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WHAT'S GOING TO HAPPEN TO MY PANCAKES?

THE IMPACTS OF CLIMATE CHANGE UPON BLUEBERRIES AND SUGAR MAPLE

by

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ABSTRACT

The United Nations believes that the foremost challenge of the future will be climate change. Because of human use of fossil fuels, greenhouse gases have been released into the atmosphere at unsustainable rates, which have resulted in an altered climate that will impact weather patterns around the globe. There have already been measurable shifts in precipitation and temperature in many regions; in the state of Maine the general trend has been toward higher temperatures and increased precipitation. This is resulting in impacts to agriculture throughout the state. Blueberries and sugar maple are two culturally and economically valuable crops which will be impacted by further climate change. This thesis reviews existing research on climate impacts to blueberry and maple crops, with a goal of synthesizing information that may be helpful to farmers and policymakers . Sugar maple is projected to move northward by 2100 and be less dense in Maine under all climate change scenarios, with a less productive tapping season and reduced sap sugar content. New tapping technology may be able to minimize the damage to the maple industry. Ensuring healthy ranges of habitat and mindful logging practices may help minimize the loss of the species. Blueberry plants may be equally or more prolific in their production, but there will likely be a greater presence of pests as winter temperatures continue to increase and enable their successful overwintering. Agricultural practices may have to be adapted, with greater need for monitoring as well as use of pest management techniques such as selective burning, biological controls, and targeted chemical treatments of infected plants and disease vectors. Summer droughts may require blueberry farmers to pay for irrigation, while late spring frosts increase the risk of bloom destruction.

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INTRODUCTION

Humans first began using fossil fuels on a large scale during the Industrial Revolution. The gaseous byproducts of fossil fuel combustion are released into the atmosphere and increase the concentrations of greenhouse gases, which trap solar radiation within our atmosphere (1). This results in an overall warming of the planet, which in turn impacts wind and precipitation patterns, causing global climate change. The effects of climate change vary substantially by region (1, 2).

Because climate is a key factor influencing agricultural possibilities within a region, it is important to consider how climate change might impact agriculture in order to prepare to address future issues (2, 3, 4). In the state of Maine, blueberries and maple syrup are important to the local economy (11, 16, 17, 19, 36, 40, 41, 42), and are hallmarks of Maine cuisine (10, 16). Past research has described climate changes to date and future predictions for Maine, as well as agricultural expectations for how climate change could impact sugar maple and blueberry crops. This report reviews and synthesizes literature and expert resources regarding the impacts of climate change on these two economically important perennial crops to aid growers and other decision-makers in learning about this topic. Additionally, for Mainers, these foods are a part of the local culture and their loss would result in a loss of common Maine traditions such as blueberry pancakes with maple syrup, a staple representative of the region. Mitigation strategies for the projected problems these crops may experience in a changing climate are discussed. Additionally, areas where further research is required are highlighted to provide further direction for interested parties.

Summary of Relevant Climate Change Impacts

Earlier in history, the Little Ice Age (aprox. 1300-1850 CE) significantly impacted European societies, both economically and physically (39). Before the Industrial Revolution, which also initiated the extensive use of fossil fuels, most European countries were agricultural. David Zhang, of the University of Hong Kong, states that, "In agricultural societies, the economy is controlled by climate," as climate determines agricultural conditions (39). Zhang worked with a team to analyze climate data from that period and found that resultant food shortages caused health issues and decreased adult height due to malnourishment (39). All this was with a smaller change in temperature than we are currently experiencing in the region. While we may not expect the same magnitude of issues with food access in Maine, there is reason to worry as climate change can indirectly produce social unrest through changes in agriculture (39).

Meteorological data analyzing historical and contemporary weather has made clear several climate trends in the Northeast region of the United States (2, 3). Thus far, Maine's average yearly temperature has already increased by 1.8°C since 1895 (3, 2). In the future, this region is expected to warm faster than the global average; while the global temperature increase is expected to reach 2°C by 2050 in 80% of the calculated emissions scenarios, in the Northeast US region it is calculated to reach a 3°C increase. The most warming to date has occurred in the winter months, with average low temperatures increasing 2 to 2.4 ºC (2). The minimum temperature determines which plants can survive the winter for perennial crops, and is increasing faster than daytime maximums and average temperatures for the other seasons (4). This has resulted in a 17%, or 2.3 inch, reduction in snowfall; however, there has been great yearly variability in the last

decades, both in temperature and seasonal snowfall (2). This could result in greater winterkill of perennial plants, as snow provides vital insulation and reduces the depth of soil freezing (5, 2).

