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Sugar Bush Management in Ontario: Identification of Resilient Adaptation Strategies for a Changing Climate

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Abstract

The purpose of this research is to gain a better understanding of human-facilitated silvicultural, biodiversity and genetic forest management in Ontario sugar bushes through a biogeographical lens to determine the social and ecological resilience to climate change impacts. Because sugar bushes are highly managed and therefore ecologically different than unmanaged sugar maple forests, a literature review combined with primary farm-level research will help to determine best management practices and adaptation decision-making to increase the resilience of these stands.

Interview results suggest that the effects of climate change are already being seen at the local level. In the last 10 years, producers have experienced seasonal fluctuations with extended warm periods in the winter followed by extreme cold periods, an increase in the frequency of extreme storm events such as microbursts, changes in species composition as a result of pests and disease like EAB and beech bark disease, over thinned areas of the forest becoming colonized by invasive plant species and a general shift in the tapping season two weeks earlier in the spring.

The overarching conclusion is that maple syrup producers in Ontario need to entrench climate change objectives within forest management. Enhancing adaptive capacity is a continually evolving process that producers need to undertake as environmental conditions change. Short-term adaptation methods like increasing inter- and intra-species diversity, removal of diseased trees and the overall maintenance of forest health are being practiced by many producers with room for improvement in others. Long-term adaptation methods relating to biogeography such as assisted population expansion, assisted range expansion, seed sourcing and provenance and restoration planting are not common among producers in the present but have the potential to be practiced more widely in the future. More research is needed on some of the long-term adaptation strategies but the time to enhance adaptive capacity is now.

Acknowledgements

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1.0 Problem Statement

The impacts of a changing climate on global forest ecosystems is an expanding area of research. Forest ecosystems have a major role in the global terrestrial carbon sink, sequestering approximately thirty percent of all CO_2 emissions annually as well as storage of carbon (Brown, 2009; Canadell and Raupach, 2008). Though forests are important in the mitigation of CO_2 emissions, they are at risk of many climate change impacts: ecologically, economically, and socially (Brown, 2009). Forests are extremely vulnerable to changes in climate due to their longevity. This longevity defines the need for long-term resiliency and provides a long-term context for current management decisions (Murphy et al., 2012). Climate change in a Canadian context will broadly increase average summer temperatures, alter precipitation patterns, and cause tree stress that will influence natural forest disturbance regimes (Colombo, 2008). This could be seen in the increase the prominence of pest and disease outbreaks, higher susceptibility to wildfire, decreased ecosystem resilience and altered age structures potentially resulting in novel communities for which there is no current management experience (Parker, 1998). Sugar maple (*Acer saccharum*) biogeography has been studied using GIS, modelling and pollen records on a broad scale. The major conclusions of these studies have been that the species may decline in the southern portion of its range and migrate northward in the future (Lamhonwah, 2011). However, this northward migration will be inhibited by conditions of the Canadian Shield, moisture stress, and reproductive rates under high temperatures (Lamhonwah, 2011).

Sugar maple forests are important in Ontario and Quebec for a variety of socio-ecological reasons. However, there is little climatological data or academic research about the impacts of climate change focused on the St. Lawrence-Great Lakes forest region; particularly those located between southern deciduous and northern boreal forest zones (the Near North), on rural woodlot landscapes, and on Indigenous traditional territories and reserves (Murphy et al., 2012). Further, while climate change projections outline the broad effects across entire regions, the impact on Canadian localities is an under-studied question, locally-specific climatological data is often lacking, and even less is known about locally-appropriate resilient adaptation strategies. Forest management options in light of climate change are important to consider, especially pertaining to assisted population expansion and assisted range expansion. Knowledge gaps here relate to adaptation decision-making. Research is needed on long-term provenance field trials to determine the climate tolerance of each seed source for optimal assisted migration strategies, and on the physiological responses of Canada's tree species to climate change in order for forest managers to match site conditions with species characteristics (Johnston et al., 2010; Johnston et al., 2009). These factors provide context for this study to evaluate the resilience of current sugar bush management and maple syrup production practices to climate change and to identify strategies for human-facilitated resilient adaptation in sugar maple ecosystems. This research aims to fill in some of the knowledge gaps that exist at a smaller scale for applicability to maple syrup production managers, forest managers, and other stakeholders. While this research is conducted in an Ontario context, many of the short and long-term management options are likely transferrable to other maple syrup producing localities. Ideally, the outcome of this research will influence adaptation strategies to increase forest resilience and sustainability in the maple syrup industry.

2.0 Purpose and Objectives

The purpose of this research is to gain a better understanding of human-facilitated silvicultural, biodiversity and genetic forest management in Ontario sugar bushes through a biogeographical lens to determine the social and ecological resilience to climate change impacts. Because sugar bushes are highly managed and therefore ecologically different than unmanaged sugar maple forests, a literature review combined with primary farm-level research will help to determine best management practices and adaptation decision-making to increase the resilience of these stands. Objectives are as follows:

1. Based on literature review and a biogeographic standpoint, outline a set of initial practices or principles that would tend to lead towards social and ecological resilience of sugar bush stands facing the impacts of climate change.
2. Conduct research to assess the extent to which the management of Ontario's sugar bushes aligns with the outlined practices for incorporating climate change adaptation into forest management.
3. Provide an assessment and recommendations regarding short-term and long-term forest management strategies including: enhancement of inter- and intra-species diversity (where applicable), selective thinning, restoration planting, seed sourcing and provenance, and assisted migration.

3.0 Literature Review

3.1 Introduction

Climate researchers have predicted that the twenty-first century will lead to large regions of current habitat becoming unsuitable for resident tree species, putting many in danger of extinction (Pereira et al., 2010; Dawson et al., 2011). Climate change is projected to cause dramatic change in tree species diversity in regions of North America (McKenney et al., 2011). Though complete extinction is an unlikely scenario for some Canadian species, climate change is expected to produce widespread biodiversity changes in local communities (Cain et al., 2011). Even forested environments that are not considered water-limited are at risk of climate stress (Allen et al., 2010). Increasing climate variability has the potential to affect the composition, structure, resilience and distribution of North American forests over the next century with species level responses on population size, distribution, and phenology (Allen et al., 2010; Brown, 2009; Parmesan, 2006).

There is particular concern about the impact of climate induced physiological stress and disturbance, such as wildfire and insect outbreaks on rates of tree mortality (Allen et al., 2010). These impacts affect ecosystem services from forests and threaten to release stores of sequestered carbon into the atmosphere (Allen et al., 2010). There are three possible outcomes for tree species in light of climate change: survival by migration to track ecological niches spatially; adaptation to new conditions in current locations; and extirpation (Aitken et al., 2008; Leimu et al., 2010). Adaptive capacity and migration will likely favor species in larger populations with high reproductive capacity, as well as those with more rapid seed and pollen dispersal rates (Aitken et al., 2008). In a North American context, wind-dispersed trees are expected to lag behind the projected climate shift (Nathan et al., 2011). This is because seed release is dependent on more factors than wind speed, and high survival rates are unlikely to occur at a great distance from the seed source (Nathan et al., 2011). Plant responses to climate change are compromised by the genetic problems associated with increased fragmentation, resulting in the need for stronger human intervention than in populations that are not fragmented (Leimu et al., 2010). One important tree species to consider is the sugar maple.

The sugar maple (*Acer saccharum)* is an important species in the northeastern United States, Ontario and Quebec for a variety of socio-ecological reasons, especially because it is the main source of maple syrup production. The northern edge of the sugar maple range extends from Nova Scotia and Quebec, west through Ontario to southeastern Manitoba. In the United States, the sugar maple is most common in the Great Lakes states, including New England, New York, Ohio and Pennsylvania (**Figure 1**). The distribution of the sugar maple species has been studied using modelling, forest inventory data and pollen records on a broad scale, with an overarching conclusion that the species may decline in the southern portion of its range and migrate northward in the future (Lamhonwah, 2011). Seed dispersal for the sugar maple is primarily wind based, which can carry seeds up to 100m. Further dispersal may rarely occur with significant implications for colonization. However, seed travel more than 15m from the forest edge is unlikely (USDA Forest Service, 2013). The northward migration of the sugar maple

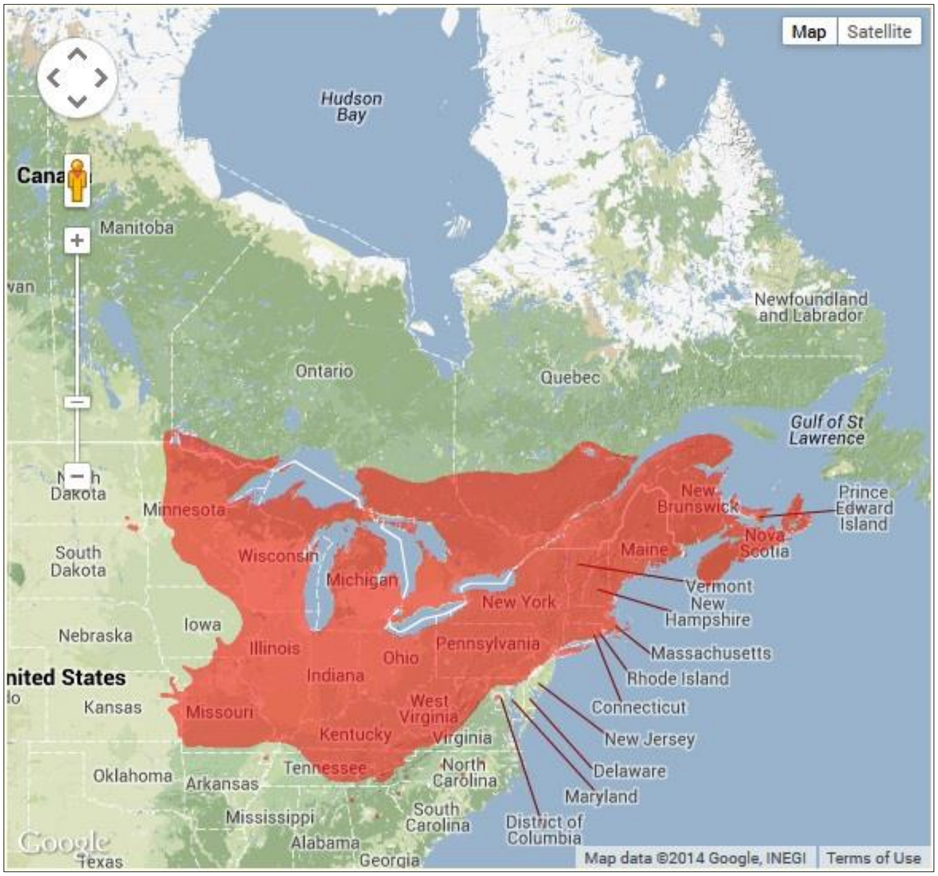

Figure 1 Current Range Map: *Acer saccharum* habitat in North America
Source: Google, 2014; Plantmaps, 2014; Canadian National Climate Data Archive

range will also be inhibited by conditions of the Canadian Shield, moisture stress, and reproductive rates under high temperatures (Lamhonwah, 2011).

3.2 Forest Responses to Climate Change Impacts

Forests are highly impacted by climatic factors including: air temperature, solar radiation, atmospheric CO_2 concentrations and precipitation, all of which drive forest dynamics and productivity. The opposite is also true because forests help to control climate change by sequestering carbon from the atmosphere and releasing it through evapotranspiration and the reflection or absorption of solar radiation (Allen et al., 2006; IPCC, 2014). Disturbance regimes greatly influence species composition in forest ecosystems through resource availability and sources of seed that are available to colonize (Parker, 1998). Widespread tree mortality and forest dieback as a result of temperature stress and drought have been documented on all vegetated continents (Allen et al., 2010; IPCC, 2014). Forest dieback has influenced forest demographics in terms of structure, age, and species composition leading to decreased species diversity and risk of colonization by invasive species (IPCC, 2014). Changes in demographic rates of forest communities, especially mortality, indicate that climate-mediated changes are occurring over longer time periods (Hogg & Bernier, 2005; Lemmen et al., 2008; Williamson et al., 2009).

Forest resilience in North America is important for a number of ecological, social and economic reasons. Impacts such as increasing temperatures, evapotranspiration and drought; changes in precipitation patterns; and increased vulnerability to natural forest disturbances, such as insect outbreaks are likely to stress sugar maples and cause notable decline in the southern portion of their ranges (Carlson, 2009; Murphy et al., 2009; Murphy et al., 2012). The results of the Hadley and Canadian Climate models predict an extirpation of *Acer saccharum* as well as other northern hardwood and boreal forest species throughout the Northeastern United States creating a favorable environment for forest dominated by oak, hickory and pine species (Perkins, 2007). However, it is important to note that there are other *Acer* subspecies that may be more adaptable to projected climate change. For example, *Acer saccharum* and subspp: *floridanum, nigrum,* and *grandidentatum* all respond differently to environmental factors. Skeptner and Krane (1998) argue that *A. saccharum* (sugar maple) and *A. nigrum* (black maple) are genetically indistinct. For sugar bushes, this could mean the possibility of seed from *A. nigrum* being planted and tapped as *A. saccharum* becomes extirpated throughout the southern portion of its range. To that end, ‘big tooth maple’ subsp. *grandidentatum* which is already adapted to drought and heat adapted ‘Florida maple’ subsp. *floridanum* (Grimm, Denk & Hemleben, 2007) may be pushed into *A. saccharum’*s current range, likely through assisted migration. It is unclear whether subsp. *grandidentatum* and subsp. *floridanum* would be viable for maple syrup production. However, this presents an interesting avenue for future research regarding the production of maple syrup using *Acer* subspecies that may be better adapted to climate change impacts in different geographic areas.

Climatological trends in the northeastern U.S. project a greater rate of warming between December and February, with an average increase of eight days in the growing season (Farrell & Chabot, 2012). A decrease in snow to total precipitation ratios as well as an increase in extreme precipitation event frequency is also projected, which would have a great impact on the sugar maple species (Farrell & Chabot, 2012). Warming temperatures and increased precipitation rates could increase turnover rates within the species, causing rapid growth, increased mortality and elevated recruitment (Zhu et al., 2014). Climate change is projected to increase average summer temperatures the most in northeastern Ontario between 3°C and 6°C, but decrease average summer temperatures in the southern and northwestern regions (Brown, 2009). Coupled with little to no precipitation increase, these temperatures could result in higher severity of drought and the occurrence and variability of extreme weather events (Brown, 2009).

Because they are so dependent on the natural environment, resource-based and non-timber forest product sectors are highly vulnerable to extreme weather events (Belliveau et al., 2007; Murphy et al., 2012; Parkins, 2008). A small-scale survey of maple syrup producers in Ontario showed that respondents were already experiencing high levels of variability in a number of weather factors such as daily temperature fluctuations, changes in precipitation and storm violence (Murphy et al., 2012). An increase in weather related natural disturbance is likely to impact forest product markets on a global scale (Brown, 2009). One example of extreme weather impacts in an Ontario context is the 1998 ice storm in Eastern Ontario that caused long term impacts on the sugar maple population (Noland et al., 2006; Murphy et al., 2012).

