare contingency plans for prompt assessment and post-storm response, increase landowner education for ice storm response, and improve documentation of ice storm damages to inform future decision-making. Consider ice storm susceptibility as a factor in species selection. Avoid planting significant numbers of highly vulnerable species in high-risk areas in order to reduce potential property damage. Proper tree placement and regular pruning will also reduce the severity or extent of ice damage.

7.3 Biotic Disturbance

Warmer temperatures increase the risks of new or exacerbated outbreaks of various insects, diseases, and invasive plants. Southern forest pests may be able to migrate and survive further north due to warmer winters, and existing pests may be able to take advantage of the changing conditions with more rapid life cycles and higher rates of activity.

7.3.1: Reduce the impact of existing stressors.

Continue emphasizing restoration programming to alleviate existing non-climatic stressors such as habitat fragmentation and loss, pollution, over-exploitation and invasive species in order to increase forest resilience and allow ecosystems to more effectively respond to climate change (Lawler, 2009; Reyer *et al*, 2009; Brandt *et al*, 2012; Rustad *et al*, 2012; Rogers *et al*, 2017). Healthy trees have the greatest ability to resist pests and pathogens. Maintaining or restoring soil quality, nutrient cycles, and site hydrology will ensure forests have the necessary resources for vigorous growth.

7.3.2: Improve stand vigour to increase pest resilience.

Reduce the risks of catastrophic forest losses to pests and pathogens through thinning to reduce density and improve stand vigour, sanitation cuts to remove infected trees, and shorter rotation lengths. Reduced stand densities also lower relative humidity and this decrease in available moisture can reduce disease prevalence. Efforts to maintain and restore soil quality, nutrient cycling, hydrology, habitat and biodiversity will also improve ecosystem resilience.

7.3.3: Protect regenerating vegetation from herbivory.

Manage herbivory and deer browsing of vulnerable species using fencing or other barriers, strategically-located deer exclosures, intensive hunting zones, or "hiding" desirable species in a mixture of less palatable plants. Regeneration can also be promoted by controlling light availability and altering harvest gap sizes. Actions taken to protect regenerating vegetation may allow existing plant communities to persist for decades longer, or favour the establishment of better-adapted tree species.

7.3.4: Prevent the establishment of invasive species.

Increase monitoring programs for invasive pests, diseases and plants. Quality monitoring data will be crucial for early detection, rapid response and intensive removal of invasive species, and will contribute to informing adaptive management. Consider insecticide, fungicide or herbicide use to protect high-value trees or natural areas, or to retain desired species on the landscape. Naturally migrating species will also be moving into the watershed and forest managers should determine if these natural species migrations should be classified as invasive and removed within a given management area. Due to the difficulty in predicting future pest dynamics, encourage policies that allow the flexibility to address surprises.

7.4 Forest Growth and Productivity

7.4.1: Include climate change variables in growth and yield models.

Climate change has diverse implications for forest productivity and forest growth models should account for these factors so that forest management and timber supply planning can proceed accordingly. Longer growing seasons and CO_2 fertilization have the potential to increase productivity, but these gains may be offset by productivity losses due to extreme weather events, heat stress, pest outbreaks and shifting species ranges.

7.5 Seed Zones

Increased environmental stress driven by climate change threatens the quality, periodicity and availability of tree seed for afforestation. Shifting climates will result in current seed zones being inadequate for supplying locally-adapted plant material in the future.

7.5.1: Support responsible forest genetic management.

In collaboration with nurseries, provincial agencies and other stakeholder organizations, support genetic conservation efforts and the development of climatically-appropriate seed zone designations, seed transfer policies and seed orchards to allow for the availability of necessary genetic material for afforestation. Genetic diversity is the foundation of forest resilience. Support increased seed collection efforts, which may be needed to support climate-suitable planting efforts.

7.6 Carbon Sequestration and Storage

Forests play an important global role in sequestering and storing atmospheric carbon dioxide. Addressing climate change will require these substantial contributions to continue, highlighting the importance of managing forests for climate change mitigation. The increasing influence of carbon markets also creates the potential for generating revenue via afforestation.

7.6.1: Prioritize forest adaptation to climate change.

Maintain or improve the vigour and diversity of current forests. As climate change imposes various threats to forest health, addressing these issues through adaptation is the most effective method for continued forest carbon sequestration and should remain the top priority.

7.6.2: Where mitigation complements adaptation, manage forests for increased carbon sequestration.