In the last 124 years, the average yearly precipitation has increased by 5.8 inches, a 15% change. This has occurred as greater rainfall, particularly due to increased intensity and frequency of heavy precipitation events and rainstorms releasing several inches of rain within a matter of hours (6, 2). The frequency of these intense rainstorms increased by 74% between 1948 and 2011, and storms releasing multiple inches of precipitation now occur approximately every 7 months instead of every 12 (2). Peak hourly precipitation rates have increased as well, by approximately 35% between 2001 and 2013. These trends are expected to continue in the future (2, 4).

With increased winter temperatures, Maine's growing season has extended by two weeks since 1950, largely due to a longer fall season before frosts (2). This shift has been occurring since 1930, and evidence suggests that it will continue to extend by 2-3 days each decade as long as warming continues (2, 4). Temperature variability during the winter/spring transition can stimulate early plant development before the final spring freeze, which often results in frost-kill (4).

Intense precipitation events, especially during the growing season, can lead to soil and seed loss, nutrient runoff, and flooding (2, 4). Seasonal precipitation patterns may further shift such that much of the additional rain will fall largely outside of the growing season; combined with higher temperatures, this is expected to result in increased frequency of drought during the summer. These changes could, in turn, affect insect and

disease occurrence and result in plant stress, thus making blueberries and maple trees potentially more vulnerable to pests (7, 8, 2, 4)

BLUEBERRIES

Background on Lowbush Blueberry Production

Wild blueberries are an iconic fruit crop native to North America (11, 10). Historically, Indigenous Peoples would dry blueberries for the winter; the method thereof varied by group. People of the Ojibwa tribe commonly consumed a dish in which the dried berries were cooked with corn and maple sugar (10). While Indigenous Peoples were the first to manage and harvest the berry, it quickly became popular among colonists and subsequent American settlers across the country (11).

Today, Maine is the single largest wild blueberry producer globally. Ten percent of all North American blueberries, both wild and cultivated, are from Maine; no other state produces wild blueberries commercially (11). Because of the significant genetic diversity within clonal rhizomes, blueberries have a great range of flavors and productivity (9). Blueberries contain phytonutrients and antioxidants, which have been demonstrated to protect against free radicals, cell damage, and disease (11). In comparison to cranberries, strawberries, plums, raspberries, and even cultivated high bush blueberries, wild blueberries have the highest total antioxidant capacity per serving (11). These factors have provided them with “superfood” status and make them very popular in the healthy food movement (11, 13). A 2009 study found that Maine wild blueberries generated $173 million in direct sales, $63 million total annual payroll, and provided 2,500 jobs (42). In 2014, wild blueberries contributed about $250 million to the state economy, under the management of 510 growers (41). In 2016, Maine was the primary global producer of wild blueberries, at 101.6 million pounds harvested. The total value of blueberries was found to be $27.7 million that year (40).

Figure 1, below, demonstrates the value in USD per pound of wild blueberries produced for both fresh and processed markets, between the years of 2007 and 2018 (35).

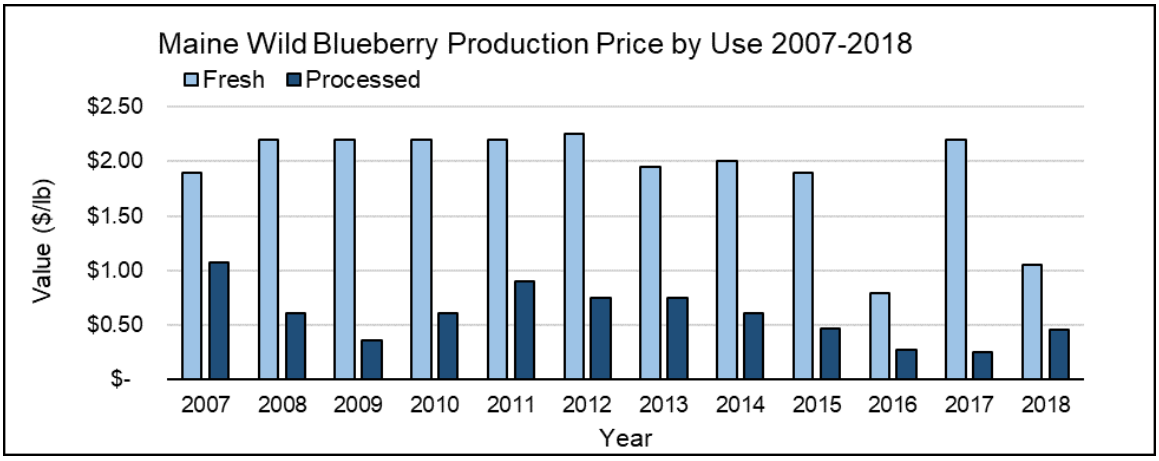

Figure 1: 1924-2014 Maine wild blueberry production price statistics (35).