Distribution changes under climate change has the potential to impact the ecological resiliency of a forested ecosystem because species compositions and genetic diversity are likely to be altered, leaving the ecosystem more vulnerable to natural disturbance (Colombo, 2008; Johnston et al., 2009). The key factors of ecosystem health that are a growing concern for maple syrup production are air pollution, invasive species and anthropogenic climate change (Colombo, 2008; Johnston et al., 2010; Lamhonwah, 2011; Murphy et al., 2012). One invasive species that is important to mention here is garlic mustard (*Alliaria petiolata*), a nonnative invasive biennial flowering plant that is currently invading the understory of North American woodlands (Prati & Bossdorf, 2004). This is important in the context of maple syrup production because garlic mustard is also allelopathic, meaning it produces chemicals that inhibit the growth of other plants and tree seedling survival (Prati & Bossdorf, 2004). Norway maple is also associated with reduction in the regeneration success of sugar maple and other flora because it has greater photosynthetic capacity and grows larger in stem diameter than the sugar maple (Paquette et al., 2012). The invasiveness of the Norway maple is maximized following canopy disturbance because of this competitive advantage, and considering the impacts of climate change on canopy disturbance already being seen, this invasiveness may increase in the future (Paquette et al., 2012).

Changes in Ontario's climate may lead to changes in insect population dynamics and drought conditions which are feared to affect the structure, composition, function and health of forest stands (Flannigan, 1998; Lamhonwah, 2011; McAlpine, 1998, Scarr, 1998; Woods, 2004). Ontario's forests are therefore threatened by a variety of disturbance and environmental stress including: changing precipitation patterns, increased evapotranspiration and drought, increased vulnerability to pest outbreaks and other stochastic events (Carlson, 2009; Murphy et al., 2009; Murphy et al., 2012). In the long-term, however, climate-induced geographic range shifts or 'migration' becomes a more pressing issue.

3.3 Climate-Induced Geographic Range Shifts

Climate change will cause tree populations to become progressively less well adapted to the environment in which they grow. Temperature increase will likely cause a shift in plant species' ranges towards higher altitudes and the poles based on the climate threshold of the species (Johnston et al., 2009; Thomas & Packham, 2007). Because of this, they will need to either adapt in place to the changing conditions or migrate to a habitat with more suitable conditions (Johnston et al., 2009). It is important here to define migration in the context of plants. Because plants are not mobile, the term 'migration' here is used to describe the impact of differential survivorship, during and after a period of environmental change (Taggart & Cross, 2009). This phenomenon is species-specific and typically occurs as a combination of relative competitiveness and reproductive success of a species (Taggart & Cross, 2009). For example, a northerly migration of plants would be the end result of competition and reproduction becoming more successful to the north and less successful in the southern portion of the species' range (Taggart & Cross, 2009). Migration is not only evolutionary success, but also successful competition relative to both native and non-native species and invasive species.

Tree species with high fecundity, short generation times and longer distance pollen flow are likely to adapt to a changing climate more successfully (Johnston et al., 2010). These types of characteristics are commonly seen in pioneer tree species that thrive during events of habitat disturbance (Aitken et al., 2009; Johnston et al., 2010). More frequent disturbance is expected in many regions of Canada, which would theoretically encourage the success of pioneer species in the future (Flannigan et al., 2005; Johnston et al., 2010). Range expansions depend on the populations at the leading edge or colonization front (Hampe, 2011). In addition to this, range expansions will be more likely in species that are able to disperse their seeds over long distances and along similar pathways which would ensure that the new area receives colonizing plants with sufficient abundance and frequency to be successful (Hampe, 2011; Lachmuth et al., 2010). Many tree species have insufficient means of seed dispersal to move seed up to several thousand meters per year to keep up with the projected rates of climate change (Davis & Shaw, 2001; Johnston et al., 2009). A reduction in local biodiversity could occur as a result of the lag between regional climatic changes and species response (Lemmen et al., 2008; Malcolm et al., 2002). Landscape fragmentation in developed areas, urban and agricultural development, and a lack of suitable soil conditions are also barriers to seed dispersal (Johnston et al., 2009).

Climate change can be expected to result in new ecosystems from those that currently exist, which may make the existing concepts of 'naturalness' meaningless. Most modern concepts of plant communities therefore reflect the role of individual competitive interactions and are not viewed as a having a fixed biological composition (Taggart & Cross, 2009; Thorpe et al., 2006). Instead, focus should be turned to maintaining resiliency, diversity and connectivity within ecosystems (Johnston et al., 2010; Thorpe et al., 2006). This theory is supported in an Ontario context by paleo ecological evidence showing the presence of deciduous forest as far north as Timmins (Lemmen et al., 2008; Liu, 1990). However, establishment is difficult in many cases because trees also have to compete with the species currently residing in the new habitat (Johnston et al., 2009).

The general picture of species distribution change is relatively consistent, projecting a northward shift of present-day climate zones up to 5000 meters per year under climate change projections (Johnston et al., 2009; Malcolm et al., 2005). With 2°C warming projected globally by 2040-2050, this could shift species abundance and distribution throughout Ontario (Malcolm et al., 2005). The regions of Southern Ontario, Quebec and the Maritimes are projected to shift 250-600km northward in climate zones suitable for many hardwood species by 2100 (Johnston et al., 2009). This means that species currently growing only south of the U.S. border may migrate northward into the region (Johnston et al., 2009). Malcolm et al. (2005) project losses of suitable habitat for sugar maple in Central Ontario, with the potential in the long-term for replacement by more southerly hardwood species, accounting for soil conditions, topography and current land-use. The average dominance is projected to decline from 15 to 11-14% (Malcolm et al., 2005). Also in this study, maple-dominated forests had a tendency to move northward, most notably in the region east of Lake Superior (Malcolm et al., 2005). Similarly, McKenney et al. (2007) use a climate envelope approach, estimating a shift in latitude of 8.9 degrees for sugar maple under a full dispersal scenario.

Some studies suggest that the core populations of sugar maple in Ontario would be preserved under most of the projected climate scenarios (McKenney et al., 2007) however, other studies indicate that current sugar maple stands are at serious risk of decline (Johnston et al., 2010; Malcolm et al., 2005). McKenney et al. (2011) modelled current and future climate tree envelope species richness for forests in North America using six different models. For Ontario, the greatest illustrated difference can be interpreted in the southern portion of the province, which would affect sugar maple forests (McKenney et al., 2011). A study by Lamhonwah (2011) took a GIS-based approach to model the response of sugar maples in Ontario to future climate projections, taking into account the SRES A1B, A2 and B2 scenarios and using maximum summer temperature, minimum spring temperature and annual precipitation as limiting factors. Consistent with the findings of Johnston et al. (2009) and Malcolm et al. (2005), this study found that sugar maples in Ontario will see an impact by the start of the 2041-2070 projection, with Southern Ontario the most susceptible (Lamhonwah, 2011). By 2100, the model projects northward migration of the sugar maple range towards the Hudson Plains border. In addition to this, Northern Ontario will develop suitable growing conditions for the species where it does not currently grow (Lamhonwah, 2011).

One major limitation to geographic range shifts is land use. Urbanization and agriculture increase fragmentation in the landscape, which can affect gene flow among populations (Davis & Shaw, 2001; Bailey, 2007). In Southern Ontario, wherein the populations are often fragmented due to higher human population density, species migration rates are highly dependent on dispersal capacity over long distances, between patches (Jacquemyn et al., 2003; Johnston et al., 2009). However, long distance dispersal events rarely exceed 100-200 meters per year (Johnston et al., 2009). Even these rare long distance dispersal events are unlikely to drive successful natural colonization in new regions at a large scale (Johnston et al., 2009). Therefore, there is inherent interplay within distribution patterns relating to fragmented landscapes between the areas of suitable habitat for a given species, species specific rates of migration between habitat patches, and species resilience in local habitats (Jacquemyn et al., 2003).

3.3.1 Sugar Maple Distribution Changes

Increasing surface air temperature and precipitation pattern changes will threaten forests with moisture-related stresses (Hogg & Bernier, 2005; IPCC, 2014). Because sugar maples have shallow rooting systems, they are susceptible to these moisture-related stresses and are vulnerable to flooding during the growing season (Bertrand et al., 1994; Burton et al., 1998). In addition to this, soil acidification can weaken the resistance of sugar maple to environmental stress (Duchense et al., 2002). When the growing conditions for the sugar maple species are linked with the climate change projections for Ontario, there is a strong indication that the species is vulnerable to climate change impacts (Lamhonwah, 2011).

Drought and warmer winters are suitable conditions for northward range expansion for the sugar maple though it is limited by moisture regime and shallow soils (Barkley, 2007; Lamhonwah, 2011; Luzadis & Gossett, 1996; University of British Columbia, 2009). Determining the scale of ecological responses to increased temperature and drought by deciduous forest species would be useful for future forest management. Observations of plant behaviour and interaction within the forest ecosystem are important to link physiological processes to long-term forest resilience (Colombo, 2008). The ecological issue remains that the conditions of the Canadian Shield such as shallow and often acidic topsoil and steep slopes will impede the ability of sugar maples to grow in more northern locations (Duchense et al., 2002; Lamhonwah, 2011). In addition to this, the migration of the species will also be highly dependent on the adaptation strategies in place. For example, higher temperatures have reportedly decreased germination and establishment of seeds in northern regions, which may inhibit regeneration capacity of sugar maples if they are to migrate north (McCarragher, 2009; Murphy et al., 2012). Recent declines in maple syrup production highlights the need for research on the impacts of climate change on sap flow, quality, and quantity of maple syrup production (MacIver et al., 2006).

Climate change has the potential to affect sugar maple ecosystems and the future of the maple sector in Ontario and Canada in general. Climate-induced changes that the maple sector may face include: earlier tapping dates because bud-burst is occurring earlier in the year (Johnston et al., 2009), reduced sap flows due to mid-winter thaws, shorter seasons, excessive summer heat, canopy damage from extreme weather events, and changes in insect population dynamics (AAFC, 2007; EcoResources, 2013; OMSPA, 2013). The maple syrup industry is especially vulnerable to changes in climate thresholds since the tapping of sugar maple trees begins forty to fifty years into their lifespan (Farrell, 2013). Because sap exudation is dependent on the size of the tree (among other factors), survivability in a given habitat for a long period of time is necessary for the tree to be successfully tapped (Farrell, 2013). Global climate models have indicated that snow packs are predicted to develop later with an earlier melting period (MacIver et al., 2006). The extirpation of sugar maple from the eastern United States can be attributed to the lack of sufficiently low temperatures to break bud dormancy along the southern edge of the current range (Chuine and Beaubien, 2001; Kozlowski et al., 1991; Whitney & Upmeyer, 2004) along with other factors associated with a changing climate such as heat stress, drought conditions and lack of precipitation. Another important factor to consider is invasive species. Invasive species success is a result of flexible ecology and genetics during colonization (Petit et al., 2004).

3.4 Implications for the Maple Syrup Industry

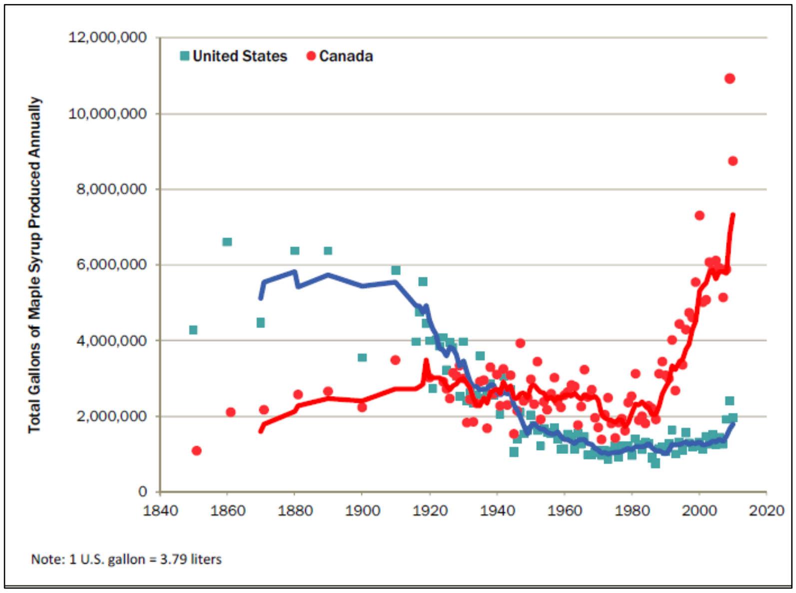

Figure 2 ***Maple Syrup Production in the US and Canada 1860-2010***
Source: Farrell & Chabot, 2012

Maple syrup production has been shifting from the U.S. to Canada since the 1940s (see **Figure 2**). In the U.S., New England and New York used to make up 80% of the total global maple syrup production and 20% came from Canada (MacIver et al., 2006). Since then, there has been a significant increase in Canadian maple syrup production, with Quebec accounting for 93% of Canada's national production (MacIver et al., 2006). There has been a 70% growth in the Canadian maple syrup industry over the last 80 years according to Statistics Canada, making it the largest global producer of maple products at $349.5 million in 2011, up 20.1% from 2010 (Statistics Canada, 2013; Whitney & Upmeyer, 2004). Ontario produces an average of 3.9 million litres of syrup annually as of 2011, with 2750 active maple producers throughout the province; making it the second largest producer in Canada, following Quebec and ahead of New Brunswick (EcoRegions, 2013; OMSPA, 2013). The maple syrup industry in Ontario produced 2.2 million litres of syrup in 2011 worth $32 559 million. Ontario's maple sector has a tendency for producing value added specialty products as well as a competitive advantage due to its proximity to urban centers and the United States market (EcoRegions, 2013). Maple syrup production occurs throughout the province but creates the most wealth in the Eastern and Southwestern regions of Ontario (EcoRegions, 2013; OMSPA, 2013).

The trend in maple syrup production has changed dramatically over the last fifty years. A significant decline in syrup yields has already occurred in the U.S., associated with warming spring temperatures and increased frequency of summer droughts (Tyminski, 2011). The northeastern U.S. has seen declines in syrup production since the mid-20th century, some of which can be attributed to various environmental and climatic factors including: forest pests and disease, elevated CO_2 levels, ice storms, droughts, nitrogen leaching, decreased snow cover, and increasing minimum and maximum temperatures during the spring (Tyminski, 2011). The New York and New England tapping season now begins about 8.2 days earlier in the year than it did 40 years ago, resulting in a season that is 3.2 days shorter; a loss 0f 10% over the 40 year period (Perkins, 2007). These changes are consistent with the overall changes in the regional climate during the same time period (Perkins, 2007). As optimal meteorological conditions for maple syrup production continue to decrease in the traditional production regions, it may no longer be economically viable for some of hobby producers and some commercial producers to continue production (Perkins, 2007; MacIver et al., 2006; Tyminski, 2011).

Maple syrup production is dependent on the quality and quantity of sap flow from the tree. *Acer spp.* develop stem pressure in a unique way that is highly dependent on temperature (Cirelli et al., 2008) and therefore vulnerable to climate change impacts. For sugar maples, sap flow requires adequate freeze-thaw cycles to produce a negative pressure in the tree causing water uptake from soil, followed by thaw-induced positive pressure causing sap flow from tap holes (Cirelli et al., 2008; Farrell, 2013; Wilmot, 2006). The expansion of gas compressed in air-filled cells within the tree occurs during freezing, followed by the stabilization of this compressed gas through osmotic pressure from sucrose accumulation (Farrell, 2013; Skinner et al., 2010). In addition to this, exudation volume post freeze-thaw is positively correlated with the concentration of sucrose in the sap, tree size, duration and rate of freezing, atmospheric pressure, and temperature during the thaw period (Cirelli et al., 2008; Farrell, 2013). Climate change has the potential to alter this process by making tapping dates occur earlier in the year, shortening the sugaring season, and reducing sap flows due to mid-winter thaws (AAFC, 2007; EcoRegions, 2013; OMSPA, 2013). Difficult growing conditions in the previous year can also reduce sugar content. Atmospheric CO_2 concentrations often stimulate photosynthesis which would lead to higher sugar production, however this is partially offset by elevated ambient temperatures and moisture stress (Perkins, 2007).

