Assessing the vulnerability of south-central Ontario's maple syrup industry to climate change: A multidisciplinary approach

A thesis presented to
The Faculty of Graduate Studies
of
Lakehead University
by
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In partial fulfillment of requirements for the degree of
Master of Science in Biology

April 10, 2023

Abstract

Productivity of Ontario's maple syrup industry is tied to a specific climate window. As climate continues to change, there is growing concern over the industry's vulnerability given its reliance on stable climate conditions for maintaining syrup quality and yield. Factors causing variation in sap sugar content can differ at local and regional contexts and may change in relative importance as climate change impacts regulating processes and mechanisms. Given the ecological and socio-economic significance of maple syrup production in Ontario, the objectives of this study were to: (a) determine which ecological factors are most important in explaining variability in sap sugar concentration across south-central Ontario, (b) explore Ontario maple syrup producer's perceptions of climate change and identify the constraints to implementing adaptation strategies that could help maintain current maple syrup production levels, and (c) explore the influence of nature-based maple syrup recreational activities and tasks associated with maple syrup production on individual well-being of adults with intellectual and developmental disabilities (IDDs) at Camphill Communities Ontario (CCO).

Seven commercial sugarbush operations were sampled in the summer of 2021 across south-central Ontario, Canada. Climate characteristics, soil conditions, and stand health data were collected for each stand. Sap sugar concentration data were collected during the spring/tapping season of 2022 at each site. Variation in sap sugar concentration was analyzed using Akaike's Information Criterion (AIC) and was explained through a combination of climate, soil, and stand health factors including proportion of maple species in the canopy, maximum ambient temperature during the growing season, mean soil temperature during the tapping season, and mean ambient temperature during the winter season (R^{2adj}=0.9788, $p<0.0001$). Regional maple sap sugar concentrations may decrease in response to changes in stand health and composition as climate continues to change.

A voluntary Likert scale survey was made available to Ontario maple syrup producers (n = 22) to better understand their perceptions of climate change and constraints for implementing climate change adaptation measures. Ontario producers want to implement adaptation measures prior to experiencing the effects of climate change (X^2 = 12.1, df = 4, p=0.017). However, lack of technical support (workers, equipment, etc.,) was a major constraint (X^2 = 16.2, df = 4, p=0.003). Ontario producers identified that using spring forecast models (X^2 = 11.1, df = 3, p=0.011), improving sanitation practices (X^2 = 8.86, df = 2, p=0.012), and implementing cost-effective, less intensive stand tending interventions that reduce inefficiencies (X^2 = 8.52, df = 3, p=0.036) were more attainable than implementing new technology (X^2 = 2.55, df = 4, p=0.64).

A voluntary Likert scale survey (n = 29) and a complementary semi-structured focus group discussion (n = 5) was conducted to explore how nature-based maple syrup production-specific activities and tasks influenced individual well-being among adults with IDDs at CCO. Participating in these activities cultivated positive emotions via feelings of connectedness with nature, self-perception through skill development, and relationship development through sharing self-produced maple products with local communities. Deductive thematic analyses revealed that adverse weather conditions and physical limitations were the main deterrents for participation.

Collectively, this study identified potential regionally-effective adaptation strategies to address the vulnerability of south-central Ontario's maple syrup industry to climate change. Furthermore, this study explored the influence of nature-based maple syrup production activities on individual well-being, a benefit of the maple syrup industry that is often overlooked. Taking a multi-disciplinary approach to managing south-central Ontario's maple syrup industry aligns with the principles of socio-ecological resilience, as information from this study can be used to help develop effective, holistic adaptation strategies that meet all stakeholder needs in perpetuity.

Keywords: *Acer spp; sugar maple; nature-based activity; well-being; cognitive disabilities; developmental disabilities; climate adaptation*; *maple syrup producers*

Acknowledgements

In completing this degree, I have so many people to thank. First and foremost, thank you to my parents for the love and support you have provided throughout my entire academic journey. You two were always quick to remind me that I am a capable young woman who can achieve anything I set my mind to. I cannot begin to express how grateful I am for all the ways you two showed your support over the years.

To my supervisor, Dr. Gerardo Reyes, thank you for allowing me the opportunity work on this unique and forward-thinking project. I greatly appreciate your encouragement to tackle new challenges and for the invaluable guidance you offered along the way. Your unwavering kindness and mentorship have truly been instrumental to my professional and personal development.

Thank you to my graduate committee, Dr. Nandakumar Kanavillil and Dr. Sonia Mastrangelo, for providing expertise in your fields of study. I would also like to acknowledge Kathrine Killam from CCO for catalyzing this project, and CCO individuals Joshua Robertson and Skylar Charlebois for agreeing to be my field assistants. Thank you to my Lakehead field assistant, Nelson Toledo-Gonzalez, who traveled near and far to collect data, play in dirt, and endure endless mosquito and deer fly bites. I would also like to thank Vicki TeBrugge for welcoming me into the Lakehead community and for positively impacting my time here.

I would also like to acknowledge the Ontario Maple Syrup Producers Association (OMSPA) and OMSPA president, John Williams, for providing provincial maple production data. A special thank you to all Ontario maple syrup producers who participated in this study. Without you, this research project (& golden maple products) wouldn't be possible.

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Prologue

I wake to the sound of my alarm at 5 o'clock in the morning. I pull on my warmest clothes and pad down the hall to my even thicker jacket and ski pants. Once I'm fully bundled with a coffee in hand, I begin walking to the backyard sugar shack. It's officially time to start up the wood evaporated pan and boil maple sap to syrup. Now, if you've never made your own maple syrup, let me assure you that it is a time-consuming activity that usually has you questioning whether your toes still exist by the 4th (sub-zero) hour. And yet, it's a highly anticipated annual tradition that gets everyone through those late winter months. It is likely my personal experiences with maple syrup production that drove the approaches I took to addressing my research objectives in this thesis project.

My research takes a multi-disciplinary approach to identifying areas of vulnerability to climate change within south-central Ontario, Canada's maple syrup industry. Chapter 1 provides background information and outlines my research objectives. Chapter 2 examines the relative importance of stand-level ecological factors influencing maple sap sugar concentrations in stands used for commercial syrup production, which helps to identify areas of vulnerability to climate change in a regional context. Chapter 3 explores the impacts of nature-based maple syrup production-specific activities on individual well-being; ultimately, to determine if the beneficial aspects of these activities can be better integrated into maple syrup production practices. Chapter 3A (Appendix) discloses the perceptions of Ontario maple syrup producers towards the impacts of climate change on maple syrup production and the constraints to implementing new technology to mitigate against the negative impacts of climate change. Chapter 4 synthesises my results and outlines some foundational steps that promote socio-ecological resilience for the maple syrup industry.

Chapter 1. Introduction

1.1 Overview

Maple syrup is an economically and traditionally significant non-timber forest product that originates from the First Nations peoples of northeastern North America (Houle *et al*., 2015; Rapp & Crone, 2014; Snyder *et al*., 2018). The practice of making maple syrup is a cogent symbol of Canadian identity and culture, with the iconic maple leaf emblazoned across the country's national flag being a testament to this (Muhr *et al*., 2016). The Canadian maple syrup industry is comprised of small-scale hobbyists, multi-generational farmers, and large-scale commercial producers.

Given the cultural significance, flavour, and growing recognition of the health benefits of maple syrup, demand for this natural, geographically unique product has increased (Kelly & Staats, 1989; Statistics Canada, 2021; St-Pierre *et al.,* 2014). Global demand continues to grow as exports increased by 21.4% during the first three quarters of 2021 compared to the same period in 2020 (Statistics Canada, 2021). To meet demand, many producers have implemented technological advances to increase yield while simultaneously reducing energy costs (Rapp *et al*., 2019). For example, vacuum pumps, elaborate tubing networks, high-efficiency evaporators, and reverse osmosis (RO) systems have been adopted by many large-scale and some mid-size maple producers. Traditional methods of sap collection (spile and bucket) and boiling over a fire are now mostly limited to small-scale or hobby farms. Regardless of how the maple sap is processed to produce maple syrup, the quality and quantity of maple sap is pertinent for producers as it directly influences profitability (Rapp *et al.,* 2019).

Total maple syrup yield is dependent on two sap characteristics: total sap volume and sap sugar content (Rapp *et al*., 2019). Total sap volume produced by a sugarbush is dependent on the reliability of sap flow during the tapping season (Rapp & Crone, 2014) which directly impacts total syrup yield (Houle *et al*., 2019). Sap sugar content determines the amount of time and energy that is required to boil maple sap to a concentrated 66˚Brix (or 66% sucrose by mass), at which point the sap is classified as maple syrup (OMSPA, 2021; Rapp *et al.,* 2019). Moreover, sap sugar content determines the volume of syrup that can be produced from a given volume of maple sap (Rapp & Crone, 2014).

Sap volume and sugar content can be highly variable between years and geographical location (Rapp *et al*., 2019). Variability in these sap characteristics has been linked to climate properties such as ambient temperature and precipitation, edaphic properties (Sullivan *et al*., 2009; Wild & Yanai, 2014), and stand health (Morrow, 1955). Because the industry is so highly dependent on stable environmental conditions to remain viable, there is growing concern over how climate change will impact production levels.

Current literature on the impacts of climate change on maple syrup production has focused on the southern and northern limits of maple tree distribution wherein the requisite freeze-thaw cycles needed for sap flow occur. Studies from northeastern United States, the southern limit of maple tree distribution wherein commercial production is viable, generally report negative effects on production levels such as shifting and constricting tapping seasons, lower sap sugar content, and reduced total yield (Rapp *et al.*, 2019). In contrast, studies from Quebec, representing the northern limit, report minimal to positive effects of climate change on maple syrup production including increased yields (Farm Credit Canada, 2021; Legault *et al*., 2019). Few studies have explored the impacts that climate change poses on maple syrup production in south-central Ontario, a region central to where maple syrup production is possible, and no studies have aimed to determine the relative importance of key stand and site-level ecological factors thought to impact maple syrup production there. Improving this understanding is critical to better understand how regional sugarbushes may be affected by a changing climate and is thus a key component of my research. The information will help regional producers assess the vulnerability and adaptive capacity of their respective sugarbushes, and to develop adaptation strategies that maintain or potentially enhance current maple syrup production levels.

1.1.1 Genus *Acer*: significant species for maple syrup production

Commercial syrup production is generally restricted to the northeastern United States and Canada, although production can occur as far south as the state of Florida in a limited capacity (Virginia Tech, 2021). Out of the 13 native North American maple species, sugar maple (*Acer saccharum* Marsh.), red maple (*Acer rubrum* L.), and less extensively black maple (*Acer nigrum* Michx. f.) and silver maple (*Acer saccharinum* L.), are most often tapped for maple syrup production in southern Ontario (MNDMNRF, 2021).

Sugar maple is the favored species for maple syrup production due to the exceptional sweetness of its sap and the long dormancy release period before budbreak (Skinner *et al.,* 2010). Although sap sugar content can vary among trees, given the variability in stand characteristics, genetic composition, and ecological factors across its natural range, sugar maples consistently produce sap with sugar content of up to 5.0% (Table 1), or the equivalent of 1 L of maple syrup per 40 L of sap (Crum *et al*., 2004; Gill & Newling, 2022; Rapp *et al.,* 2019). Sugar maple is a common hardwood species in southern Ontario, Canada. Its natural range spans from the Great Lakes-St. Lawrence region of southeastern Canada to the northeastern United States coast and extends westward to the midwestern United States (Figure 1a) (Fryer, 2018).

Red maple is also commonly used for maple syrup production. Sap sugar content from red maple averages 1.7-2.5% (Crum *et al.,* 2004). Given the lower sap sugar content than that of sugar maple, red maple has considerably higher energy costs to produce an equivalent amount of syrup from its sap. Moreover, red maple typically exhibits earlier bud break than sugar maple, which results in a shorter tapping season. Syrup produced from trees after budbreak is of lower grade and value given its undesired flavour and consistency (Burns & Honkala, 1990). Red maple has the largest natural range of distribution of all commercially tapped maple species, spanning from southeastern Canada to the Gulf Coast of the United States (Figure 1b) (Fryer, 2018).

Black maple is commonly tapped in the mid-western United States due to its high sap sugar content of approximately 2.0-2.5% (Crum *et al.,* 2004). Owing to its sparse distribution in southern Ontario (Figure 1c), its use for production is limited in this region (Fryer, 2018). Silver maple has the lowest sap sugar content of the commercially tapped maple species, averaging 1.0-2.0% and is thus, less commonly used for syrup production (Crum *et al.,* 2004). Silver maple ranges from the Great Lakes-St. Lawrence region of southern Ontario south to the midwestern United States (Figure 1d) (Fryer, 2018).

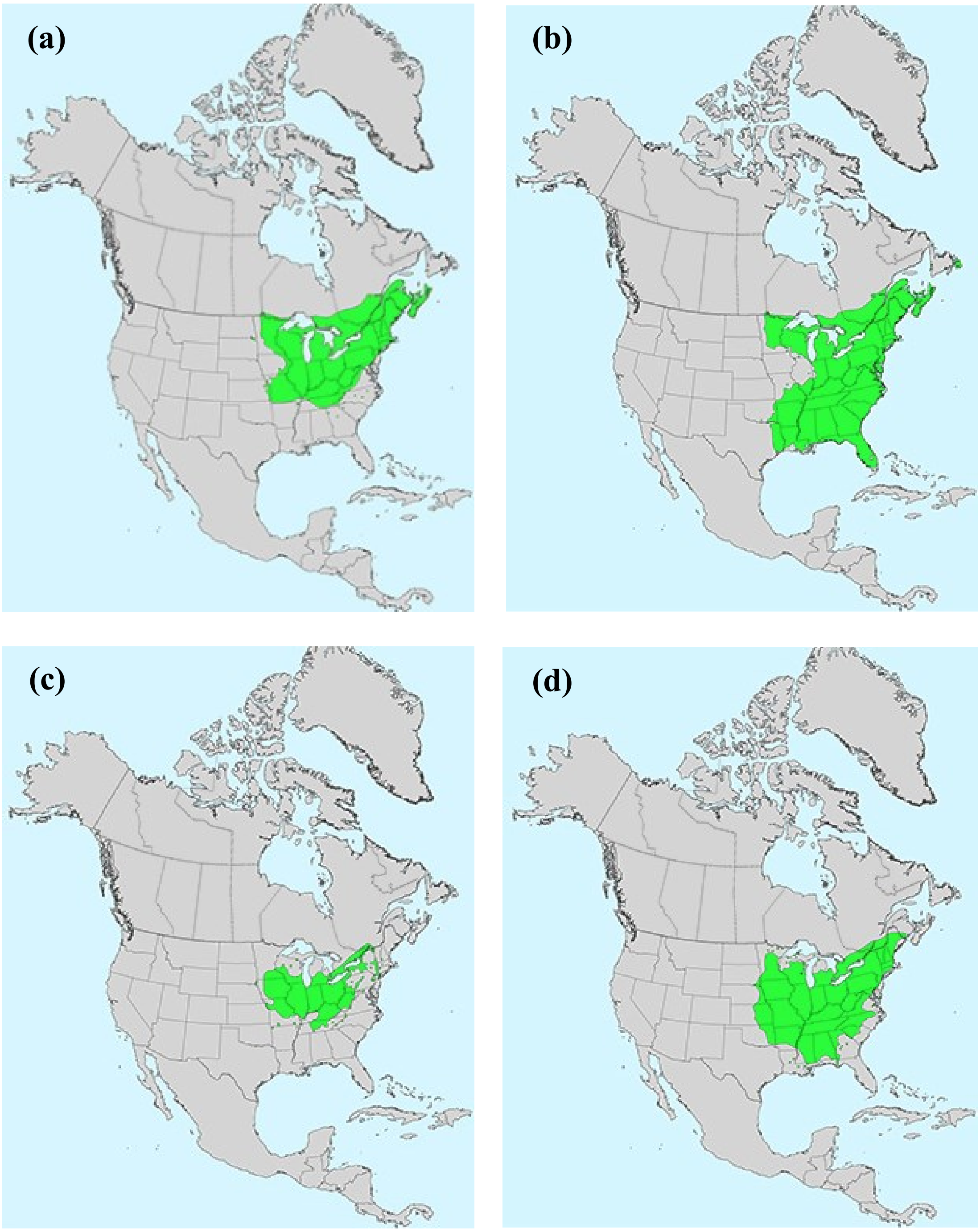

Figure 1. Natural distribution range of (a) sugar maple, (b) red maple, (c) black maple, and (d) silver maple (Fryer, 2018; Virginia Tech, 2021).

Table 1. Common maple tree species used for commercial maple syrup production in southern Ontario, Canada and the corresponding mean sap sugar content for each species.

Common Name	**Scientific Name**	**Mean Sap Sugar Content (˚Brix)**
Sugar Maple	*Acer saccharum* Marsh. L	2.0 - 5.0
Red Maple	*Acer rubrum* L	1.7 - 2.5
Black Maple	*Acer nigrum* Michx. F	2.0 - 2.5
Silver Maple	*Acer saccharinum* L	1.0 - 2.0

1.1.2 Production and storage of carbohydrates

Carbohydrates are the primary source of energy for plants and trees (Magel *et al*., 2000). They are critical for supporting leaf development, flowering, defense, and ultimately survival (Magel *et al*., 2000). Carbohydrates are of particular interest for maple syrup producers as they also produce the eminent sweetness of maple syrup. Carbohydrate production relies on the process of photosynthesis in which plants utilise carbon dioxide (CO_2), water (H_2O), and sunlight to produce oxygen (O_2) and simple sugars such as glucose (Rost *et al*., 2006). Glucose can be recruited and transported to different parts of the tree via the phloem, can be converted to sucrose, or form long chains of polysaccharides such as starch by polymerization reaction for future use (Rost *et al*., 2006). When rates of photosynthesis exceed that of respiration, maple trees actively store these non-structural carbohydrates (NSCs) in their roots and ray cells (Liu *et al*., 1991).

A tree's ability to store NSCs is influenced by the number and size of ray cells (Wild & Yanai, 2014). Trees with a greater number and size of ray cells have a greater ability to store NSCs, and thus have the potential to produce sap with greater sap sugar content (Morselli *et al*., 1978). Both the number and size of ray cells within a tree are dependent on its condition, with larger, faster growing, healthy trees possessing more ray cells for NSC production (Morselli *et al*., 1978; Wild & Yanai, 2014).

During early winter, the stored NSCs are converted to sugars and transported to the bole and branches of the tree to initiate dormancy release and budbreak (Muhr *et al*., 2016; Houle *et al*., 2019). The rate at which starch is converted to sugar for transportation is dependent on cellular respiration rates of the tree, and thus, can be temperature dependent (Sauter *et al*., 1973).

1.1.3 Sap flow process

Sap flow in maple trees (*Acer* spp.) is dependent on the presence of a diurnal freeze-thaw cycle wherein the ambient temperature drops below 0˚C overnight and exceeds 0˚C during the day (Duchesne & Houle, 2014; Skinner *et al.,* 2010). The temperature swing creates pressure changes in the xylem of the tree which produces gas bubbles in maple sap and stimulates sap flow (Skinner *et al*., 2010).

During a freeze-thaw event, the freezing overnight temperature creates negative pressure in the bole of the tree. The negative pressure acts to draw sap up from the root system to the bole and branches. Following an overnight freezing event, the daytime thawing temperatures create positive pressure in the bole of the tree. This positive pressure forces the sap to return to the roots, which is when sap will flow out of tapholes and into tubes or buckets (University of Vermont, 2021).

1.2 Ecological factors influencing maple syrup production

Rising global temperatures and shifting precipitation patterns have disrupted both natural and anthropogenic systems. Global surface temperatures are expected to rise an additional 1.0 to 5.7˚C during the 21st century, hastening the poleward shift of bioclimatic zones in both hemispheres (IPCC, 2021). Moreover, the intensity and frequency of extreme events such as heavy precipitation and droughts will increase (IPCC, 2021), which will further impact ecosystem conditions at local and regional scales as disturbance regimes change. These changes in climate will continue to have large effects on the phenology and geographic range of many plant and tree species (Ray *et al*., 2015).

The maple syrup industry is highly dependent on climate conditions. In accordance with the poleward shifts of bioclimatic zones (IPCC 2021), a general northward shift in ecosystem conditions favorable to maple productivity and vigour is occurring (Rapp *et al*., 2019). Since maple syrup production is closely tied to very specific climatic conditions, there is concern over the viability and stability of Ontario's maple syrup industry.

1.2.1 Meteorological factors

Ambient temperature has a large influence on annual and inter-annual maple syrup yields by directly regulating the occurrence of sap flow via freeze-thaw events. Ambient temperature can also have an indirect effect on maple sap characteristics via impacting tree growth and overall stand health during the growing, winter, and tapping seasons.

1.2.1.1 Growing season

The balance of photosynthesis and respiration in maple trees drives sugar production and storage in maple trees, which is directly influenced by ambient temperature during the growing season (Rapp *et al*., 2019). Faster growing trees with larger xylem rays produce sweeter sap (Morselli *et al*., 1978). Ambient temperatures exceeding 3˚C during spring are considered growing degree days for maples given that radial growth is possible (Duchesne & Houle, 2014). Maple syrup yield is greatest when 75 days of the year are suitable for tree growth (Duchesne & Houle, 2014). However, during the hottest part of the day, rates of respiration exceed that of photosynthesis, and negatively affect carbohydrate production and storage (Kozlowski, 1992). Mean ambient temperatures less than 20˚C result in higher sap sugar content (Rapp *et al*., 2019). As ambient temperature increases, rates of respiration increase faster than rates of photosynthesis, reducing carbohydrate production and storage, and thus, syrup yield (Gunderson *et al*., 2000; Kozlowski, 1992). Moreover, Rapp *et al*. (2019) indicate that sap sugar content will decline by 0.1° Brix for every 1 °C increase in mean growing season temperature.

There is a negative relationship between growing season precipitation levels and syrup yield, which is likely a response to increased cloud cover, reduced rates of photosynthesis, and thus, carbohydrate production (Duchesne & Houle, 2014). Conversely, drought stress during the growing season can result in reduced tree growth and crown dieback (Horsley *et al.,* 2002). This can be problematic given that stunted growth is associated with lower quantities of ray cells for storing sugar while crown dieback decreases photosynthesis and thus, sugar production (Morselli *et al*., 1978; Noland *et al*., 2006).