Blueberries, like cranberries, are part of the Heath family, in the genus *Vaccinium* (10, 11). Several species of wild blueberries are native to Maine; the most common is the species *V. angustifolium*, a lowbush with dark blue berries (11). Lowbush blueberries grow to be between 4 and 15 inches tall. *V. nigrum*, another common lowbush species, has black berries which are slightly larger and sweeter than *V. angustifolium* (11). The mid-sized sourtop blueberry species, *V. myrtilloides*, grows in upland areas, producing berries that aren't as large or sweet as *V. angustifolium*. The plant grows to a height of 6 to 24 inches (11). Growing over six feet tall and often found near bodies of water, highbush *V. corymbosum* can cross with lowbush plants to produce hybrids; they are the base variety of cultivated blueberries. Several huckleberries are also part of the *Vaccinium* genus (11).

Exceptionally adapted for Maine's climate, wild blueberries range between northern Quebec and North Carolina, and west into Minnesota and Manitoba (9, 10). The primary species of cultivated wild blueberries, *V. angustifolium*, is primarily grown in the northern bounds of its habitat – Maine, Michigan, Canada, and New Hampshire (9). Unlike many plants, wild blueberries do exceptionally well in soils with an acidic pH reaching 4.0 (9). They grow naturally in the forest understory from seed, and can spread clonally via underground stems called rhizomes (9, 10, 11). Because almost seventy percent of the plants' biomass is within the rhizomes, lowbush blueberries regrow quickly and actually are more productive if pruned biennially (9). Blueberries are early successors and spread rapidly in open areas that have been disturbed (10).

Cultivated varieties of blueberries, when grown from seed, are typically germinated on a mixture of milled sphagnum and sand (10). Blueberry plants can also be bought by growers (10). The smaller species *V. angustifolium* and *V. myrtilloides* are most abundant in areas which have been burned, clearcut, or are being reclaimed by nature. Historically, North American Indigenous Peoples would burn fields to increase blueberry production (11). Many of these areas became lowbush blueberry fields that are harvested commercially today (10).

Cultivated fields are typically pruned every other year to maximize production; the following growing season, flower buds and other growth develops (10, 11). Blooms last two to four weeks, and require cross pollination, ideally from honeybees, bumblebees, and native bees, in order to have a successful fruit set (10, 11).

Common blueberry pests are blueberry maggot, spanworm, flea beetle, and thrips. Diseases affecting blueberries are exacerbated by wet weather during blooming; the primary two are mummy berry and blossom blight (9, 10, 11).

Lowbush Blueberry Production in a Changing Climate

The early impacts of climate change have been noticed by local Maine wild blueberry farmers (13). Referenced below are perspectives from two Maine wild blueberry farmers who participated in 2019 University of Maine research interviews. These interviews were conducted as part of a larger USDA-AFRI funded project being led by the University of Vermont, which interviewed small-medium scale farmers from a range of sectors with the intention to learn more about their perspectives and decision-making concerning climate change. Farmer 1 stated that in regards to climate change:

> *I see it as a reality and as a huge challenge. Here in Maine, I've been involved in farming starting as an apprentice up to now owning my own farm for 30 years and know of a time when spring weather was much more predictable and when frost dates in the spring and first frost in the fall when they used to be and when they are now. There's been dramatic changes and, in particular, an unpredictability* (13).

This farmer's experience reflects historical weather data (2, 4) suggesting that the growing season in Maine has indeed shifted and that there has been considerable seasonal temperature variability in recent years. This variability has ramifications for the timing of crop treatments and harvests, likely making it harder for farmers to predict the timing of field operations and manage their crops as efficiently. This farmer went on to add that:

> *There is no normal anymore. Just in the past two to three springs, there's been a lot of heat early on and the wild blueberries fruit in August, but when they actually produce their blooms has been changing a lot the past couple years being kind of relatively earlier, this year being much later… and then we have long stretches of drought and long stretches of wet weather. This spring has been*

> *very wet. The past two summers have been very dry. So, again, there's an unpredictability now… Yeah. The amount of rain – lack of, or too much of – is what's faced us as a big, big challenge just in the past two or three years* (13).