For sugar maples, optimal sap flow conditions during the spring are between -5°C and 5°C, with a 10°C maximum daily temperature from February until the end of March and nighttime temperatures no higher than 0°C (MacIver et al., 2006). Climate data from 14 weather stations across northeastern North America indicate that these optimal conditions have seen increases in Quebec, but non-significant decreases in Ontario and Vermont (MacIver et al., 2006). The highest mean winter temperature (December to February) to sustain growth and sap production is 0°C but a warming winter trend of 1.5-2.5°C over the last 40 years has occurred. The maximum winter temperature threshold however, has not yet been reached (MacIver et al., 2006). Effective growing degree days (EGDD) are days with a mean daily temperature greater than 5°C after budburst; and higher EGDD positively influence sap production. The minimum threshold of EGDD is 1150. So far, EGDD have had significant increases at eight of the fourteen stations observed in the study by MacIver et al. (2006), therefore not yet limiting maple syrup production.

Farrell (2013) estimates that there are 100 million potential sugar maple taps in North America, but that 45% occur in areas where the density is not high enough for maple syrup production. While there may be a large resource of sugar and red maples not used for producing maple syrup, climate change is an important consideration because the climate in these areas may not be suitable for high sap yields (Farrell, 2013). Specifically for Ontario, there is strong development potential as only 0.04% of Crown lands are currently tapped for maple production due to access restrictions (EcoRegions, 2013; OMSPA, 2013). In addition to this, management practices on Crown lands are often restricted. According to a study by EcoRegions consulting for the Ontario Maple Syrup Producers' Association[1] (OMSPA) in 2013, improved access to Ontario's Crown lands, even at a 2% increase, would double the volume of maple syrup produced in the province (EcoRegions, 2013; OMSPA, 2013). The sector also has an important cultural and historical value, especially in rural communities (EcoRegions, 2013).

3.5 Resilience, Adaptation and Management

A commonly accepted definition of resilience is "the magnitude of disturbance that can be absorbed before the system changes its structure by changing the variables and processes that control behavior" (Holling & Gunderson, 2002: 4). Resilience thinking has been developed to provide a contrasting view from older ecological science models that relied on the 'balance of nature' concept which implied stable states of equilibrium within an ecosystem, often with a single outcome called a climax community (Clements, 1936; Cote, 2012). In the late 1980s to early 1990s, literature emerged that proposed an understanding of ecosystem dynamics as having multiple stable states which encompassed variability, disturbance and unpredictability (Botkin, 1990; Conway, 1987; Cote, 2012; Pimm, 1991; Holling, 1987). These theories and the creation of the Resilience Alliance at the Berijer Institute in Stockholm in the 1990s led to the development of linkages between ecological and social resilience through the dependence of communities and their economic livelihoods on ecosystems (Adger, 2000; Anderies et al., 2004; Cote, 2012; Norgaard, 1994).

[1] http://www.ontariomaple.com/

A social-ecological system (SES) can be defined as "an ecological system intricately linked with and affected by one or more social systems" (Anderies et al., 2004: 3). Another important aspect of current resilience thinking is the role of vulnerability and adaptive capacity within social-ecological systems (Adger, 2000; Cote, 2012; Pike et al., 2010). In ecology, vulnerability can occur when a stress is placed on individual or communities of species and the potential of surpassing a threshold where irreversible change arises (Adger, 2000; Janssen et al., 2006). More generally, systems lose resiliency when key thresholds are exceeded and the feedback loops within the system are shifted (Bueno, 2012). Resiliency in social-ecological systems can be defined when ecological resilience concepts are combined with a social science perspective (Adger, 2000; Walker et al., 2006). Therefore, "a resilient social-ecological system is synonymous with a region that is ecologically, economically, and socially sustainable" (Holling & Walker, 2003: 1). Because these concepts bridge the gap between institutions and economies (social systems) and the natural resources upon which they depend, resilience thinking is vitally important to future resource management (Adger, 2000) and in the case of this research, increasing the adaptive capacity of maple syrup production systems to climate change impacts. This study is based on the premise that the maple syrup industry is very much a SES. The ecological system of the sugar maple bush is linked in many ways to social systems, both economically and culturally. The resilience of the maple syrup SES is dependent upon the short-term and long-term adaptation strategies put in place by producers as well as environmental factors that producers cannot control, such as soil quality, temperature and extreme storm events.

Review of the extant literature, including the modelling study by Lamhonwah (2011) indicates strong evidence that the well-being of maple syrup producers is vulnerable to climate change projections. In an Ontario context, producers will be impacted by factors of decreased sap yield from unfavorable freeze-thaw conditions, tree stress and displacement, and moisture-related stress (EcoRegions, 2013; Lamhonwah, 2011; OMSPA, 2013). Current research in this field seeks to understand the effects of climate change already occurring at a local level in order to gauge best management practices and opportunities for resilient adaptation. Adaptation in this context can be defined as “an action, process or outcome within a system required in order to better cope with, manage, or adjust to a given changing condition” (Smit & Wandel, 2006).

Most temperate forests are managed, meaning any change that occurs within them is to a large extent anthropogenic (IPCC, 2014). It is important to note in the context of this research, that sugar bushes are highly managed. Therefore, adaptation strategies in the maple syrup industry seek to enhance adaptive capacity. Adaptive capacity refers to the capacity of a system to adapt in an environment that is constantly changing. A no-regrets approach is one that has a high benefit or payoff under current climate risks as well as future climate change scenarios (Heltberg et al., 2009). These no-regrets interventions are applicable here, because they generate net social benefits under all future climate change scenarios (Heltberg et al., 2009). There has been little research thus far on adaptation strategies for the maple industry in light of climate change impacts (Perkins, 2007); however this study suggests both short-term and long-term strategies as well as no-regrets adaptations that align well with the five objectives by Johnston et al. (2009) to mainstream climate change into forest management (see below). Mainstreaming climate change adaptation into forest management can be explained as giving consideration to climate change during activities like planning, reforestation, silvicultural practices and harvesting (Johnston et al., 2009). The five objectives are as follows:

1. Reforest Managed Forest Land
2. Conserve Genetic Diversity
3. Maintain Species Productivity

4. Maintain Forest Health
5. Enhance Adaptive Capacity

3.6 Short-Term Adaptation

In the short term, mainstreaming climate change into forest management can increase adaptive capacity. Proactive silvicultural practices could include increasing intra- and inter-species diversity in reforestation, harvesting stands that are susceptible to disease or insect infestation, and thinning of higher value stands to reduce moisture stress in the forest (Johnston et al., 2010). Forest management plans are beginning to incorporate climate change objectives more frequently in recent years, and the latest standards for sustainable forest management include climate change planning, communication and research (Johnston et al., 2010). The creation or maintenance of corridors to facilitate species and genotypic migration of trees can aid in enhancing adaptive capacity, as well as using silvicultural systems that maintain genetic and species diversity (Johnston et al., 2009). In addition to this, the development, sharing and adoption of climate sensitive best management practices can help maple syrup producers increase the adaptive capacity of their stands (Johnston et al., 2009).

Some adaptation strategies that are already being used by maple syrup producers and will continue to be improved upon as research develops include: shifting the tapping window to accommodate seasonal variability; improving tapping technology through the use of osmotic pumps to optimize sap extraction; and assisted migration planting of sugar maple seedlings from different geographic areas to increase genetic diversity within the stand, thereby increasing forest resiliency to natural disturbance (MacIver et al., 2006; Murphy et al., 2012; Skinner et al., 2010; Whitney & Upmeyer, 2004). While disturbance regimes will differ between sites, populations with high genotypic diversity and plant provenance have the best chance of survival (Bischoff et al., 2010). An admixture seed sourcing method with a focus on a wide selection of genotypes from various environments with no spatial bias towards the sites would be a useful planting strategy (Breed et al., 2013).

In the United States, recent research concludes that during the 21st century, sap flow days in the northeastern U.S. are likely to decline (Skinner et al., 2010). Currently, adaptation is possible by moving the tapping window a month earlier across New England and northern New York resulting in no difference to sap flow days for production (Skinner et al., 2010). However, this is not a permanent solution. In the event of further climate warming, by 2100 the optimal tapping window will occur during the coldest time of the year (Skinner et al., 2010). The maintenance of current sap flow levels is possible by moving the conventional tapping window and may even increase the tapping period slightly (Skinner et al., 2010). To this end, the same may be true in a Canadian context, especially in regions of Southern Ontario, given the climate change projections for the region. There remains a lack of understanding of natural controls over factors such as sap volume, sap sugar content, and sap quality; therefore, the impacts of climate change on these factors is difficult to predict (Skinner et al., 2010).

3.7 Long-Term Adaptation

In the long term, forests can be managed for increasing genetic diversity to buffer climate change impacts by increasing the probability that the forest contains a proportion of adapted populations (IPCC, 2014; Johnston et al., 2010). A higher level of genetic diversity is achievable by planting a wider range of species within the forest, often through some level of assisted migration (IPCC, 2014; Johnston et al., 2010). Assisted migration is possible via three different routes: assisted population expansion, assisted range expansion, and translocation of exotics. Most applicable in the context of sugar bush management, however, is assisted population expansion and the possibility of assisted range expansion in future scenarios. Assisted population expansion is a lower risk option that involves the movement of populations within the current range of the species with the consideration that the distance of migration ensures both establishment success and adaptation to future climate change projections (Johnston et al., 2009).

Assisted range expansion is a more extreme measure that involves the regional expansion of the range limits of species for reforestation as a means of tracking climatic niches (Johnston et al., 2009). In this situation, populations are planted beyond their historical range while remaining contiguous with current distribution (Johnston et al., 2009). The difference with this option is that a sophisticated understanding and modelling of how species climate envelopes will shift is required for success. Richardson et al. (2009) add a social aspect to the assisted migration topic, arguing for a more inclusive approach to decision making that considers the societal willingness to pursue managed relocation and the impact on the surrounding community. With any assisted migration project, provenance tests that assess the performance of each provenance in a range of climate conditions are useful to ensure successful establishment (Johnston et al., 2010). This is because provenances that are planted southward are adapted to lower temperatures and could grow slower in warmer environments; and provenances planted northward can be damaged by cold temperatures (Johnston et al., 2010; Rehfeldt et al., 2001).

Increasing genetic diversity in reforestation and ecological restoration projects is an important sugar bush management practice to maintain long term forest health and resiliency, and to aid recovery following disturbance. Provenance and genotypic diversity are important factors to consider when conducting ecological restoration activities. In sugar bush management, genotypic diversity increases the stand’s resiliency to natural disturbance, and using seeds and plants of local provenance helps to ensure survivability within the habitat conditions as well as preventing the spread of undesired alien genotypes (Bischoff et al., 2010). Because of the benefits of genotypic diversity, some researchers recommend that seed collection for restoration activities should use as many mother plants as possible (Bischoff et al., 2010). However, in terms of sugar bush management, these mother plants should be carefully selected for optimal sap production. Reconciliation planting can also be considered here which aims to return species to their area of provenance while also merging them with the biodiversity that is already present (Rosenzweig, 2003). This could present an integrated approach for sugar bush managers to do restoration planting and maintain species diversity, while also maintaining the productivity of their stand.

The prevailing opinion in current literature encourages a more biologically diverse stand of trees within a sugar bush, whereas in the past it was recommended to remove all other species to increase productivity (Barkley, 2007; Ruble, 2014; Whitney & Upmeyer, 2004). This is important for forest management because adaptation should strive for not only the most productive trees, but a diverse stand that is able to adapt to changing local conditions. Commercial maple sugar bushes have the potential to play a large role in biodiversity conservation and habitat protection, while contributing to sustainable development because the land use is primarily forest and will remain forested for maple syrup production (Clark & McLeman, 2012). When practiced well, small scale sugar bush operations have an inherent environmental sustainability associated with them (Clark & McLeman, 2012). The study by Clark and McLeman (2012) concludes that biodiversity conservation ideals were received well by sugar bush operators in Eastern Ontario.

Future research into long-term adaptation methods could involve sugar maple breeding programs to test if high yielding trees could be improved upon by genetic selection and consistent reproduction (Barkley, 2007). Further work is also needed in distribution modelling. Climate envelope modelling approaches have developed valuable results thus far, but increasing CO_2 levels that would impact seedling establishment and growth need to be considered (Johnston et al., 2010). The development of a more comprehensive analytical approach to vegetation modeling would increase the understanding of the vulnerability of Ontario's tree species (Johnston et al., 2010). Johnston et al. (2009) suggests the development of ecological and genecological modeling that addresses the uncertainties of species distribution shifts, assisted migration, and genetic diversification in reforestation. It is also important to continue to identify key knowledge gaps that could pose as barriers to adaptation and take action to address them (Johnston et al., 2009).

Local adaptation occurs when populations have the highest relative fitness in the core of their range and lower levels of fitness at the edges of their range limit (Savolainen et al., 2007). Extensive experimental forest plantation studies show that populations of trees can survive and grow in areas outside the core of their range, however, genotypic distribution is limited by inter- and intra-specific competition (Savolainen et al., 2007). The populations of species occurring in the rather extreme environment at the edge of their geographic range limit typically have reduced genetic variation and compromised fitness, making them less adaptable to changing environmental conditions (Johnston et al., 2010; Savolainen et al., 2007). However, climate warming has the potential to decrease stress to the high-latitude or elevation populations because of the genetic material from the core populations being pre-adapted to warmer climate conditions (Johnston et al., 2010). With regards to range shifts, the borders of the geographic range of a species are genetically invaluable for the species. This is because there may be specific genetic variation in these areas that could have long-term value for the species (Booy et al., 2000).

To maintain productivity, successful management might also mirror that of the northeastern United States by adjusting tapping windows for optimal sap collection in light of environmental change. I expect that the climate change impacts currently being seen are minimal in comparison with the United States, but may be affecting sugar bushes in Southern Ontario. These impacts could include seasonality changes, moisture stress due to decreased snowfall, and an increased presence of pests. Interviewing maple syrup producers was an interesting way to learn first-hand what the climate change impacts are that are currently being seen in their forests and how their management strategies have adapted to cope with these changes.

<u>4.0</u> <u>Methods</u>

4.1 General Approach

For this research, I used a multi-methods approach that combines qualitative and quantitative research methods to incorporate both the social and ecological aspects of sugar bush management. More specifically, semi-structured interviews were conducted with sugar bush operators and farmers as well as an analysis of quantitative data obtained through plot sampling in five of the sugar bushes, representing different geographic areas.