Prevent deforestation and create new canopy cover as these remain the best methods for enhancing carbon sequestration. There may be trade-offs involved between other mitigation and adaptation strategies, and managers should approach these decisions carefully; for example, shorter rotation lengths enhance forest adaptation but result in less carbon storage, while conversely carbon sequestration can be increased with longer rotation lengths. Mitigation options that can be considered on a case-by-case basis include:

- Choosing forest management practices and equipment that reduce GHG emissions;
- Favouring rapidly-growing or long-lived species to improve carbon sequestration; or
- Increasing carbon storage via lengthening harvest intervals, reducing removals, or opting to use higher stocking levels. These practices may increase climate risks and slow adaptive responses, and are listed here more for completeness than as a recommendation for the LSRCA’s programs.

7.6.3: Encourage the use of local forest products for construction.

Where possible and practical, the use of local wood products in LSRCA building projects should be encouraged. In addition to sustainably using our own resources, using wood for construction allows for the long-term storage of forest carbon. The criteria developed for sustainable construction and design programs such as LEED or the Living Building Challenge should be considered as guidelines for projects.

7.6.4: Stay informed on trends in global carbon markets.

Carbon credits are an intriguing option for mitigating climate change while generating revenue for afforestation programs, so forest managers should stay informed on carbon market trends. Ensure that forest management with the primary goal of carbon sequestration aligns with any specified program requirements.

7.7 Silviculture

Forest managers are concerned about how to manage stand structure and resiliency, and sustainable harvesting in an uncertain future.

7.7.1: Prepare for seasonal operational limitations and reduced winter harvest.

Plan for a reduced winter harvesting window involving warmer temperatures, more frequent freeze-thaw cycles and reduced snow cover, which will create increasingly variable and difficult conditions for safe winter harvesting practices. One option is to adjust to the shorter, warmer winters by reducing the length of winter harvest operations, or potentially allowing for greater operational flexibility to account for unseasonably warm temperatures. Alternative harvesting practices are another possibility, which may involve constructing more all-weather logging roads or utilizing different types of equipment on sensitive sites. These practices could allow winter harvests to continue, but will likely increase costs. In particularly challenging winters it may be necessary to shut down or postpone all logging and hauling operations to prevent excessive stand damage.

7.8 Tourism

Extreme weather events, pest outbreaks, and shifting species ranges have the potential to dramatically increase forest stress, dieback and mortality, resulting in a more frequent incidence of hazard trees on conservation properties. This concern is compounded by a rise in conservation area use due to a growing population, increasing use of green spaces, and warmer temperatures.

7.8.1: Be more active in risk mitigation for hazard trees.

An increased focus on the hazard tree program, including more frequent hazard tree identification and removal will be important to mitigate risks.

7.9 Urban Stressors

Trees in urban environments are already subject to challenging growing conditions, which will be further exacerbated by climate change.

7.9.1: Select suitable tree and shrub species for urban environments.

While long-term climatic change will not typically be a high-priority stressor due to the relatively short expected lifespans of street trees, species selection for urban parks and open spaces should consider a species' current and future climate suitability. Urban forestry programs already have considerable experience planting more southerly species within the Lake Simcoe watershed (e.g. Kentucky coffeetree, tulip tree, honey locust) due to the relatively high urban tolerances of these species. Adaptation approaches in urban areas are more likely to incorporate novel species or cultivars. Larger stature tree species (eg. oaks, maples) with larger leaf surface areas should be planted where space allows, such as within municipal parks, to capitalize on the greater benefits provided by bigger, longer-lived trees.

7.9.2: Continue research and trials for LID-appropriate tree species.

Continue investigating the unique set of challenges inherent in installing trees in LIDs, most of which relate to the tree's ability to survive and thrive in this challenging growing environment. The species selection process for trees in LIDs already includes numerous factors, including soil type, moisture, exposure, tolerance for drought, salt and pollution, growth rate, and size considerations. It is recommended that this selection process also consider a species' current and future climate suitability.

7.9.3: Enhance site preparation and maintenance practices.

Increase emphasis on tree care, including watering, mulching and pruning in the critical first three to five years following planting. Protection of root zones during construction activities can partially safeguard trees against root damage caused by soil compaction or trenching. Increased site preparation, monitoring and maintenance programs for urban trees will be beneficial for improving tree vigour and survival in response to all stressors, including climate change. These practices may include experimenting with ground stabilizers or permeable paving, more frequent monitoring of tree health to identify biotic stressors, expanded watering and pruning programs, supporting and providing incentives for expanded community involvement in tree maintenance and monitoring programs, and developing extreme weather response plans for the urban forest.