A number of research studies (2, 3, 4) have found precipitation patterns are changing and suggest that summer drought may become an increasing challenge in future, while the spring season may experience greater rainfall and thus risk bloom destruction. Interviewee blueberry Farmer 2, who had about a decade of experience, also had concerns for the industry's future in the face of changing climate:

> *... it could be hail, it could be frost at the wrong time, it could be an extra-long growing season so then your plants are trying to bloom again in the fall or something… but the climate change, if you don't get rain or if you get too much rain, that's a game changer, obviously… my neighbor, who is in her 90s, always used to worry about frosts and she would always say, 'You've got to get them in before there's a frost.' And we haven't* (13).

Climate change has implications beyond precipitation and temperature changes; novel conditions might also impact the presence of blueberry pests. Farmer 1 worried that:

> *with milder winters – which we've been having too – many more pests both for wild blueberries and all of agriculture – insects in particular but also diseases, fungus, virus – will have a longer season and even can survive over winter in Maine and not have to move up from the south where they historically have been over winter and/or spread very rapidly around the world, across the country. There's a major insect pest new to wild blueberries and all small fruits in the northeast in the past five years – the spotted winged Drosophila… has come all the way to Maine and it causes great damage to a lot of fresh fruit. So, things like that are real and they're happening… I'm seeing – in the past two years – a greater proliferation of a certain disease – Mummy Berry – Monilinia – in fields which for 20 years I've been doing certified organic wild blueberries and have never seen the extent in a field right now this spring and then in a different field last year and I don't know why, you know"* (13).

David Yarborough, Blueberry Specialist and Professor of Horticulture, notes that there have indeed been changes in pest and disease pressure in recent years (14). Spotted wing Drosophila (*Drosophila suzukii*) is a fruit fly native to Asia that was first detected in

Maine in 2012 and poses an emerging threat to small fruit production systems (45). Blueberry leaf diseases have also worsened, according to Yarborough (14). Furthermore, Lyme disease has spread within the state of Maine, which does not directly impact blueberry plants but has indirect import through its impacts on blueberry farmer health (14).

While climate change will likely be a significant influence upon a number of factors impacting blueberry production, Maine's naturally acidic soils may help support continued blueberry production; Farmer 1 expressed that "your soil probably is more important than what's happening in the climate," and Farmer 2 elaborated upon the topic, saying that:

> *the real interesting thing with wild blueberries… is that it is a native crop to this part of the world. This is the part of the world where it evolved, it grew, has always grown since the last glacier retreated. So, we're working with and in the area of the greatest, deepest, genetic diversity on earth with this species, which cannot be said for any other farming here in the US other than wild blueberries, raspberries, and cranberries. They're kind of the three native crops to this part of the world that we still farm on a conventional scale and a large scale for regular human consumption. So, it's [a] really unique position to be in and what it kind of suggests in the face of climate change is, 'Well, okay, hopefully we then have the greatest resiliency possible'* (13).

Because blueberries have evolved in this region and have a large native range beyond Maine in all directions, they are clearly able to tolerate a range of climatic conditions (9, 10, 11). There is often high genetic variability present in a blueberry field (9, 10) and genetic variability in a population can increase resilience to stressors including disease (46). Therefore, it is likely these farmers are correct and downeast Maine will continue to be a suitable environment for growing blueberries for decades to come. Farmer 2 was hopeful about continued blueberry demand, as:

> *... again, kind of the bigger – even global – picture for us is important. It's great*

> *that kind of here in the US – but also worldwide – interest in fruit has returned again… I mean it's a health conscious demand driven. The demand rise for fresh fruit – in particular blueberries – has been a health one and there's now been 20 years or so of really good science in blueberries in particular, the phytonutrients and the anthocyanins and the cancer fighting health benefits and even for Alzheimer's and your eyes and your memory. There's a whole web full of the scientific research of how blueberries – and wild blueberries in particular – are usually top of the list of some of the most healthy foods. So, that's been great for us, but that's also led to the huge expanse of production of high bush Blueberries* (13).

Wild blueberries have an extremely high total antioxidant capacity per serving; because of the demonstrated health benefits of antioxidants, this has fueled demand by classifying these berries as a "superfood" for the health conscious (11). With modern concerns over cancer and human health trends propelling the market beyond traditional market considerations of flavor and cost, blueberries remain a desired crop (11, 12, 34, 40, 41).