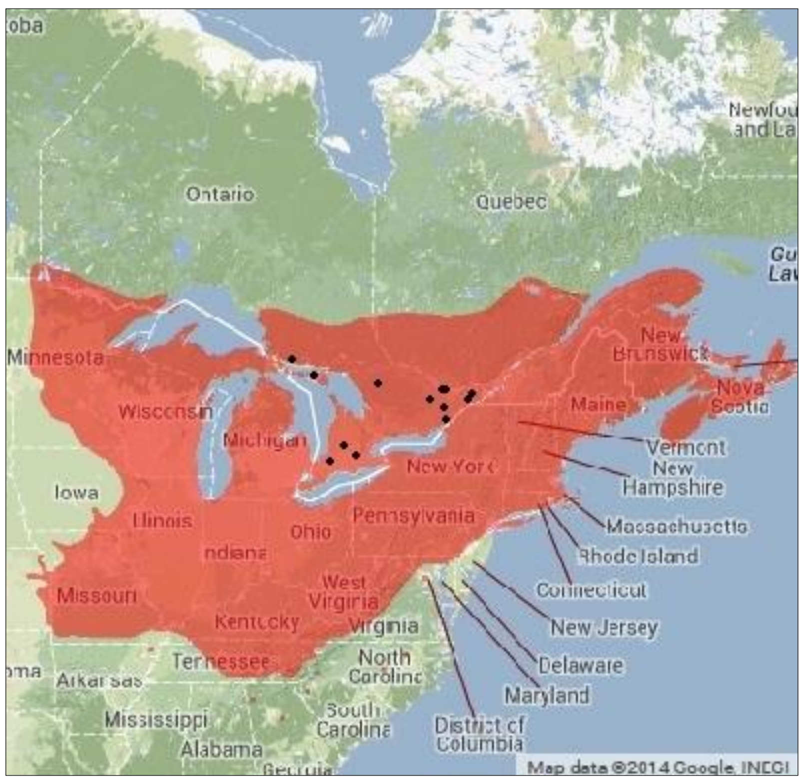

Figure 3 Distribution of Interview Locations
Source: Google, 2014; Plantmaps, 2014; Canadian National Climate Data Archive

The quantitative plot data was used in conjunction with the qualitative data to develop a deeper understanding of how producers are managing their sugar bush. Face-to-face interviews and forest walks were augmented in 5 of the cases with plot sampling. The 15 participants involved in this study were chosen based on geographic area, size of the operation and involvement with OMSPA. Criteria used to determine plot sampling was based on geographical area and the size of the operation. I conducted plot sampling in each part of the sugar maple range in Ontario, and at small, medium and large scale operations.

Figure 3 overlays the sugar bush locations involved in the interviews with the current range map of the sugar maple species. Participants were selected from small, medium and large scale operations across Ontario with a multitude of backgrounds and experience. Approximately 30 percent of the participants in this study have formal forestry training, about 75 percent have years of practical experience, a few produce maple syrup as a hobby, and any combination thereof. This selection of diverse participants and plot locations from different Ontario geographies and the use of a multi-method approach increased the depth, reliability and generalizability of the results, even though the sample size is small.

What one would expect to see in these types of forests, especially in southern and eastern Ontario, is a hardwood forest co-dominated by sugar maple and beech (Nelson & Wagner, 2014). These types of forest are often found on moist, well-drained soils with typically few shrubs and herbaceous plants, however, tree seedlings may be abundant (Cornell University, 2015). The other species commonly occurring with sugar maple and beech in Ontario are basswood (*Tilia americana*), white ash (*Fraxinus americana*), yellow birch (*Betula alleghaniensis*), hop hornbeam (*Ostraya virginiana)* and red maple (*Acer rubrum)* with sub-canopy species such as witch hazel (*Hamamelis virginiana*) and alternate-leaved dogwood (*Cornus alternifolia*) (Cornell University, 2015). In Northern Ontario locations, however, beech is less prominent and forest ecosystems are typically dominated by mixed hardwoods or white birch mixed wood stands. The first is a more optimal environment for sugar maple, occurring along the northern portion of its range in diverse stands of balsam poplar (*Populus balsamifera)*, black ash (*Fraxinus nigra)*, bur oak (*Quercus macrocarpa)*, basswood, Manitoba maple (*Acer negundo)* and yellow birch (Sims et al., 1998). In the latter, white birch (*Betula papyrifera)* is typically the only hardwood in the canopy layer, occurring with balsam fir (*Abies balsamea)*, white spruce (*Picea glauca)*, black spruce (*Picea mariana)* and jack pine (*Pinus banksiana)* (Sims et al., 1998). The extrapolation of the quantitative field data has allowed me to determine the percent composition of sugar maple versus other tree species within the sugar bush, which will show the level of biodiversity in each of the five forests. The qualitative data obtained during the interview process has been used to gauge what is currently being done in sugar bush management, if indications of a changing climate are being seen, and how sugar bush operators are responding to disturbances within their stands. With this qualitative research, I also determined producers' opinions on the long-term sustainable forest management practices that increase adaptive capacity and resilience to climate change.

Qualitative research is broadly defined as social research wherein the researcher aims to explore the meaning of human action through the systematic collection, organization and interpretation of text rather than numerical data (Carter, 2007; Malterud, 2001; Pope and Mays, 1995; Schwandt, 2001). In qualitative research, open questions are often asked in their natural context to deeply explore a topic or hypothesis, providing insight and underlying reasons or motivations, and to uncover prevalent trends in opinions. Qualitative researchers have described their research methods as a reflective, contestable process that requires systematic inquiry and attention to such issues as replicability, validity and transferability beyond the study (Malterud, 2001). In contrast, quantitative research is a more structured process that aims to test a predetermined hypothesis by quantifying data and generalizing results (Carter, 2007).

Semi-structured interviewing is a qualitative approach that provides a method of exploring hypotheses while enhancing the accuracy by pre-determining the survey questions (Malterud, 2001). In this approach, the interviewer and respondents engage in a formal interview while the interviewer uses an interview guide. The guide consists of a predetermined set of questions and topics that need to be explored during the interview, but the interviewer can follow conversation trajectories that stray from the guide (RWJF, 2008; World Bank; 2011). The guide is a way for the interviewer to ensure the same information is obtained from multiple interviewees (World Bank, 2011). Depending on the conversation, this can allow the interviewer to discover and explore new ways of understanding the topic. While semi-structured interviews are a systematic and comprehensive approach that allows questions to be explored more in-depth at the interviewer's discretion, one weakness is that that it does not permit the interviewer to pursue unanticipated topics that were not included in the guide (World Bank, 2011). The difference between this method and a standardized open-ended interview is that the latter requires the interviewer to ask each person the same questions in the same sequence, and is used to minimize variation during evaluation (World Bank, 2011). The fallback with the standardized open-ended interview method is that the extent to which individual differences and opinions are explored is lowered (World Bank, 2011).

Because qualitative and quantitative methods do not study the same phenomena, cross-validation between the two is not possible (Sale et al., 2002). Also, procedures for textual interpretation are different than statistical analysis (Malterud, 2001). However, the two types of methods complement each other in many ways. The two methods share a goal of understanding and improving the human condition, and for disseminating knowledge for practical use (Reichardt and Rallis, 1994; Sale et al., 2002). The multi-method approach is a way of linking qualitative, quantitative and statistical research, thereby increasing the confidence of a single method's findings (Collier & Elman, 2008). Multiple and diverse observations are important in thoroughly understanding a complex phenomenon (Malterud, 2001). Transparency is crucial in a mixed methods approach and it is important to label which phenomena is being examined by each method (Sale et al., 2002). Qualitative methods are often used to investigate and explore generalized findings from quantitative studies to gain a more in depth understanding of the issue (Malterud, 2001). The same applies to my research. The multi-method approach used in this study enhances the findings by providing quantitative measurements of species composition to measure the current biological diversity of the selected sugar bushes. This provided an opportunity to correlate findings from the interview data with the ecological measurements, deepening the understanding of the sugar bush as an SES, with associated management and adaptation challenges and opportunities.

4.2 Required Information

In order to answer my research question, I gathered information regarding opinions and current management strategies being used by sugar bush operators throughout Ontario. I attained this information by conducting semi-structured interviews with maple syrup producers and forest walks of each property. I have also compiled a literature review of the forest response to climate change, including: climate induced geographic range shifts and the implications for genetic diversity of populations; species response to factors such as disturbance, heat and moisture stress, and pests; climate change implications for the maple syrup industry; and short-term and long-term methods for increasing resilience and adaptive capacity of sugar bushes. Interview data was obtained from the different geographic regions within the sugar maple range in Ontario: southern, eastern, and Northern Ontario. Interviewees were selected based on geographic location, the size and productivity of the sugar bush, whether there are management strategies already in place, and activeness in the OMSPA community.

Interviews inquired about current forest management practices such as observed changes in the ecology of the sugar bush, afforestation and reforestation practices, genetic and species diversity within the stand, tapping procedures, and the ownership limitations on management of the property. In addition to this, I inquired as to whether producers are incorporating climate change and other principles of sustainable forest management (SFM) into their forest management plans and whether they thought SFM practices would increase the resilience of their sugar bush. Opinions on long-term adaptation methods that may not be currently practiced by producers was also discussed, including inter- and intra-species diversity within the forest, invasive species removal and crown release to reduce moisture stress and promote higher sap volumes.

At each of the five sites, three circular plots with a 5.64m radius were taken and extrapolated (multiplied by 100) to determine the stems per $100m^2$ of each of the sampled tree species. This allowed me to estimate the percent composition of sugar maple and other tree species within the stand. Diameter at breast height (dbh) measurements were also taken of the >10m trees to compare the average diameter across sites. As preparation for the field portion of my research, I thoroughly examined aerial photographs of each site. I used these images combined with the advice of the sugar bush manager to choose representative tapped areas of the sugar bush in which to conduct the plot sampling. In addition to this, satellite maps of the property were used to track the areas of forest observed at each site and mark where the plots were taken. This was obtained primarily through the use of google satellite imagery through an offline mapping program called Track Kit Pro. Within each area of the sugar bush, I chose the plot based on a random transect walked from the path into the area. The distance I walked into the area corresponded to a list of randomly generated numbers.

The plot sampling procedure used is as follows:

1. The plot sampling area was subjectively chosen to represent the dominant vegetation composition for each of the main areas of the sugar bush;
2. I then measured 5.64m in all directions from the plot center tree using measuring tape, flagging the trees along the plot perimeter;
3. Any trees that fell within the plot were recorded by size (dbh) and height class (0.5-2m, 2-10m, >10m);
4. Once each tree within the plot was recorded, steps 1-3 were repeated for each additional area delineated on the aerial photograph.

4.3 Techniques Used

Figure 4 NVivo Coding: Final themes and sub-themes

The textual data was digitally recorded, transcribed and then coded using NVivo software. With NVivo, I was able to access any part of the data easily. Using this type of software to track the ways in which data is coded during analysis ensures transparency in the research process from data analysis to textual interpretation (Hoover, 2011). Interview data is coded to help generate ideas and identify patterns within the subject matter of the interviews. I coded and grouped together all interview data about a similar theme, see **Figure 4**. Each of the nodes were examined separately using a deductive approach to develop themes based on the principles and ideas from the literature review. This allowed me to determine the prevailing opinion about each aspect of forest management based on the broad spectrum of individual responses. I also looked inductively for ideas that arose from the collected data.

For the plot sampling data collected from each site, I calculated species composition distributions using Microsoft Excel. Species compositions will be conducted in the seedling, sapling and sub-canopy layers of the forest where the diameter of each tree is much smaller. To do this, I used the stems per 5.64m plot of each species and extrapolated that to determine a stems per $100m^2$ measurement. The output of this information produced a summary graph for each site that includes the percentage of the total stand composition that each tree species occupies. This is an indication of the biodiversity of the forest and how much of the stand is occupied by sugar maple, however this technique does not accurately portray the entire species composition of the forest because of the small sampling areas. This information on species composition was then compared to what was said during the interview process to determine differences based on management styles, geography and the scale of the operation.

5.0 <u>Results from Interview Data</u>

5.1 Knowledge Acquisition, Experience, and Involvement with the Industry

During the interview process, producers were asked about how they gather their knowledge, their practical experience in the industry and whether or not they have formal forestry training, and about their involvement with the maple syrup industry. Practical experience ranged from 10 years to 45 years, with a lot of producers growing up with maple syrup production on family farms. It is important to note that the majority of interviewees have taken on maple syrup production as part of a family business or as a hobby post-retirement.

The level of knowledge and formal training varied among interviewees with many of them stating their knowledge was attained through practical experience, involvement in the industry at a young age, and available resources. Approximately 30 percent of the interviewees stated that they do have formal training. For some, this came in the form of Registered Professional Forester (RPF) status. Others had an educational background in biology, conservation, environment and resource management, and crop science. This impacted management approaches because these producers tended to have a higher focus on species diversity with more conservative tapping practices. Nearly all of those interviewed stated that they actively seek or have sought the advice of forestry professionals in the creation of a forest management plan, the marking of trees to be removed, or for restoration initiatives.

All of the producers interviewed stated that they refer to sugar bush management guidelines for best practices, management advice and tapping sizes. Interviewees gather knowledge from a variety of sources, with a common theme being that maple syrup production is a constantly evolving practice that requires continual learning. Involvement with the Ontario Maple Syrup Producers Association (OMSPA) was prominent throughout the interviews, touching on the usefulness of the association's publications, seminars, summer tours and website. In addition to this, some producers also mentioned involvement with the International Maple Syrup Institute, an international body made up of the 4 producing provinces and 13 producing states that deals with policy, supply and demand, quality assurance and international trade.

The majority of producers value the knowledge base of other producers, stating that they learn a lot from the advice of other producers and forest managers. The importance of knowledge sharing transcended all levels of forestry knowledge, geography and operation sizes. Involvement with other organizations was also a common theme, including the Ontario Woodlot Association[2], the Growing Forward program[3], the Managed Forest Tax Incentive Program (MFTIP)[4] and

[2] http://www.ont-woodlot-assoc.org/
[3] http://www.omafra.gov.on.ca/english/about/growingforward/gf2-index.htm
[4] https://www.ontario.ca/environment-and-energy/managed-forest-tax-incentive-program

involvement with Forest Standards Council (FSC) Certification[5] and the Program for the Endorsement of Forest Certification (PEFC)[6]. Many producers spoke of talking to academics, being involved in research, and reading technical papers from the University of Vermont, Cornell University, Wilfrid Laurier University, State University of New York and many from universities across Quebec. Knowledge gathered through equipment dealers was also highly valued among producers. Some interviewees were either equipment dealers themselves, worked for equipment companies or gained knowledge by talking to equipment dealers about suitable equipment for their operation and how to maximize production.

5.2 Silvicultural Practices

Thinning was the most common management practice discussed during the interview process. Thinning practices differed among producers depending on whether or not they used wood, outsourced wood pellets, or oil in their evaporators. Similarly, the amount of thinning within the woodlot was directly proportional to the size and scale of the operation and available resources. In other words, more thinning was done on larger operations. There was also thinning done on small and medium scale operations that had sufficient resources to do so. All but one of the small (under 2000 taps) and medium sized (2000-5000 taps) operations use a wood fired evaporator as well as one of the larger operations (5000+ taps). Many of these producers indicated that using wood to fuel their evaporator rather than pellets or oil encouraged them to be more active in managing their sugar bush and provided them with a renewable resource to use for production rather than having to buy fuel. Some producers also gained income by selling excess firewood harvested from their forest.

[5] https://ca.fsc.org/
[6] http://www.pefccanada.org/

There were three main reasons that producers provided for thinning their sugar bush: to regenerate the sugar maple population and high value trees through release thinning or crown release, to maintain health and productivity of the forest, and to improve the stand over time. Crown release requires the thinning of canopy trees to promote the regeneration of sub-canopy and sapling layer trees and structural diversity. This was the most popular silvicultural practice, used by all of the producers interviewed. According to those interviewed, crown release is an important silvicultural practice to achieve maximum production from the sugar maples. This practice occurred mostly to accent sugar maples but was also done to encourage the growth of valuable trees for logging. All producers stated that they selectively harvest trees during thinning: taking out the lower quality and invasive trees such as ironwood (*Ostrya virginiana*) that are hindering maple, or removing damaged trees to promote regeneration and renewal in the sub-canopy layer. Thinning for forest health was also mentioned frequently, involving the removal of diseased or declining trees. Thinning involves an inherent level of forward thinking because producers look at what is growing around the tree they wish to remove so that they know what will grow in its place. Interviewees also mentioned that thinning is about balance. Too much thinning could result in a warmer microclimate on the forest floor, deterioration in heat-sensitive species such as white birch (*Betula papyrifera*), wind damage and conditions such as sun scald on maples. One memorable quote on proper thinning practices is as follows:

> *"I'm looking for longevity. So when I look in our sugar bush, I want to see trees of all different ages: saplings, pole size trees coming onto tappable size and some mature trees."*

Producers were also asked about silvicultural practices pertaining specifically to sugar maples, including crop tree selection and sweet tree testing. Crop tree selection was most common among small and medium scale producers. Those that discussed crop tree selection said it was difficult to do on a larger scale, so instead they often managed for the healthiest looking maple trees that would be most likely to become high quality canopy trees. Sweet tree testing was a less common theme among producers. All producers knew what sweet tree testing was, but most stated they did not use it in their management because with a pipeline system in place, it does not make a difference in overall production. It was also mentioned that sweetness among maples is dependent upon environment and varies throughout the year. Some producers stated that they have done sweet tree testing in the past, most often when they were on a bucket system, but that they did not use the results of the testing to select progeny and breed for the highest yielding, sweetest trees.