1.2.1.2 Preceding winter months

Ambient temperature during the winter months prior to the tapping season not only impacts the duration of sap flow but also total sap yield, sap sugar concentration, and sap quality (Houle *et al.,* 2015; Pothier, 1995; Rapp *et al*., 2019). For example, maple trees in northern regions produce more syrup during colder winters and later spring conditions (Houle *et al.,* 2015). Snow cover during these preceding winter months is critical in preventing root frost damage, which negatively impacts sap sugar content (Comerford *et al*., 2013). Reduced snow cover in stands can negatively affect starch concentrations in sugar maples (Comerford *et al.,* 2013). Additionally, reduced snow cover has been linked to soil acidification, which can lead to loss of critical base cations that can reduce rates of growth and sap production (Comerford *et al.,* 2013).

Early spring conditions typically mark the end of the tapping season as prolonged periods of warmer ambient temperature initiates bud break in maple trees (Perry & Fiore, 2020). These warmer spring conditions can accelerate microbial growth and activity and result in undesirable changes to maple sap quality (Perry & Fiore, 2020). Common sap defects include 'buddy sap,' which is a result of microbial accumulation and metabolic changes within the tree in early spring (Holgate, 1950), 'ropy sap' caused by bacterial contamination and yeast which results in stringy syrup with undesirable mouthfeel (Lagace, 2018; Pelletier, 2018), and 'sour and discoloured sap' which is a type of microbial contamination that results in the accumulation of acid via microbial hydrolysis (Wasserman, 1963). Mild temperatures in early spring typically mark the end of the tapping season as the physical plugging of the tap begins to occur via bacterial invasion and vessel blockage by microorganisms (Duchesne & Houle, 2014).

1.2.1.3 Tapping season

The timing and duration of the tapping season are economically significant for producers, and variability in the tapping season can significantly impact maple syrup yield. Rapp *et al.* (2019) found that mean temperatures during the tapping season, specifically January through to late March, influenced total sap yield by regulating the occurrence of the freeze-thaw cycle required for sap flow. Ho & Gough (2006) reported that the shoulder months of the sap flow season, December and April, may experience greater variation in the timing and duration of freeze-thaw cycles as climate changes, thus impacting maple syrup yield. Additionally, Skinner *et al.* (2010) suggest that the sap flow season will shift to earlier in the year as temperatures warm. The expected shift in the timing of sap flow is dependent upon region, with trees located in the southern limits of sugar maple's sap production range experiencing more drastic shifts compared to those in northern regions. Within-season variability in sugar content has also been reported. Taylor (1956) indicated that sap from trees tapped at the beginning of tapping season was sweeter.

1.2.2 Soil properties

Maple trees are typically found in moist, well-drained, slightly acidic soils (Collins *et al.,* 2018). Base cations are a critical component of soil fertility in tree stands (Sullivan *et al*., 2013). Greater levels of base cations such as potassium (K^+) and calcium (Ca^{2+}) can positively affect maple tree growth and vigor (Bailey *et al*., 2004; Sullivan *et al.,* 2013). These critical base cations are displaced when sulfur (SO_x) and nitrogen (NO_x) oxides are deposited into the soils from anthropogenic activity (Horsley *et al*., 2002; Sullivan *et al*., 2013). Additionally, Sullivan *et al.* (2013) found a positive relationship between sugar maple health and percent base cation saturation levels. Maple stands deficient in base cation levels suffered from increased interspecific competition that in some cases led to competitive exclusion. Sullivan *et al.* (2013), for example, suggested that as soil base cations declined, species such as American beech (*Fagus grandifolia*) were favoured over sugar maple.

Higher concentrations of both N and P are associated with greater rates of tree growth (Gradowski & Thomas, 2008; Kluber *et al*., 2012). Nitrogen is often the most limiting nutrient in northern temperate forests (Aber *et al.,* 1998; Ellsworth & Liu, 1994). Higher concentrations of N in soils have been associated with increased growth of sugar maples (Thomas *et al*., 2010; Wild & Yanai, 2014). Nitrogen concentrates in sugar maple foliage and can increase rates of photosynthesis, and thus can influence maple sap sugar content (Ellsworth & Liu, 1994). Phosphorus is a limiting nutrient in soils that are sufficient in N (Gradowski & Thomas, 2008).

Phosphorus availability can be inhibited in highly acidic soils (Braun *et al*., 2010; Kluber *et al*., 2012). Acidic soils mobilize aluminum (Al^{3+}), which binds to inorganic P and reduces availability of P for uptake by trees (Braun *et al*., 2010; Kluber *et al*., 2012). Low P availability reduces maple tree growth and vigour, and can negatively impact overall sap production (Casson *et al*., 2012). Reduced soil fertility also increases the risk of adverse responses to other stressors such as defoliation, drought, spring frost, extreme weather, and susceptibility to disease (Duchesne & Houle, 2014; Hallett *et al*., 2006; Horsley *et al*., 2002; Watmough & Dillon, 2003).

Table 2. Summary of some key ecological factors known to influence maple sap sugar concentrations during the preceding growing (green), winter (blue), and tapping (orange) season across the natural range of maple trees.

Variable	Sap Sugar Concentration	Study Location	References
↑ ambient temperature (> ~16˚C)	↓	Tennessee & Michigan, USA; North America (excludes Ontario)	Gunderson *et al*. (2000); Rapp *et al*. (2019)
↑ # days w/ precipitation	↓	North America (excludes Ontario); Ontario, CA	Duchesne & Houle (2014); Goldblum & Rigg (2005)
↓ Crown cover	↓	Vermont, USA	Rapp & Crone (2014)
↓ Maple growth rates	↓	Lab study	Morselli *et al*. 1978
Stress event (i.e., drought, insect outbreak, disease)	↓	North America	Horsley *et al*. (2002)
↓ Soil fertility	↓	New York, US	Sullivan *et al*. (2013); Wild & Yanai (2014)
↓ Snow cover	↓	New Hampshire, USA; Massachusetts, USA	Comerford *et al*. (2012); Reinmann & Templer (2015)
Early spring onset	↓	North America (excludes Ontario); Maine, USA	Houle *et al*. (2015); Perry & Fiore (2020)

1.3 Socio-economic significance of the Ontario maple syrup industry

1.3.1 The maple syrup industry as an important economic driver of Ontario's economy

Canada accounts for 75% of global maple syrup production (Agriculture & Agri-Food Canada, 2021). Production in Canada has increased over the past 15 years and is expected to continue to grow (Statistics Canada, 2021). Canadian producers experienced an 8.3% increase in production levels and a 7.9% increase in total sales between 2019 and 2020 (Agriculture & Agri-Food Canada, 2021). Note, however, that Ontario reported a 7.0% decrease in production levels in 2021, which was offset by an increase in the value of maple products per gallon (Agriculture & Agri-Food Canada, 2021). Ontario produced 1.77 million litres of maple syrup in 2020, representing 3% of the Canadian market (Agriculture & Agri-Food Canada, 2021). Over 600 maple syrup producers are represented by the Ontario Maple Syrup Producer's Association (OMSPA), an association that promotes the provincial maple syrup industry and aims to help producers sell high quality maple syrup products.

The Ontario maple syrup industry is not only a large contributor to global maple syrup production but is also a culturally significant practice in Ontario communities (Agriculture & Agri-Food Canada, 2021). Festivals and events throughout Ontario are based around maple syrup products and production and are important stimulators of the economy for many rural communities (Murphy *et al*., 2012).

1.3.2 Perceptions and concerns of maple syrup producers on the current and potential impacts of climate change on production

Minimising the socioeconomic risks associated with climate change is important for the long-term success of Ontario's maple syrup industry. Understanding the concerns and attitudes of producers towards climate change will help the maple syrup industry develop locally relevant adaptive strategies that maintain production for future generations.

Most studies that explore maple syrup producers' perceptions on the current and potential impacts of climate change on production focus on the southern or northern regions of maple tree distribution having the requisite diurnal freeze-thaw cycles that allow for commercial production. Those from the southern limits of viable maple syrup production; n.b., the northeastern United States, reported moderate to severe negative impacts of climate change on production levels. In contrast, those from the northern limits; n.b., Quebec, Canada, have mainly reported experiencing minimal to positive effects. Current literature underrepresents sentiment from southern Ontario, a region in the centre of maple tree distribution wherein syrup production is commercially viable that may be experiencing different effects of climate change compared to the northern and southern limits (Figure 2). Thus, our hope is to uncover the commonalities and differences between regions so that more appropriate management strategies can be developed and adapted specifically for Ontario producers.

The timing window for the tapping season is predicted to continue to shift in the coming decades (Duchesne & Houle, 2014). Missing the first day(s) of the tapping season can result in significant economic loss. Mozumder *et al*. (2015) found that approximately 33% of all surveyed producers (n = 241) missed the first day of sap flow season in previous years. Fifty-nine percent of respondents also reported that the beginning of the sap flow season was occurring earlier in the year than previously. Murphy *et al.* (2009) in Near North Ontario found that 50% of sugar makers (n = 19) reported experiencing negative effects of climate change on production, including variable timing and duration of the tapping season, and variable annual yield. Further, Legault *et al*. (2019) found that 64% of respondents (n = 354) believed that climate change would negatively impact maple syrup production in the next 30 years, that 77% of producers were interested in adopting adaptation strategies that resulted in increased maple syrup production, and finally, that the largest barrier for producers to implement new adaptation strategies was lack of information, lack of financial means, and lack of technology.

Understanding the perceptions of Ontario maple producers towards climate change and their willingness and constraints to implementing new adaptive measures is pertinent in identifying regionally appropriate and attainable measures to mitigating the effects of climate change.

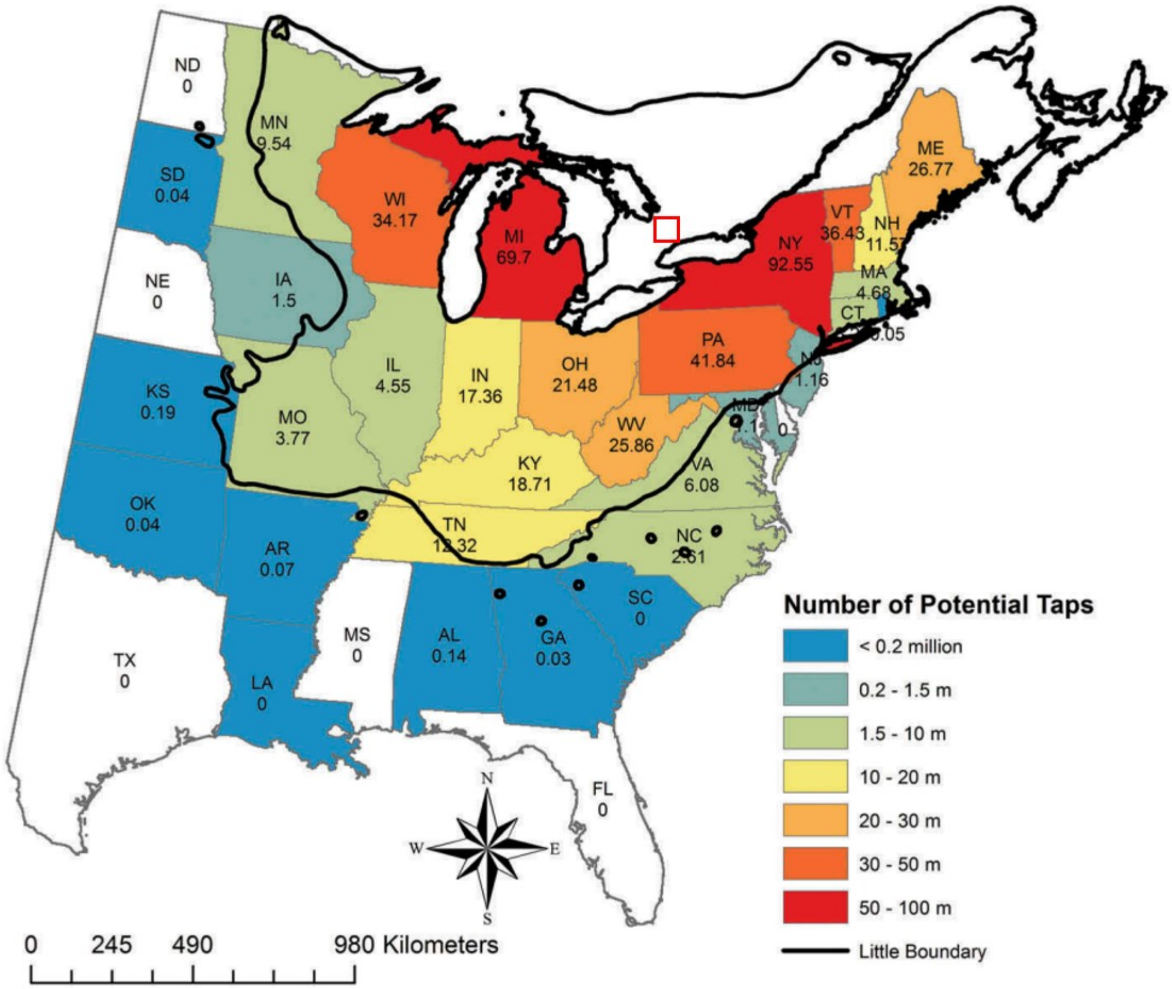

Figure 2. Approximate range of commercial maple syrup production represented by area outlined in black (Matthews & Iverson, 2017). The approximate location of our study is outlined by the red square in south-central Ontario, Canada.

1.3.3 Maple syrup production to improve well-being and promote inclusivity: A Camphill Communities Ontario (CCO) case study

An individual's well-being is complex and multifaceted. Studies have found that nature-based activities, skill building, and creating meaningful relationships with others cultivate positive emotions and feelings that contribute to one's well-being (Barton & Pretty, 2009; Lyman *et al.,* 2014). Working outdoors, collecting maple sap, carrying buckets, and boiling sap are daily tasks that sugar makers undertake during the tapping season. Completing recreational activities outdoors can have physical and cardiovascular benefits to an individual's health and can increase feelings of connectivity with nature (Barton & Pretty, 2009). In addition to outdoor activities, tasks such as bottling, labelling, advertising, consulting with other producers, and selling maple syrup products are also undertaken. These activities provide opportunities for positive social interactions and can further enhance an individual's well-being given the increased feelings of connectivity and sense of belonging to a community (Lyman *et al*., 2014). Thus, the physical, social, and personal aspects of working in the maple syrup industry have the potential to increase an individual's feelings of self-worth and well-being, including those with disabilities (Wilson & Christensen, 2012).

1.3.3.1 Nature-based Activities

Physical activity is a proven method for reducing the risk of chronic diseases including cardiovascular disease, type 2 diabetes (Johnson, 2009), obesity, and premature mortality (Hsieh *et al*., 2015). Physical activity has also been linked to increased perception of self-concept and independence, and thus has psychological and emotional benefits (Johnson, 2009). Compared to the general population, individuals diagnosed with an intellectual and/or developmental disability (IDD) have higher or equal rates of physical inactivity (Hsieh *et al.,* 2015), with one systematic review finding that only 9% of adults with an IDD met the recommended 30 to 60 minutes of daily physical activity (Dairo *et al.,* 2016).

Wilson & Christensen (2012) found that individuals with IDDs that participated in outdoor recreation four to six times per week had greater well-being and lower mental illness scores compared to those who participated fewer than three times per week. Further, those who participated in outdoor recreation once per week had greater risk of mental illnesses than those that participated at least three times per week but were at a lesser risk than those who did not partake in any weekly outdoor recreational activities. Multiple reports indicate that outdoor recreational group activities benefit cardiovascular health, mental clarity, skill development, and the establishment of meaningful and supportive relationships (Barton & Pretty, 2009; Wilson & Christensen, 2012; Jakubec *et al*., 2016).

By participating in the maple syrup production process, individuals with an IDD would have an opportunity to perform outdoor physical activities such as tapping maple trees, collecting maple sap, and boiling sap into syrup. The numerous physical tasks associated with maple syrup production typically require individuals to work in a small group in a natural outdoor environment during the winter and spring, and may offer physical and mental benefits for individuals with an IDD.

1.3.3.2 Skill development

Skill development can pertain to the development or advancement of social skills, motor skills, or skills that lead to economic inclusion or employment (Ozdemir *et al.,* 2018; Ebrahim *et al.*, 2022). Skill development can improve an individual's social integration, health, productivity, and positively impact well-being (Lyman *et al.,* 2014). Participation in skill-building activities such as sports (D'Andrea *et al*., 2013) or other group settings such as social development programs (Ebrahim *et al.,* 2022) can help individuals diagnosed with an IDD learn decision-making skills, functional skills, and enhance their capacity to successfully accomplish tasks and goals (Lyman *et al.,* 2014). For example, several qualitative studies reported positive effects of skill development through group programs that focused on emotional (D'Andrea *et al*., 2013), cognitive (Laberge *et al.,* 2012), and social life skills in vulnerable populations (Bean *et al.,* 2014; Guivarch *et al*., 2017).

1.3.3.3 Relationships

Participation in recreational activities can generate social capital as it allows like-minded individuals to interact in a common goal-oriented context (Bartolomeo & Papa, 2019). An individual's social support is largely dependent on the opportunities available to the individual (Ebrahim *et al.,* 2022). The buffer hypothesis suggests that an individual's social support network may positively affect mental health by buffering the negative effects of stress (Olstad *et al*., 2001). Social support and relationship development are major factors in preventing chronic health problems while also contributing to an individual's quality of life (Lippold & Burns, 2009). Individuals diagnosed with an IDD are at a higher risk for isolation and lack of social integration due to a reduced ability to navigate social cues and societal perceptions (Lyman *et al*., 2014).

The Maple Syrup Social Enterprise program at Camphill Communities Ontario (CCO) may offer individuals with an IDD the opportunity to participate in a recreational activity that can positively impact physical health, and concurrently, develop meaningful relationships given the interactive nature of many of the tasks. Thus, through participation in the program, individuals with an IDD may report increased well-being.

My case study focused on CCO's Maple Syrup Social Enterprise program that is managed by and for adults with IDDs. Specifically, I explored the impact that maple syrup production-related activities have on the well-being of individuals with an IDD; ultimately, to identify the facets of the operation that help improve it.

1.4 Objectives

My research addressed several critical knowledge gaps for the Ontario maple syrup industry. While past studies focused on factors impacting syrup production near the northern and southern range limits of commercial viability, very few studies addressed impacts in central regions, such as south-central Ontario, Canada, where impacts may both contrast and/or be comparable to either range limit depending on the parameter in question. Moreover, most studies addressed the timing of the tapping season or examined the impacts of individual factors on sap sugar content. Few studies have explored the relative importance of multiple environmental factors that may be impacting sap sugar content, a critical component of maple sap that directly affects total yield and profitability. Determining which environmental factors are most critical to sap sugar content in south-central Ontario will help to develop adaptation strategies relevant to regional producers. I also addressed the current knowledge gap surrounding the perceptions of Ontario producers on the impacts of climate change on regional production levels and identified important limitations of and potential barriers to adopting adaptive measures against climate change. Lastly, I explored the perceptions of a vulnerable population to further understand how the practice of making maple syrup contributes to individuals with an IDD's well-being, and gain insight as to how management can be approached from an integrative, holistic perspective. These knowledge gaps were addressed through the following objectives:

1) *Determine which environmental factors are most important in explaining differences in sap sugar content in commercial production forests across south-central Ontario, Canada*

2) *Explore Ontario maple syrup producer's perceptions of climate change and identify the constraints to implementing adaptation strategies that help maintain current maple syrup production levels as our climate changes**

3) *Explore Camphill Communities Ontario's (CCO) maple syrup social enterprise program and identify the main aspects of the production process that improve the well-being of adults with intellectual and developmental disabilities*

* Please note that this research chapter is located in Appendix 3A

Prologue to Chapter 2

Sap sugar concentration is an important sap characteristic that directly determines the amount of maple syrup that can be produced from a given volume of maple sap and influences the boiling time required to obtain maple syrup. My study determined the relative importance of stand-level ecological factors known to influence maple sap sugar concentration in south-central Ontario, Canada. The results helped to identify key areas of vulnerability to climate change for regional maple syrup production, focusing specifically on its impacts on maple sap sugar concentration. This information can provide regional maple syrup producers the foundation to develop effective adaptation strategies that will help to mitigate the negative effects of climate change on sap sugar concentration.

Chapter 2. Examining the relative importance of stand level ecological factors influencing maple sap sugar content in south-central Ontario, Canada.

2.1 Abstract

Sap sugar concentration is a critical factor impacting commercial production of maple syrup. It determines the amount of maple syrup that can be made from a given volume of maple sap, with sweeter sap generally associated with greater yield; and thus, lower production costs. Causes of variability in sap sugar content can differ at local and regional contexts and may change in relative importance as climate change impacts regulating processes and mechanisms. The purpose of this study was to determine which ecological factors best explain the variability in maple sap sugar concentrations in commercial sugarbush operations located in south-central Ontario, Canada. Data were collected were during the 2021 growing season and subsequent 2022 maple syrup production season. Various combinations of climate characteristics, soil conditions, and stand health factors were evaluated using multiple linear regression models. Relative model quality was assessed using Akaike Information Criterion (AICc). Sap sugar content among sites can be explained through a combination of climate, soil, and stand health factors including proportion of maple species in canopy, maximum ambient temperature during the growing season, mean soil temperature during the tapping season, and mean ambient temperature during the winter season (R^{2adj}=0.9788, p<0.0001). Regional maple sap sugar concentrations may decrease in response to changes in stand health and composition as climate conditions change. Addressing the factors and mechanisms driving these changes is critical to mitigating the negative impacts on the maple syrup industry.

Key words: sap sugar concentration, *Acer spp.*, maple syrup production, climate change

2.2 Introduction

Maples are important commercially tapped tree species found throughout northeastern North America. Maple sap flows in early spring when a cycle of overnight freezing temperatures followed by warm daytime temperatures begins. This diurnal freeze-thaw cycle creates differential pressures in the xylem of the tree that stimulates sap flow. Sap is mostly composed of water and sugar and has a small quantity of other organic and inorganic amino acids, minerals, and peptides (Ball, 2007; Perry & Fiore, 2020). The sap sugar content is of particular interest to producers as it determines the amount of time, energy, and litres of sap needed to produce maple syrup.