The increasingly irregular precipitation patterns expected with accelerating climate change will likely require more farmers to use irrigation to maintain blueberry production, which is an additional cost (13, 14). However, if farmers could capture and store excess water during spring rains, it might be possible to diminish the financial burden of irrigation (14). To address the prevalence of pests, farmers are encouraged to use integrated pest management, particularly through biological control, to minimize the costs of treatment (14). In recent years, more land has been cleared for lowbush blueberry cultivation in northern Maine and Canada (14). This has resulted in greater competition from Canadian blueberry production; both Maine and Canada have had increasing blueberry crops, and Canada is another producer of wild blueberries (15). While this is partly due to improved management, it is also related to the extended growing season provided by climate change, as "longer falls and earlier springs allow plants to store more nutrients in buds, store more buds, and ultimately produce a larger crop," according to

David Yarbough, PhD. In fact, Maine's wild blueberry crop yield almost tripled between 1999 and 2010 (15).

While Canada may have an extended growing season, the risk of spring frosts destroying flower buds may be increased due to the observed variability in spring temperatures (2, 32). Even with a general trend towards greater production, Canada may be unable to regularly compete with Maine's market. The future of the Maine blueberry industry will likely be impacted by the complicated interplay between the magnitude of climate changes that occur and complexities around product demand and international trade.

MAPLE

Background on Maple Syrup Production

In the words of Senator Angus King,

> *"Nothing says spring in Maine quite like the taste and smell of maple syrup… maple syrup is a symbol of what makes Maine, Maine. As we take pride in this important economic engine and its heritage in our state, we must not forget the impact climate change can have on many of our traditional industries that rely on a healthy Maine environment to grow and thrive. Whether it is maple syrup, lobsters, wild blueberries, potatoes, or tourism up and down our coast, protecting Maine's natural resources is critical to helping our economy and supporting our way of life.*" (16).

Sugar maple, *Acer saccharum*, is a native US deciduous hardwood tree species, having significant social and economic value (17). It is considered an indicator species, whose presence and condition are indicative of the health of an ecosystem, and can indicate changes therein. Found in eastern states and Canada, sugar maple can grow up to 130 feet in height (18).

Behind Vermont and New York, Maine has the third largest US maple industry, made up largely of small farms (19). Average licensed producers have a quarter century's worth of experience, and farms are often multi-generational. Annually, an output of $48.7 million, over 800 jobs, and a labor income of $25.1 million is associated with Maine's maple industry (19). In *Figure 2*, below, the total number of taps, as well as yield per tap and final syrup production is provided for various states. With over 1,000 thousand taps each year, Maine actually has the second-highest yield per tap. The total amount of syrup produced is nearly equal to that of New York, and makes up a large percentage of the total United States production (36).

Maple Syrup Taps, Yield, and Production – States and United States: 2015-2017

State	Number of taps			Yield per tap			Production		
	2015	2016	2017	2015	2016	2017	2015	2016	2017
	(1,000 taps)	(1,000 taps)	(1,000 taps)	(gallons)	(gallons)	(gallons)	(1,000 gallons)	(1,000 gallons)	(1,000 gallons)
Connecticut	85	85	86	0.224	0.224	0.233	19	19	20
Indiana [1]	(NA)	60	62	(NA)	0.200	0.194	(NA)	12	12
Maine	1,850	1,860	1,890	0.299	0.363	0.375	553	675	709
Massachusetts	310	315	320	0.242	0.244	0.263	75	77	84
Michigan	470	400	440	0.270	0.225	0.250	127	90	110
Minnesota [1]	(NA)	76	77	(NA)	0.184	0.182	(NA)	14	14
New Hampshire	560	545	550	0.275	0.310	0.280	154	169	154
New York	2,310	2,515	2,650	0.260	0.281	0.287	601	707	760
Ohio	440	370	400	0.261	0.189	0.200	115	70	80
Pennsylvania	620	660	660	0.266	0.217	0.211	165	143	139
Vermont	4,550	4,850	5,410	0.310	0.410	0.366	1,410	1,990	1,980
West Virginia [1]	(NA)	51	61	(NA)	0.118	0.148	(NA)	6	9
Wisconsin	760	765	735	0.283	0.307	0.272	215	235	200
United States	11,955	12,552	13,341	0.287	0.335	0.320	3,434	4,207	4,271

(NA) Not available.
[1] Estimates began in 2016.

Figure 2: Maple Syrup Taps, Yield, and Production – States and United States: 2015-2017 (36).