5.3 Species Diversity

"We do take a positive approach to multiple species because we don't want a monoculture. That's never a good thing. If you think about the beech bark disease, if you had a bush that was almost all beech because that's the only species you promoted to come ahead, you'd be in trouble. Same goes for maple."

Species diversity varied depending on the geographic location, the size and scale of the operation, and the level of forestry knowledge. The prevailing strategy among producers, especially those with a background in forestry, was to accent sugar maple presence within the forest for syrup production by gradually removing over mature trees from the canopy to allow for maple regeneration, while ensuring the inter-species diversity remains sufficient for the reproductive success of non-maple species. However, the size and scale of the operation influenced these priorities. Smaller or hobby scale operations tended to have less intensive management, allowing the bush to regenerate naturally and only removing damaged trees or those hindering a sugar maple. Medium scale producers and those with formal forestry training tended to be more active in forest management, promoting high species diversity. Large scale commercial producers however, tended to accent maple presence within the bush in order to be economically viable. Two of the larger scale producers mentioned an approximate goal of 2-5% non-maple species in the canopy layer.

Producers with formal forestry training, forest management plans or high levels of practical experience undertook activities to promote species diversity, such as succession planting for maple regeneration, selective thinning to maintain high species diversity, preservation of rare species, and mimicking natural disturbance by leaving some standing snags and deadfall on the ground for wildlife diversity. Succession planting for maple production was also practiced by some producers, planting different species to prepare for maple regeneration because maple requires shade and wind protection to be successful (see **Figure 5**). This often involved planting plantations of fast-growing species, like red pine (*Pinus resinosa)* and interspersing sugar maple saplings once the red pines are established. Then when the red pine is mature enough for harvest, it is thinned out leaving maple to regenerate in its place.

Figure 5 Photographs of Succession Planting in early stages (left) and mature (right)

In terms of specific species, this varied by geographic location. Issues with declining white ash (*Fraxinus americana*) was a common theme when talking about species diversity because of the presence of the emerald ash borer (*Agrilus planipennis*) insect in Ontario. Producers in the Southern Ontario region stated that they have either lost their ash population or are in the process of removing it now, with many ash trees showing signs of distress. They also mentioned that they are seeing a lot of maple and ash regeneration in the open canopy areas where mature ash trees have been removed. The prevailing opinion in the Eastern Ontario region was that producers have not yet seen the presence of emerald ash borer (EAB) in their forests but they are worried with will appear soon and are paying close attention to the ash population. Some producers even mentioned they have begun to select ash species over others for removal during thinning for this reason. Producers in Northern Ontario mentioned encouraging ash regeneration and conserving their ash population because they have not yet been affected by EAB. The reason for this is that if the ash species is eliminated in other parts of Ontario, they may be able to help with the regeneration of the species once the threat of EAB is gone.

Some producers noted the presence of upwards of 15-18 tree species in their sugar bush. Many mentioned selectively trying to encourage black cherry for its logging value, pruning and thinning around it because of its high light requirement. Red oak and white oak were also mentioned for their logging value. Others mentioned encouraging diversity among hardwoods, with an emphasis on species such as bitternut hickory, soft maple, and yellow birch. In more northern areas where coniferous species were present, producers talked about conserving hemlock, spruce, and white pine. The most commonly removed species were ironwood, basswood and in some cases beech for the large canopy and the amount of shade they produce. Beech was also said to be declining in some areas with little to no regeneration or high amounts of deer browse.

5.4 Genetic Diversity and Planting

Genetic diversity was discussed with interviewees, asking their opinions about genetic diversity within their forest and planting of saplings not sourced from within their own sugar bush. A majority of producers indicated that the sugar maples within their forest are naturally regenerating and they do not feel the need to externally source saplings to plant. However, many did indicate that they have read research on genetic diversity among sugar maples and learned that stands with higher genetic diversity tend to be more resilient to disturbance such as pests and disease. Some producers also said they were interested in planting "super sweet" sugar maples, bred from trees with high sugar content. There is concern with this process though: producers stated they did not want to plant thousands of cloned saplings because the gene pool would be too small. Two medium scale producers have existing plantations (**Figure 6**) up to 11 acres (4.45 hectares) in size and practice succession planting for sugar maple establishment, while some other producers have begun planting sugar maple in open areas on their property or mentioned interest in creating a sugar maple plantation in the future.

Figure 6 Sugar maple plantation on producer's property

Some medium scale producers in southwestern and Eastern Ontario do practice replanting of saplings sourced from adjoining forest or pockets within their sugar bush. The producers that purchase nursery stock for planting planted not only sugar maple, but also less common species such as sweet chestnut (*Castanea dentata*), black cherry (*Prunus serotina*) and white oak (*Quercus alba*). A few producers also mentioned being involved in a butternut breeding program for resistant trees, planting specimens on their property and monitoring their condition over time. For the producers actively recruiting seedlings from other areas, they chose stock that was sourced from the same geographic area and protect planted seedlings with rodent guards and fencing, flagging some specimens for monitoring. There are limitations on the ability of producers to practice reforestation planting including site conditions such as soil compaction from grazing, shallow or poor soil conditions, and soil degradation from agriculture that inhibit sugar maple establishment and growth.

5.5 Changes in Climate

The general consensus among the producers interviewed was that climate change is indeed a reality. It was difficult at times for producers to relate their individual experiences with bigger picture climate trends but many of them have noticed changes in the past ten years. Many producers stated that production is cyclical, resulting in good and poor years for maple syrup production with warmer, drier and colder years all affecting the trees differently. Some producers noted fluctuations between drought conditions and abnormally wet conditions. The issue with excessive moisture is that it de-stabilizes the root system in the soil, making trees more likely to tip over in extreme storm or wind events. One producer in Northern Ontario mentioned that the cooler summers with less sunlight over the past two years have resulted in growing degree days between 1800-2000 whereas it is usually about 2400. Climate change observations overall varied by geographic location with producers in Northern Ontario being less concerned about future production than those in Southern Ontario. Many producers mentioned that the changing seasonality may result in shifting the tapping window to be earlier in the year, much like Virginia where tapping occurs in December to January and the sugaring season is over by February.

5.5.1 Temperature and Seasons

The main observation about changes in seasonality and temperature was that extended warm periods in the winter followed by extreme cold periods are becoming increasingly prominent. Producers noted that there is more variability in the spring season with a general warming trend, causing sap runs earlier in the year some years. Temperature swings were also a general consensus among interviewees, who talked about extreme cold temperatures of around -20°C rising to 10°C in a matter of days. Over the last ten years, many producers commented that there have been circumstances where temperatures got unusually warm mid-winter causing a degree of thawing in the trees. When this happened, the temperature would drop to very cold again, causing decline and dieback visible on individual branches within the canopy. Many producers also said that winter 2013 was an anomaly, inhibiting tapping because of the extended cold period.

5.3.1 Wind and Storm Events

Producers from all geographic areas agreed that over the last 10 years there has been a higher frequency of extreme storm events, especially wind storms and microbursts resulting in the loss of a lot of mature trees. Some of these producers mentioned, however, that the number of wind storms has not increased but the impacts have become more drastic in recent years. One of the producers discussed a systemic way to think about the issue. There is a positive feedback system that is observed here in that extreme storm events cause damage and weakening in mature trees, causing thinning within the stand over time. This type of damage will predictably be exacerbated in future extreme storm events because the now thinner areas of forest will be more susceptible to wind damage. It was the prevailing opinion among producers that well managed areas stand up better than the non-managed sections during extreme storm events. Producers also agreed that microbursts are becoming more common in the last 10 years. A microburst is a sudden, localized air current that is more intense than regular high wind events that can cause significant damage to mature trees. One producer mentioned losing 75 canopy trees in a microburst event. Susceptibility to wind damage also varies by site condition because trees with shallow root systems, often in more northern areas where soil conditions are poorer, are the ones that tend to fall over in wind storm events. The 1998 ice storm was a common theme among Eastern Ontario producers. Many producers mentioned a high crown loss, with one producer noting a 30% reduction in canopy cover. Since this event, extreme storm events have become more common but are often quite localized in nature.

5.3.1 Changes in the Tapping Season

The overarching opinion among the producers interviewed is that the tapping season is getting earlier, with the exception of spring 2014. Overall, producers agreed that the tapping season has shifted about two weeks earlier because there is not the same duration of winter as there used to be. One producer from Southern Ontario noted that when they were younger, they would never tap before March 10th but now tapping occurs in the last or second last week of February. Another producer said that March 9th was a consistent tapping date for their family but 3 of the last 5 years have been earlier than that. Spring 2014 was the latest tapping season that any of the producers interviewed had ever experienced. While talking about this, one producer stated that the latest boiling has started is March 17th but this year it was March 30th. Despite these changes, almost all participants have up-scaled their operation in the last five years either by expanding the tapped area of their own sugar bush or in some cases, leasing neighboring lands or starting a sugar maple plantation. Expansion was either a result of gradually adding taps every year, because it is easier for producers to expand if they use a pipeline system, or in some cases because new equipment has allowed for higher levels of production. With the exception of a few hobby scale producers, there was generally room for producers to expand the size of their operation. If there was not room for expansion in their own sugar bush, other producers noted that they have leased neighboring lands to tap or have planted sugar maple for tapping in the future. Producers that have not up-scaled their operation have maintained the same number of taps for the last five years or more.

5.4 Ecological Changes

5.4.1 Changes in Flora and Fauna

The largest changes in flora mentioned were a result of EAB, causing a dieback or loss of ash trees and encouraging undergrowth on the forest floor. It was also mentioned that butternut (*Juglans cinerea*) has also been lost from the species composition as well as some other tree species such as bitternut hickory (*Carya cordiformis*) in Southern Ontario as a result of the hickory bark beetle (*Scolytus quadrispinosus*). Producers noted that beech has been declining in recent years as a result of beech bark disease and heavy deer browse on regeneration. In addition to this, changes in flora were prevalent in Eastern Ontario following the disturbance of the ice storm.

Changes in fauna were most commonly observed in the deer population. Producers in Eastern Ontario experienced a high deer population up until about 5-10 years ago which inhibited regeneration. Many producers said that they had to adapt and contend with the high deer population, fencing off areas of the sugar bush, taking lines down during the winter or protecting planted seedlings. Another common theme in terms of fauna was the cyclical nature of small game populations such as squirrels after a drought year because of the higher seed production. Following this, producers noted an increase in predatory populations such as coyotes because there was more food available for them to eat. Some producers noticed changes in bird populations. For example, increase in the presence of snowy owl, decrease in grouse and barn swallows, and an increasing number of crows and ravens.

5.4.2 Regeneration

Regeneration was an important theme to all producers. An overall observation was that drought conditions led to high seed production in the spring following the drought year as a defense mechanism for the tree. This often results in a lot of maple regeneration with some producers speaking of a monoculture of maple seedlings in the internal area of the forest. Management was an important concept to all producers in terms of regeneration. They agreed that sugar bush management enhances regeneration, allowing it to develop and thrive by opening the canopy and allowing light to enter the understory. Regeneration was most commonly talked about in terms of sugar maple with few producers promoting the regeneration of other tree species at the seedling level. One producer mentioned a goal of 18-20% sunlight to the forest floor to encourage seedling growth. Many practice thinning of raspberry and other undergrowth competing with the seedlings. Regeneration is also inhibited on compacted soil or in drought conditions, with one producer mentioning that they ploughed an area to loosen the soil for maple seedlings. An interesting link was drawn by one producer, that more vigorous maple regeneration could be the result of increasing of CO_2 concentration in the atmosphere.

5.4.3 Invasive Species

There was unanimous concern about the impact of invasive species on forest health. Some producers even stressed the importance of diversity within the sugar bush for resilience to invasive species. Producers in eastern and Southern Ontario noted a proliferation of European buckthorn that has been ongoing for many years, around the forest edge or in areas that have been over thinned. The most commonly talked about invasive species was EAB which had a large impact on ash populations for many producers. Many producers are becoming less tolerant to ash trees because they expect them to die; saying if there is even a question about whether to remove it, they will remove the ash. Many producers voiced concern about the Asian longhorned beetle that has been spotted in Ontario but none have found it yet. Some also said they were consistently looking for the presence of Norway maple (*Acer platanoides*) because they are aware of the impacts the species can have on the ecosystem. Garlic mustard was not mentioned in the discussion of invasive species by any of the participants, possibly because ground level herbaceous flora are not always a concern. However, proper identification and eradication of this species is recommended so it does not interfere with sugar maple seedling establishment.

It was interesting that producers did not necessarily equate invasiveness with non-native species. For example, ironwood, native to Ontario, was considered an invasive species among producers and was often removed for firewood. Prickly ash (*Zanthoxylum americanum)*, a shrub common in Eastern Ontario, is also being managed for as it can interfere with maple regeneration. The level of invasive species management varied depending on the size of the operation, tending to be less of a focus for most large scale producers.

5.5 Resilience and Producer Accepted Practices

5.5.1 Resilience

The producer accepted practices mentioned within this study were often sustainable, prioritizing tree health above other management objectives. However, with regards to the five objectives to combine forest management and climate change adaptation outlined by Johnston et al. (2009), the resilience and adaptive capacity of some of these practices could be improved upon for the long-term. Resilience and adaptive capacity among producers varied depending on the size and scale of the operation, forestry knowledge, and economic strategies in place. Small scale producers tended to focus less on practices that foster resilience and enhance adaptive capacity because they have fewer resources available for thinning, planting and restoration activities (often producing maple syrup alone or with minimal assistance). Many also had other jobs and did not rely on syrup production for income or were retired, producing syrup as a hobby.

Almost all medium scale producers prioritized resilience-oriented practices in the sugar bush rather than focusing only on production. As mentioned previously, many of the medium scale producers interviewed had a background in forestry, focusing on species diversity, conservative tapping practices and restoration within the sugar bush. In addition to this, some of these producers were also retired, had other jobs, or had pancake houses and other value added methods in place to supplement their income. The large scale producers interviewed did do a lot of silviculture in the sugar bush but their main priority was most commonly maximum production. This was because these producers often had access to a lot of land for expansion and saw restoration planting and other resilience-oriented practices as less of a priority. Also, species diversity tended to be less of a concern for most large scale producers because from an economic perspective, a higher density of sugar maple within tapped areas increases syrup production.