Climate characteristics (Rapp *et al.,* 2019), soil conditions (Sullivan *et al.,* 2013; Wild & Yanai, 2014), and stand health (Morrow, 1955) are thought to indirectly or directly impact sap sugar content. For example, favorable ambient temperatures during the growing season, i.e., up to 14 to 16 ^{o}C (Rapp *et al*., 2019), may positively influence the growth rate and crown development of maple trees (Goldblum & Rigg, 2005; Horsley *et al*., 2002; Rapp & Crone, 2015). Faster growing maple trees with larger crowns typically produce sweeter sap given that these trees typically have a greater number of ray cells for sap sugar storage (Morselli *et al*. 1978). However, climate stressors during the growing season including drought and defoliation can lower maple sap sugar content by reducing photosynthetic rates (Horsley *et al*., 2002; Liu *et al*., 1997). Unusually high levels of precipitation can also inhibit growth due to increased cloud cover, which reduces total days suitable for photosynthesis (Enright, 1984). High levels of precipitation can also alter soil nutrient availability (Horsley *et al*., 2000). Similarly, long-term exposure to atmospheric acidic deposition can cause tree decline or ultimately tree death because of changes to site quality (Bell *et al*., 1998; Horsley *et al*., 2002; Sullivan *et al*., 2013).

Soil conditions play an important role in maple tree growth, and thus, sap sweetness (Taylor 1956; Wild & Yanai, 2014). Greater levels of N and P are associated with higher growth rates in maple trees (Gradowski & Thomas, 2006; Casson *et al.,* 2012). Bailey *et al.* (2004) and Sullivan *et al.* (2013) found that base cations, including potassium (K^+) and calcium (Ca^{2+}) also improve maple tree growth and vigour. However, acidic deposition has resulted in the loss of base cations from maple-dominated stands (Smith, 1991; Sullivan *et al*., 2013). As pollutants such as NO_x and SO_x are deposited into soil, critical base cations are leached from the soil which reduces potential for uptake by maple trees (Sullivan *et al*., 2013). Moreover, the lowered soil pH mobilizes Al^{3+} which binds to inorganic P, exacerbating nutrient loss (Driscoll *et al*., 2001; Kluber *et al.,* 2012). Low soil temperatures during the winter months also negatively influence sap sugar content, likely due to susceptibility to frost damage of the shallow rooting systems of most maples (Braun *et al.,* 2010; Kluber *et al.,* 2012; Duchesne & Houle, 2014). Frost damage to roots can be especially problematic when snow cover is absent (Comerford *et al*., 2013).

As climate continues to change, more studies within the southern limit of production, such as mid-eastern U.S., are reporting negative effects on maple syrup yield, likely a result of a shifting tapping season and reduced sap sugar content (Matthews & Iverson, 2017; Rapp *et al*., 2019). Northern regions of maple production are also expected to experience a decrease in sap sugar content (Rapp *et al*., 2019). However, reduced sugar concentrations may be offset by an increase in sap volume, resulting in a neutral to positive effect on annual maple syrup yield for this region (Farm Credit Canada, 2021; Legault *et al*., 2019).

Previous research on sap sugar concentration focused on the impacts of single environmental factors and/or were from areas near the southern and northern range limits of where maple syrup production is commercially viable. However, sap sugar concentration is likely impacted by a combination of factors, and the relative importance of these factors may change depending on regional context. Few studies have examined the relative importance of a suite of environmental factors associated with climate characteristics, soil conditions, and stand health on sap sugar concentration, and currently, none have done so within the central portion of sugar maple's distribution wherein maple syrup is commercially produced. Understanding their relative importance would help reveal commonalities and differences in the driving factors impacting sugar content between the central region and the southern and northern range limits.

The purpose of this study is to determine the relative importance of key stand and regional-level ecological factors on maple sap sugar concentration in south-central Ontario, Canada. Addressing the knowledge gap surrounding sap sugar variation within the mid-region of maple syrup production may aid in the development of more regionally appropriate management strategies for local producers.

2.3 Methods

2.3.1 Study area

Sampling was done in seven commercial sugarbush farms located between 44.7048˚ to 44.7360˚N and 79.5025˚ to 80.9324˚W (Figure 3). All farms are located in deciduous woodlots within the Huron-Ontario (L.1), Georgian Bay (L.4d), and Sudbury-North Bay (L.4e) sections of the Great Lakes-St. Lawrence Forest Region (Rowe, 1972). Topography is flat to rolling and is comprised of glaciofluvial landforms such as drumlins, eskers, moraines, and spillways formed by glacial streams (Prest *et al.,* 1968) (Table 3b). Climate for the region is cold temperate with the mean annual temperature being 9.0˚C. Mean daily minimum of the coldest month is -9.0˚C, while the mean daily maximum of warmest month is 27.0˚C. Mean annual rainfall for the region is 534.9 mm (Environment Canada, 2021).

Common natural disturbances within the region include wind, ice and snowstorms, insect and disease outbreak and to a lesser extent, low- to moderate-severity fire (Simcoe County Forests, 2011). Extreme disturbance events such as catastrophic fire are infrequent in this region but are expected to increase with climate change (Flannigan 1998; Simcoe County Forests, 2011).

Ground-truthing of deciduous woodlots used for syrup production in this study indicate that approximately 60.0 ± 6.5% of all canopy trees are maple species, with sugar maple (*Acer saccharum* Marsh.) representing approximately 95.8 ± 0.02% of them. Sugar maple is favoured for maple syrup production due to its exceptionally high sap sugar content (Gill & Newling, 2022). Red maple (*Acer rubrum*) and silver maple (*A. saccharinum*) were the other maples tapped. Other associated canopy species include white ash (*Fraxinus americana*), green ash (*Fraxinus pennsylvanica*), oak species (*Quercus* spp.), ironwood (*Ostrya virginiana*), basswood (*Tilia americana*), trembling aspen (*Populus tremuloides*), white birch (*Betula papyrifera*), yellow birch (*Betula alleghaniensis*), and American beech (*Fagus grandifolia*).

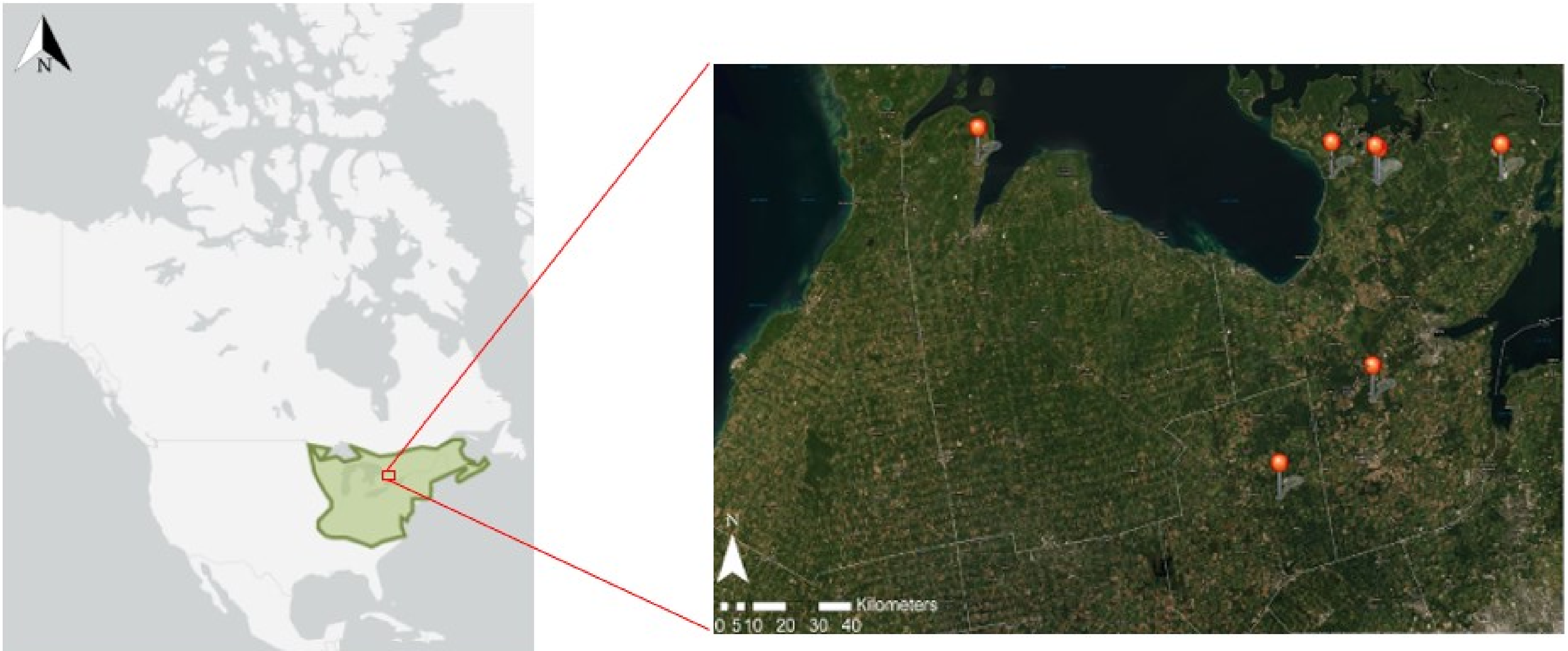

Figure 3. Location of sample sites within south-central Ontario, Canada, a mid-region of maple syrup production.

Table 3a. Average climatic conditions for respective sample sites in south-central Ontario, Canada.

Site	Camphill Communities Ontario (CCO)	Maple Grove Syrup & Sleigh	Kemble Mountain Maple	William's Farm	One Chicken Ranch	Mikoliew Mach Maple Syrup	Sugar Ridge	Regional mean
Mean growing temperature (˚C) (May-Aug)	17.57 (±0.41)	18.74 (±0.49)	16.89 (±0.47)	18.74 (±0.49)	18.19 (±0.49)	17.78 (±0.49)	18.74 (±0.49)	18.09 (±0.27)
Mean winter temperature (˚C) (Nov-Jan)	-4.74 (±0.72)	-6.71 (±0.75)	-3.57 (±0.54)	-6.71 (±0.75)	-4.26 (±0.65)	-3.16 (±0.66)	-6.71 (±0.75)	-5.12 (±0.59)
Mean tapping temperature (˚C) (Feb – March)	4.29 (±0.72)	2.24 (±0.74)	4.19 (±0.76)	2.24 (±0.74)	3.03 (±0.68)	6.36 (±0.73)	2.24 (±0.74)	3.51 (±0.58)
Total annual precipitation (mm) (rain + snow)	830.8 (±0.42)	999.8 (±0.30)	1006.8 (±0.31)	999.8 (±0.30)	821.4 (±0.35)	722.8 (±0.29)	999.8 (±0.30)	911.6 (±44.38)
Distance from weather station (km)	14.2	8.7	13.9	24.7	30.5	10.5	25.3	18.3

Table 3b. Comparison of physiography between sample sites in southern Ontario, Canada.

Site	Camphill Communities Ontario (CCO)	Maple Grove Syrup & Sleigh	Kemble Mountain Maple	William's Farm	One Chicken Ranch	Mikoliew Mach Maple Syrup	Sugar Ridge	Regional mean
Elevation (masl)	210.9	204.7	252.1	279.9	238.9	441.9	254.3	269.0
Slope (%)	8.7	1.7	15.8	10.5	1.7	3.5	12.3	7.7
Latitude (˚)	44.3	44.7	44.7	44.7	44.7	44.1	44.7	44.6
Longitude (˚)	-79.9	-79.5	-80.9	-79.8	-79.9	-80.1	-79.9	-57.1
Soil Type	Podzolic	Luvisolic	Cambisolic	Luvisolic	Podzolic	Luvisolic	Luvisolic	
Soil Texture	Loamy sand	Sand	Sandy loam	Sand	Loamy sand	Sand	Sand	

2.3.2 Sampling protocol

We examined a suite of environmental factors associated with climate characteristics, soil conditions, and stand health to assess their impacts on sap sugar content (Table 4). Climate data for each farm were retrieved from the nearest weather station (Table 3a). Data were categorised into three time periods: growing season (May-August), winter/dormant season (December-February), and tapping season (March-April), from which monthly minimum, maximum, and mean temperatures as well as total precipitation were determined.

Soil samples were taken approximately 10 cm below the litter layer to test soil pH, while nutrient probes were used to measure nitrogen (N), potassium (K), and phosphorus (P) concentrations. Soil temperatures over the dormant and tapping seasons were recorded at 30 cm depth using two dataloggers (Omega Industries, Elitech) at each farm. One datalogger was planted near the centre of the woodlot while the other was planted along the edge to account for potential differences in soil temperature between edge and interior conditions. All data loggers were planted in areas of the woodlot that were used for maple syrup production. Temperatures were recorded at 02:00 and 14:00 (12-hour rotation) between December 01, 2021, and May 01, 2022.

Stand health variables were examined within three to six 20x20 m quadrats randomly established within areas of each woodlot designated for maple syrup production. The total number of quadrats at each farm was dependent on woodlot size, physiography, and the canopy species and structural variation therein. A minimum of 20 m between each plot was maintained to avoid autocorrelation (Millers *et al*., 1991). Within each quadrat, tree density and % crown cover were documented. All trees ≥10 cm diameter breast height (DBH) were identified to species and further assessed for height (see Appendix 1 Figure 1) and overall tree health using a modified decay class scale developed by Steventon (2010) (see Appendix 1 Figure 2).

Sap properties data were collected throughout the 2022 tapping season. This included: sap sugar content (˚Brix), total sap volume (L), total maple syrup yield (L), as well as the first and last day of sap collection for each site. Sap sugar content was determined daily or weekly (depending on the woodlot) using handheld Brix refractometers (RHW-25, accuracy: +0.2%).

Table 4. Environmental variables used to assess variation in sap sugar content among commercial sugarbushes in south-central Ontario, Canada.

Group	Variable	Mean values across sample sites
Climate characteristics	Growing season T_{mean} (˚C)	18.09 ± 0.27
	Growing season T_{max} (˚C) **	23.62 ± 0.36
	Growing season T_{min} (˚C)	12.53 ± 0.36
	Winter season T_{mean} (˚C) **	-5.12 ± 0.59
	Winter season T_{max} (˚C)	-1.22 ± 0.39
	Winter season T_{min} (˚C)	-10.16 ± 0.52
	Tapping season T_{mean} (˚C)	3.51 ± 0.58
	Tapping season T_{max} (˚C)	7.66 ± 0.53
	Tapping season T_{min} (˚C)	-2.02 ± 0.31
	Total annual precipitation (rain + snow) (mm)	911.6 ± 44.38
Soil conditions	pH	6.07 ± 0.37
	[Nitrogen] (µg/Kg)	2.26 ± 0.99
	[Potassium] (µg/Kg)	4.1 ± 1.97
	[Phosphorus] (µg/Kg)	3.1 ± 1.41
	Winter season T_{soil} (˚C)	1.76 ± 0.26
	Tapping season T_{soil} (˚C) **	2.77 ± 0.25
Stand health	Tree Height (m)	21.14 ± 2.44
	Tree DBH (cm)	30.46 ± 5.99
	Decay Class*	2.14 ± 0.26
	Proportion Maple spp.**	0.64 ± 0.064
	Crown Cover (%)	81.42 ± 2.26

* see Appendix 1 Figure 2
** indicates significant variables retained in the final model

2.3.3 Statistical Analyses

Potential differences in soil temperature between data logger location (n.b., internal *versus* edge location), and for between temperature recording times (n.b ., 2:00hr *versus* 14:00hr) were assessed using one-way ANOVA (at $p = 0.05$). No significant differences were found in soil temperatures between data logger locations ($F_{1, 3622} = 3.32$, $p = 0.069$) or between recording times ($F_{1, 3622} = 2.178$, $p = 0.14$). Thus, these data were pooled in subsequent analyses.

Determining the environmental factors that best capture variance in sap sugar content was done using multiple linear regression models. Models contained suites of environmental predictor variables grouped according to: (i) climate characteristics, (ii) soil conditions, (iii) stand health, and iv) all predictor variables. Data were categorised in this manner to build a suite of models for comparison (Rapp & Crone, 2015); i.e., to determine if particular stand-level environmental qualities more strongly influenced sap sugar content. To avoid multicollinearity between model predictor variables, variance inflation factors (VIFs) were assessed, and individual predictor variables were removed according to highest VIF values until all VIFs were <2 (Queen & Keough, 2010). Sample size-corrected Akaike Information Criterion (AICc) values and weights were calculated for each model within each group using the R packages library(car) and library(MuMIn). AICc is a conservative version of Akaike's Information Criterion (AIC) generally used for smaller sample sizes (Burnham & Anderson, 2002). The best models from each group were selected based on the lowest AICc scores and a subsequent AICc was ran to compare these models. This global model was further scrutinised by performing the dredge function using the library(MuMIn) package in R to consider all possible linear combinations of the terms in the global model (Burnham & Anderson, 2002). The overall top model was selected from this dredging process (Burnham & Anderson, 2002; Richards, 2005).

A partial regression analysis was then run to better understand the relative importance of key ecological variables (Table 4) and their relationship with sap sugar content (Collins *et al*., 2018). This was achieved by removing key variables from the top model one at a time and assessing the standardised coefficients and differences in the R^2 values. Prior to each analysis, diagnostic plots were used to visually assess data distribution and when necessary, data were $\log_{10}$ transformed to address non-linear trends. All R coding can be accessed here [https://docs.google.com/document/d/1amXp-VSkrj8mrjKLzPgwan5xEbDi0n-mpJ6fNv7ly_4/edit?usp=sharing].

2.4 Results

The 2022 Ontario maple syrup season commenced during the first week of March with the first boil, which is typically concurrent with the first true sap flow date, occurring as early as March 5th and the latest occurring on March 23rd (J. Williams, personal communication, 09/01/23). The tapping season lasted approximately five weeks with the final boil date occurring on April 23rd. Among our study sites, the earliest boiling date occurred on March 5th while the latest boiling date occurred on April 13th. The timing and duration of the 2022 maple syrup season was consistent with previous production years over the last decade in Ontario, except for 2018 when sap flow started in late February and continued for seven weeks (OMSPA, 2022). Mean sap sugar content among our sample sites was $2.24 \pm 0.1^{\circ}$ Brix, which was consistent with values reported by other regional producers (2.2˚Brix), and with the entire province 2.3˚Brix (OMSPA, 2022).

Variation in sap sugar content was best explained as a function of climate characteristics and stand health variables (Table 5). The top model explained 97.9 % of the variance in maple sap sugar content (R^{2adj}=0.9788, AICc=-2815.2, w_i=0.471, overall p<0.0001). [1]

$$\text{Sap sugar content} = -\text{Proportion of Maple spp} - T_{max}\text{ Growing Season} + T_{soil}\text{ Tapping Season} - T_{mean}\text{ Winter Season} \quad [1]$$

Partial regression models revealed that the proportion of maple species has the largest negative impact on sap sugar content (Figure 4a, R^{2adj} = 0.9718) relative to the other environmental variables identified in our top model [1]. The maximum ambient temperature during the growing season (Figure 4b, R^{2adj} = 0.944) also negatively impacted sap sugar concentration, while the next significant variable, mean soil temperature during the tapping season, positively impacted sap sugar (Figure 4c, R^{2adj} = 0.904). Mean ambient temperature during the winter season significantly impacted sap sweetness but had the lowest influence on sugar content relative to the other variables (Figure 4d, R^{2adj} = 0.075).

Table 5. Summary results of the AICc selection process using the dredge function. The model weights were used to determine which linear model best predicted sap sugar concentration (nb., selected model shown in bold font).

Intercept	Canopy cover (%)	Proportion maple spp.	T_{max} (growing season)	Soil T_{mean} (tapping season)	T_{mean} (winter season)	AICc	ΔAICc	Weight
5.99	0.0004	-2.07	-0.20	0.21	-0.007	-2815.4	0.00	0.529
6.05	**---**	**-2.07**	**-0.20**	**0.21**	**-0.008**	**-2815.2**	**0.23**	**0.471**
5.82	0.001	-2.07	-0.20	0.22	---	-2779.5	32.84	0.00
5.97	---	-2.07	-0.20	0.22	---	-2758.5	56.83	0.00
4.78	0.003	-2.01	-0.14	---	-0.02	-1095.1	1720.33	0.00
5.25	---	-2.00	-0.15	---	-0.03	-1082.4	1732.94	0.00
4.31	0.005	-2.00	-0.12	---	---	-1072.2	1743.21	0.00
4.95	---	-1.98	-0.13	---	---	-1025.7	1789.71	0.00
0.80	0.012	-1.86	---	0.12	0.05	-845.9	1969.52	0.00
0.96	0.009	-1.83	---	0.08	---	-722.9	2092.5	0.00

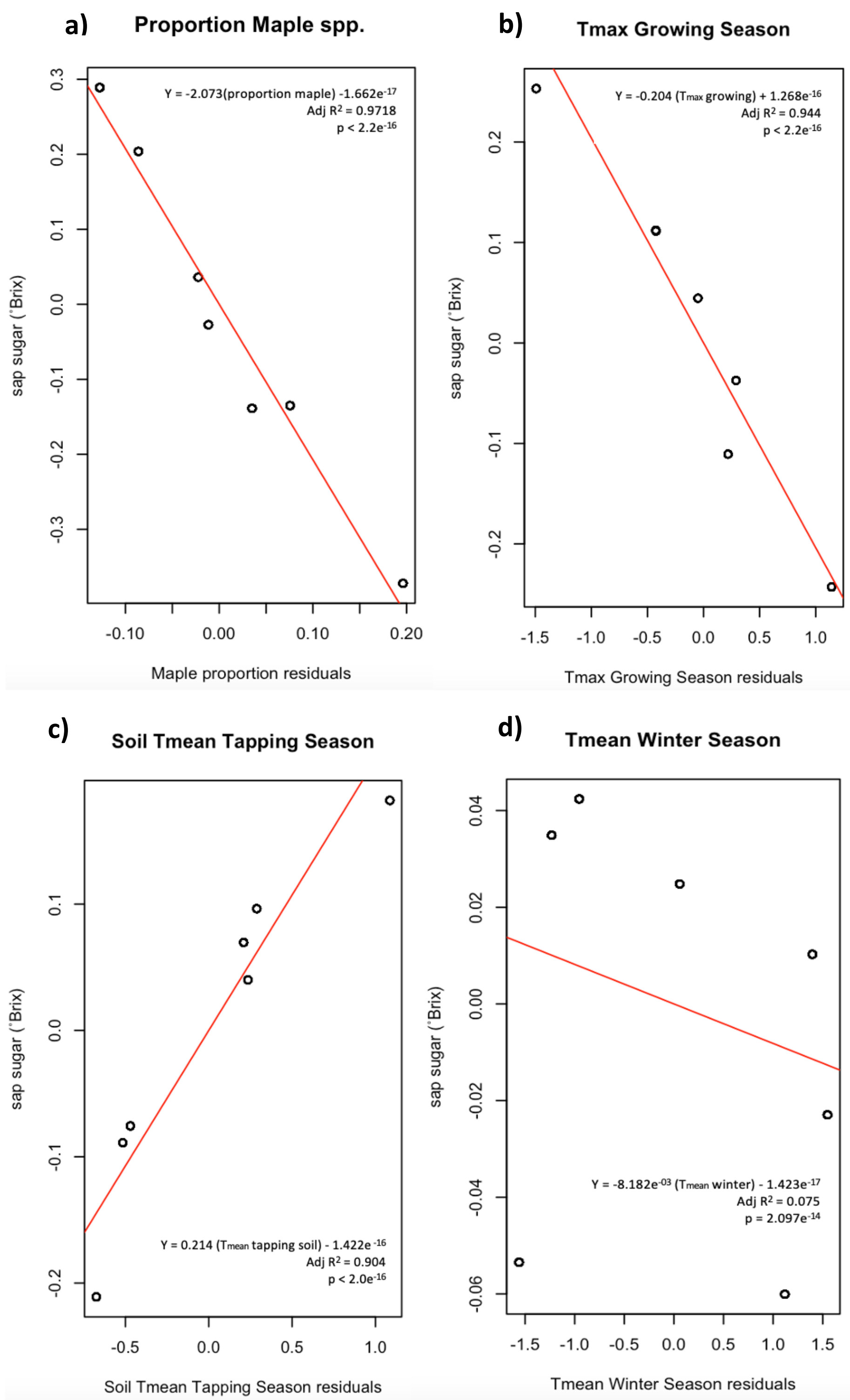

Figure 4. Partial regression plots showing key factors influencing sap sugar content in south-central, Ontario, Canada: (a) proportion maple spp., (b) maximum ambient temperature during the growing season, (c) mean soil temperature during the tapping season, and (d) mean ambient temperature during the winter season.