7.10 Watershed Planning

Forests provide a multitude of essential ecosystem services that may become more vulnerable with climate change, and preserving the ecological integrity, biodiversity and habitat composition of forest ecosystems will be challenging. Climate change also threatens culturally significant tree species, compromising the collection of foods and medicines, as well as traditional First Nations practices.

7.10.1: Maintain or create refugia.

Climate refugia should be identified and maintained in order to promote habitat persistence and allow for the long-term retention of sensitive or culturally-valuable species and ecosystems. Refugia are favourable geographic locations that should maintain relatively stable climatic and biophysical conditions, such as sheltered spring-fed stands or cold valleys. For certain highly vulnerable species, artificial reserves such as nurseries or arboreta may be the best option to maintain species until a viable long-term solution can be identified, such as translocation to new habitat. Rare plant species often have specialized environmental requirements and low genetic diversity, so conservation and recovery programs for these species may need to be re-evaluated to consider climate impacts.

7.10.2: Increase landscape connectivity and ecosystem redundancy.

Habitat connectivity should be enhanced through restoring forest corridors along important dispersal pathways, which will allow for improved movement of species across the landscape, fostering migration and sustaining genetic flow to improve resilience. Ecosystem redundancy is the practice of maintaining similar habitats at multiple sites in order to spread risks, improve the likelihood of adaptation and increase monitoring information. Redundancy should be increased to improve resilience.

7.10.3: Increase support for woodland protection, restoration and creation.

Woodland protection in governing policies for the watershed is a crucial component of sustainable land management and forest ecosystem conservation. Natural heritage systems planning framework should protect woodlands in their entirety, identify adequate buffers and support expanding them through linkages to further economic, social and environmental benefits. Policies should be directed to restore degraded woodlands and improve resiliency against threats.

7.10.4: Promote high quality habitat.

Ensure that climate change adaptation measures result in high quality habitat and support canopy cover targets in the watershed. High-quality reserves and other natural heritage areas preserve important physiographic diversity and environmental heterogeneity, improving the chances of biodiversity protection, species migrations and ecological adaptation to climate change. In many situations, climate change adaptation will involve continuing programs and projects already established in support of maintaining healthy ecosystems, healthy people and a healthy economy, which is already a key focus of the Lake Simcoe Protection Plan.

7.10.5: Connect with organizations that have experience planting southern species.
Seek out first-hand technical knowledge of new species' characteristics, planting requirements and growth potential. Forestry practitioners from conservation authorities and other organizations in more southerly seed zones, such as seed zones 32, 37 and 38, may provide their knowledge and experience with both enduring and advancing species, as described in *Adaptation Strategy 9.2.1*.Knowledge transfers should also include the ecological, economic, social and cultural aspects of how these species are valued and utilized. Coordinate with more northerly organizations to share this information for species that will be new to those regions.

8.1 Resources
Addressing climate change will require a variety of resources to respond to impacts and adapt programs. Adequate funding, time, staffing, nursery stock and knowledge will be required to implement changes, provide enhanced tree maintenance and rapidly adapt to unexpected conditions.

8.1.1: Increase resources for adaptation initiatives.
Seek out additional resources (funding, time, staffing and knowledge) to support effective forestry program adaptation in a changing climate. Forest management will need to be more active than current practices, and should be supported with increased investments.

8.1.2: Allocate limited resources to where they will be most useful.
Adopt a triage approach to prioritizing scarce resources. Action on low priority impacts (e.g. species or ecosystems that are not immediately threatened) can be postponed until resources become available, whereas other adaptation actions should be emphasized as high-priority items (e.g. species or ecosystems that will require immediate and constant management to avoid extirpation). Some impacts may even be unmanageable with current resources, in which case it can still be valuable to observe and learn (Lawler, 2009). Low-cost practices with known benefits (e.g. increasing species and structural diversity) should be emphasized over projects with higher upfront costs and greater uncertainty.

8.2 Education & Awareness
There is an integral need for education to support adaptation initiatives in the forestry sector. Whether engaging the public to support citizen science and gather observations, encouraging landowners to consider the impacts of climate change on their plantations or woodlots, or discussing desired tree species with commercial tree nurseries, implementing adaptation actions will not be nearly as effective without increased public awareness.

8.2.1: Maintain an engaged network of stakeholders.
Continue active interagency collaboration with forestry practitioners and the research community to share knowledge, resources and best practices in order to improve adaptation planning and management.

8.2.2: Increase public awareness and appreciation for forestry adaptation initiatives.
Build capacity to monitor and respond to impacts, and secure political buy-in and financial support for adaptation from local communities. Since many factors contributing to climate change vulnerability are social in nature, it is crucial to engage with the public via educational outreach, planting events and communications campaigns in order to raise awareness of climate change risks and the need for adaptation.