During the summer, sugar maples produce sugars via photosynthesis, which the tree stores over the winter (17, 20). These sugars are typically stored as starch grains; as temperatures begin to increase, the trees release an enzyme that converts these grains into sucrose and encourages its movement within the tree tissues (37, 38). The sucrose is what provides the sweetness in the sap; average sugar maple sap contains between 1-7 % sugar, with an average of 2.5 % sugar present (37). Interestingly, lower winter temperatures produce more sugar within the tree stem, and further stimulate sap flow during thawing (22). As osmotic pressure increases due to the sugar concentration, sap rises through the tree via positive pressure (17, 20, 22). Sub-freezing nights result in negative pressure that pulls the sap back into the roots; as temperature climbs during the day, the sap moves back up to the branches (22). Small holes drilled under the bark, called taps, allow sap to be collected; a single tree can provide 10,000 gallons of sap per tap each season. Daytime temperatures above freezing and night time temperatures below freezing provide the required conditions for sap flow; as long as this cycle continues, the

sap can be tapped. However, once the plant begins to bud, the sap becomes cloudy and takes on a bitter flavor (21, 36, 37). Because the maple sap contains a mixture of sucrose, amino acids, and other minerals, it is difficult to ascertain the reason for this shift. However, some research from the University of Vermont suggests that organic sulfur content changes and results in this flavor deterioration (37, 38). Warm winters can impact the length of collection, either positively or negatively (20, 17).

Maple Syrup Production in a Changing Climate

A 2016 report found that sugar maple habitat is expected to decline by 2100 under a high-emissions scenario (22). Evidence from a report from the New England Climate Change Response Framework suggests that sugar maple, as well as red maple and birch, have declined in the last decades as American beech has proliferated in Maine forests as a result of changing climate (23). If these trends continue, a decrease in maple syrup production both on a per-tree basis and overall is expected; it is estimated that almost 5 million more taps will be needed to maintain current levels of production before the end of the century (22). Even in the best case emissions scenario, sugar maple would still need additional management to maintain current production levels (22). Depending upon the progression of climate change and mitigation strategies employed, sugar maple and other species such as paper birch may survive or die out in Maine (24, 25). With determined mitigation efforts and minimum climate change, sugar maple could remain fairly widespread throughout the state (22, 24, 25). However, even before reaching the most extreme projections of climate change, sugar maple will no longer be expected to be

present within Maine, and likely be less prevalent in Canada (22, 23). Furthermore, the locality with maximum sap flow is projected to shift north by about 400 km (31).

Historical records show that maple tapping is already occurring earlier, although there is significant variability on a yearly basis (21, 17). While interviewed for the Conway Daily Sun Newspaper article on March Maple Weekend with local Governor Chris Sununu, maple producer Mark Cooper of Coopers Maple Products discussed this issue, as "weather typically was colder in February and gradually warmed as March progressed. The last several years we have been seeing huge swings in daily or weekly temps throughout the season" (16). Reduced snow cover due to higher winter temperatures also allows the ground to freeze deeper, potentially damaging tree roots when ice cuts through them (21). Deeper frosts can also reduce the availability of soil water before thawing (21). Because sugar maple needs an initial thaw followed by a refreeze in order to absorb soil moisture, earlier springs may result in a shortened tapping season (21). These trends are expected to continue in future. Research published in 2019 determined that maple sap collection is expected to be 4.3 days earlier for every 1°C increase in mean March temperature, with sap volume reaching peak levels with a mean temperature of 1°C in the January through May period (31).

With summers expected to become hotter and thus drier in the future, maple tree growth will be slowed and regrowth will take longer (16). This means that both seasonal damage regrowth and tree development will require more time; tree mass within the state is expected to decrease as a result. Mark Cooper of Coopers Maple Products indicated that this is a phenomenon growers are already experiencing, stating that "the frequency of high wind weather events has also had a significant impact on tree health" (16).

Additionally, increased temperatures seem to have worsened deer foraging activities on trees, including maple (27). The presence of invasive plants has also increased, worsening competition for space and nutrients (27). Introduced worm species disrupt the natural biology of forest ecosystems in Maine; areas with high incidence of worm activity also displayed higher deer foraging and invasive plant density (27). The presence of any of these biotic factors seemed to increase the likelihood of each of the others, though it is uncertain whether invasive earthworms make it easier for invasive plants to grow or if the habitats that are more easily invaded by earthworms are also more susceptible to other invasive species. However, invasive species appear to be more likely with warmer temperatures and increasing soil pH (27). These factors could all place additional stress via predation, competition, and habitat disruption on native plants including sugar maple beyond that already caused by forest fragmentation and destruction (27). Even the new climate conditions alone may be significant stressors for Maine forests, and storms or other natural events will be more likely to degrade soil and weaken the forest ecosystem (28). Maine, and New England in general, has been losing forest acreage in recent decades, which only aggravates the impacts of climate change (29, 30).