2.6 Discussion

Suppressed maple trees produce sap with lower sap sugar content (Morrow, 1955; Laing & Howard, 1990). The negative relationship between the proportion of maple trees and sap sweetness (Figure 4a) may be linked to the reduced resource availability associated with heightened intra-specific competition as stand density increased. The proportion of overstory maple trees among our sample sites ranged from 45.2 to 95.8 %, with highest sap sugar content recorded from the stands with the lowest proportion of maple species. Overstory maple trees in the more mixed-hardwood sites were usually interspersed with ironwood (*Ostrya virginiana*) and white ash (*Fraxinus americana*). However, maple trees within these mixed stands were usually taller and/or had greater girth compared to the associated ironwood and white ash trees (Table A3). Despite having proportionally fewer maple trees in these stands, the individual trees generally held dominant crown positions (Table A4). Given that carbohydrate production and storage in maple trees is largely dependent on tree health, crown size (Morrow, 1955), and the balance between photosynthesis and respiration (Kozlowski, 1992), it is likely that maple vigour at these sites was less impacted by the presence of other species. In the stands with greater maple densities, intraspecific competition for critical limiting nutrients such as soil nitrogen may have impacted sap sugar content since sugar maples exhibit the greatest nitrogen uptake per unit mass (Templer & Dawson, 2004) and have the lowest N pools (Finzi *et al.*,1998) relative to the other hardwood species on our sites. Stands depleted in soil nitrogen have been associated with reduced sap sweetness (Wild & Yanai, 2014). In our sites, stands with lower proportions of maple species generally had greater soil nitrogen availability. Thus, it is likely that increased competition for soil nitrogen between maples species drove this relationship.

Sap sugar is derived from non-structural carbohydrates stored by trees during the preceding growing season (Muhr *et al*., 2016), and is largely influenced by the ambient temperature during these warmer months (Rapp *et al*., 2019). We observed a negative relationship between the maximum ambient temperature during the preceding growing season and sap sugar content (Figure 4b), with the preceding growing season temperatures across all sample sites (T_{max}growing = 18.1 ± 0.3) exceeding the optimum temperature for sugar production (~16˚C) (Rap *et al*., 2019). The higher temperatures during the growing season cause respiration rates to exceed that of photosynthesis (Liu *et al*., 199; Gunderson *et al*., 2000), negatively affecting maple tree growth and vigour (Reinmann & Templer, 2016), and thus, non-structural carbohydrate storage important for sap sweetness (Kozlowski, 1992).

Soil temperature plays a critical role in carbon uptake, rates of transpiration, and root dynamics in maple trees (Comerford *et al.,* 2013; Tierney *et al*., 2001). Freezing winter soil temperatures reduce overall nutrient uptake and increase transpiration rates during the following growing season (Harrison *et al*., 2020), and result in lower total sap sugar released during the tapping season (Robitaille *et al*., 1995). In our sites, warmer soils during the tapping season produced sweeter sap. Soil temperatures across our study sites ranged from 0.1 to 9.1˚C, with a regional average soil temperature of 2.8 ± 0.3 ˚C during the tapping season. Given that internal temperature gradients along tree axial distribution pathways are responsible for the distribution of carbohydrates (Sperling *et al*., 2017), it is likely that the positive relationship between soil temperature during the tapping season and sap sugar content (Figure 4c) is a result of temperature-dependent carbohydrate allocation.

Sites with colder ambient temperatures during the winter season produced sweeter maple sap in our study (Figure 4d). The negative relationship between sap sugar and mean ambient temperature during the winter season is likely a result of cold hardiness adaptations of maple trees. Soluble sugar availability in maples is correlated with frost hardiness (Sakai, 1960) and plays a critical role as a membrane and protein stabiliser, and acts as a biological antifreeze (Yuanyuan *et al*., 2009). Thus, soluble sugar concentrations increase during cold acclimation in trees (Bertrand *et al*., 1999). Furthermore, colder ambient winter temperatures result in the passive leakage of sucrose into the apoplast and xylem parenchymal cells (Bertrand *et al*., 1999; Sperling *et al*., 2017), which could positively influence sap sugar concentrations during the succeeding tapping season. Thus, the negative relationship between ambient winter temperature and sap sugar content is thought to be a function of the role of carbohydrates during cold acclimation as colder winter ambient temperatures stimulate carbohydrate production to prevent freezing (Yuanyuan *et al*., 2009). Although colder ambient winter temperature is associated with sweeter sap in our study, this relationship may only hold true in a small climatic window. Historically, snowpack acts as a protective layer of insulation for soil and root systems (Reinmann & Templer, 2016). As climate continues to change, the depth and duration of snowpack is anticipated to decrease, potentially increasing susceptibility to root damage. Therefore, colder ambient winter temperatures without adequate snowpack for protection may negate some of the benefits of colder ambient temperatures on sap sugar content. Thus, there is likely an intricate balance between ambient temperature and soil temperature during the winter and growing seasons that is optimal of carbohydrate allocation important for sap sweetness.

Interestingly, our model indicates that crown cover did not impact sap sweetness. We expected crown cover to be a significant predictor of sap sweetness given that larger, fuller canopies typically producer sweeter sap (Morrow, 1955; Moore *et al*., 1951). However, little variation in crown cover was observed among our sample sites, as at all sites maples were consistently well-represented (mean crown cover = 81.4 ± 2.3 %). Thus, this factor could not be fully explored given this lack of variation.

As regional temperatures are projected to increase (ECCC, 2022), timely management attention to mitigate the effects of reduced sap sugar (Rapp *et al*., 2019) is required. Because the latitudinal climate gradient optimal for maple production is shifting northward (Rapp *et al*., 2019), the mid-region of production, including south-central Ontario, is at greater risk of experiencing declines in productivity relative to the current northern limits of production in Quebec, Canada. More large-scale producers have begun implementing reverse osmosis technology to reduce water content and subsequently increase sugar concentration of maple sap prior to boiling (Heiligmann *et al*., 2006). However, many smaller Canadian producers identified lack of financial resources as the largest constraint to adopting new technology (Legault *et al*., 2019), and thus, reverse osmosis pumps and other costly technological adaptations may not be feasible. Given the importance of stand health variables on sap sweetness (Figure 4) and the positive perception of North American producers towards stand management strategies to mitigate climate change effects (Legault *et al*., 2019), cost-effective stand management plans may be the most attainable and effective adaptation strategy for south-central, Ontario.

Stand structure and density impact sap sugar content. Maple trees in well-managed, optimally-spaced stands are more vigorous relative to trees in unmanaged, dense stands (Chapeskie *et al*., 2006). Trees in dense stands compete for resources and canopy positioning, typically forcing shade tolerant maple trees to remain in suppressed states (Heiligmann *et al*., 2006), which compromises carbohydrate production. Lancaster *et al*. (1976) suggest that approximately 200 to 250 well distributed maple trees per hectare is considered an adequately stocked stand. Thus, creating management plans that promote canopy diameter development and dominant overstory positioning while simultaneously reducing intra-specific resource competition should increase maple sugar concentrations.

Given the importance of root temperature and health on carbohydrate allocation, extra care should be given when working in sugarbushes during the winter and spring months. Early spring marks sap flow, which comes with increased activity within stands. Rutting and skidding damage to soils have been linked with long-term damage for maple syrup production (Chapeskie *et al*., 2006), likely due to root damage. Thus, as climate continues to change, producers should be aware of the importance of preserving natural processes that are dependent on root temperature and health.

2.7 Conclusions

This study examined the relative importance of key stand and regional-level ecological factors on maple sap sugar concentration in south-central Ontario, Canada. Our model suggests that it may be challenging for regional producers to maintain consistently sweet sap without adopting adaptation measures that offset changes to stand, soil, and climate conditions. Managing stand density such that maple trees have dominant overstory positioning and adequate soil nutrients important for carbohydrate production may aid in maintaining sap sweetness as climate changes. Furthermore, stand management practices should be carried out during low-risk periods in which root systems are less susceptible to damage. Additional research is also needed to better understand how variability within the respective growing, winter, and tapping season (i.e., short pulses of extreme low or high temperatures) may impact carbohydrate production and allocation for sap sweetness, as current studies are limited to using seasonal average data. Furthermore, our study focused on the impacts of environmental factors on sap sugar concentration. Future studies should also address the relative importance of key environmental variables on sap volume so that the most appropriate management approaches are developed for the region.

2.8 Acknowledgements

The completion of this study was made possible through grants provided by Camphill Communities Ontario (CCO), SSHRC, the Faculty of Graduate Studies, the Faculty of Sciences and Environmental Studies, and the Department of Biology at Lakehead University. A special thank you to the Ontario Maple Syrup Producers Association (OMSPA) for providing provincial production data, as well as my Lakehead and CCO field assistants, Nelson Gonzalez-Toledo, Skylar Charlebois, and Joshua Robertson who worked tirelessly to help me collect data.

Prologue to Chapter III

In the previous chapter, I explored the relative importance of ecological factors influencing sap sugar concentration in south-central Ontario, Canada. I now explore the influence of maple syrup production-specific activities on the well-being of individuals with intellectual and developmental disorders (IDDs). Specifically, I wished to better understand the aspects of nature-based maple syrup production-specific activities that individuals with IDDs enjoy. This understanding will allow us to consider how the desirable aspects can be better integrated into maple syrup production practices to foster the well-being of individuals who partake in CCO's maple syrup social enterprise.

Chapter 3. Exploring a nature-based activity on the well-being of adults with intellectual and developmental disabilities: A mixed methods case study

3.1 Abstract

Individuals with intellectual and developmental disabilities (IDDs) face greater physical and social barriers and are at greater risk of morbidity. Nature-based activities can promote individual well-being by placing individuals in situations and contexts that promote positive emotions and mood. This case study used self-reported experiences of adults with IDDs to better understand how nature-based activities may influence individual well-being. A voluntary Likert-scale survey was administered to 29 of 44 (66%) individuals who reside at a not-for-profit organisation, Camphill Communities Ontario (CCO), and a semi-structured focus group was conducted with a subset of individuals (n = 5) who currently participate in, or who are interested in becoming involved with nature-based maple syrup production-specific activities at CCO. Our survey focused on exploring the perceptions of individuals towards: (a) *nature-based recreational activities and tasks* associated with maple syrup production, (b) *skill development*, and (c) *relationship development* on individual well-being, while complementary focus group interviews provided detailed, supplementary information on individual experiences and perceptions towards the nature-based activities. *Nature-based recreational activities and tasks* associated with maple syrup production and opportunity for *skill development* were the most positively perceived aspects of nature-based maple syrup production-specific activities, followed by the opportunity for *relationship development*. Participating in nature-based maple syrup production-specific activities cultivated positive emotions via feelings of connectedness with nature, self-perception through skill development, and sharing self-produced maple products with local communities. Adverse weather conditions and physical limitations were the main deterrents for participation.

Key words: *Disability, nature-based program, well-being, skill development, social integration, outdoor recreation, self-efficacy*

3.2 Introduction

Approximately 1.4% of Canadians aged 15 years and older have intellectual and developmental disabilities (IDD) (Statistics Canada, 2018). Individuals with IDDs have higher rates of physical and mental ailments (Cooper *et al*., 2015; Reppermund *et al.,* 2019), reduced life expectancy (Bittles *et al*., 2002), and face greater barriers to resources and activities compared to the general population (Van Schijndel-Speet *et al*., 2014). Additionally, these individuals often have difficulty recognising and/or navigating social cues, which can lead to impaired social interactions (Green *et al*., 2009). As a result, individuals with IDDs are usually more inactive than neurotypical individuals (Draheim *et al*., 2002; Pan *et al*., 2011), further increasing their susceptibility to developing adverse health conditions (Booth *et al*., 2012; Rodiek, 2002; Wilson & Christensen, 2012). Promoting well-being through situations that evoke positive emotions and mood (Tough *et al*., 2017) can mediate some physical and psychological challenges faced by individuals with IDDs (Godbey, 2009; Holt-Lunstad *et al*., 2010).

Nature-based recreational activities can be one such avenue as they generate positive emotions from feelings of increased connectedness with nature (Mayer *et al*., 2009) and promote physical and psychological well-being through a more active lifestyle (Shimitras *et al*., 2003; Sudimac *et al*., 2020). Nature-based recreational activities can also help individuals develop functional and problem-solving skills (Sproule *et al*., 2013) that allow them to achieve specific goals when navigating challenging natural environments (Sterba, 2006). This can, ultimately, promote self-efficacy and boost self-confidence (Hermens *et al*., 2017; Marks *et al*., 2005). Furthermore, nature-based recreational activities provide opportunities for positive social interactions and engagement (Lais, 1987; Zachor *et al*., 2016), potentially increasing one's self-confidence (Henderson *et al.*, 2007) and social capital (Ferlander, 2007). Social capital, through the development of meaningful relationships, can help individuals with IDDs to better cope with stress (Cohen & Wills, 1985; Olstad *et al.,* 2001) and improve overall quality of life (Ware *et al*., 2008).

Nature-based recreational activities can take many forms. We explored the influence of nature-based activities associated with maple syrup production on the well-being of adults with intellectual and developmental disabilities at Camphill Communities Ontario (CCO), a not-for-profit organisation in Angus, Ontario, Canada that supports individuals with IDDs. Given the nature-based setting, and the variety of novel activities and tasks that individuals with IDDs can participate in, our case study aimed to better understand perceptions of individuals with IDDs towards: (a) *nature-based recreational activities and tasks* associated with maple syrup production, (b) *skill development*, and (c) *relationship development* on individual well-being.

3.3 Methods

3.3.1 Study Area: Camphill Communities Ontario

Camphill Communities Ontario is part of the Camphill Association that has established rural and urban community centres throughout North America. They offer individuals with IDDs opportunities to connect, build relationships, and collaborate with local and regional communities. Community integration is made possible through CCO's day-activity programs, outreach initiatives, and periodic special events. Given our focus on impacts of nature-based recreational activities, we worked specifically with adults with IDDs associated with their 113-ha mixed-use rural property located at 7841 4th Line in Angus, Ontario, Canada (Figure 5). It consists of residential units, a cultural hall, a woodshop, and an art studio intermixed with cultivated lands, pastureland, and a deciduous woodlot that are the foundations of several nature-based programs including the maple syrup social enterprise, animal husbandry, pasture and forest management, woodworking, and biodynamic/organic agriculture (Figure 6).

Approximately 32 individuals with IDDs reside onsite, with 12 individuals living in supported independent living. An additional 15 individuals with IDDs participate in day-activity programs but do not live in CCO residences. Approximately 15% of all individuals with IDDs associated with CCO participate in the maple syrup social enterprise program. The nature-based activities associated with this program are carried out in CCO's deciduous woodlot and sugar shack. The specific outdoor activities and tasks include stand tending, tapping maple trees, maintaining gravity-fed tubing systems, and transporting collected maple sap from the holding tank to the sugar shack for processing. Once the maple sap arrives at the sugar shack, activities and tasks include operating a reverse osmosis system to reduce sap water content, heating maple sap in a warming pan, and boiling sap to syrup using a wood-fired evaporator pan. When the sap reaches the appropriate sugar concentration such that it is classified as maple syrup, it is then bottled and labelled according to syrup grade and bottle size. Maple syrup products are sold to the general public through their retail store located in Barrie, Ontario, Canada, as well as at maple syrup festivals and other community outreach events. CCO also provides a delivery system which allows individuals with IDDs to deliver their maple syrup products directly to customer's homes.

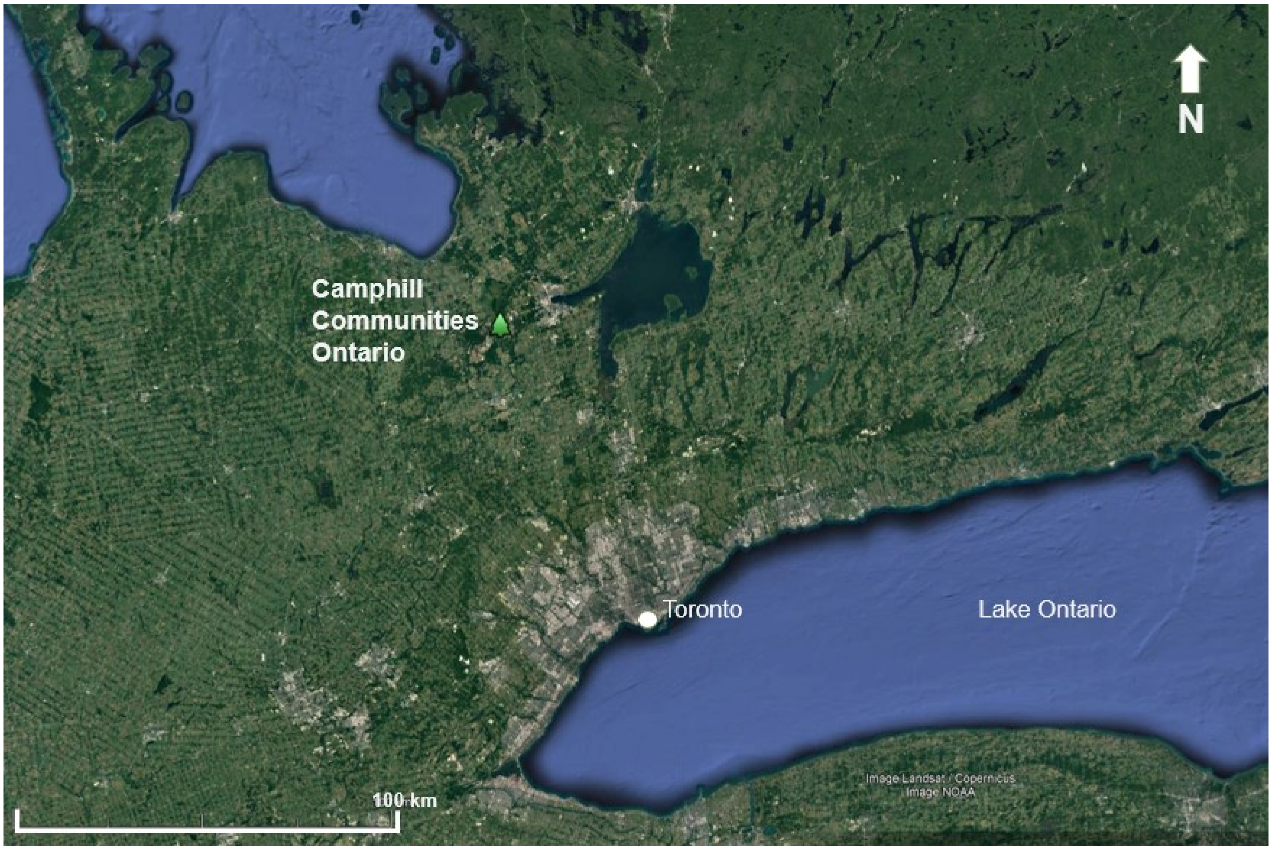

Figure 5. Location of Camphill Communities Ontario (CCO) in Angus, Ontario, Canada.