8.2.3: Transfer knowledge.
Pursue opportunities for knowledge transfer to community stakeholders, private landowners and forestry practitioners in other organizations. This process may include venues such as workshops, conference presentations, website content and distribution of this report.

8.2.4: Initiate climate change training for forestry staff members.
Ensure current scientific knowledge on climate change is understood by forestry staff and used to inform forest management decisions, as understanding climate change impacts and available adaptation strategies will be crucial for effective on-the-ground implementation. This may include training on up-to-date climate projections for species ranges, adaptation strategy selection, or invasive species identification and safety considerations.

8.3 Planning for the Future
Climate change adds complexity and uncertainty to traditional forest management. A long-term planning horizon is required to manage forest resources over a span of many decades, while the rapid rate of climate change may necessitate increased flexibility in order to respond to new challenges and opportunities.

8.3.1: Incorporate climate change adaptation into forest management planning.
Increasing the climate-sensitivity of forest management objectives should be integrated into all management activities, and climate change should be identified as a priority or guiding theme in strategic planning documents in order to lay the groundwork for undertaking more focused adaptation actions. Managing forests in an increasingly complex, dynamic and uncertain environment is a substantial challenge, but early action is the economically-efficient approach to reducing potential risks and benefitting from new opportunities. Adaptation is the process of recognizing and understanding climate change impacts, planning for their consequences, and undertaking deliberate management efforts to maintain ecosystem integrity. Climate adaptation measures such as facilitated migration, better genetic management and improved forest resilience have been recognized as a necessity. Climate change adaptation actions are consistent with the principles of sustainable forest management, as both share the goal of increasing forest health and resilience in response to external pressures.

8.3.2: Ensure that every project has a well-defined objective.
The LSRCA should be purposeful in ensuring that all forestry projects have well-defined objectives, which will be crucial to selecting appropriate adaptation strategies. The crucial first step for effective adaptation is to set a clear management objective. It is unlikely that adaptation can address all the impacts of climate change or that all present forest values will be preserved, so forest managers will need to make difficult decisions on where to focus efforts and limited resources. Selecting adaptation

strategies that are robust across multiple future climate scenarios will help to minimize the risks of maladaptation. Swanston and Janowiak (2012) outline the following process for planning adaptation:

1) Define area of interest, management goals and objectives, and time frames.
2) Assess climate change impacts and vulnerabilities for the area of interest.
3) Evaluate management objectives, given projected impacts and vulnerabilities.
4) Identify adaptation approaches and tactics for implementation.
5) Monitor and evaluate effectiveness of implemented actions.

8.3.3: Conduct more frequent and intentional reviews of 20-year management plans.

Long-term management plans should be reviewed regularly to revise objectives and account for new information, as weather patterns, species ranges and pest outbreaks have the potential to change quickly and unpredictably in unprecedented ways, making it difficult to achieve stated forest management objectives.

8.3.4: Adopt adaptive management practices.

In an environment of increased uncertainty, encourage policies that are robust over a range of future conditions rather than trying to select the optimal strategy based on an anticipated trajectory. Regular monitoring and assessment of climate adaptation strategies will allow for continuous improvement and course-correction as necessary.

9.1 Species Selection

Selecting appropriate species and seed zones becomes more difficult in a rapidly changing climate.

Practitioners are also concerned about the impacts of climate change on the timing, site conditions and logistics of the spring tree planting season.

9.1.1: Select climatically-appropriate tree species.

To increase the chance of survival, species selection should consider climatic range projections in addition to more traditional factors such as soil type and site tolerances. Favouring climate-suitable species has been identified as a key adaptation strategy for improving ecosystem resilience. Project objectives should inform species selection, and even retreating species should see some continued use for meeting particular goals. A climate-suitable planting list for LSRCA projects has been developed and will be elaborated on in the following sections.

9.2 Tree Planting Logistics

Addressing the unpredictability of site access, changes in growing season length, planting season start dates, and staff resources will require a multi-pronged approach.

9.2.1: Increase the species, genetic and structural diversity of planted stock.

The LSRCA should consider increasing diversity for all planting projects. Trees have different vulnerabilities to a variety of environmental stressors depending on species, genetic composition and age. Overall site resilience will be improved by with a greater emphasis on diversity. To improve a species' genetic resilience at a planting site, local and southerly plants from at least two different southern seed sources should be mixed in the ratio of approximately 50% local, 25% from one seed zone to the south, and 25% from two seed zones to the south.