That being said, most producers did say they are constantly thinking of how to improve the resiliency of their sugar bush. They also agreed that best management practices and proper tapping procedures will enhance resilience in the long term. One producer said that the health of the sugar bush can be gauged not by the number of taps per acre, but by the pounds of sugar produced per acre. Some mentioned options such as decreasing vulnerability to pests and disease by planting higher quality seedlings and thinning less aggressively, trying not to open the canopy too much to minimize wind damage. Regeneration was a general concern because structural diversity among the trees is an important part of resilience. For the same reason, species diversity was also stressed by producers. This is important because if you were to get a serious insect or pest in the forest that preferred a certain species, much like EAB, there would still be some diversity left if that species was lost. One producer stated the importance of sustainable management activities such as renewal, making sure trees have sufficient space to grow and develop, and encouraging regeneration because these practices increase resilience over time. Some producers also noted that a healthy, well-managed stand is the best safeguard against extreme storm events. It is important to note here that site conditions with deeper soil that allow for deeper roots will naturally be more resilient to wind damage.

5.5.2 Perspectives on Accepted Practices

Tapping size varied among producers. Small and medium scale producers tended to be more conservative with their tapping practices because they still had a lot of room for expansion in their operation. Producers with formal forestry training shared similar views. This was not always the case for most large scale operations where there is a lot of money invested in production. However, longevity was important for all producers. Some producers begin tapping at 10” (25.4 cm) in diameter, whereas others wait until 12-15” (30.5-38 cm) before tapping. Others say that tapping size depends on the health of the tree, looking at crown, composition and foliage; and the strength of the vacuum system. This is less of a concern when using buckets because that system relies on gravity to draw the sap out of the tree. For two taps, many producers indicated a requirement of 18” (46 cm) in diameter but others wait until 22” or even 30” before adding multiple taps. One rule that was used among producers was that if they could not touch their fingers around the tree, they added a second tap. Some producers mentioned that they used to place three taps but since converting to a vacuum system, do not exceed two. Three or more taps were only used by a few producers on trees that are very old and/or declining. Similarly, one producer said that they tap 7” trees and add two taps to 12-14” trees if they plan to cut them in the near future. Tapping size was a big concern among producers because of the impact on the tree from tapping too soon. One producer used this analogy: an 18” tree under high vacuum gives you 8% of the sap from the tree. A small 8” tree under the same high vacuum system takes about 25% of the sap from the tree. Some also agreed that what they benefit by waiting a few years for the trees to grow before tapping them outweighs what they get from tapping them too soon. Overall, many participants maintained that conservative tapping can be considered a beneficial adaptive strategy under climate change conditions.

Accepted practices among maple syrup producers are constantly evolving. Producers spoke a lot about accepted practices during the interviews with an overarching theme that the priority is to maintain forest health because this leads to better maple syrup production. Many producers mentioned burning wood as a positive for maple syrup production, encouraging more active forest

Figure 7 Example of anchor trees (left and center) and concrete block substitute (right)

management and cutting fuel costs. One interesting best management practice to mention was that a producer has put large concrete blocks in certain areas within the sugar bush to act in place of the anchor trees for pipeline (**Figure 7**). This producer had observed that the anchor trees could suffer a lot of damage with the tension of the wires wrapped them and used these blocks to reduce the stress placed on those trees.

Many producers agreed that if you maintain many single tap trees and ensure they are healthy, you will produce more sap than having an over mature stand of larger trees with multiple taps. The most commonly used spile was the 5/16” health spile. Proper management of the vacuum system was also mentioned as being an important best management practice. If producers do not leave the vacuum on long enough and turn it off before freezing is complete, some of the sap that has been exposed gets sucked back into the tree allowing bacteria to enter. Vacuum strength was also a key factor among producers. A few producers noted that their trees appeared healthier with a more conservative vacuum system that isn’t too high. Many producers knew that a 25” or 26” vacuum system may improve production but in the interest of longevity, chose a less intensive option. Lastly, it was interesting that some use the water that is a byproduct of the reverse osmosis machine for cleaning equipment.

6.0 Results from Plot Sampling

Species compositions reflected management intensity, size of operation and geographic location with the presence of conifers such as black spruce showing up in more northern locations. It is important to note here that plot sampling was done in tapped areas of each sugar bush, meaning that the species compositions reflected in this data may be different and/or have a higher prominence of sugar maple than other areas of forest managed by some of these producers. Compared to what one would expect to see in an Ontario maple-beech forest, these sugar bushes had a higher density of sugar maple in the canopy and seedling layers, with a more open canopy (Cornell University, 2015). This lower biodiversity is in line with other managed woodlots in Ontario, especially those that have been harvested in the past because beech has become an undesirable species for landowners (Nelson & Wagner, 2014). American beech is not only susceptible to beech bark disease (*Neonectria faginata*) but once it becomes a dominant canopy species, most of them decline and die, keeping it as a sub-canopy species that rarely exceeds a dbh of 20cm (Houston, 1994; Nelson & Wagner, 2014).

Of the five sites that were sampled (below) for species composition, the medium scale operation in Southern Ontario with the high level of management in **Figure 8** showed the highest inter-species diversity. This sugar bush showed four prominent species in all layers with many others observed during the forest walk. This composition corresponds to this producer's opinions during the interview process, taking a positive approach to sustainable forest management and prioritizing forest health over maximum production potential. The density of sugar maple in the sub-canopy and canopy layers is in line with the interview results that higher levels of management encourage the growth and release of sub-canopy trees. **Figures 11 and 12** are also medium scale operations however the species compositions at these sites differ by geography and level of management. The manager of the Northern Ontario site depicted in **Figure 11** takes a positive approach to inter-species diversity but manages for tapping areas within the forest that are predominantly sugar maple to increase the efficiency of the pipeline system. Because of this, plot sampling shows a dominant sugar maple canopy and sub-canopy layer with density similar to **Figure 8. Figure 12** was sampled on a site in Eastern Ontario that had been owned by the producer's family for many generations, resulting in many over mature sugar maples in the canopy layer. This producer's management intervention is low. It is evident by the low density of sugar maples in sub-canopy and canopy layers that thinning does not occur as frequently at this site as at the other medium scale operations.

The smallest operation sampled (**Figure 9**) practiced minimal forest management resulting in many mature sugar maple trees with some other naturally occurring species that are not removed. The density here is quite similar to **Figure 8** however, with less non-maple species in the canopy layer. In contrast to these results, **Figure 10** shows a large scale commercial operation in Northern Ontario where management practices prioritize maximum production over inter-species diversity. This is depicted in the graph, showing only sugar maple in the sub-canopy and canopy layers at a much higher density than the other sites. Because this producer manages for maximum production to ensure the economic viability of the operation, sugar maple is the dominant canopy tree.

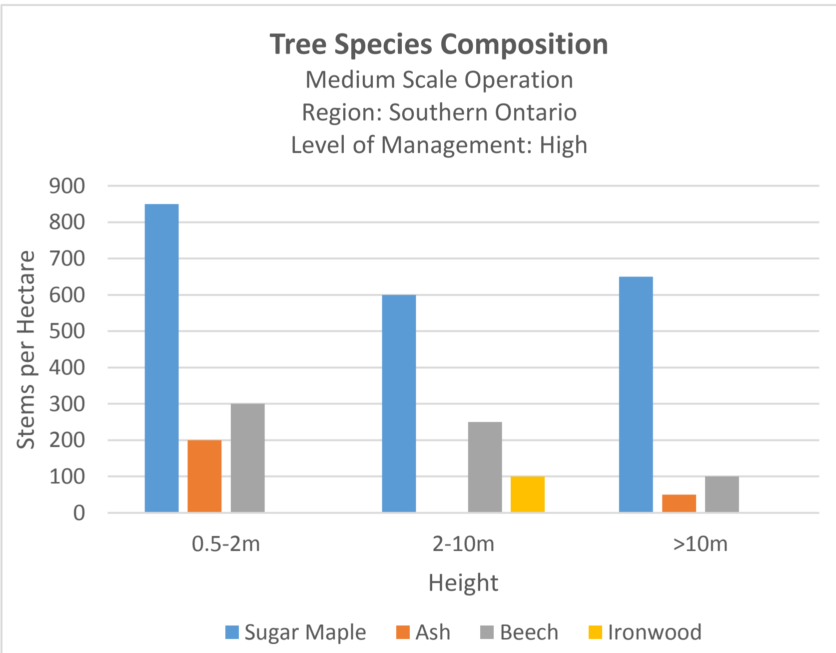

Figure 8 Medium Scale Operation in Southern Ontario

Figure 8: Sugar maple (*Acer saccharum)* composed 63% of the sapling layer (0.5-2m), 63% of the sub-canopy layer (2-10m) and 81% of the canopy layer (+10m) with an average diameter at breast height (dbh) measurement of 25.4cm in the canopy trees. White ash (*Fraxinus americana)* composed 15% of the sapling layer, 0% of the sub-canopy layer and 6% of the canopy layer with an average dbh of 49.4cm in the canopy trees. American beech (*Fagus grandifolia)* composed 22% of the sapling layer, 26% of the sub-canopy layer and 13% of the canopy layer with an average dbh of 14.1cm in the canopy trees. Ironwood (*Ostrya virginiana)* composed 0% of the sapling layer, 11% of the sub-canopy layer and 0% of the canopy layer.

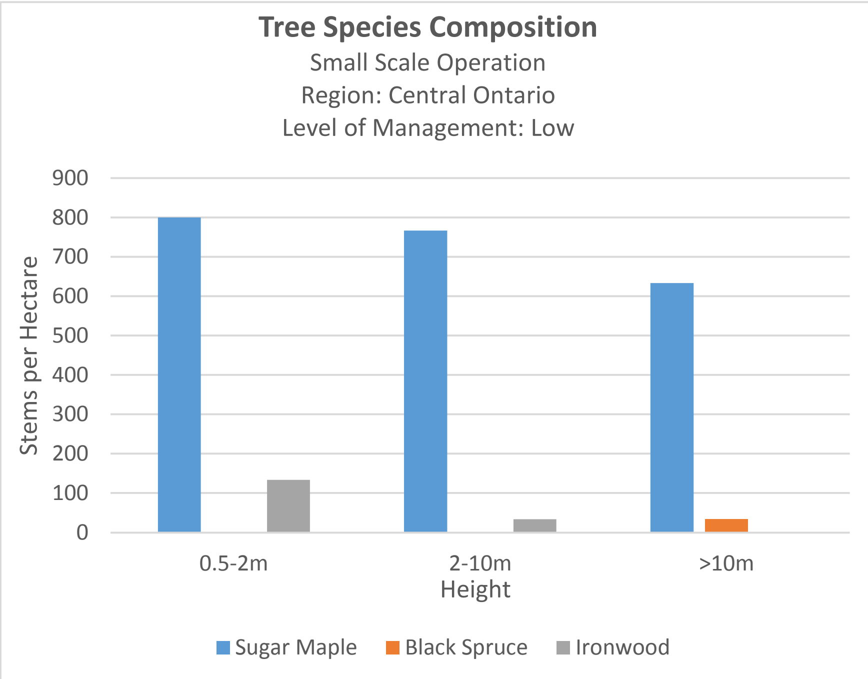

Figure 9 Small Scale Operation in Central Ontario

Figure 9: Sugar maple composed 84% of the sapling layer, 96% of the sub-canopy layer and 94% of the canopy layer with an average dbh measurement of 28cm in the canopy trees. Ironwood composed 16% of the sapling layer but was not present in the sub-canopy or canopy layers. Black spruce (*Picea mariana)* was only found in the canopy layer, composing 6% when extrapolated for a 100m^2 area.

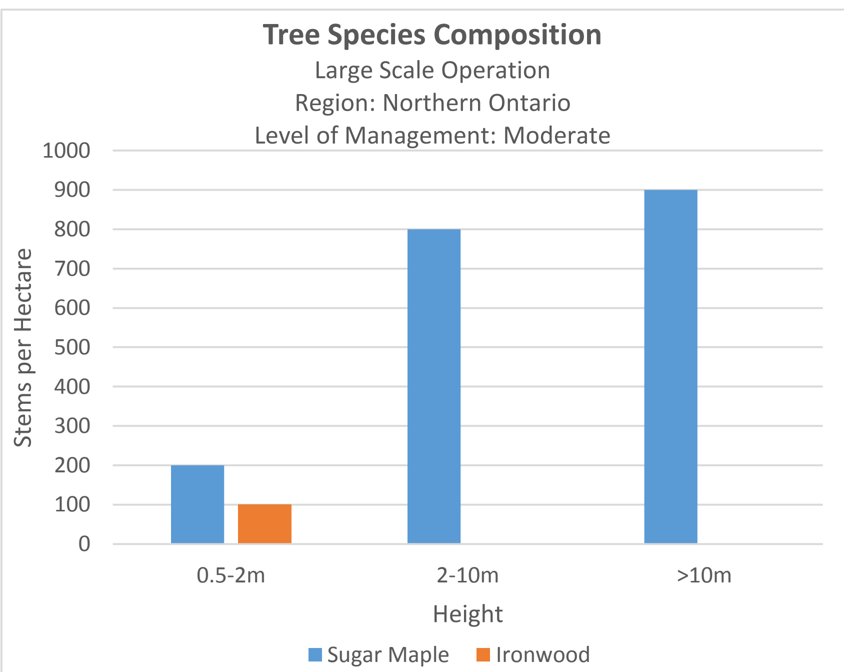

Figure 10 Large Scale Operation in Northern Ontario

Figure 10: Sugar maple composed 66% of the sapling layer and 100% of both the sub-canopy and canopy layers. The average dbh measurement of the sampled sugar maple trees was 19.8cm. Ironwood was also found in this area, composing about 34% of the sapling layer.

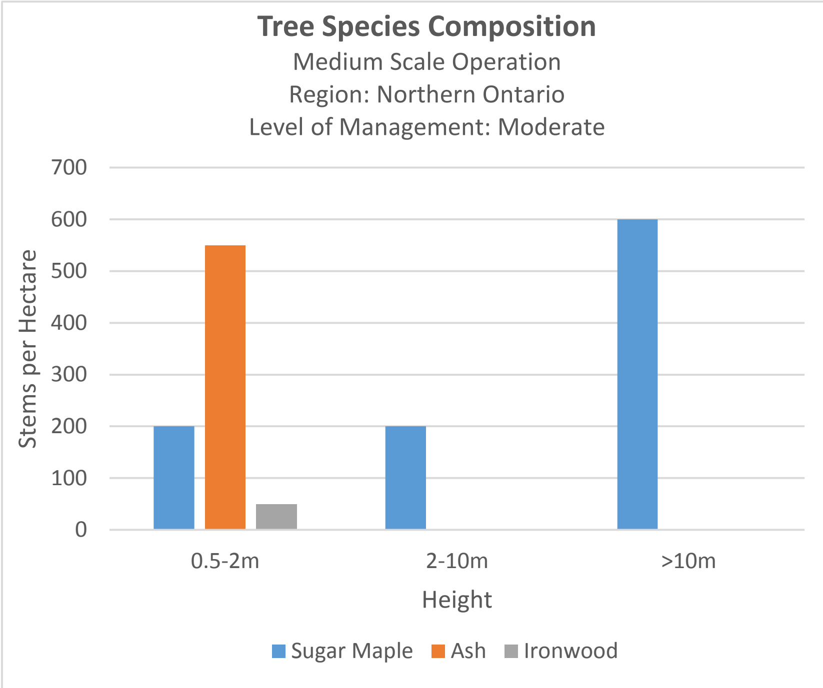

Figure 11 Medium Scale Operation in Northern Ontario

Figure 11: Sugar maple composed 23.5% of the sapling layer and 100% of both the sub-canopy and canopy layers. The average dbh measurement for the sampled sugar maples was 22.7cm. Ash and ironwood were both present in the sapling layer, composing 68.5% and 8% respectively.