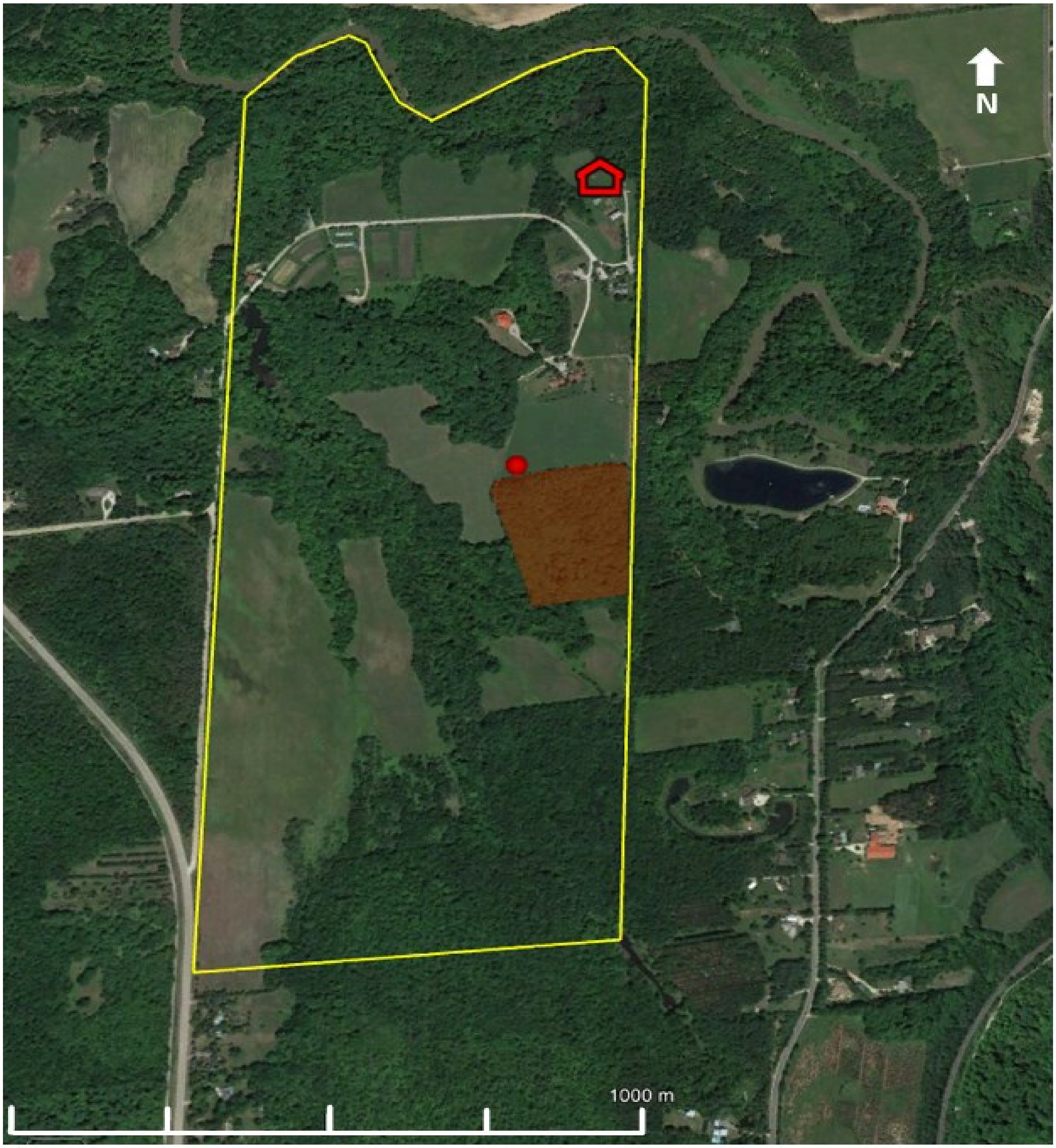

Figure 6. Camphill Communities Ontario (CCO) rural property located near Angus, Ontario Canada. Yellow perimeter: approximate property line of CCO. Important infrastructure for the maple syrup social enterprise is denoted in red. Red polygon: sugar shack for boiling and bottling; red circle: sap holding tank; red shaded area: sugarbush used for maple syrup production.

3.3.2 Sampling protocol

A voluntary Likert-Type survey was administered to 29 of 44 (66%) individuals who reside at CCO. Secondly, a voluntary semi-structured focus group interview session was conducted with a subset of individuals who currently participate in, or are interested in participating in the maple syrup social enterprise program. The survey was used to better understand the relative importance of: (a) *nature-based recreational activities and tasks* associated with maple syrup production, (b) *skill development*, and (c) *relationship development* on individual well-being (see Appendix 2A), while the focus group session provided detailed, supplementary information on individual experiences and perceptions (see Appendix 2A). All outreach documents, consent forms, survey, and interview protocols were approved by the Lakehead University Research Ethics Board (see Appendix 2B).

3.3.3 Analyses

3.3.3.1 Quantitative survey analysis

Responses to each Likert-Type survey question were analysed using a Chi-square test of independence (X^2). Fisher's exact approach was used with a Bonferroni correction to control against Type I error when pair-wise comparisons were needed (Bland & Altman, 1995; Shan & Gerstenberger, 2017). Likert Scale data were analysed using GLM procedures. Data met the assumptions of normality and homogeneity of variance (at $p = 0.05$). Thus, Tukey's HSD test was used for multiple comparisons. Cronbach's Alpha (α) was used to determine internal consistency of Likert Scale data (Emerson *et al*., 2021; Taber, 2018). Cronbach's Alpha values indicated acceptable levels of internal consistency (Griethuijsen *et al*., 2015; Taber, 2018) except for skill development which did not meet requirements (Table 1).

Table 6. Cronbach's Alpha (α) values used to assess internal consistency of survey items associated with nature-based activities and their influence on well-being.

Pre-Defined codebook	**Cronbach's Alpha (α)**
General perception towards maple activities	0.93
Nature-based environment and tasks associated with maple syrup	0.80
Skill Development	0.59
Relationship Development	0.69

3.3.3.2 Qualitative Interview Analysis

The semi-structured focus group interview session was assessed using deductive thematic analysis (Nowell *et al*., 2017). Thus, a pre-defined codebook was created based on key sources of well-being identified in the literature prior to data collection and analysis (Crabtree & Miller, 1992). The codes used in this study were: (1) *nature-based recreational activities and tasks*, (2) *skill development*, and (3) *relationship development*. Interview transcription followed code development. This involved carefully reviewing all interview material multiple times to identify themes that emerge. Rigour was achieved by developing thorough data collection and analysis strategies such as making initial interview notes that facilitated precise documentation of participant responses and behaviours and carefully reviewing recorded transcripts, codes, and thematic trends of the interview material. Triangulation of the data added validity and credibility to the research conducted (Zitomer & Goodwin, 2014).

3.4 Results

3.4.1 General sentiment towards nature-based recreational activities and tasks associated with maple syrup production

Having social outdoor maple syrup activities at CCO ($n = 28$, 84% yes, $X^2 = 29.1$, $p<0.001$) and continuing to make an all-natural maple product ($n = 25$, 84% yes, $X^2 = 26.4$, $p<0.001$) were important to individuals with IDDs:

> "*… us, we made it! It's the best!*"
> "*I like sharing the history of maple syrup ...*"

Sixty-nine percent of individuals were interested in participating in the maple syrup enterprise at CCO ($n = 28$, $X^2 = 18.5$, $p<0.001$).

3.4.2 Nature-based recreational activities and tasks associated with maple syrup production

Common activities and tasks that individuals were interested in included delivering sale products to customers (n = 28, 71% yes, 28.6% no, $X^2 = 5.14$, p = 0.023), selling maple syrup products at the store (n = 27, 64% yes, 35.7% unsure, $X^2 = 3.0$, p = 0.083), working as a maple tour guide (n = 28, 54% yes, 11% unsure, 36% no, $X^2 = 7.79$, p = 0.02), bottling and packing maple syrup (n = 28, 54% yes, 14% unsure, 32% no, $X^2 = 6.5$, p = 0.039), and collecting sap and boiling off water content (n = 28, 61% yes, 3% unsure, 36% no, $X^2 = 13.79$, p = 0.001):

> "*I like delivering and making the maple syrup here and doing a bit more hands-on work.*"
> "*I like wearing the little GoPro* [camera] *on my chest.*"

Planning and attending meetings (n = 28, 57% yes, 43% no, $X^2 = 0.57$, p = 0.450) promotional tasks such as taking photos and videos of maple syrup products and maple program activities/events (n = 28, 64% yes, 36% no, $X^2 = 2.29$, p = 0.131), and counting and tracking inventory (n = 28, 54% yes, 46% no, $X^2 = 0.14$, p = 0.705) were also considered to be favourable tasks by some individuals. Further, 74% of respondents (n = 27, $X^2 = 20.22$, $p<0.001$) were looking forward to having the opportunity to participate in future maple syrup activities and tasks, with 40% of respondents (n = 25, $X^2 = 2.0$, p = 0.368) indicating that they enjoy tasks related to maple syrup production more than other tasks and programs offered at CCO. However, some respondents (n = 26, 39%, $X^2 = 0.56$, p = 0.756) reported that some of the activities available with the maple program are too physically demanding. Deductive analysis revealed that physical limitations may be an important constraint for participation:

> "*I can't carry buckets because of my hip.*"

Sixty-four percent of individuals (n = 28, X^2 = 12.07, p = 0.002) were more interested in participating in indoor tasks than outdoor, while only 50% of respondents (n = 28, X^2 = 4.36, p = 0.113) indicated that they would enjoy the outdoor tasks associated with the maple program. Adverse weather was a common deterrent for participation in the outdoor activities:

> "*I don't like the cold so much during the winter*."

3.4.3 Skill development

Eighty-four percent of individuals indicated that participation in the maple syrup program offers opportunities to develop new skills (n = 25, X^2 = 11.56, p<0.001):

> "*Yes, please! I would like that* [try a new tool]*!"*

Most individuals felt that learning a new skill is challenging (n = 25, 68% yes, 12% unsure, 20.0% no, X^2 = 12.54, p = 0.002), but agreed that developing a new skill evokes feelings of happiness (n = 25, 92% yes, 8.0% unsure, X^2 = 35.62, p<0.001).

3.4.4 Relationship development

Most individuals (n = 26, 73% yes, 15% unsure, 12% no, X^2 = 18.54, p<0.001) claimed that working in a group or team environment creates feelings of happiness:

> "*It* [the sugarbush] *makes me happy. I like taking my friends out in the woods at Camphill!"*

Most individuals felt comfortable asking CCO co-workers/peers (n = 24, 83% yes, 17% unsure, X^2 = 10.67, p = 0.001) and support staff (n = 25, 84% yes, 16% unsure, X^2 = 11.56, p<0.001) questions when unsure of how to do something. Furthermore, the majority of respondents reported that they liked to help co-workers/peers with their tasks and jobs during their day (n = 26, 85% yes, 11% unsure, 4% no, $X^2 = 31.0$, p<0.001), with 80% of individuals feeling as though their work is appreciated by other CCO individuals and support staff (n = 25, $X^2 = 9.0$, p = 0.003). Participation in this program also helped individuals make new friendships that carried on outside of work (n = 25, 60% yes, 20% unsure, 20% no, $X^2 = 8.0$, p = 0.018):

> "*I would do it* [collect sap] *with her* [friend], *and I'd feel pretty good.*"

Most respondents (n = 25, 68% yes, 28% unsure, 4% no, $X^2 = 15.68$, p<0.001) indicated that outdoor maple syrup social activities provide them with opportunities to interact with the local and regional community during sales events such as farmers' markets and maple syrup festivals. Most individuals also indicated that making maple syrup and selling it to the general public is meaningful work that directly helps unite the community (n = 25, 68% yes, 28% unsure, 4% no, $X^2 = 15.68$, p<0.001):

> "*..this was the first year we had the maple syrup festival at* [neighbouring farm] *and I really enjoyed that work!*"

> "*It feels really good* [to interact with our local community] *because I haven't seen people for three years because of COVID.*"

3.4.5 Relative importance of pre-defined aspects of nature-based activities

Significant differences in preferences towards specific pre-defined aspects of nature-based activities were observed ($F_{2, 84} = 4.691$, $p = 0.012$). *Nature-based recreational activities and tasks* and *skill development* were the most positively associated themes of individual well-being among respondents (Figure 7). Further, *nature-based recreational activities and tasks* were more important than *relationship development* towards well-being ($p = 0.01$). No other significant differences were observed (all $p>0.05$).

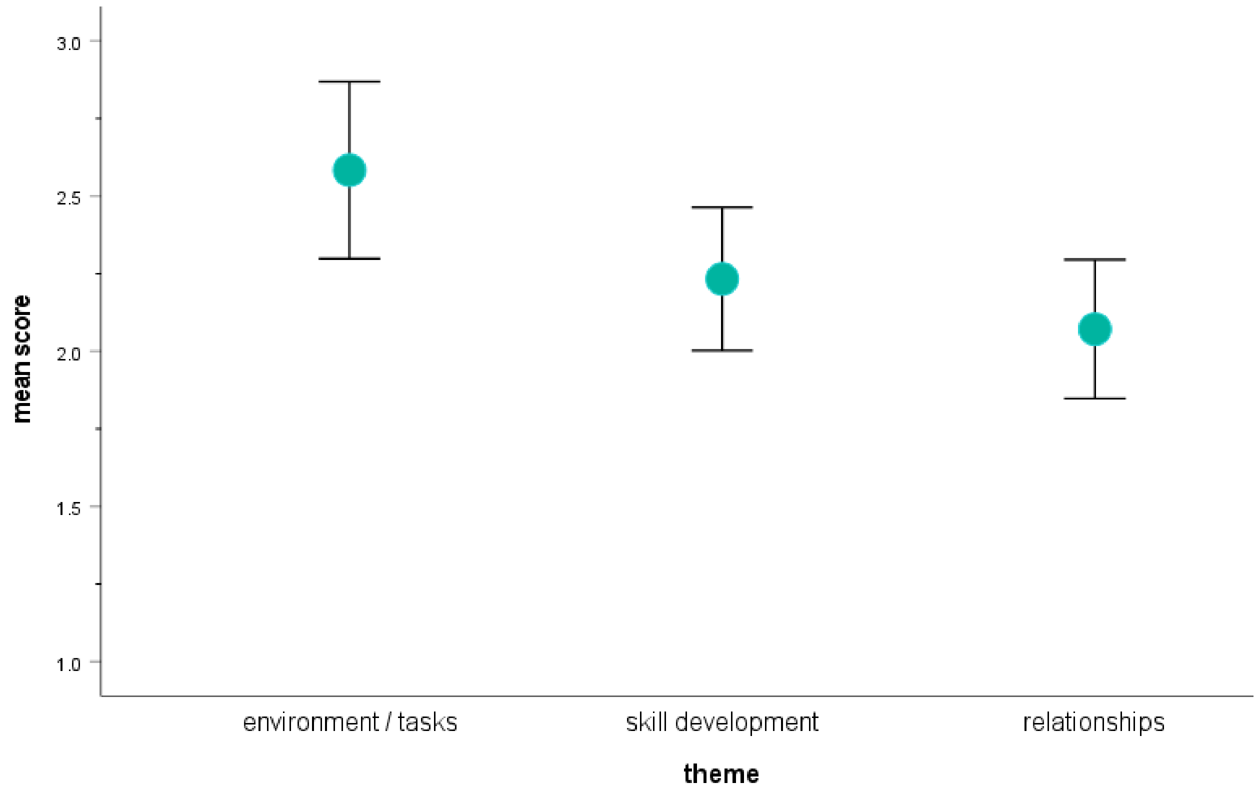

Figure 7. Comparison of mean (1 = low agreement, 2 = unsure, 3 = high agreement) scores based on key aspects of nature-based maple syrup production-specific activities associated with well-being ($F_{2, 84} = 4.691$, $p = 0.05$). Black bars above and below each mean indicate 95% CI.

3.4.6 Individual perceptions towards nature-based maple syrup production-specific activities and emerging focus-group themes

Adults with IDDs generally reported that participating in CCO's maple syrup social enterprise program evoked positive emotions, improved self-perception, and provided opportunities for positive social engagement. Specifically, nature-based maple syrup production-specific activities at CCO were particularly effective at generating feelings of happiness and connectedness to nature. Some individuals were drawn to spending time in the sugarbush due to the opportunity for more hands-on work:

"I had a good time doing more hands-on work."

"Seeing what's new or old or what's changing the past year [in the sugarbush]."

while others were drawn to the colours and scenery of the sugarbush:

"I love going for walks through forests, it also makes me happy."

"It was a really sunny day, and it was a great experience!"

"I like the colours."

Self-perception and self-efficacy were drivers of well-being and were observed through skill development opportunities. The opportunity to develop a new skill with the specific end goal of making maple syrup was generally well received:

"*Yes, please! I would like that* [try a new tool]!*"*

Self-perception and social integration were observed through opportunities to engage with the surrounding community. Specifically, positive impacts on self-perception were apparent when individuals shared their experiences of selling maple products and their knowledge of the maple syrup production process with their peers and the local community:

"Looking at different products with actual vendors to do something good. It makes me feel pretty good actually!"

"I really like sharing the history of maple syrup."

"I was on [local] news and basically that's what happened. I got to talk in the microphone and was asked why we like maple syrup and why we are here."

In contrast, some individuals expressed their preference for working alone at times:

"Well, I don't like going with a friend sometimes. I just don't like it."

3.5 Discussion

Nature-based activities can reduce adverse physical and mental health conditions (Dorsch *et al*., 2016; Rodiek, 2002). Adults with IDDs generally felt that participating in CCO's maple syrup social enterprise program evoked positive emotions through activities and tasks that allowed them to spend quality time in the sugarbush, develop new skills, and have opportunities for meaningful social engagement. While all three examined themes associated with well-being were well regarded, *nature-based activities and tasks* and *skill development* were the most positively perceived themes of the maple syrup social enterprise program. The nature-based activities promoted a positive self-perception important for fostering the willingness to participate in new activities (Allender *et al*., 2006; Humberstone *et al*., 2018). Moreover, it appears that the variety of novel activities that may be performed indoors or outdoors during maple syrup production was attractive to participants. Specifically, having a variety of ways in which individuals can participate in nature-based maple syrup production-specific activities creates opportunity for different experiences, and tailors to the personal preference of individuals to engage in physical tasks, detail-oriented tasks, or more creative experiences such as admiring natural colours or designing labels. Regardless of experiential preferences among individuals, individuals with IDDs positively perceived the variety of maple syrup production-specific tasks available to them.

An individual's positive perceptions towards maple syrup production-specific tasks, as well as recurrent feelings of happiness and connectedness to nature among interviewees suggest that there may be an intrinsic link between production-specific tasks and nature that promotes well-being. Interestingly, respondents indicated a preference to participate in the indoor *versus* outdoor activities. Given that maple sap flows during late winter and early spring, the preference for indoor over outdoor activities is likely a result of the timing in which the majority of maple syrup production takes place. Jakubec *et al*. (2016) found that weather and physical limitations are challenges for participation in nature-based activities, which aligns with our findings, as adverse weather conditions and physical limitations were the two largest deterrents for participation.

Considering the positive perception of maple syrup production-specific activities among respondents and the evidence that outdoor activities can improve mood (Hull & Michael, 1994; Rodiek, 2002), addressing these barriers should be paramount to ensure that outdoor activities are accessible to all individuals. For example, implementing an outdoor education program for individuals with IDDs may promote participation in these outdoor activities. Dillenschneider (2007) suggests that accommodations addressing strength, motor control, cognitive processing/planning, and mobility barriers may promote inclusion in outdoor education programs. Furthermore, outdoor education programs should be extended to support-workers, as lack of educated staff can be an obstacle to inclusiveness (Brodin, 2009). In instances where individuals do not wish to spend time outdoors during winter, developing nature-based maple syrup production-specific activities that can be carried out during warmer weather is an option. These activities may include maintenance of tubing systems and other infrastructure, carrying out sylviculture and other stand management tasks, or working on promotional aspects of production.

Skill development through recreational social programs can aid in the development of cognitive life skills (Hermens *et al*., 2017), and was also a highly valued benefit of participating in the maple syrup social enterprise program. The importance of novel skill development was interesting given that lack of confidence, specifically when faced with unfamiliar settings, is a common deterrent for participation in recreational programs (Allender *et al*., 2006). Perhaps participation in other daily recreational activities at CCO helped improve self-determination and confidence (Palisano *et al*., 2012) and thus, helped to encourage participation in the maple syrup enterprise program.

The extent to which an individual feels connected and valued within a community has a large effect on overall health and well-being (Emerson *et al*., 2020). Moreover, the number and length of positive social interactions influence an individual's social integration (Newton *et al*., 1995; Holt-Lunstad *et al*., 2010). Relationship development was a positively perceived aspect of well-being but was less important relative to nature-based recreational activities and tasks (Figure 7). Most participants reported that they were comfortable asking for clarity when unsure of how to do something, were willing to help peers finish their tasks at the end of their day, and that they established relationships that continue outside of the maple syrup social enterprise program related activities, providing ample evidence of positive social interactions important for social integration. Given that individuals at CCO live and complete daily activities alongside peers and support workers, it is not surprising that relationship development was positively perceived by individuals but was not the main driver for participation. Nevertheless, interview results suggest that sharing self-made maple products and knowledge of the maple syrup production process with their peers and local communities were important social benefits of participating in the program and is thought to contribute to individual well-being through positive social experiences.

3.7 Conclusions

Nature-based recreational activities and tasks associated with maple syrup production provide important opportunities for individuals with IDDs to promote well-being. Although unique to each individual, positive emotions and feelings of connectedness to nature were emergent experiences through participating in nature-based activities and tasks, skill development, and relationship development. Thus, having different tasks and aspects of maple syrup production-specific activities that individuals with IDDs can participate in likely drives the widespread positive perception towards the maple syrup social enterprise program at CCO and promotes individual well-being. It is likely that the aspects of maple syrup production-specific activities that promote positive emotions and contribution to individual well-being will translate to other nature-based activities. Efforts to ensure that all individuals have equal access to the nature-based activities that they are drawn to must be made. Additionally, opportunities to cultivate well-being through the maple syrup social enterprise program exist during the summer months. Promoting growing season-specific activities and tasks would provide individuals put off by adverse weather conditions opportunities to be involved.

3.8 Acknowledgements

The completion of this study was made possible through grants provided by Camphill Communities Ontario (CCO), SSHRC, the Faculty of Graduate Studies, the Faculty of Sciences and Environmental Studies, and the Department of Biology at Lakehead University. A special thank you to Kathrine Killam, CCO's Community Participation & Innovation Manager, and the individuals at CCO who shared their experiences and perceptions with us by participating in the voluntary survey and interview work.

Prologue to Chapter 4

Chapter 2, 3, and 3A* of this thesis project collectively strove to identify different areas of vulnerability to climate change within south-central Ontario's maple syrup industry. Chapter 4 synthesises my research findings and establishes a framework for the development of adaptation strategies that promote socio-ecological resilience of south-central Ontario's maple syrup industry.