9.2.2: Consult and collaborate with nursery growers.

Actively engage and collaborate with tree nursery growers to ensure that sufficient site and genetically appropriate stock are available for afforestation projects. Consultation should begin 3 or more years in advance of planting projects to ensure that nurseries are able to collect and propagate the tree seeds required to growing seedling stock for outplanting. Active engagement with nurseries will also facilitate the exchange of information necessary to ensure that afforestation programming continues to be adaptive to climate change.

9.2.3: Modify planting programs to increase flexibility and spread risk.

Projects should allow for greater flexibility in timing and delivery. Spring variability has always been a challenge and industry shifts to accommodate a longer growing season will be gradual, but organizations should begin preparing for the implications. It may be beneficial to conduct large projects over multiple years, bet-hedging against years with unfavourable conditions for establishment. Experimentation and monitoring of different stock types (i.e. seeds, seedlings, or caliper stock), planting timeframes (spring or fall), and site preparation strategies (mechanical, cover cropping, companion plantings) will provide insight on what combination of options results in the best performance.

9.2.4: Prepare for earlier planting timeframe.

While industry shifts to accommodate a longer growing season will likely be gradual, organizations should begin preparing for the implications on labour, program timelines, seedling storage and planting equipment. Variable spring weather has always been a challenge, but an earlier spring thaw and longer growing season has additional implications for nursery stock distribution and labour availability for planting.

9.2.5: Increase post-planting tending activities.

Watering, weeding, mulching, pruning, predator/pest control and vegetation management all have the potential to substantially improve seedling survival and establishment, and while financial and logistical constraints will inevitably limit tending, these activities should be considered based on site conditions and environmental pressures. Monitoring and experimentation can help determine whether such measures will be more or less necessary for particular species. In order to allow tending to occur in the first 3-5 years following planting, programs should be modified to require longer-term commitments from landowners, and secure resources at the time of planting that will support the ability of LSRCA staff to monitor and maintain planted sites (eg. building future management costs into per seedling planting costs).

Appendix II: Tree Planting List

Higher temperatures, a longer growing season, variable precipitation patterns, extreme weather and invasive species are all having significant impacts on our forests now, and we can expect more change and challenges in the future. We know that these changes will impact the survival of our trees and forests, with certain commonly planted species no longer suitable for planting. To increase the chance of survival, species selection should consider climatic range projections, in addition to more traditional factors such as soil type and site tolerances. An initial list of climatically-suitable species options for the Lake Simcoe watershed has been prepared to help guide the LSRCA planting program. Additional details may be found in the *Adapting Forestry Programs for Climate Change* report.

Retreating species are those projected to be unsuitable for our watershed in the coming decades. Continuing to plant these species may be appropriate depending on project objectives, but foresters should be prepared for the potential of reduced growth, shorter lifespans and a lack of natural regeneration. Increased tending activities should help these species establish.

- White spruce (*Picea glauca*)
- Balsam fir (*Abies balsamea*)
- Eastern white cedar (*Thuja occidentalis*)
- Paper birch (*Betula papyrifera*)
- Tamarack (*Larix laricina*)
- Trembling aspen (*Populus tremuloides*)

Enduring species are currently common in our watershed and will continue to be suitable in the future. Southern seed sources will likely prove to be better adapted than native seed over longer time horizons.

- American Beech (*Fagus grandifolia*)
- Black cherry (*Prunus serotina*)
- Maple (sugar, red, silver) (*Acer saccharum*, *A. rubrum*, *A. saccharinum*)
- Oak (red, white, bur) (*Quercus rubra*, *Q. alba*, *Q. macrocarpa*)
- White pine (*Pinus strobus*)

Advancing species options will become suitable to plant in our watershed as the climate continues to warm. Seek out information on a new species' characteristics, planting requirements, growth potential, and how these trees are performing in nearby areas.

- Hackberry (*Celtis occidentalis*)
- Hickories (e.g. shagbark hickory, bitternut hickory, pignut hickory) (*Carya ovata*, *C. cordiformis*, *C. glabra*)
- Southern oaks (e.g. swamp white oak, eastern black oak, Chinquapin oak, scarlet oak) (*Quercus bicolor*, *Q. velutina*, *Q. muehllenbergii*, *Q. coccinea*)
- Sycamore (*Platanus occidentalis*)
- Tulip tree (*Liriodendron tulipifera*)
- Blackgum (*Nyssa sylvestre*)
- Various other Carolinian species

Aside from the species listed here, projections for thousands of other plant species are available through planthardiness.gc.ca. You can explore species-specific maps and models across multiple time periods and climate scenarios, and access detailed information on the modeling process.