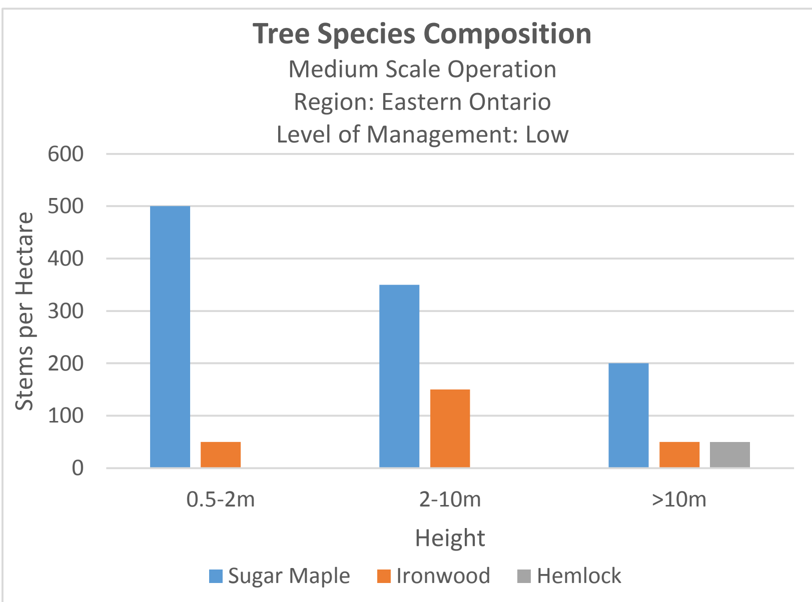

Figure 12 Medium Scale Operation in Eastern Ontario

Figure 12: Sugar maple composed 90% of the sapling layer, 62.5% of the sub-canopy layer and 66.5% of the canopy layer. The average dbh measurement for the canopy sugar maples was 55cm. Ironwood was present in all three layers, comprising 10% of the sapling layer, 37.5% of the sub-canopy layer and 16.5% of the canopy layer. The average dbh measurement was 24cm. Lastly, Eastern hemlock (*Tsuga canadensis*) was present among the canopy trees, composing approximately 17% with an average dbh measurement of 21.3cm.

7.0 Discussion

This section provides an analysis of interview and plot sampling findings in concert with the main themes of the literature review. The discussion divides the primary and secondary data into two main categories: the evaluation of the resilience of current sugar bush management and maple syrup production practices to climate change and the identification of strategies for human-facilitated resilient adaptation in sugar bushes. The first theme discusses findings related to environmental change, extreme storm events, forest demographics and species diversity and the second discusses the topics of short-term adaptation, long-term adaptation and best management practice.

7.1 Evaluation of the Resilience of Current Practices

The concern about the impact of climate induced physiological stress and disturbance on rates of tree mortality discussed by Allen et al. (2010) is mirrored by Ontario maple syrup producers. Tree mortality and forest dieback related to temperature stress has already had an impact in Canada according to the literature (Allen et al., IPCC, 2014) and this has also been experienced to varying degrees by the producers interviewed. In accordance with the findings of the literature that the sugar maple species is or will be declining in the southern portion of its range and migrating northward in future climate change scenarios (Lamhonwah, 2011), producers perceptions of this issued varied by geographical area.

Though the southern portion of the sugar maple range extends well into the United States, syrup production depends greatly on optimal winter temperatures. It is likely because projections show that Southern Ontario is more vulnerable to climate change impacts that producers here were more concerned about the future of their forest and production than those in northern Ontario. Climatological trends for the northeastern U.S. project a greater rate of warming between

December and February (Farrell & Chabot, 2012). In concert with this, producers in Ontario have observed higher variability in seasons with extended warm periods in the winter followed by extreme cold periods. This variability may prove to be an issue for producers in southwestern and Eastern Ontario geographies because mid-winter thawing was observed to cause decline and dieback within the canopy.

Increases in extreme storm events are projected in future climate change scenarios and have already been observed by producers in all geographies over recent years. The dependency on the natural environment makes the maple syrup industry vulnerable to extreme weather events (Belliveau et al., 2007; Murphy et al., 2012; Parkins, 2008). Producers' responses aligned well with the findings by Murphy et al. (2012) that high levels of variability in temperature, precipitation and storm violence are already being experienced. This is exemplified by producers' experiences in the 1998 ice storm in Eastern Ontario and the wind storm damage in the past ten years. The inherent vulnerability of forests to storm damage has encouraged maple syrup producers to practice sustainable forest management because the prevailing opinion is that well-managed areas are more resilient to these events. This is an example of a no-regrets adaptation, where the short term immediate benefits (decreased storm damage) extend into the long term survival of the sugar bush.

Current research on changes in the tapping season states that the highest mean winter temperature for sap production has not yet been reached, but a warming winter trend of 1.5-2.5°C has occurred across northeastern North America in the last forty years (MacIver et al., 2006). Despite this, Ontario producers have not noticed an overall decrease in production outputs, likely as a result of new technology allowing for increasing sap collection, but they have agreed that the tapping season has shifted about two weeks earlier. Consistent and even increasing maple syrup production in the future for Ontario could be a result of room for expansion for individual producers on their own land and the strong development potential on crown land (EcoRegions, 2013; OMSPA, 2013). Almost all producers indicated that they have either increased the number of taps in their sugar bush or up-scaled the area of forest they tap in the last 5 years. The adaptation of Ontario producers to a changing tapping season also correlates to technological advances in the industry with updated equipment allowing for a higher production output.

Given the literature review, the key management strategies that will promote socio-ecological resilience for sugar bush management are those that incorporate climate change adaptation into forest management by maintaining productivity of the sugar bush while increasing resilience to climate change. Good management will enhance adaptive capacity and could involve increasing the genetic diversity of the sugar maples within the stand as well as the species diversity of the other trees present. As stated in the results section, formal forestry or ecological training influenced participant management approaches, with these individuals prioritizing species diversity and conservative tapping practices. However, long-term adaptation was often a shortcoming for participants. Producers could increase the genetic diversity of the sugar maples in their stand by sourcing seed from other geographic regions where trees may be adapted to warmer temperatures or drought conditions (IPCC, 2014; Johnston et al., 2010). Increasing the biodiversity of the forest could be done by planting or preserving existing species of trees known to grow well with sugar maple without outcompeting the species, such as American beech, Hickory spp. and others including sub-canopy trees that mimic natural forest structure.

The findings of this study align with Clark and McLeman (2012) in that Eastern Ontario responded well to ideas of biodiversity conservation, however, the response was more positive in medium scale producers or those with formal forestry training. In addition, the current study was able to expand this work and demonstrate that most small and medium scale producers throughout

Ontario also responded well. Given the strongly inter-connected North-American maple syrup industry, it is likely that producers from other jurisdictions are also embracing ideas associated with biodiversity conservation and that the best practices outlined in the current study would be transferable to other jurisdictions. However, further research will be needed to confirm this assertion.

7.1.1 Forest Demographics

It was evident through the extant literature and individual producer experiences that long term environmental changes are occurring in Ontario, leading to decreased species diversity and risk of colonization by invasive species (Hogg & Bernier, 2005; IPCC, 2014). Changes in forest demographics as a result of pests and disease was a common theme during the interviews, affecting the species composition with the gradual loss of species like ash, American beech, butternut, bitternut hickory, and in the past, elm. The primary example of this is the EAB infestation in Southern Ontario that has caused severe dieback or loss of ash trees. The large openings in the canopy encourage the growth of invasive species like wild raspberry (*Rubus idaeus)* (see **Figure 13**), and European buckthorn (*Rhamnus cathartica*) that can impact ecosystem health over time. That being said, producers have not noticed any significant decline in the overall health of their sugar maple populations and have even noted vigorous regeneration in the species. Because the growing

Figure 13 Proliferation of wild raspberry in over thinned areas of two different sugar bushes

concerns for maple syrup production are so closely linked with ecosystem health, it is important to manage for changes in forest demographics to prevent colonization by invasive species. Encouraging species diversity is stated in the literature as a way to increase forest resilience to pests and disease, and many respondents shared similar views. Plot data in areas affected by EAB showed ash in the regeneration but very little in the sub-canopy and canopy layers. On the four properties in Southern Ontario where this is the case, these openings in the canopy have allowed for proliferation in ground cover such as wild raspberry. Three of these producers have begun to adapt, trimming the raspberry undergrowth to allow for the regeneration of sugar maple in the canopy openings.

With the threat of invasive species such as Asian longhorned beetle (*Anoplophora glabripennis*) on the horizon, producers need to pay close attention to ecosystem health for early signs of infestation and many producers mentioned they were already worried about this insect. In terms of plant species, wild raspberry, European buckthorn and other invasive plants in Ontario can compete with the regeneration of sugar maple and other trees. The importance of ecosystem health and biodiversity for forest resilience is stressed throughout the literature and recognized by most maple syrup producers. Small and medium scale sugar bush operations may be less at risk of invasive species colonization in the understory when managed well, including thinning invasive plants in open canopy areas to promote regeneration and paying close attention to signs of tree stress; and although many of large scale producers interviewed noted that it is difficult to incorporate goals of invasive species eradication into their management plans for financial reasons, commercial maple sugar bushes have the potential to play an important role in the management of invasive species and biodiversity conservation (Clark & McLeman, 2012).

7.1.2 Species Diversity and Plot Sampling

The current literature takes a more proactive approach to climate change adaptation, encouraging resilience in sugar bush operations through a more species rich stand of trees rather than removing all other species to increase productivity (Barkley, 2007; Ruble, 2014; Whitney & Upmeyer, 2004). Producers who took a stronger approach to maintaining species diversity by including practices such as selective harvesting, encouraging natural regeneration and planting other species within the sugar bush showed a higher stand diversity in the plot sampling data. Though there are limitations to the small sample size of this study, the species compositions tended to reflect the management priorities outlined during the interviews.

Figure 8 is an example of a Southern Ontario sugar bush that has the presence of ash, beech and ironwood within the stand in addition to sugar maple. This species composition is typical of a Southern Ontario deciduous forest, however, it is lacking some species diversity in favor of sugar maple. One would expect to also find species such as hop hornbeam, red maple, oak spp. or dogwood spp. on a site like this one (Cornell, 2015). This medium-scale producer stated during the interview that they prioritize forest health and species diversity over maximum production of the sugar bush, which resulted in an abundance of sugar maple in all layers of the canopy as well as ash and beech regeneration. The sugar maple presence in all canopy layers is indicative of forest management for a diverse age structure and resilience, practicing crown release for seedlings and saplings in the understory. EAB was also a factor here, causing decline in the ash population thereby altering the canopy structure. This producer also noted the resilience of the canopy trees to high wind events which could be attributed to effective management practices for density and age diversity, allowing the trees to support each other during these events. This could also correspond to the deeper soil in this region, meaning the canopy trees could have deeper root systems and hold up better in wind storms.

The producer whose plot data is represented in **Figure 9** in Central Ontario also mentioned taking a positive approach to species diversity but does less active forest management than the participant's operation in **Figure 8.** This producer also observed that for as long as they have owned the property, the forest has been dominated by sugar maple with vigorous regeneration which factors into the sampled species composition. The dominance of sugar maple in the canopy and sub-canopy layers of the forest with little management intervention could be a result of the species outcompeting a majority of the other trees present that may have less vigorous regeneration or is less suited to the environmental conditions in the area. Because this site is located quite far north of the sugar bush in **Figure 8**, the soil conditions could be a factor in the species composition observed here. Though there was some black spruce observed, a more mixed forest structure would typically occur on a site like this, combining hardwood species like sugar maple, birch and balsam poplar with softwoods including black spruce and balsam fir (Sims et al., 1998).

The medium-scale operation in **Figure 12** in Eastern Ontario produces maple syrup as a hobby, using an oil powered evaporator and is less active in forest management. This stand showed hemlock in the canopy layer as well as ironwood in the sub-canopy layer. There was a lower density of sugar maple in the canopy layer here because many trees were over mature, creating dense shade that did not allow for canopy release in many sub-canopy maples. This lack of sub-canopy diversity is a common occurrence in mature, unlogged forests like this one, however, one would expect to see a higher presence of American beech occurring with the sugar maple. Reiterating the point of Nelson and Wagner (2014), this could be explained by the fact that American beech often declines once it reaches the canopy layer and is at risk of beech bark disease in Ontario. More active silvicultural practices in this sugar bush could open the canopy, encouraging regeneration of sugar maple and non-maple species and allowing crown release for the sub-canopy sugar maples. This would create a higher age and structural diversity among the trees, thereby increasing resilience to extreme storm events.

In contrast to these producers, **Figures 10 and 11** represent two different scale operations in northern Ontario. **Figure 11** is a medium-scale operation where the producer has a very positive attitude to species diversity but only moderate management intervention. There was a fairly diverse age structure in the sugar bush here, with many sub-canopy and canopy sugar maple trees. The plots on this property were taken in the tapped areas of the sugar bush however, it is important to note that there was a high level of species diversity in adjacent areas of the forest. The untapped areas of forest at this site were consistent with the mix of hardwoods expected in this part of Northern Ontario and included yellow birch, red maple, bur oak and basswood species (Sims et al., 1998). This site provides an example of the fact that sugar bush operations are highly managed and therefore ecologically different than unmanaged sugar maple forests. The difference in species diversity on this one site between the tapped and untapped areas was significant. The ash regeneration in this stand was abundant as a result of openings in the canopy created by an extreme wind event. A lot of wild raspberry was also present in the ground layer in over thinned areas, inhibiting maple regeneration to a degree. The management objectives of this producer corresponded to efficiency in the pipeline system, promoting a dominant population of sugar maple in tapped areas to create maximum production while extending the pipeline into less area. Increased invasive species management in over thinned areas to eradicate wild raspberry and promote the regeneration of sugar maple could be a way for this producer to increase sap collection in these areas while also enhancing resilience to future storm events by reducing the amount of open space in the canopy.

Figure 10 is an example of a large scale commercial operation with different management objectives than the other four sampled areas. This producer values productivity of the sugar bush, managing for a dominant population of sugar maple within the forest. These management priorities from the interview were mirrored in the results of the plot sampling, which showed some ironwood in the regeneration but only sugar maple in the canopy and sub-canopy layers in high density. There was a definite lack of diversity compared to what one would expect to see on a site this large in Northern Ontario as a result of long term management for maple syrup production. A higher prominence of balsam poplar, bur oak and basswood would definitely be expected given these site conditions (Sims et al., 1998). The management objectives for this producer may also correspond to the geography of the sugar bush, with producers in Northern Ontario being less vulnerable to climate change impacts than Southern Ontario. Long-term adaptation is something that can be improved upon in this case with such a dominant population of sugar maple in the forest. Very few non-maple species were observed here and other large scale producers shared similar strategies. The economic vitality of these large scale operations is currently dependent on maximum production, however the sustainability of these operations relies on longevity. Given that large scale sugar bush operations can play a crucial role in the conservation of biodiversity, more active forest management that enhances adaptive capacity would be beneficial. In other words, because large sugar bush operations have access to so much land, producers have the potential to do more to increase sugar maple resilience on a broad scale.

In light of climate change projections, the extant literature has shifted to recommend sugar bush management for biodiversity and resilience over maximum production. The general consensus of the producers' interviewed reflects this way of thinking. While some producers manage specifically for high levels of biodiversity, others focus on maintaining forest health. The combination of these two priorities would greatly improve adaptive capacity in the short term, allowing for a high species diversity while also removing unhealthy or damaged trees. It is important to note however, that changes in species composition and forest structure is an ongoing process so sugar bush managers will need to continually monitor, learn and adapt to these changes to maintain resilience. From a biogeography point of view, long-term adaptation strategies are also crucial for the sustainability of sugar bushes. Intra-species diversity plays a crucial role in resilience, increasing the probability that the forest contains specimens that are more adapted to the projected environmental conditions in light of climate change.