* Please note that this chapter is located in Appendix 3A

Chapter 4. Multi-disciplinarity yields sweet socio-ecological resilience for Ontario's maple syrup industry

Maple syrup production in south-central Ontario, Canada is a significant cultural and economic practice (Murphy *et al*., 2012) that is highly vulnerable to climate change (Rapp *et al*., 2019). Ideally, maple syrup producers collect maple sap with high sap sugar concentrations to maximise annual maple syrup yield and profitability (Rapp & Crone, 2015). However, climate change has introduced volatility to the production process that has impacted producers throughout North America (Legault *et al*., 2019; Rapp *et al*., 2019; Skinner *et al.,* 2010). In the southern limits of production, including the mid-eastern US, lower sap sugar concentrations along with an earlier and shorter tapping season is threatening industry viability (Duchesne & Houle, 2014; Rapp *et al*., 2019). In contrast, areas at the northeastern limit of production, i.e., Quebec, Canada, are experiencing neutral to positive effects (Matthews & Iverson, 2017; Rapp *et al.,* 2019). Although the mechanisms behind variability in maple sap sugar concentrations are not well understood, some studies have explored the effects of ambient temperature (Duchesne & Houle, 2014; Rapp *et al*., 2019), physical tree parameters and genetics (Morrow, 1955; Morselli *et al*., 1978) , and soil fertility (Horsley *et al.*, 2002; Wild & Yanai, 2014). Currently, few studies have examined the relative importance of known ecological drivers of sap sugar content within south-central Ontario, Canada, a region situated in the middle of sugar maple's historic nature range. Given this knowledge gap, these drivers were examined here. I also addressed some of the social and economic impacts that climate change poses on key stakeholders in the Ontario maple syrup industry. Specifically, I investigated the perceptions of Ontario maple syrup producers towards climate change and the perceptions of individuals with IDDs towards the impact of nature-based recreational activities and tasks associated with maple syrup production on their well-being. Collectively, this socio-ecological study sought to identify areas of vulnerability and potential adaptation strategies to mitigate the effects of climate change on maple production in south-central Ontario, Canada, while highlighting often overlooked sociological benefits associated with maple syrup production.

4.1 Synopsis

My results indicate that regional variability in sap sugar content is best explained through a combination of climate characteristics, stand health variables, and soil conditions. Stand management practices that address stand dynamics (optimise composition & density over time), soil and root health, and using forecast models to predict growing season conditions may be a viable management strategy to help maintain sap sugar concentration in south-central Ontario sugarbushes.

Ontario maple syrup producers believe that maple production is closely linked with climate and wish to adopt adaptation strategies that preclude or at least reduce the onset of any negative effects of climate change. However, given logistic constraints, producers are more likely to implement mitigation strategies such as using spring forecast models, improving sanitation practices, and implementing cost-effective, less intensive stand tending interventions that reduce inefficiencies. For individuals with IDDs, taking part in the maple syrup social enterprise evoked positive feelings of connectedness with nature, instilled confidence through development of new skills, and provided positive social engagement opportunities, all of which are beneficial to well-being. Creating opportunities to engage with nature through stand tending and equipment maintenance activities during the summer season may provide alternatives for those hesitant to participate during the winter months.

4.2 Synthesis

My multi-disciplinary approach aligns with socio-ecological resilience, which refers to the capacity to adapt to unexpected changes in socio-ecological systems in ways that enhance our well-being (Chapin III *et al*. 2010; Reyes & Kneeshaw 2014). My hope is that results from this study will help to develop an effective, holistic adaptation strategy that accounts for multiple stakeholder needs. I did this by exploring the ecological, sociological, and economic impacts of climate change on regional maple syrup production (Figure 8). Together, these layers of information will help to identify socio-ecological adaptation strategies to climate change that ensures viable maple syrup production that meets all stakeholder needs.

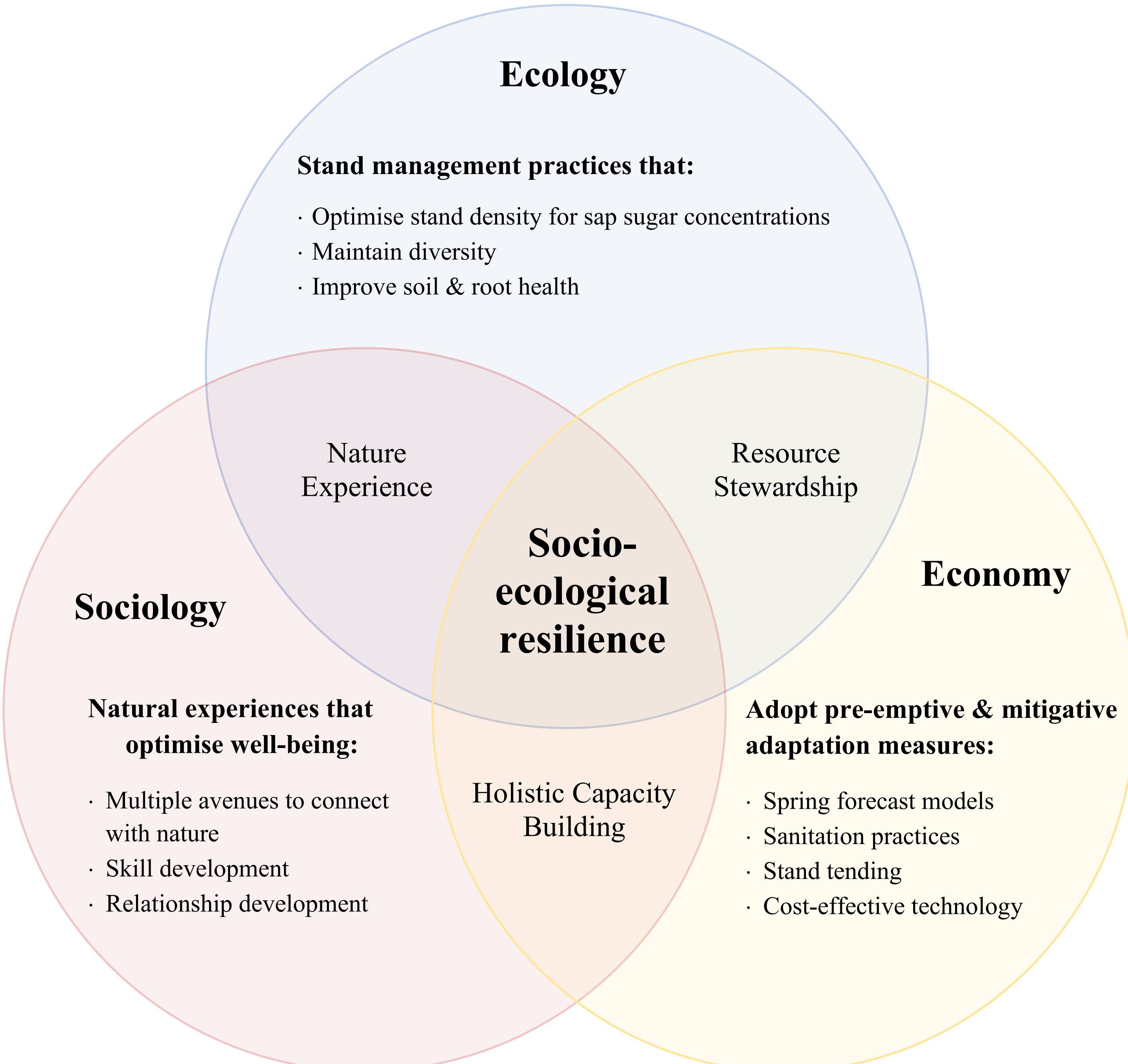

Figure 8. A multi-disciplinary approach to achieve socio-ecological resilience of south-central Ontario's maple syrup industry.

4.3 Future Directions

Because people and nature are intimately linked, determining if and how activities in the maple syrup industry potentially lead to sugar maple forest ecosystem degradation must also be explored and adapted to foster natural ecosystem stability. Continuing activities without adapting them to account for climate change may push the system to an undesirable state that is difficult to reverse (Reyes & Kneeshaw 2014). Thus, equally important is improving knowledge of the impacts of current commercial maple syrup producer activities on tree health, syrup quality, and productivity. Together, these multiple layers of information will help to shape socio-ecological adaptation strategies to climate change, and thus, ultimately ensure that sugarbush operations continue to meet all stakeholder needs.

This research project identified the relative importance of ecological variables explaining variability in maple sap sugar concentrations over a one-year maple syrup production year. Long-term monitoring of the variables identified in this study is needed to better understand their importance to sap sugar concentrations. Future research should also focus on identifying the key environmental variables influencing sap volume, given the sap yield is important for annual maple syrup yield (Chapeski *et al*., 2006). Furthermore, regional producers have raised concerns surrounding the impacts of ambient temperature volatility during the tapping season which is thought to negatively influence annual maple syrup and syrup yield (P. Renaud, personal communication, 11/04/22). This has yet to be explored in literature. Lastly, spring forecast models are used to predict the beginning of sap flow, but no such models exist for the length or end of the sap flow season, which are arguably just as important for annual yield (P. Renaud, personal communication, 11/04/22).

4.4 Epilogue

The maple syrup industry is one that holds both cultural and economic significance. Thus, it is critical to identify and address vulnerabilities within the maple syrup industry to ensure its viability. Achieving socio-economic resilience within south-central Ontario's maple syrup industry is important for maintaining general ecosystem functioning across the natural range of sugar maple, economic stability for maple syrup producers across the region of maple syrup production, and sociological benefits for all individuals involved in the maple syrup production process as our climate changes.

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Appendices

Appendix 1

Table A1. Data sheet used for all in field data collection to inventory species composition and tree health within each quadrat and subplot for each sample site.

Tree Inventory & Individual Tree Assessment				Farm:							
Plot #	Tree #	Species	DBH (cm)	Bole Defect (y or n)	Causal Agent	Decay Class	Height (m)	Subcanopy vs Overcanopy	Gap Disturbance (y or n)	N, P, K, & pH values	Quadrat % Transparency

Table A2. Suite of categorized multiple linear regression models (orange: stand health, blue: climate conditions, yellow: soil conditions, green: all variables). Models were first assessed using AICc for each category. The top models from each category were then analyzed against one another using a subsequent AICc.

Model Variables	AIC	AICc	ΔAICc	Weight
DBH	14.95	14.98	0.00	0.52
DBH (cm) + Decay class	15.1	15.16	0.18	0.48
Decay class	26.78	26.82	11.84	0.001
Intercept	27.56	27.58	12.60	$9.5e^{-4}$
Height (m)	27.78	27.81	12.83	$8.5e^{-4}$
Height (m) + Decay class	29.08	29.13	14.15	$4.3e^{-4}$
T_{max} Growing + T_{min} Tapping	-205.75	-205.69	0.00	1.00
T_{mean} Growing + T_{mean} Tapping	-147.	-147.92	57.78	$2.85e^{-13}$
T_{min} Tapping	-125.36	-125.32	80.37	$3.54e^{-18}$
T_{max} Growing	-41.98	-41.95	163.75	$2.77e^{-36}$
T_{mean} Tapping	1.51	1.54	207.23	$1.0e^{-45}$
T_{max} Tapping	9.93	9.97	215.66	$1.48e^{-47}$
T_{mean} Growing	14.29	14.32	220.01	$1.68e^{-48}$
Intercept	27.56	27.58	233.27	$2.22e^{-51}$
[soil N] + Soil T_{mean} Tapping	-156.08	-156.02	0.00	1.00
[soil N]	-120.08	-120.05	35.97	$1.55e^{-8}$
Soil T_{mean} Winter	-43.70	-43.67	112.35	$4.00e^{-25}$
Soil T_{mean} Tapping	-5.39	-5.36	150.67	$1.92e^{-33}$

Intercept	27.56	27.58	183.60	$1.35e^{-40}$
Proportion maple spp. in canopy + Canopy cover (%) + T_{max} Growing + T_{mean} Winter + Soil T_{mean} Tapping	-2815.53	-2815.38	0.00	1.00
Proportion maple spp. in canopy + Canopy cover (%) + T_{mean} Tapping + Soil T_{mean} Winter + T_{max} Growing	-2519.98	-2519.55	295.55	$6.64e^{-65}$
Proportion maple spp. in canopy + Canopy cover (%) + T_{mean} Tapping + Soil T_{mean} Winter + T_{max} Growing	-2519.98	-2519.55	295.55	$6.64e^{-65}$
[soil N] + Proportion maple spp. in canopy + Decay class + Canopy cover (%) + T_{max} Growing + T_{mean} Tapping	-2337.99	-2337.80	477.58	$1.97e^{-104}$
[soil N] + Proportion maple spp. in canopy + T_{max} Growing + T_{min} Tapping	-1831.56	-1831.44	983.94	2.19e-214
[soil N] + Proportion maple spp. in canopy + Canopy cover (%) + Decay class + T_{min} Tapping + T_{max} Growing	-1781.92	-1781.77	1033.61	3.58e-225

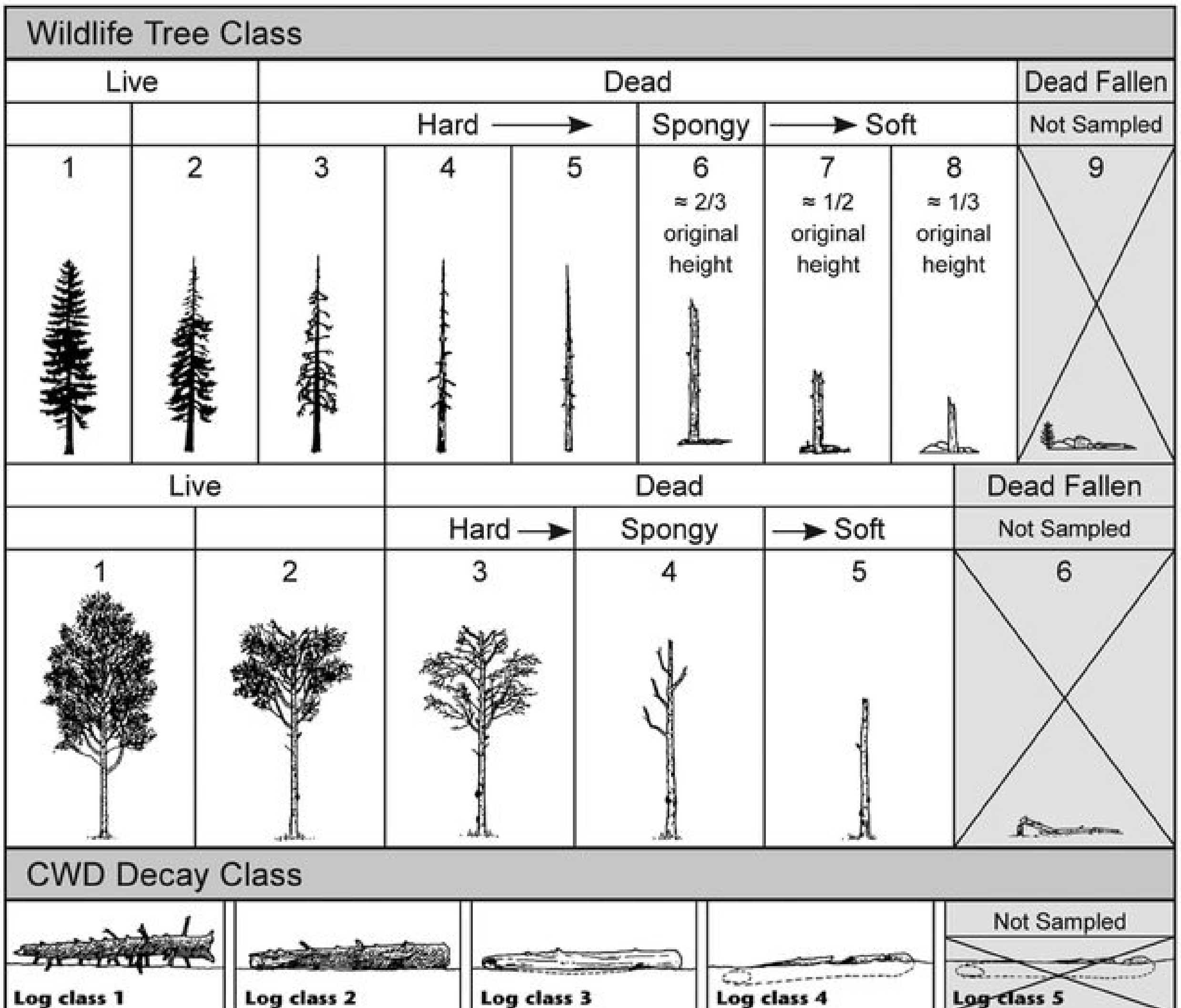
[soil N] + Proportion maple spp. in canopy + Decay class + T_{max} Growing + T_{min} Winter	-1674.18	-1674.03	1141.35	1.44e-248
Proportion maple spp. in canopy + Canopy cover (%) + Decay Class + Soil T_{mean} Winter + T_{mean} Growing	-800.65	-800.50	2014.89	0.00
[soil N] + Proportion maple spp. in canopy + Decay class + Canopy cover (%) + T_{mean} Tapping	-725.82	-725.67	2089.71	0.00

Table A3. Comparison of the proportion maple species in canopy and common tree species across sample stands and corresponding tree characteristics including DBH (cm) and height (m).

Sample Site	**Proportion Maple species in canopy (%)**	**Tree Species**	**Mean DBH (cm)**	**Mean Height (m)**
CCO	52.60	Maple spp.,	30.6 ± 2.1	23.5 ± 0.7
		Ironwood	50.4 ± 0.0	30.4 ± 0.0
		White Ash	42.9 ± 11.7	26.6 ± 4.5
Maple Grove	45.21	Maple spp.,	23.8 ± 1.5	16.6 ± 0.5
		Ironwood	15.2 ± 0.8	13.3 ± 0.5
		White Ash	15.6 ± 1.2	15.8 ± 0.7
Williams	64.0	Maple spp.,	27.4 ± 1.6	19.4 ± 0.7
		Ironwood	12.2 ± 1.0	12.7 ± 1.2
		White Ash	0.0 ± 0.0	0.0 ± 0.0
Sugar Ridge	95.83	Maple spp.,	18.8 ± 4.7	26.7 ± 0.5
		Ironwood	0.0 ± 0.0	0.0 ± 0.0
		White Ash	38.4 ± 2.5	25.1 ± 1.0
4M	71.29	Maple spp.,	26.4 ± 1.3	21.0 ± 0.6
		Ironwood	15.7 ± 1.6	18.3 ± 3.7
		White Ash	29.0 ± 2.0	24.9 ± 0.6
Kemble Mountain	65.15	Maple spp.,	32.3 ± 2.0	22.1 ± 0.9
		Ironwood	19.7 ± 0.0	16.1 ± 0.0
		White Ash	20.4 ± 3.2	20.0 ± 1.5
OCR	50.56	Maple spp.,	22.2 ± 1.9	18.2 ± 0.9
		Ironwood	15.1 ± 4.5	17.4 ± 1.6
		White Ash	20.8 ± 2.6	18.0 ± 1.4

Table A4. Comparison of stand conditions including proportion maple species in canopy, soil N concentrations (μg/Kg), and crown cover (%) across sample sites.

Site	Proportion maple species in canopy (%)	[soil N] (μg/Kg)	Crown Cover (%)
CCO	52.6	2.3 ± 0.7	74.3 ± 2.6
Maple Grove	45.2	5.2 ± 1.1	88.4 ± 0.9
Williams	64.0	0.3 ± 0.1	83.1 ± 4.2
Sugar Ridge	95.8	0.9 ± 0.2	82.3 ± 0.02
4M	71.3	0.6 ± 0.2	85.8 ± 0.9
Kemble Mountain	65.2	6.6 ± 1.1	83.9 ± 0.02
OCR	50.6	0.0 ± 0.0	72.1 ± 4.6
Study Average	64.0	2.3 ± 1.0	81.4 ± 2.3



Log class 1	Log class 2	Log class 3	Log class 4	Log class 5
Hard	Sap rot (but still hard)	Advanced decay (spongy)	Extensive decay (crumbles/mushy)	Many small pieces, soft
Bark firm	Loose bark	Bark trace/absent	Bark absent	Bark absent
Elevated	Sagging	Sagging to settled on ground	Fully settled on ground	Partly sunken in ground
Hard branches with twigs	Soft branches	Branches stubs/ absent	No branches	No branches
Supports person	May not support person	Breaks easy	Shape collapses when stepped on	Collapsed oval
No invading roots	No invading roots	Roots in sapwood	Roots in heartwood	Roots in heartwood

Figure A1. Tree decay classification chart used to determine tree condition within sample sites.

Appendix 2A

Questions about participating in CCO's maple syrup program

Understanding what you like and dislike about Camphill Community Ontario's (CCO) maple syrup program will help us make your experience with the program even better. Thank you for participating in our survey!

General Questions	You are welcome to complete this survey whether you have already participated in activities associated with the maple syrup program or not. Please note that the words in brackets are included for those of you who haven't participated in the program.

1. I (would) enjoy participating in the maple syrup program

   Mark only one oval.

   - Yes
   - No
   - Unsure

2. I (would) enjoy the outdoor jobs available to do at the maple syrup program

   Check all that apply.

   - [ ] Yes
   - [ ] No
   - [ ] Unsure

3. I (would) enjoy the indoor jobs more than the outdoor jobs available at the maple syrup program

Check all that apply.

- [ ] Yes
- [ ] No
- [ ] Unsure

4. It is important to me that CCO continues to have the maple syrup program

Check all that apply.

- [ ] Yes
- [ ] No
- [ ] Unsure

5. It is important to me that we are creating an all-natural maple syrup product

Check all that apply.

- [ ] Yes
- [ ] No
- [ ] Unsure

Skill Development

6. Learning a new skill is challenging

Check all that apply.

- [ ] Yes
- [ ] No
- [ ] Unsure

7. Learning a new skill makes me happy

Mark only one oval.

- ◯ Yes
- ◯ No
- ◯ Unsure

8. There are opportunities to learn a new skill when participating in the maple syrup program

Mark only one oval.

- ◯ Yes
- ◯ No
- ◯ Unsure

Job satisfaction	Please note that the words in brackets are included for those of you who haven't participated in the program.

9. I look forward to participating in the activities and/or jobs that I can do at the maple syrup program

Check all that apply.

- ☐ Yes
- ☐ No
- ☐ Unsure

10. I (would) enjoy collecting sap and using machines to make maple syrup

Mark only one oval.

- Yes
- No
- Unsure

11. I (would) enjoy bottling maple syrup and packing the bottles into boxes

Mark only one oval.