Appendix III: Workshop 1 Summary

Climate Change & Forestry Programming

Attendees:

Chippewas of Georgina Island First Nation	Kerry-Ann Charles, Heather Charles
Halton Region Conservation Authority	Meghan Clay, Jennifer Roberts
Ministry of the Environment and Climate Change	Clare Mitchell
Ministry of Natural Resources and Forestry	Bohdan Kowalyk
Nottawasaga Valley Conservation Authority	Alisha Tobola
Severn Sound Environmental Association	Michelle Hudolin
Simcoe County	William Cox
South Simcoe Streams Network	Silvia Pedrazzi
Toronto and Region Conservation Authority	Ralph Toninger
Town of Newmarket	Ruurd van de Ven
York Region	Angie Hutnick, Kevin Reese
Lake Simcoe Region Conservation Authority	Phil Davies (Chair), Alex Cadel, Cory Byron, Bill Thompson

The Lake Simcoe Region Conservation Authority (LSRCA) hosted a workshop on climate change and forestry at their offices in Newmarket on August 3rd, 2017. This summary of proceedings has been prepared for the participants.

Workshop Recap:

Introduction – Phil Davies

Phil opened the workshop by welcoming the participants and providing some background on the project and objectives for the workshop:

- The LSRCA has commenced a study into how climate change will impact its forestry programs, and how these programs might be adapted
- The project has been funded by the Ministry of the Environment and Climate Change (MOECC) to support the Lake Simcoe Protection Plan
- From an initial focus on species selection, the study has expanded to consider implications for afforestation, forest management, managing risk trees, and green infrastructure
- Project recommendations will be implemented into LSRCA program delivery, with an additional focus on sharing results with forestry practitioners in and beyond our watershed
- This workshop has been organized to provide a forum for interactive discussion, the sharing of knowledge and experience, and to obtain input on how we can ensure our work is valuable to the wider forestry community in and around the Lake Simcoe watershed

Climate Change Project Overview – Alex Cadel

To set the stage for dialogue, Alex provided a brief presentation on the fundamentals of climate change and more detail about the LSRCA project being undertaken:

Part 1: Climate Change 101

- Best practices for utilizing climate models and scenarios in adaptation studies were reviewed
- Climate change impacts are being experienced locally and we can project anticipated impacts for the coming decades based on the climate warming to which we have already committed
- Given the long lifespan of trees and the uncertainty over future emissions, it is important to identify solutions which are robust over a range of climate scenarios

Part 2: LSRCA Project

- The primary objectives of this work are to develop a revised tree planting list, incorporate program changes into LSRCA operations and transfer knowledge to other organizations involved in planting or managing trees within the Lake Simcoe watershed and beyond
- We are currently in a literature review and stakeholder consultation phase, which will be followed by preparing recommendations, presenting results and planting and monitoring of specimen trees selected according to study recommendations
- To date, we have completed our internal consultation process and begun examining species-specific climate projections to determine which species are particularly vulnerable or resilient
- Preliminary review of the literature indicates that several species (white spruce was given as an example) will begin to be pushed out of our watershed by mid-century, while the climate will become more suited to a variety of Carolinian species
- We plan to more thoroughly investigate these issues in the coming months through comprehensive literature review and interviews with subject matter experts

Discussion Questions – All

Discussion at the workshop centred around three questions posed to the group. That discussion has been summarized into the broad themes addressed through each question, with a brief description of the major points raised for each. Due to timing constraints we were unable to have a full discussion of Question #3, but the dialogue and input we sought was largely captured in Questions 1 and 2. We did also receive a few specific responses to Question 3, which have been included.

Question #1: In consideration of the impacts that climate change will have, what concerns do you have with respect to your ongoing forest management and/or tree planting programs?

1) **Resource scarcity**: Whether through dealing with impacts or adapting programs, addressing climate change will require a variety of resources. Forestry practitioners are concerned about having adequate funding, time, staffing, nursery stock and knowledge to be able to implement changes, provide enhanced tree maintenance and rapidly adapt to unexpected conditions.

2) **Impacts on forest health**: Climate change threatens the longevity of trees in natural forest stands, plantations and urban settings due to altered species ranges and damage from extreme weather

events. Of particular concern are the increasing risks of new or exacerbated infestations of various pests, insects and diseases. Those involved in managing forests are additionally concerned about how to manage stand structure and resiliency, and sustainable harvesting in an uncertain future.