Season-length change is an emerging challenge for maple producers, as tappers now have more difficulty predicting sap flow (21). As Andy Whitman, Manomet's Director of Sustainable Economies Program, stated in a Manomet publication,

> *scientists have documented how our winters have warmed and how this has led to shorter maple syrup tapping seasons. The tapping season in Maine now starts about eight days earlier and ends 11 days earlier than 50 years ago. This gives producers a season that is 10 percent shorter. And the start of the season has become more unpredictable, so producers are more likely to miss the best syrup of the season or start too early and have their season cut short* (16).

The maple industry has experienced significant variability since 2014 in terms of season beginning and duration (17). A 2016 report on the Northeast Maple Syrup production from the USDA determined the length of the 2014 through 2016 tapping seasons. The 2014 season began on January 10 and ran until May 1. The following year, the season began March 18 and ended April 13, with less than a month of production. In 2016, the first tapping was on January 27 and the season ran until April 30 (17). Overall, production has decreased significantly over the last century; in the 1890's New Hampshire had a peak of 4.2 million gallons of syrup, while today it produces about 200,000 gallons (17). Mark Cooper of Coopers Maple Products added that:

> *since starting our maple operation 31 years ago we have seen significant changes that are climate-related. Not on a year to year basis but over 10, 20, 30 years the weather has changed and has had an impact. Our season typically used to start late February to early March, but now sap runs in January and early February seem almost normal. Our season used to end consistently April 6-8, but now we see a much broader range March 24-April 17* (16).

Adapting production to employ different technology can help reduce these impacts of climate change. Instead of using the traditional tapping buckets, tubing systems enable tappers to use sterile check-valve spouts that help vacuum the sap out. The tubes also prevent bacteria from entering the sap, and enable tappers to make the most of the season (33, 16). Mark Cooper commented on this, saying "Production per tap especially in traditional buckets or gravity tubing has dropped considerably here. We have used technology to overcome that with the expanded use of a high vacuum system. Unfortunately all this has done is mask the issue of reduced sap flow" (16). The increased temperatures, particularly in the winter, that Maine is expected to experience might further impact the quality of sugar maple sap (17, 21, 31). The sugar content may be

lower, which means that more sap would be required to produce the same quantity of maple syrup. In New Hampshire, the amount of sap required to produce a single gallon of syrup has doubled to 50 gallons over time, according to Ray LaRoche, owner/operator of Maple Meadow in Durham (17). Earlier springs may also result in faster leaf emergence, which degrades the flavor of maple sap (21, 36, 37). This would likely result in a decrease of syrup yield and greater occurrence of poor syrup production in most US maple sugaring regions (31).

At present, Canada already produces the vast majority of maple syrup – about seventy percent – for the worldwide market (43). Excess syrup is carefully stored and managed by the Federation of Québec Maple Syrup Producers (43). This Federation is a union of syrup producers that is sanctioned by the government; the goal is to maintain a desirable price for the syrup and to ensure that there is enough to sell even in bad years (43). It is likely that this union will continue to operate even with reduced American maple syrup production to ensure maintenance of competitive prices.

DISCUSSION & MANAGEMENT RECOMMENDATIONS

As Maine's climate grows warmer and the winter and spring seasons become wetter (2), local agriculture will have to adapt. With proper management practices and planning, the negative impacts of climate change can be minimized (22, 13, 2). However, it is important to note that the two crops considered herein – lowbush blueberry and sugar maple – will be affected differently by the same climate changes. Managers could benefit by acting now to preemptively address blueberry pest and sugar maple habitat shifts before the respective stresses these species are facing become more serious.