- Yes
- No
- Unsure

12. I (would) enjoy labelling bottles

Mark only one oval.

- Yes
- No
- Unsure

13. I (would) enjoy planning and attending meetings

Mark only one oval.

- Yes
- No
- Unsure

14. I (would) enjoy selling maple syrup products at the store

Check all that apply.

- [ ] Yes
- [ ] No
- [ ] Unsure

15. I (would) enjoy working on promotions, taking photos, and/or videotaping maple syrup program activities

Mark only one oval.

- Yes
- No
- Unsure

16. I (would) enjoy delivering our products we sell to customers

Mark only one oval.

- Yes
- No
- Unsure

17. I (would) enjoy counting and tracking bottles

Check all that apply.

- [ ] Yes
- [ ] No
- [ ] Unsure

18. I (would) enjoy working as a tour guide

Check all that apply.

- [ ] Yes
- [ ] No
- [ ] Unsure

19. Some activities and/or jobs that are available to do with the maple syrup program are too physically demanding

Mark only one oval.

- Yes
- No
- Unsure

20. I enjoy the activities I can do with the maple syrup program more than other program activities offered at CCO

Mark only one oval.

- Yes
- No
- Unsure

Peer relationships & communication

21. Working in a group or team environment makes me feel happy

Mark only one oval.

- Yes
- No
- Unsure

22. I like to help my co-workers with their tasks/jobs for the day

Mark only one oval.

- Yes
- No
- Unsure

23. I prefer to work alone

Mark only one oval.

- Yes
- No
- Unsure

24. I often feel unhappy because I do not get along with my co-workers

Check all that apply.

- [ ] Yes
- [ ] No
- [ ] Unsure

25. I am comfortable asking my co-workers questions when I am unsure of how to do something

Check all that apply.

- [ ] Yes
- [ ] No
- [ ] Unsure

26. I am comfortable asking support staff questions when I am unsure of how to do something

Check all that apply.

- [ ] Yes
- [ ] No
- [ ] Unsure

27. I feel that the jobs I do are appreciated by my coworkers and CCO staff

Check all that apply.

- [ ] Yes
- [ ] No
- [ ] Unsure

28. Participating in the maple syrup program helps me make new friends that I can socialise with outside of work

Check all that apply.

- [ ] Yes
- [ ] No
- [ ] Unsure

29. Participating in the maple syrup program gives me an opportunity to interact more with our local community

Mark only one oval.

- ◯ Yes
- ◯ No
- ◯ Unsure

30. Making maple syrup for our local community is meaningful work as it helps to bring the community together

Check all that apply.

- [ ] Yes
- [ ] No
- [ ] Unsure

Companion & Day-use Visitor Interview Questions

For companions & day-use visitors with past experience working with the maple syrup program:

What activities/tasks do you do?

Which activity/task do you enjoy the most when working with the maple syrup program? *Why* is this your favourite activity/task?

What activity/task do you enjoy the least when working at the maple syrup operation? *Why*? What could make it more enjoyable?

How long have you been involved with the maple syrup program? Are you more involved with the maple syrup program now than you were in previous years?

Have you learned any new skills since helping with maple syrup production? Do you use this skill (or some aspect of it) in any other program at CCO or job (outside of CCO)?

Was learning this new skill enjoyable/fun/challenging?

Do you feel more connected to your fellow companions when working to collect, make, or sell maple syrup?

Would you like to be more involved with the program? What (else) would you like to do?

Is being outdoors (in nature) important to you when participating in the maple syrup program?

Do you feel that the maple syrup program is an important part of CCO? Why (not)?

How important is it to be able to communicate with our local community?

For companions & day-use visitors without past experience working with the maple syrup program:

Would you like to be involved with the program in the future?

If so, what activities/tasks would you like to do?

If not, why? What could be done to make you want to participate?

Which programs at CCO do you like to participate in?

Do you feel that the maple syrup program is an important part of CCO? Why (not)?

Appendix 2B

Lakehead UNIVERSITY

Research Ethics Board
t: (807) 343-8283
research@lakeheadu.ca

November 11, 2021

Principal Investigator: Dr. Gerardo Reyes
Co-Investigator: Dr. Sonia Mastrangelo
Students: Erin Valenzuela, Breanne Lywood, Claudia Flores Moreno
Science and Environmental Studies\Sustainability Sciences (Orillia)
Lakehead University
500 University Ave, OR 1035
Orillia, ON L3V 0B9

Dear Dr. Gerardo Reyes and Research Team:

Re: Romeo File No: 1468726
Granting Agencies: Camphill Communities Ontario, Lakehead University, and SSHRC
Agency Reference #: 1468384

On behalf of the Research Ethics Board, I am pleased to grant ethical approval to your research project titled, "Fostering the socio-ecological resilience of Camphill Communities Ontario's maple syrup operation in the face of climate change".

Ethics approval is valid until November 11, 2022. Please submit a Request for Renewal to the Office of Research Services via the Romeo Research Portal by October 11, 2022, if your research involving human participants will continue for longer than one year. A Final Report must be submitted promptly upon completion of the project. Access the Romeo Research Portal by logging into myInfo at:

https://erpwp.lakeheadu.ca/

During the course of the study, any modifications to the protocol or forms must not be initiated without prior written approval from the REB. You must promptly notify the REB of any adverse events that may occur.

Best wishes for a successful research project.
Sincerely,

Dr. Claudio Pousa
A/Chair, Research Ethics Board
/sa

Dear Companions and Day-Use Participants,

My name is Breanne Lywood and I am a graduate student in the MSc Biology program at Lakehead University.

Lakehead University in partnership with Camphill Communities Ontario is studying how climate change is impacting CCO's maple syrup production and determining what can be done to ensure that CCO continues to successfully run the maple syrup program. Part of this requires knowing about your level of interest in participating in the activities associated with the maple syrup program.

I am reaching out today as I am looking for companions and day-use participants who are interested in providing their thoughts about participating in the activities associated with the maple syrup program through an online survey. You are welcome to complete the survey whether you have already participated in activities associated with the maple syrup program or not. If you are interested in participating in our online survey, please click **here**. This link will send you to our Information Sheet and Consent form that provides more detailed information about our survey. Should you provide your consent, you will gain access to our survey through another hyperlink at the bottom of the consent form. For potential participants requiring a parent, guardian, or substitute decision maker for help completing the survey Information Sheet and Consent form please click **here**.

Please note that the survey is anonymous, entirely voluntary, and under no circumstances are you required to answer any of the questions. If you would like a paper copy of the survey instead, please contact me, Breanne Lywood, by email at **blywood@lakeheadu.ca** or phone at **(905) 246-0176**.

Secondly, we are also interested in interviewing companions and day-use participants who would like to provide their thoughts about participating in the activities associated with the maple syrup program in more detail. Interviews will be done via Zoom, Skype, or telephone. You are welcome to complete the interview whether you have already participated in activities associated with the maple syrup program or not. If you would like to participate in our interviews please click **here**. The link will send you to our Information Sheet and Consent form that provides more detailed information about the interview process. Should you provide your consent, I will contact you using the contact information that you provide so that we can set up an interview time convenient for you. For potential participants requiring a parent, guardian, or substitute decision maker for help completing the interview Information Sheet and Consent form please click **here**

Please note that you are under no obligation to participate in the survey or the interview, and CCO will not be aware if you decide to participate or not. For further information and/or if you have any questions about the survey, interview, or the project in general, please do not hesitate to contact me. Thank you in advance for taking the time to read about the project and considering this opportunity to help!

Kind regards,

Breanne Lywood, MSc (candidate)

Lakehead UNIVERSITY

PARTICIPANT'S INFORMATION SHEET

Project Title: Exploring the Resilience and Adaptive Capacity of Camphill Communities Ontario's maple syrup program to Climate Change

Principal Investigator:	Gerardo Reyes, PhD
Co-Investigator:	Sonia Mastrangelo, PhD
Co-Investigator:	Breanne Lywood, MSc (candidate)
Co-Investigator:	Erin Valenzuela, MSc (candidate)
Co-Investigator:	Claudia Flores, PhD (candidate)
Research Partner:	Kathrine Killam, MA; Community Development Officer, CCO
Research Funders:	Camphill Communities Ontario (CCO) Social Sciences and Humanities Research Council (SSHRC)

This research study has been reviewed and approved by the Lakehead University Research Ethics Board. If you have any questions related to the ethics of the research and would like to speak to someone outside of the research team, please contact Sue Wright at the Research Ethics Board at 1(807)343-8283 or by email at: susan.wright@lakeheadu.ca; research@lakeheadu.ca

Dear Potential Participant,

Thank you for considering participating in our study. Your time is highly valued and greatly appreciated!

Taking part in this study is voluntary. Before you decide if you want to participate, it is important that you understand the purpose of the study, what you will be asked to do, any potential risks and benefits associated with participating, and how your confidentiality will be protected. Please carefully review the information below.

Purpose of our study

Lakehead University has partnered with Camphill Communities Ontario (CCO) to explore how well CCO's maple syrup program can cope with climate change. More specifically, we wish to identify the activities associated with the maple syrup production process that make companions and day visitors want to participate in the operation so that these aspects can be maintained and/or enhanced when developing adaptation strategies to climate change.

Your involvement

You are being asked to voluntarily complete this online survey. If you agree to participate in this study, we will ask questions regarding your likes and dislikes about working in CCO's maple syrup program. The questions should take about 10 minutes to answer. You may skip questions if you do not wish to respond to them. At the end of the survey, you will be asked to click <*submit*>.
Please note that your responses will only be included in our study if the <*submit*> button is clicked, and that doing so will demonstrate your full consent to participate.

Can you withdraw from the study?

Taking part in our study is entirely voluntary. You may withdraw your consent at any point up to clicking the <*submit*> button at the end of the survey. You may withdraw by simply closing the browser. You will not be penalised in any way for withdrawing. Please note that once you click <*submit*> that your responses cannot be withdrawn because they are anonymous and cannot be linked back to you.

Risks and expected benefits

There are no known or potential risks associated with participating in this study. Your participation is entirely voluntary. Participants remain anonymous as no identifying information is collected, and CCO will not be aware if you participated or not.

No direct benefits to participants will be gained from participating in this study. However, the information gathered will ultimately help to ensure that CCO companion and day visitors' wishes and needs are met when developing adaptation strategies to climate change. Thus, long-term benefits of this study may include enriched work experiences, increased knowledge of sugarbush management, and a sustainable CCO programming option that can provide a stable source of income for CCO.

Confidentiality

Due to collection and storage of data via an online tool, we cannot absolutely guarantee the full confidentiality and anonymity of your data. With your consent to participate, you acknowledge this.

Nonetheless, the survey is anonymous and will not be labelled to identify who completed it. As such, participants are not asked to provide any identifying information within the survey, making linking responses to an individual participant's name or other unique identifiers extremely unlikely.

Only the researchers named in this study have access to the data as collected. Your individual responses will not be shared with anyone outside of the research team. To further protect your information, data are coded and securely stored on a password-protected computer at Lakehead

University for 5 years, after which, they will be deleted. Data will be used for public presentations, summary documents for CCO and the community, Breanne Lywood's MSc thesis, Claudia Flores' PhD thesis, and publications in peer-reviewed open-access journals. Any future presentations or publications, including those listed above, will only include summary statistics; i.e., no raw data will be presented or published.

Further questions and/or concerns

If you have questions and/or concerns about the research or about your role in the study, please feel free to contact Gerardo Reyes at (705)330-4008 x2698 or by email (greyes@lakeheadu.ca); Sonia Mastrangelo at (705) 330-4008 x2635 or by email (smastran@lakeheadu.ca); Breanne Lywood by email (blywood@lakeheadu.ca); Erin Valenzuela by email (ecrawfor@lakeheadu.ca); Claudia Flores by email (cflores2@lakeheadu.ca); or Kathrine Killam at (705) 309-6713 or by email (kkillam@camphill.on.ca). Should you wish a copy of our results once published, please feel free to contact Gerardo Reyes via email.

PARTICIPANT'S CONSENT FORM

- I have reviewed the Participant's Information Sheet and understand the nature and purpose of the study
- I understand that I have the right to withdraw from the study at any time until I press <*submit*> at the end of the survey, after which, it is not possible to withdraw
- I understand that I may choose not to answer any question
- I understand the potential risks and/or benefits of participating in this research study, and what those are
- I understand that the survey is anonymous and that I will not be asked to provide any identifying information
- I understand that I will remain anonymous in any publication or public presentation of research findings
- I understand that the information I provide will be securely stored at Lakehead University for a minimum of 5 years following completion of the project
- I understand that in no way does my consent waive my legal rights or release the researchers or the institutions involved from their legal and professional responsibilities

Please keep a completed copy/screenshot of this Consent Form for your future reference

I have read and understand the information provided above and agree to take part in the study according to the terms outlined in this Consent Form by clicking [*NEXT*]

Thank you once again for your interest in our study. We look forward to the opportunity to work alongside Camphill Communities Ontario members on this really important issue!

Sincerely,

Gerardo Reyes, PhD
Sonia Mastrangelo, PhD
Breanne Lywood, MSc (candidate)
Erin Valenzuela, MSc (candidate)
Claudia Flores, PhD (candidate)
Kathrine Killam, MA

Appendix 3A

Prologue to Chapter 3A

Thus far, my research has explored the ecological and sociological aspects of maple syrup production in south-central Ontario, Canada. Collectively, these chapters aimed to identify areas of vulnerability within regional stands important for sap sugar content and explored the influence of nature-based maple syrup production-specific activities on individual well-being to better understand how to promote well-being through maple production. The last aspect of maple syrup production that I wish to explore in my thesis is the economic consequences of climate change on maple syrup production by interviewing Ontario maple syrup producers. Chapter 3A aims to understand the perceptions of provincial maple syrup producers towards the impacts of climate change on production trends and their constraints to implementing new mitigation strategies. Having knowledge surrounding the ways that regional producers are willing and able to address climate change is pertinent for identifying feasible adaptation strategies for maple syrup production.

Chapter 3A. Perceptions of Ontario maple syrup producers towards the effects of climate change and their willingness and constraints to implementing mitigation strategies

3.1 Abstract

Maple syrup production is a significant cultural practice and economic driver across northeastern United States and southeastern Canada. Industry success is contingent upon maintaining historic climate conditions that promote sap flow and/or increase sugar concentrations. As climate continues to change, there is growing concern over the challenges that commercial producers may face in order to maintain current production levels. The purpose of this study was to explore perceptions of Ontario maple syrup producers (n = 22) towards: (i) the impact of climate change on production, (ii) the impact of climate change on stand health, (iii) willingness to implement adaptation strategies, (iv) potential adaptation strategies, and (v) constraints to implementing new adaptation strategies. Likert-scale survey results indicate that Ontario producers are aware that climate and maple syrup production are closely linked (X^2 = 19.1, $p<0.001$) and that the beginning of the sap flow season is now more volatile between years (X^2 = 6.6, p = 0.036). The use of spring forecast models (X^2 = 11.1, p = 0.011), adopting effective sanitation practices such as periodic tubing and spout cleaning, annual spout replacement (X^2 = 8.9, p = 0.012), and practicing silvicultural management to maintain optimal tree densities (X^2 = 8.5, p = 0.036) are viable mitigation strategies favoured by regional commercial maple syrup producers. Lack of technical support (workers, equipment, etc.,) was identified as the greatest barrier for adopting new climate change adaptation strategies (X^2 = 16.2, p = 0.003).

Key words: *commercial maple syrup producers, climate change, adaptation strategies, maple syrup production*

3.2 Introduction

Maple syrup production is a culturally significant practice originating from northeastern North America (Whitney & Upmeyer, 2004). Modern day maple syrup operations are important economic drivers for many rural communities across Ontario, Canada (Murphy *et al*., 2012) and provide other cultural and socio-ecological benefits to producers and the surrounding natural habitats (Hinrichs, 1998). Canada is responsible for producing 75% of global maple syrup products each year. Ontario is responsible for 4.0% of this total, representing approximately 1.8 million litres of syrup in 2020 (Agriculture & Agri-Food Canada, 2021).

Maple syrup production is reliant on specific climatic conditions for success (Rapp *et al*., 2019). In particular, consecutive diurnal freeze thaw events are required in order for sap to flow during late winter/early spring, and ambient temperatures of up to 20 ˚C during the growing season are needed to optimise carbohydrate production, since carbohydrate production is positively related with sap sweetness (Rapp *et al*., 2019). Because of the reliance on stable climate conditions for maple syrup production, there is growing concern over the viability of the maple syrup industry moving forward (Rapp *et al*., 2019; Duchesne & Houle, 2014). In fact, 50% of Ontario maple syrup producers (N = 33) believe that the industry is already experiencing the negative effects of climate change (Murphy *et al*., 2009). Furthermore, approximately 34% of North American (n = 102) producers claim to have inaccurately predicted, and consequentially missed, the beginning of the sap flow season (Mozumder *et al*., 2015), negatively affecting annual profit margins (Duchesne & Houle, 2014). Maple producers also report that the quantity and quality of maple sap is decreasing due to climate change (Mozumder *et al*., 2015) and predict that maple syrup yield will continue to decline as climate changes (Legault *et al*., 2019).

Equipment and technology have evolved to increase the efficiency of making maple syrup (Heiligmann *et al*., 2006), with large-scale operations being the most likely to implement new adaptation strategies (Legault *et al*., 2019). Newer technology such as vacuum pumps and reverse osmosis systems aid in the sap collection and refinement process, respectively, to reduce labour costs and help to address uncertainties surrounding sap flow (Heiligmann *et al*., 2006; Snyder *et al*., 2018). However, the main constraints for North American maple syrup producers to implement new adaptation strategies includes a lack of financial means and lack of information about climate change vulnerability (Legault *et al*., 2019).

Canadian producers face regionally unique challenges and constraints (Legault *et al*., 2019; Rapp *et al*., 2019). Given the significance of the maple industry in Ontario, this study aimed to better understand the perceptions of Ontario maple syrup producers towards: (i) the impact of climate change on production, (ii) the impact of climate change of stand health, (iii) willingness to implement adaptation strategies, (iv) potential adaptation strategies, and (v) constraints to implementing new adaptation strategies. Exploring regional maple syrup producers' perceptions and constraints to addressing climate change concerns will help to identify both effective and attainable adaptation measures for Ontario maple syrup producers.

3.3 Methods

3.3.1 Sampling protocol

A voluntary, anonymous, online five-point Likert-scale survey was made available to Ontario maple syrup producers during the winter and spring of 2022. The survey was broadcast to all Ontario Maple Syrup Producer's Association (OMSPA) chapters and via two consecutive OMSPA e-newsletters. The survey was used to better understand Ontario maple syrup producers' perceptions towards (i) the impact of climate change on production, (ii) the impact of climate change of stand health, (iii) willingness to implement adaptation strategies, (iv) potential adaptation strategies, and (v) constraints to implementing new adaptation strategies. All outreach documents, consent forms, and survey protocols were approved by the Lakehead University Research Ethics Board (see Appendix 3C).

3.3.2 Statistical analysis

Responses to each survey question were analysed using a Chi-square test of independence (X^2) (Curtis & Youngquist, 2013). Cronbach's Alpha was used to assess internal consistency of Likert Scale data (Taber *et al*., 2018). Cronbach alpha values for sections (i) and (ii) exceeded 0.7, suggesting appropriate levels of internal consistency of Likert scale items (Taber *et al*., 2018). Survey sections (iii), (iv) and (v) had Cronbach alpha values less than 0.7, suggesting they did not meet requirements for internal consistency.

3.4 Results

3.4.1 Impacts of climate change on maple syrup production

Eighty-six percent of Ontario producers believe that maple syrup production is closely linked with climate (n = 22 , X^2 = 19.1, p<0.001, 22% somewhat agree, 64% strongly agree). The majority of producers (n = 22, X^2 = 6.64, p = 0.036, 23% somewhat agree, 59% strongly agree) believe that the beginning of sap flow is more variable between years and are confident that multiple environmental factors influence maple sap/syrup production (n = 21, X^2 = 14.6, p = 0.002, 38% somewhat agreed, 52% strongly agreed), but are less confident that they are able to identify areas of vulnerability within stands (n = 21, X^2 = 5.86, p = 0.119, 38% - slightly disagreed, 38% unsure, 14.3% somewhat agreed, 9.5% strongly agreed).

3.4.2 Impacts of climate change on sugarbush stand health

Ice storms (n = 22, $X^2 = 9.64$, p = 0.022, 50% strongly disagreed, 27% somewhat disagreed, 18% unsure, and 5% somewhat agreed), hail (n = 21, $X^2 = 17.4$, $p<0.001$, 76% strongly disagreed, 10% somewhat disagreed, 14% unsure), drought (n = 22, $X^2 = 14.4$, p = 0.006, 50% strongly disagreed, 23% somewhat disagreed, 14% unsure, 9% somewhat agreed, 5% strongly agreed), and soil acidification (n = 22, $X^2 = 18.4$, $p<0.001$, 64% strongly disagreed, 18% somewhat disagreed, 14% unsure, 5% strongly agreed) were not important sources of stand damage across Ontario maple operations, while insect outbreak was reported to cause damage in some stands (n = 22, $X^2 = 0.73$, p = 0.948, 18% strongly disagreed, 27% somewhat disagreed, 18% unsure, 18% somewhat agree, 18% strongly agree). Maple crown dieback (n = 22, $X^2 = 2.55$, p = 0.637, 27% agreed, 23% unsure, and 50% disagreed) and maple decline (n = 22, $X^2 = 4.36$, p = 0.359, 23% agreed, 32% unsure, 45% disagreed) are not common occurrences in Ontario sugarbushes, according to regional producers.

3.4.3 Willingness to implement adaptation strategies

Most producers wish to implement adaptation strategies before experiencing the effects of climate change on production levels (n = 21, $X^2 = 10.8$, p = 0.013, 5% somewhat disagree, 29% unsure, 52% somewhat agree, 14% strongly agree), and would likely implement new adaptation strategies if they resulted in increased annual yield (n = 21, $X^2 = 10.67$, p = 0.031, 5% strongly disagree, 5% somewhat disagree, 24% unsure, 24% somewhat agree, 43% strongly agree). Producers are either uncertain or do not feel that information regarding the impacts of climate change on regional maple syrup production is readily available (n = 21, $X^2 = 13.5$, p = 0.009, 10% strongly disagree, 29% somewhat disagree, 48% unsure, 10% somewhat agree, 5%

strongly agree). Maple producers do not feel that there are numerous adaptation strategies that they can integrate into their operations (n = 21, X^2 = 8.52, p = 0.036, 1% strongly disagreed, 38% somewhat disagreed, 43% unsure, 5% somewhat agree), and reported that new adaptation measures are needed (n = 21, X^2 = 14.2, p = 0.003, 10% somewhat disagree, 29% unsure, 57% somewhat agree, 5% strongly agree).