7.2 Strategies for Resilient Adaptation

7.2.1 Short-Term Adaptation

This research has sought to understand the effects of climate change on maple syrup production occurring at a local level in order to determine best management practices and opportunities for resilient adaptation. Proactive silvicultural practices, such as increasing intra- and inter-species diversity, harvesting stands susceptible to disease or insect infestation, and thinning to reduce moisture stress all provide ways to increase adaptive capacity in the short term (Johnston et al., 2010). Some more technical adaptation strategies already in place in the U.S. and Canada and exemplified in the interview data include shifting the tapping window to accommodate seasonal variability and improvements in tapping technology (MacIver et al., 2006; Murphy et al., 2012; Skinner et al., 2010). These strategies are constantly evolving as information is shared and technological improvements are made within the industry.

Participants mentioned many of the five objectives by Johnston et al. (2009) to incorporate climate change into forest management. The first objective is to reforest to manage forest land. Some producers have begun to plant sugar maple in open space on their property, as a succession planting with red pine, and in over-thinned areas as a result of wind or storm damage. There is large planting potential for producers in the storm damaged, over-thinned areas of the sugar bush. Planting within these areas, especially if the trees are sourced externally, has the potential to increase the genetic diversity of the core forest habitat, thereby increasing the resilience of the sugar bush as a whole. Producers have also exemplified the reforestation or afforestation objective by planting species other than sugar maple to increase the species diversity within the forest. Though many of the producers interviewed do not actively participate in reforestation initiatives, they took a positive approach to this concept. Participants stated that they either have ample untapped forest and therefore room for expansion of their operation before reforestation is needed, they would like to or will be involved in planting programs in the future, or they are interested in learning more about the benefits of reforestation and sourcing trees externally.

The second objective is to conserve and enhance genetic diversity. As previously mentioned, most producers do actively conserve interspecies diversity but genetic diversity within the sugar maple population was a less common theme. Many producers stated that they have not yet considered genetic diversity in their management practices. Although disturbance regimes will differ between producers, high genotypic diversity among populations is an asset for survival (Bischoff et al., 2010). For this practice, the literature suggests a seed sourcing method that focuses on a wide selection of genotypes from various environments however, mother plants should be selected for optimal sap production (Breed et al., 2013). For example, sourcing from areas with more heat tolerance could be beneficial in future climate change projections. There are practical challenges that exist here, such as widespread recommendations against sourcing outside the seed zone of the planting area, though these are often rooted in an unchanging ecological perspective. In addition to this, getting seeds sourced from outside the country may be difficult. An important area for improvement in combining climate change adaptation into forest management would be restoration planting of sugar maple seedlings from different geographic areas that may be more adapted to the projected environmental conditions in order to increase genetic diversity and adaptive capacity of the species (MacIver et al., 2006; Skinner et al., 2010; Whitney & Upmeyer, 2004). Restoration planting using plants of local provenance is a way to enhance genotypic diversity that may be more applicable for producers in the short term, helping to ensure survivability within the habitat conditions (Bischoff et al., 2010). Encouraging the growth and regeneration of non-maple species within the forest would aid in enhancing genetic diversity, helping to conserve interspecies genetic diversity.

The third objective, maintaining species productivity, is the most common of the objectives for maple syrup producers, resulting from selective thinning and crown release practices. The management practices that allow for structural diversity within the forest open the canopy to allow for sub-canopy trees to prosper and encourages regeneration by allowing sunlight to penetrate to the forest floor. The maintenance of species productivity of other tree species however is considered less often.

The fourth objective pertains to forest health. Maintaining a healthy forest over time will make it more resilient to environmental changes. Forest health is definitely a concern of maple syrup producers, especially in light of recent threats such as EAB and Asian longhorn beetle, and will play a key role in the maintenance of syrup production in a changing climate. Forest health is important now and in current climate scenarios because a healthy forest will be more resilient to environmental changes and stressors.

Lastly, the fifth objective: enhancing adaptive capacity is an important piece of resilience for maple syrup production. Adaptive capacity is the capacity of a system to adapt if the environment is changing. All of the objectives listed above are ways to enhance sugar bush resilience. The application of these objectives to short-term and long-term management practices has the potential to greatly enhance adaptive capacity of sugar bushes in Ontario. Proactive management to enhance adaptive capacity and the application of best management practices will be the most effective ways to ensure forest health and production in the future.

7.2.2 Long-Term Adaptation

Producers across Ontario have described climatic changes in much the same way: an increase in extreme storm events, changes in seasonality, and canopy dieback. Because trees are sessile throughout most of their lives making ‘migration’ a product of a decline in the southern portion of their range and an increase reproductive capacity at the northern edge, biogeographic changes may be difficult for producers to notice in their sugar bush. Species response to regional climatic changes may occur over a long period of time, resulting in a reduction in local biodiversity (Lemmen et al., 2008; Malcolm et al., 2002). As explained in the literature review, the sugar maple species will face unfavorable conditions on the Canadian Shield that will impede their ability to grow if the range is to migrate north. Assisted migration was a controversial topic among the interviewed producers, however all were interested in learning more about it. Assisted population expansion, movement of populations within the current range of the species, is the most applicable to sugar bush management and may be an important next step for producers. Producers did describe transplanting sugar maple seedlings and saplings from different areas within their sugar bush, but when asked about sourcing seeds externally, often they did not feel it was necessary with such healthy regeneration already present.

It is difficult to conceptualize the need for long-term adaptation when Ontario maple syrup producers tend to describe their sugar bush and business as healthy, thriving and growing. Increasing adaptive capacity of forests and sugar bushes in the long-term requires management for what the environmental conditions will look like in future scenarios. There is a knowledge gap here that exists between the literature on assisted migration and adaptation decision-making of maple syrup producers on a local level. While there is still a need for further research on long-term provenance field trials to determine the climate tolerance of each seed source for optimal assisted migration strategies, increasing intra-species diversity by sourcing seeds for restoration planting from different geographic areas and from as many mother plants as possible could be an effective example of a no-regrets adaptation. The outcome of increasing genetic diversity, especially within the sugar maple population, will benefit the sustainability of the sugar bush in the long-term whether optimal assisted migration strategies are in place or not. Managing for increasing genetic diversity will enhance adaptive capacity to climate change in the long term by increasing the probability that the forest contains a proportion of adapted populations (IPCC, 2014; Johnston et al., 2010). High genetic diversity can increase sugar bush resilience to disturbance such as pests and disease by possibly introducing resistant populations, as well as resilience to changing environmental conditions such as drought and warming temperatures. A potential downside to sourcing seeds adapted to projected climate conditions, however, is that they may be less well adapted to the current environmental conditions and may be outcompeted by the regeneration of the existing trees.

7.2.3 Best Management Practices

Effective sugar bush management promotes socio-ecological resilience while also aiming to incorporate climate change adaptation objectives into management strategies. Best management practices within the maple syrup industry are constantly evolving. The continuous development, sharing and adoption of climate sensitive best management practice between producers, equipment dealers, professional organizations and academics help producers to enhance the adaptive capacity of their sugar bush. Respondents sourced their information from being involved in the industry with organizations such as OMSPA, staying current with the literature on maple syrup production and sustainable forest management, and attending workshops and meetings that allow them to gather knowledge from forestry professionals and share knowledge amongst one another. The producers that were adamant about constantly gathering knowledge from these sources tended to manage their stands for best management results such as higher inter-species diversity, invasive species eradication, conservative tapping practices and thinning to maintain forest health. Given the importance of this knowledge base, the industry is encouraged to provide information sharing opportunities for producers on enhancing adaptive capacity both in the short-term and long-term. Workshops and forest walks are also invaluable, allowing producers to see management practices first-hand. In addition to this, newsletters and research articles should be shared as often as possible.

In order to maintain productivity, successful management may also require adjusting tapping windows for optimal sap collection. Producers are already adapting to changes in seasonality and freeze thaw cycles by shifting their tapping season accordingly. Because many producers now use pipelines to collect sap from their sugar maples, it is no longer possible to monitor the individual output of each tree. Conservative thinning practices were a common best management practice among producers, thereby minimizing wind damage within the stand. Other best management practices to increase resilience to extreme weather events include encouraging natural regeneration and structural diversity, and making sure trees have sufficient space to grow and develop. In alignment with these practices, producers agreed that forest health directly corresponds to maple syrup production. Best management practices that enhance forest health will result in a higher production output.

Proper tapping procedures are an important best management practice for maple syrup production. The minimum tapping size used by most of the respondents is 12’’ depending on the health of the tree, with 18-22” being the consensus for two taps. Effective best management practices according to the interview results, will result in multiple single tap trees that provide a higher overall sap output than fewer over mature trees with multiple taps. The use of a 5/16” health spile is also an important practice. The proper management of the vacuum system is a best management practice stressed by producers and equipment dealers, ensuring exposed sap does not re-enter the tree. Using all of the resources at one’s disposal can also provide an effective best management practice for producers. One example of this could be the use of the water byproduct from the reverse osmosis process for cleaning equipment. One recommendation is that producers who do not use wood as a fuel source could adopt some of the management strategies of those that do, practicing silviculture more actively.

8.0 Conclusions and Recommendations

The future of the maple syrup industry in Ontario is dependent upon the resilience of sugar bush operations to climate change. That being said, there is little academic research about the impacts of climate change focused on the St. Lawrence-Great Lakes forest region and on rural woodlot landscapes. Climate change projections tend to cover the broad effects across large regions, but the impact on Canadian localities and locally-appropriate resilient adaptation strategies are important for the maple syrup industry. The goal of this paper was to gain a better understanding of human-facilitated silvicultural, biodiversity and genetic forest management in Ontario in order to determine the social and ecological resilience to climate change impacts.

Interview results suggest that the effects of climate change are already being seen at the local level. In the last 10 years, producers have experienced seasonal fluctuations with extended warm periods in the winter followed by extreme cold periods, an increase in the frequency of extreme storm events such as microbursts, changes in species composition as a result of pests and disease like EAB and beech bark disease, over thinned areas of the forest becoming colonized by invasive plant species and a general shift in the tapping season two weeks earlier in the spring. The overarching conclusion of the plot sampling data exemplifies that sugar bush operations are highly managed, making them ecologically different than the forest communities one would expect to see in Ontario. That being said, many producers do strive for structural diversity and forest health within their stands.

Based on the initial practices and principles outlined in the literature review to increase socio-ecological resilience to climate change impacts, the overarching conclusion is that maple syrup producers in Ontario recognize the need to entrench climate change objectives within forest management. Enhancing adaptive capacity is a continually evolving process that producers need to undertake as environmental conditions change. Short-term adaptation methods like increasing inter- and intra-species diversity, removal of diseased trees and the overall maintenance of forest health are being practiced by many producers with room for improvement in others. One important recommendation is for producers to implement short-term adaptation methods now, if they are not already doing so, as a no-regrets strategy.

Long-term adaptation methods relating to biogeography such as assisted population expansion, assisted range expansion, seed sourcing and provenance and restoration planting are not common among producers in the present but have the potential to be practiced more widely in the future. More research is needed on some of the long-term adaptation strategies but the time to enhance adaptive capacity is now. Government or otherwise funded programs to aid producers in resilient adaptation practices would be incredibly beneficial. For example, assisted migration strategies, often inhibited by sanitary protection government policies, limited the transport of plant material across international borders and long distances. One recommendation is that government programs could assist producers in long-term adaptation strategies, playing a role in the supply and transport of trees for restoration planting initiatives. For many producers, the knowledge and interest in resilient adaptation methods exists but there is a financial barrier to putting them into place. The desire of many producers to learn more about short-term and long-term adaptation methods points to the potential application of these strategies in the future.

The limitations of the plot sampling methods are that there was variation between producers dependent on geographic location and individual management strategies. Also, because only five of the fifteen locations were sampled for tree species composition, the output data from each of the plot sampling locations represents one sugar bush within a much larger geographic area. Opinions and observations about climate change impacts and successful management practices may also differ between producers. Given that this study takes place during one field season and climate change is an ongoing process, an important next step would be to monitor tree health, mortality, and diversity within the forest over a longer period of time than this study allows. In addition to this, follow-up interviews would allow for producers to make note of any other climate change impacts they observe in their forest. Limitations also exist within the interview data, using a small pool of fifteen respondents. However, the goal of the interviews was to select producers from different regions with operations of varying sizes to attain results that represent the diversity of Ontario maple syrup producers.

Next steps for this research include further investigation into the economic application of short-term practices to enhance adaptive capacity. Short-term adaptation methods can be implemented by producers now to increase forest resilience to the climate change effects already being seen at a local level. Further research may also align with the recommendations of Johnston et al. (2010) for long term provenance field trials to determine optimal assisted management strategies and the physiological responses of tree species to climate change. Sugar maple breeding programs to test if high yielding trees could be improved upon by genetic selection are already being studied and could prove beneficial for the industry. More quantitative research on the benefits of high inter-species diversity within sugar bushes may be a beneficial avenue for future studies, potentially solidifying the link with resilience to climate change impacts. On a larger scale, climate envelope modeling on the impact of CO_2 on seedling establishment and growth would be useful. Since few studies have been done in an Ontario setting, any research that examines the future of maple syrup production specific to Ontario geographies would be a beneficial step to the industry. In the meantime, the evolution and sharing of the knowledge base among producers, equipment suppliers, professional organizations and academia is invaluable.

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10.0 Appendix

10.1 Interview Guide

1. Could you please tell me a little about yourself, your sugar bush and your involvement with maple forest management and/or maple syrup production
   - How long have you been involved?
   - What specific aspects of the management/industry have you been involved with?
   - How big is your sugar bush, how many taps do you typically put in? Have there been any changes in the size of the sugar bush or are there any planned?

2. Have you seen any recent changes in the number or type of animal or plant species (positive or negative)? And are these changes a result of your management practices?
   - What specifically have you noticed? Over what time period? Over what geographical area?
   - Such as natural disturbance, pest outbreaks, invasive species, changes in tree health, tree canopy and growth pattern, changes to the broader maple tree ecosystem, quality and quantity of syrup production, and the length of the syrup production season.

3. What do you think is the main driver of these changes?
   - For example: climate, pollution, land use change or other ecosystem changes

4. What are the main strategies you use to manage your forest? For example, do you remove surrounding trees to release the crowns of high yielding maples?

5. Is the management of your forest inhibited by anything such as land regulations and restrictions, incentives (such as MFTIP), and other priorities such as eradicating invasive species?
   - Prompt for main invasive species affecting the forest

6. What are your main concerns when managing your forest?
   - To mimic the natural ecosystem processes? I.e. little management and intervening to fell dead/dying trees

7. Is maintaining a high **species** diversity a priority in the management of your forest? And/or do you typically focus on increasing or maintaining the amount of high yielding or sweetest maples?
   - Is maintaining a high **genetic** diversity a priority?

8. Do you undertake reforestation/restoration planting or planting of seedlings in your sugar bush that are not a result of natural regeneration? Why or why not?

9. If not, do you do anything to protect or assist these natural seedlings?

10. If so, from where do you source these seeds/seedlings? How do you decide which seeds/seedlings to buy? If necessary, probe:
    - Geographical area? Whether within the sugar bush, from another sugar bush, or purchased.
    - Purchased stock; from which vendor or grower?
    - Was seed zone important in the sourcing of these seeds? If so, how (same, more southerly)?

11. If so, what do you do to ensure the propagation and growth of these seeds/seedlings?

12. Have you noticed any changes to seeds and seedlings in the sugar bush that could indicate climate change? Can you think of anything else that might be important for me to know?