3) **Degraded forest value**: Beyond the value of individual trees, forests provide a multitude of essential ecosystem services that may become more vulnerable with climate change. Another concern, therefore, is how to preserve the ecological integrity, biodiversity and habitat composition of forest ecosystems. Climate change also threatens culturally significant tree species, compromising the collection of foods and medicines, as well as traditional First Nations practices.

4) **Tree planting logistics**: With the potential for a rapidly changing climate, forestry practitioners are concerned about selecting appropriate species and seed zones for planting. Maintaining the diversity of long-lived, locally adapted trees in the natural and urban forest will strongly depend on seed quality and availability. Practitioners are also concerned about the impacts of climate change on the timing, site conditions and logistics of the spring tree planting season.

5) **Education & awareness**: There is an integral need for education to support adaptation initiatives in the forestry sector. Whether engaging the public to support citizen science and gather observations, convincing landowners to consider the impacts of climate change on their plantations or woodlots, or discussing desired tree species with commercial tree nurseries, implementing adaptation actions will not be nearly as effective without increased public awareness.

Question #2: What actions has your organization taken (or plan to take) to address these concerns?

1) **Strategic planning**: One action many organizations have taken is to address climate change in the planning process, whether through a forest management plan, urban forest master plan, climate adaptation strategy, or other similar strategic planning document. At this broad scale climate change is often identified as a priority or guiding theme, laying the groundwork for undertaking more focused adaptation actions.

2) **Adaptations to tree planting programs**: Organizations are experimenting with modified approaches to their tree planting programs, including greater flexibility in the timing of spring planting projects, increasing the species and size diversity of planted stock, and sourcing stock from more southerly seed zones. Several organizations have begun assisted migration trials through limited planting of Carolinian species such as tulip tree, sycamore and bur oak, with varying levels of success thus far. There is also a growing recognition that enhanced monitoring and tending programs will be required to improve tree establishment.

3) **Collaboration & education**: Numerous comments focused on the desire to build partnerships, coordinate efforts, share information, support research and otherwise collaborate with other organizations as we work towards a common goal of addressing climate change in our forestry programs. From the groups who are already actively working towards adaptation to those who are

just starting out, everyone is interested in improved collaboration and education to share best practices and integrate recommendations into programs.

Question #3: What additional information would you find helpful in assisting you to make your decisions/recommendations?

The following responses were provided by participants:

- A list of resources to help us inform our decisions, potentially as an annotated list of reference material for practitioner use
- It would be useful to know the percentage of our planting mix over the past 5, 10, or 20 years
- Are there any parallels between the changes in forest composition that occurred after the last glaciation (in the warming period known as the hypsithermal) and future climate change?

Next Steps – Phil Davies

Phil thanked participants for their participation in the workshop and provided a brief overview of next steps for the study:

- The LSRCA will be reaching out to additional forestry practitioners who were unable to attend this workshop, in addition to engaging with stakeholders in tree nurseries and academia
- Project work will continue with the literature review process and developing recommendations, with a focus on exploring the themes and questions raised through the workshop
- A second stakeholder session will be held once the project has been completed in order to share results and recommendations
- Tree planting trials will be implemented and monitored starting in the spring of 2018

Appendix IV: Workshop 2 Summary

Adapting Forestry Programs for Climate Change

Attendees:

Barrie	Kevin Rankin
Conservation Ontario	Rick Wilson
Chippewas of Georgina Island First Nation	Heather Charles
Credit Valley Conservation	Rod Krick
Dufferin County	Caroline Mach
Forest Gene Conservation Association	Melissa Spearing
Forests Ontario	Kerry McLaven
LEAF	Brenna Anstett
Ministry of the Environment and Climate Change	Clare Mitchell
Ministry of Natural Resources and Forestry	Bohdan Kowalyk
Nottawasaga Valley Conservation Authority	Rick Grillmayer, Alisha Tobola
Severn Sound Environmental Association	Michelle Hudolin
Simcoe County	Will Cox
Somerville Nurseries	Dave Harbec
South Simcoe Streams Network	Silvia Pedrazzi
Toronto and Region Conservation Authority	Andrew Chaisson
York Region	Kevin Reese
Lake Simcoe Region Conservation Authority	Phil Davies (Workshop Chair), Alex Cadel, Cory Byron, Bill Thompson, Susan Jagminas

The Lake Simcoe Region Conservation Authority (LSRCA) hosted a workshop entitled Adapting Forestry Programs for Climate Change at the Old Town Hall in Newmarket on December 1st, 2017. This summary of proceedings has been prepared for the participants.

Workshop Recap:

Introduction – Phil Davies

Phil opened the session by welcoming the participants and providing some background on the project and objectives for the workshop.