3.4.4 Potential adaptation strategies

Using spring forecast models to predict the beginning of sap flow (n = 22, X^2 = 11.1, p = 0.011, 9% somewhat disagree, 23% unsure, 55% somewhat agree, and 14% strongly agree), adopting strong sanitation practices such as tubing, spout cleaning, and annual spout replacement (n = 21, X^2 = 8.86, p = 0.012, 5% unsure, 38% somewhat agree, 57% strongly agree), and practicing silvicultural management to maintain favourable tree density (n = 21, X^2 = 8.52, p = 0.036, 5% somewhat disagree, 14% unsure, 43% somewhat agree, 38% strongly agree) were adaptation strategies that were positively perceived by regional maple producers. Adaptation measures that were less well perceived by producers included increasing the number of sugarbush taps (n = 22, X^2 = 0.727, p = 0.948, 14% strongly disagree, 23% somewhat disagree, 23% unsure, 18% somewhat agree, 23% strongly agree), fertilizing and liming stands (n = 21, X^2 = 2.1, p = 0.718, 24% strongly disagree, 19% somewhat disagree, 29% unsure, 19% somewhat agree, 10% strongly agree), and implementing high-pressure vacuum tubing systems (n = 22, X^2 = 2.55, p = 0.637, 18% strongly disagree, 18% somewhat disagree, 27% unsure, 9% somewhat agree, 27% strongly agree).

3.4.5 Limitations and constraints for implementing new adaptation strategies

Lack of technical support (not enough workers, lack adequate equipment, etc.) was the main constraint for implementing adaptation measures (n = 22, X^2 = 16.2, p = 0.003, 5% strongly disagree, 14% somewhat disagree, 50% unsure, 27% somewhat agree, 5% strongly agree). Lack of financial means (n = 22, X^2 = 4.36, p = 0.359, 18% strongly disagree, 23% somewhat disagree, 32% unsure, 23% somewhat agree, 5% strongly agree), and lack of information (n = 21, X^2 = 0.867, p = 0.867, 33% somewhat disagree, 29% unsure, 38% somewhat agree) were also concerns for Ontario producers. Producers were also asked whether they believed that climate change will not have an impact on production levels, and thus, do not feel like they need to implement adaptation measures. Most producers disagreed with this perception (n = 22, X^2 = 14.0, p = 0.003, 55% strongly disagreed, 32% somewhat disagreed, 9% unsure, 5% strongly agree).

3.4.6 Future outlook

Regional producers are concerned about the difficulty of adapting to the negative impacts of climate change over the next 10 to 15 years (n =21, X^2 = 6.36, p = 0.05, 5% strongly disagreed, 10% somewhat disagreed, 24% unsure, 43% somewhat agreed, 19% strongly agreed). Producers were less confident that their businesses would experience growth over the next 10 to 15 years (n = 22, X^2 = 1.18, p = 0.88, 18% strongly disagreed, 27% somewhat disagreed, 14% unsure, 23% somewhat agreed, 18% strongly agreed), and whether they would be able to gradually adapt to climate change over the next 10 to 15 years (n = 22, X^2 = 6.36, p = 0.095, 5% somewhat disagreed, 32% unsure, 41% somewhat agreed, 23% strongly agreed).

3.5 Discussion

Maple syrup production is projected to experience marked changes from historic trends because of a shift in the timing of sap flow, reduced sap sugar concentrations (Rapp *et al*., 2019), and the increased risk of disease outbreaks (MacIver *et al*., 2006; Chapeskie *et al*., 2006). Most Ontario maple producers believe that climate change and maple syrup production are closely related, and that the start of the sap flow season is now more variable between years relative to historic trends. These perceptions and experiences of Ontario producers may also be a function of their geographical location. Ontario producers are within the central portion of sugar maple's natural range where production is commercially viable. Given that the severity of climate change effects are expected to occur along a latitudinal gradient, and that progressively more producers north of sugar maple's southern range limits are reporting negative effects (Legault *et al*., 2019; Rapp *et al*., 2019), awareness surrounding the forthcoming impacts of climate change among producers in more northerly regions is growing. Ontario maple producers were confident that multiple factors influence syrup production, which makes them a unique group within the Canadian agriculture sector. Crop, livestock, and poultry producers generally focus on ambient temperature as the primary driver of climate change impacts (Reid *et al*., 2006).

Causes and severity of stand damage were not consistent among stands. For example, insect outbreak was reported by some producers, while others indicated that insect outbreak was not a significant source of damage in their stands. This may be reflective of the Spongy moth (*Lymantria dispar* L.) outbreak that Ontario endured in 2020 (Government of Ontario, 2022). The variability in producer's responses is likely driven from differences in stand conditions since Spongy moth infestation is dependent on forest condition and relative abundance of preferred host species (Humble & Stewart, 1994). Well-stocked stands dominated by oak, cherry, white birch, trembling aspen, and maple, and/or sites under stress from nutrient deficiencies are generally most susceptible (Humble & Stewart, 1994).

The use of spring forecast models, adopting effective sanitation practices such as tube and spout cleaning, annual spout replacement, and practicing silvicultural management to maintain optimal tree density were the mitigation strategies favoured by Ontario commercial maple syrup producers. These preferences align with survey research across North America (Legault *et al*., 2019). In terms of silviculture, producers are more likely to implement or improve management strategies that address stand health in a cost-effective manner over adopting new equipment or labour-intensive management interventions into current practices. This preference aligns with feelings of lack of technical support, lack of financial means, and lack of information (Legault *et al*., 2019).

Ontario producers want to implement adaptation measures before experiencing the effects of climate change and are likely to incorporate mitigation strategies if they result in increased annual yield. This perception differentiates Ontario producers from US producers who would rather wait to experience negative effects of climate change on production before implementing new strategies (Legault *et al*., 2019), suggesting that Ontario maple producers are more proactive and concerned about the potential financial losses associated with climate change. Interestingly, only 23% of Canadian producers felt that there were many ways to adapt to climate change, which contrasts the 43% of American producers who felt that that were many adaptation options available (Legault *et al*., 2019). This suggests that information associated with potential climate change adaptation options for Ontario maple syrup producers may not be readily available.

Concern surrounding the difficulty of adapting to the negative impacts of climate change over the next 10 to 15 years was prevalent among Ontario producers, which may be a result of poor information transfer and apprehension over the feasibility of implementing viable, cost-effective adaptation strategies (Legault *et al*., 2019). Furthermore, the average age of North American maple syrup producers is between 50 and 60 years old (Caughron *et al*., 2020; Snyder *et al*., 2019). Older producers may face barriers related with physical ability and question whether younger generations will wish to continue producing maple syrup (Butler *et al.,* 2016). Thus, the demographic of maple syrup producers may be influencing the concerns that Ontario maple syrup producers have regarding adapting to climate change over the next 10 to 15 years.

3.6 Conclusions

Our findings suggest that regional maple syrup producers are conscious of the need to mitigate and/or adapt to climate change, as most are already observing some impacts on production. As climate continues to change, regional producers may have difficulty recognising specific areas of vulnerability in their sugarbushes. Furthermore, increased access to information regarding climate change vulnerability and viable adaptation options is needed so that producers who wish to adopt pre-emptive mitigation strategies can do so. Regional producers are more likely to modify current stand management practices and use available research to help navigate a changing climate over adopting new technology or initiating labour or cost-intensive interventions. Future research should focus on creating climate projection models, such as spring forecast and tapping season variability models, that can be used to reduce production inefficiencies.

3.7 Acknowledgements

The completion of this study was made possible through grants provided by Camphill Communities Ontario (CCO), SSHRC, the Faculty of Graduate Studies, the Faculty of Sciences and Environmental Studies, and the Department of Biology at Lakehead University. A special thank you to the Ontario Maple Syrup Producer's Association (OMSPA) and OMSPA president, John Williams, for distributing our survey to local producers.

Appendix 3B

Maple Syrup Producer Survey

The maple syrup industry is both culturally and economically significant in southern Ontario, Canada. As climate continues to change, we hope to identify the stand-level effects that maple syrup producers are experiencing. Additionally, we wish to explore the willingness and limitations that producer's experience for implementing potential adaptation strategies to help maintain future production levels.

Our goal is to help develop climate change adaptation strategies for producers in southern Ontario by drawing from survey work and research findings. This survey has been constructed from prior research done by Legault et al. (2019).

Impacts of climate change on sugar bushes

Indicate the extent to which your stand has been impacted in the last TEN years by the following climatic conditions

1. Ice storm

Mark only one oval.

	No Damage
1	⬭
2	⬭
3	⬭
4	⬭
5	⬭
	Significant Damage

2. Hail

Mark only one oval.

	No Damage
1	⬭
2	⬭
3	⬭
4	⬭
5	⬭
	Significant Damage

3. Drought

Mark only one oval.

No Damage

1 ◯

2 ◯

3 ◯

4 ◯

5 ◯

Significant Damage

4. Windstorm

Mark only one oval.

No Damage

1 ◯

2 ◯

3 ◯

4 ◯

5 ◯

Significant Damage

5. Insect outbreak

Mark only one oval.

No Damage

1 ◯

2 ◯

3 ◯

4 ◯

5 ◯

Significant Damage

6. Soil acidification

Mark only one oval.

No Damage

1 ⬭

2 ⬭

3 ⬭

4 ⬭

5 ⬭

Significant Damage

Impacts of climate change on production levels

7. Maple syrup production is closely related to climate

Mark only one oval.

Strongly Disagree

1 ⬭

2 ⬭

3 ⬭

4 ⬭

5 ⬭

Strongly Agree

8. The beginning of tapping season has shifted to earlier in the year

Mark only one oval.

Strongly Disagree

1 ⬭

2 ⬭

3 ⬭

4 ⬭

5 ⬭

Strongly Agree

9. The beginning of tapping season is variable between years

Mark only one oval.

Strongly Disagree

1 ⬭

2 ⬭

3 ⬭

4 ⬭

5 ⬭

Strongly Agree

10. It is difficult to determine the best time to start tapping maple trees

Mark only one oval.

Strong Disagree

1 ⬭

2 ⬭

3 ⬭

4 ⬭

5 ⬭

Strongly Agree

11. It is easy to understand why some years yield more maple sap/syrup than others

Mark only one oval.

Strongly Disagree

1 ⬭

2 ⬭

3 ⬭

4 ⬭

5 ⬭

Strongly Agree

12. It is easy to identify one environmental factor that influences sap/syrup yield

Mark only one oval.

Strongly Disagree

1 ⬭

2 ⬭

3 ⬭

4 ⬭

5 ⬭

Strongly Agree

13. I believe multiple environmental factors influence sap/syrup yield

Mark only one oval.

Strongly Disagree

1 ⬭

2 ⬭

3 ⬭

4 ⬭

5 ⬭

Strongly Agree

14. It is easy to identify areas of vulnerability within my sugarbush

Mark only one oval.

Strongly Disagree

1 ⬭

2 ⬭

3 ⬭

4 ⬭

5 ⬭

Strongly Agree

15. I have observed an increase in maple decline in my stand

Mark only one oval.

Strongly Disagree

1 ⬭

2 ⬭

3 ⬭

4 ⬭

5 ⬭

Strongly Agree

16. I have noticed an increase in crown dieback in my stand

Mark only one oval.

Strongly Disagree

1 ⬭

2 ⬭

3 ⬭

4 ⬭

5 ⬭

Strongly Agree

Willingness to implement adaptation strategies

17. Information on the impacts that climate change has on maple syrup production is easily accessible

Mark only one oval.

Strongly Disagree

1 ⬭

2 ⬭

3 ⬭

4 ⬭

5 ⬭

Strongly Agree

18. There are already numerous adaptation strategies for maple syrup producers to implement

Mark only one oval.

	Strongly Disagree
1	◯
2	◯
3	◯
4	◯
5	◯
	Strongly Agree

19. New adaptation measures are needed for maple syrup producers

Mark only one oval.

	Strongly Disagree
1	◯
2	◯
3	◯
4	◯
5	◯
	Strongly Agree

20. I am likely to adopt new adaptation strategies if it could increase yield

Mark only one oval.

	Strongly Disagree
1	◯
2	◯
3	◯
4	◯
5	◯
	Strongly Agree

21. Before implementing any new climate adaptation strategies, I will wait to see the effects that climate change has on my maple syrup production

Mark only one oval.

Strongly Disagree

1 ⬭

2 ⬭

3 ⬭

4 ⬭

5 ⬭

Strongly Agree

22. I want to implement adaptation strategies before I experience the effects of climate change on my maple syrup production

Mark only one oval.

Strongly Disagree

1 ⬭

2 ⬭

3 ⬭

4 ⬭

5 ⬭

Strongly Agree

Potential adaptation strategies

Please indicate which adaptation strategies you would be interested in implementing

23. Increasing number of sugarbush taps

Mark only one oval.

Not Willing

1 ⬭

2 ⬭

3 ⬭

4 ⬭

5 ⬭

Very Willing

24. Implementing a high-vacuum tubing system for sap collection

Mark only one oval.

	Not Willing
1	◯
2	◯
3	◯
4	◯
5	◯
	Very Willing

25. Using spring forecast models of sap flow to predict when to start tapping maples

Mark only one oval.

	Not Willing
1	◯
2	◯
3	◯
4	◯
5	◯
	Very Willing

26. Practicing silvicultural management to maintain favourable tree density and biodiversity

Mark only one oval.

	Not Willing
1	◯
2	◯
3	◯
4	◯
5	◯
	Very Willing

27. Fertilizing and liming sugarbush soil

Mark only one oval.

Not Willing

1 ( )

2 ( )

3 ( )

4 ( )

5 ( )

Very Willing

28. Adopting strong sanitation practices (tubing, spout cleaning, annual spout replacement)

Mark only one oval.

Not Willing

1 ( )

2 ( )

3 ( )

4 ( )

5 ( )

Very Willing

29. Tapping different species of maple trees

Mark only one oval.

Not Willing

1 ( )

2 ( )

3 ( )

4 ( )

5 ( )

Very Willing

30. Keeping track of new research regarding maple production

Mark only one oval.

Not Willing

1 ⬭

2 ⬭

3 ⬭

4 ⬭

5 ⬭

Very Willing

Limitations for implementing new adaptation strategies

Please indicate the limitations and/or constraints for implementing new adaptation strategies.

31. Lack of information

Mark only one oval.

Strongly Disagree

1 ⬭

2 ⬭

3 ⬭

4 ⬭

5 ⬭

Strongly Agree

32. Lack of financial means

Mark only one oval.

Strongly Disagree

1 ⬭

2 ⬭

3 ⬭

4 ⬭

5 ⬭

Strongly Agree

33. Lack of technical support (i.e., not enough workers, lack of equipment, etc.)

Mark only one oval.

Strongly Disagree

1 ⬭

2 ⬭

3 ⬭

4 ⬭

5 ⬭

Strongly Agree

34. I do not believe that climate change will have an impact my production levels and do not need to implement new adaptation measures

Mark only one oval.

Strongly Disagree

1 ⬭

2 ⬭

3 ⬭

4 ⬭

5 ⬭

Strongly Agree

Future Outlook

35. I expect my business to grow over the next 10-15 years

Mark only one oval.

Strongly Disagree

1 ⬭

2 ⬭

3 ⬭

4 ⬭

5 ⬭

Strongly Agree

36. I can adapt to climate change gradually over the next 10-15 years

Mark only one oval.

Strongly Disagree

1 ⬭

2 ⬭

3 ⬭

4 ⬭

5 ⬭

Strongly Agree

37. I am concerned about negative impacts of climate change that are difficult to adapt to over the next 10-15 years

Mark only one oval.

Strongly Disagree

1 ⬭

2 ⬭

3 ⬭

4 ⬭

5 ⬭

Strongly Agree

36. I can adapt to climate change gradually over the next 10-15 years

Mark only one oval.

Strongly Disagree

1 ◯

2 ◯

3 ◯

4 ◯

5 ◯

Strongly Agree

37. I am concerned about negative impacts of climate change that are difficult to adapt to over the next 10-15 years

Mark only one oval.

Strongly Disagree

1 ◯

2 ◯

3 ◯

4 ◯

5 ◯

Strongly Agree

Appendix 3C

Department of Biology &
Sustainability Sciences
e: blywood@lakeheadu.ca
t: (705) 330-4008x2698

Letter of Information

Project Title: Impacts of Climate Change on Southern Ontario's Maple Syrup Industry
Principal Investigator: Gerardo Reyes, PhD
Co-Investigator: Breanne Lywood, MSc candidate
Research Partner: Kathrine Killam, Community Development Officer, CCO
Research Funders: Camphill Communities Ontario (CCO)
Social Sciences and Humanities Research Council (SSHRC)

Date: March, 2021

Dear Producer,

Thank you for taking interest in our research study!

Lakehead University has partnered with Camphill Communities Ontario (CCO) to explore how Ontario's maple syrup industry is recognising and responding to the impacts of climate change. In particular, we wish to investigate producer's concerns over a changing climate and the perceived affect it may have on maple syrup production, identify current adaptation strategies used by regional maple syrup producers, and finally, develop adaptation strategies for CCO's maple syrup operation based on our findings.

You are being invited to complete a brief survey. Questions about your current production practices, perceived areas of vulnerability within your sugarbush, current adaptation strategies, and opinions on adding new adaptation strategies to your operation will be asked. The survey should take about 15 minutes to complete. Participation is entirely voluntary and under no circumstances are you obligated to participate. You may choose to not answer any or all of the questions. Should you decide not to participate in this study or if you wish to withdraw from participating at any time after starting the survey, please note that you are completely free to do so.

We anticipate that you will not be exposed to any risks, harms, or inconveniences while participating in this study. Your identity will remain anonymous as no identifying information is collected. No immediate benefits will be gained from completing this survey. However, the information gathered will ultimately help to identify key areas of vulnerability and determine the effectiveness of current adaptation strategies used by regional maple syrup producers. Thus, long-term benefits of this study may include increased knowledge of sugarbush vulnerabilities, the potential regional changes in maple syrup production, as well as adaptation options to implement in your own sugarbush.

We stress that you will not be asked to provide any identifying information. Therefore, all survey participants will remain completely anonymous. Responses to the survey are summarized, coded with Arabic numerals, and will not be associated with any identifying information. Your answers will only be used for the Lakehead University and CCO research partnership study. No identifying or personal information will occur in any presentations, reports, publications, or any other documents relating to this study

Data will only be accessible to the principal investigator, Dr Gerardo Reyes, co-investigator, Breanne Lywood and our CCO research partner, Kathrine Killam. All project materials will be kept in a locked filing cabinet for a minimum of five years from the end of the study in accordance with the policies of the university's Research Ethics Board and the *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans*. Any electronic data will be coded and stored on Lakehead University computers, which are password-protected, and backup copies will be stored on an external drive or in hard copy (as appropriate) in a locked filing cabinet at the university.

If you have any questions or concerns about the study, please contact Breanne Lywood by email (blywood@lakeheadu.ca); or Gerardo Reyes at (705)330-4008 x2698 or by email (greyes@lakeheadu.ca). This study has been approved by the Lakehead University Research Ethics Board. If you have any questions related to the ethics of the research and would like to speak to someone outside of the research team, please contact Sue Wright at the Research Ethics Board at (807)343-8283 or by email at research@lakeheadu.ca. Thank you once again for your interest in our study. We look forward to the opportunity to work alongside Ontario maple syrup producers!

Sincerely,

Gerardo Reyes, PhD
Breanne Lywood
Kathrine Killam

Department of Biology &
Sustainability Sciences
e: blywood@lakeheadu.ca
t: (705) 330-4008x2698

Producer Consent Form

Project Title: Impacts of Climate Change on Southern Ontario's Maple Syrup Industry
Principal Investigator: Gerardo Reyes, PhD
Co-Investigator: Breanne Lywood, MSc candidate
Research Partner: Kathrine Killam, Community Development Officer, CCO
Research Funders: Camphill Communities Ontario (CCO)
Social Sciences and Humanities Research Council (SSHRC)

Date: March, 2022

[ ] No, I do not consent to participate in the research study
[ ] Yes, I agree to participate in the research study as outlined in the Letter of Information.
Specifically:

- [ ] I have read and understand the information contained in the Information Letter
- [ ] I agree to participate in the research described
- [ ] I agree to the use of anonymous quotations in any thesis or publication that comes of this research
- [ ] I understand the perceived risks and benefits of participating in the study
- [ ] I understand that I am a volunteer and can withdraw from the study at any time and may choose not to answer any question
- [ ] I understand that the data collected will be securely stored at Lakehead University for a minimum period of 5 years following the completion of the research project
- [ ] I understand that I am entitled to access the information they provided at any time while it is in storage as specified above
- [ ] I understand that the research findings will be made available upon request
- [ ] I understand that my identity will remain entirely anonymous
- [ ] I understand that by giving consent to participate, I have not waived any rights to legal recourse in the event of research-related harm.

Specifically, I understand I have the right to withdraw from the study at any time. I understand that any information gathered will be protected and only the principal investigator, Dr. Gerardo Reyes, co-investigator, Breanne Lywood and research partner at CCO, Kathrine Killam will have access to the information. Your answers will only be used for the Lakehead University and CCO research partnership study. No identifying or personal information will occur in any presentations, reports, publications, or any other documents relating to this study. I acknowledge that all data will be kept secure for a minimum of 5 years, at which time it will be destroyed or securely archived. I understand that no identifying information will be shared and that there are no potential risks for participation in this study. I also understand that no financial or other means of compensation will be provided for participation in this study. I understand there will be no penalizations if participation in this study is declined.

Name of participant: ______________________
Signature of Participant: ______________________
Date: ______________________

OR

I have read and agree to the above information and by completing and submitting this survey, give consent and agree to participate.

https://docs.google.com/forms/d/e/1FAIpQLSd9MrM5pdBHm_V4mWBWRpbb9xA33onv7qjN9qwPmtTSeE7y6g/viewform?usp=sf_link