- The LSRCA has conducted a study into how climate change will impact its forestry programs, and how these programs might be adapted.
- The project has been funded by the Ministry of the Environment and Climate Change (MOECC) to support the Lake Simcoe Protection Plan and Lake Simcoe Climate Change Adaptation Strategy.
- Work has included literature review and stakeholder engagement via workshops and interviews.
- Project objectives include a revised tree species list, adaptation strategies for tree planting, forest management and tree risk management, and ongoing knowledge transfer.

- Workshop objectives were to:
    - Share results of the research project and proposed adaptation strategies; and
    - Provide a forum for discussion of practical applications for forestry program delivery.

LSRCA Project Part I: Impacts of Climate Change & Planning for the Future – Alex Cadel

Alex discussed the numerous impacts climate change will have on forests, and how planning for the future is crucial to selecting appropriate adaptation strategies to address these impacts.

- Effectively implementing forest adaptation in an uncertain future will require an increased focus on intentional objective-setting and adaptive management.
- Reviewed downscaled climate projections for the Lake Simcoe watershed, highlighting the major temperature and precipitation trends driving ecosystem changes.
- Impacts and adaptation strategies were discussed for a number of topics, including ecosystem disequilibrium, extreme weather, biological stressors, carbon sequestration, forest values, silviculture, and hazard trees.

Findings from Central Ontario Forest Adaptation Report – Melissa Spearing, FGCA

Melissa reviewed some of the work the FGCA has done on climate change with the SFL holders in Central Ontario, and discussed the critical importance of tree seed for climate change adaptation.

- The FGCA has developed climate change adaptation principles to guide foresters in addressing concerns, avoiding the worst outcomes, and enhancing resilience.
- Reviewed artificial seed banking practices compared to needs in Ontario, the importance of source-identified seed, and the FGCA's efforts to build a "climate-ready" seed source network.
- Examples given of seed procurement maps for future time periods, which are being used to direct the FGCA's work on implementing assisted migration trials for southern seed sources.

LSRCA Project Part II: Species Selection in a Changing Climate – Alex Cadel

Alex provided an overview of the challenges facing tree planting, and demonstrated how the LSRCA will be making use of available science and modeling data to inform future species selection decisions.

- Selecting suitable tree species and seed zones becomes more difficult in a changing climate, and there will be greater uncertainty related to certain operational aspects of afforestation.
- The revised LSRCA planting list will include consideration of species-specific climate projections, identifying species that are retreating, persisting, or advancing into our watershed. Species selection should be closely aligned with project objectives.
- Organizations should recognize the importance of responsible forest genetic management, and support these practices where possible.
- Unfavourable conditions for tree establishment will become more common, meaning that projects focused on flexibility, spreading risks, and increased tending activities are more likely to be successful.

Assisted Migration in Practice – Will Cox, Simcoe County

Will discussed an assisted migration trial conducted at Simcoe County's Packard Tract in 2013, in collaboration with the FGCA and other partners.

- A great deal of planning went into the trial setup and layout, with over 1,400 trees on the 1.2ha site planted in alternating blocks for each stock type. These included bur oak and red oak from seed zones 36, 37 and 38 in Ontario, in addition to bur oak from Illinois and Tennessee.
- Project goals included monitoring and data collection of tree growth and phenology, as well as establishing a seed source for future seed collection.
- Despite the robust study design, site preparation and careful planting, the plantation failed and could not continue due to a significant infestation of European chafer grubs. Efforts were made to address the grubs and recover the project, but it was ultimately abandoned and planted with more conventional conifer species. All partners remain interested in further assisted migration trials.

Environment Connections – Rick Wilson, Conservation Ontario

Rick (presenting on behalf of Karissa Reischke) introduced us to Environment Connections, an online collaborative resource hub developed by Conservation Ontario.

- Environment Connections is a web-based ArcGIS platform that can help different user groups report and collaborate, with a variety of features to support data collection and sharing.
- Rick provided examples of how Environment Connections has been used in other projects (links can be found in the attached presentation).
- With a strong desire for collaboration on climate change issues in the forestry community, a platform like Environment Connections could be a useful tool for sharing spatial information between different organizations (for example, on assisted migration trials across the province).

Next Steps – Phil Davies

Phil thanked participants for their participation in the workshop and provided a brief overview of next steps for the study:

- Completion of our final report is on track for late-January, and will be shared with interested stakeholders at that time.
- Content on climate change and forestry will be made publically available on the LSRCA website.
- Tree planting trials will be implemented and monitored starting in the spring of 2018.
- Knowledge transfer will continue with presentations at several conferences and symposia.