Emerging risks to the Maine blueberry industry include increased pest and disease pressure, as well as higher cost of plant maintenance due to irrigation requirements. There have already been changes in cultivation that have increased productivity, such as the use of beehives for maximizing pollination and the increasing interest in integrated pest management and organic farming practices (9). Blueberry farmers should continue to prune their fields biennially as suggested, while ensuring that this is tailored to address the particular issues each field may be experiencing. Allowing wildflowers and natural bee habitats to grow along the periphery can be a cost-effective method to increase pollination without resorting to hiring hives (9, 10, 11). Keeping some distance between fields to reduce the crossover of diseases should become standard practice; having mixed plant barriers between fields may minimize disease spread and aid in pathogen isolation without the use of chemical fertilizers (9). Increased usage of these techniques may help prevent the worsening trends predicted for blueberry pest migration (9, 11, 13). Foresight in capturing and storing excess precipitation during the spring rains would be another way to reduce upcoming financial burdens, as would the preemptive addition of

irrigation, which could be done section by section across several years to ease the upfront cost (11). Additionally, due to the aforementioned genetic diversity of blueberries and the variety of species available, there is the possibility that new crosses or strains may be able to survive and ensure a future for Maine's blueberries (10, 11, 13).

Climate change poses greater challenges to the long-term viability of sugar maple in the state of Maine; a long growing time and dependency upon very specific conditions limit adaptations in cultivation (17, 22). The best method (23, 24) for preserving maple trees into the future would be to protect forested areas where the species is present and avoid harvesting of the tree by foresters. Perhaps, like Iceland, Maine can grow these trees and selectively breed them to best withstand the changing conditions (44). Other mitigation strategies could include the examination of imported timber to minimize the movement of pests, and strategic cutting to isolate weakened areas and thus reduce spread of pests and diseases. Careful tracking of weather and soil frost conditions might make it easier to predict the ideal time to begin tapping to make the most of each season. This weather tracking could also provide wind storm warnings specifically intended for maple harvesters to alert them to the risk of tree windthrow. The development of suction tubing could be furthered, perhaps with more efficient technology to filter out some minerals and reduce bitterness of late-season sap or reduce boiling energy requirements. This might extend the season slightly and enable tappers to use more of the sap that is collected.

Unfortunately, there remains a lack of detailed and focused research on climate impacts to these crops. Much of the research that has been done is found within scientific reports and is not always dispensed or publicized to audiences who may benefit from the

information. Many questions are not answered sufficiently, particularly in terms of expert economic expectations and ongoing changes encountered by farmers. Additionally, future climate change will largely be dependent upon emission rates and mitigation strategies, which are challenging to predict. With the COVID-19 epidemic and lockdowns, various news outlets including the BBC have reported the rapid improvement in polluted cities' air quality. This is the time to recalibrate our use of fossil fuels and environmentally degrading materials; with effort, it should be possible to avoid overstepping the threshold of extensive climate change consequences (2). Hopefully, future changes will not be so significant as to force farmers to abandon these crops; with the projections gathered by various research teams, a number of methods to address upcoming difficulties have been discussed.

This report aimed to summarize existing knowledge of climate impacts on two staple crops enjoyed in the traditional Maine breakfast of blueberry pancakes with maple syrup. Climate change is already impacting blueberry and maple production, and growers are adapting. Changes are expected to continue and intensify, with ramifications for the futures of these industries that will not happen in isolation from market forces and the complexities of international trade. This foray into Maine's agricultural future served to reinforce that agriculture depends upon both local and international actions. Management practices must be adapted by growers (2, 12, 13, 14, 22). Meanwhile, everywhere, in order to minimize climate change on a global scale, people must reduce consumption of fossil fuel products and resulting emissions (2, 22).

REFERENCES

1: Herring D. Are humans causing or contributing to global warming?: NOAA Climate.gov. Are humans causing or contributing to global warming? | NOAA Climate.gov. 2014 Jan 23. https://www.climate.gov/news-features/climate-qa/are-humans-causing-or-contributing-global-warming

2: Fernandez, I., S. Birkel, C. Schmitt, J. Simonson, B. Lyon, A. Pershing, E. Stancioff, G. Jacobson, and P. Mayewski. Maine's Climate Future 2020 Update. Orono, ME: University of Maine; 2020.

3: Karmalkar, A.V., and R.S. Bradley. 2017. Consequences of global warming of 1.5 °C and 2 °C for regional temperature and precipitation changes in the contiguous United States. PLoSONE ,12(1):e0168697. doi.org/10.1371/journal.pone.0168697

4: Farm Response to Changing Weather - Maine Climate and Ag Network - University of Maine. Maine Climate and Ag Network. https://umaine.edu/climate-ag/farm-response-changing-weather/

5: Casson, N.J., A.R. Contosta, E.A. Burakowski, J.L. Campbell, M.S. Crandall, I.F. Creed, M.C. Eimers, S. Garlick, D.A. Lutz, M.Q. Morison, A.T. Morzillo, and S.J. Nelson. 2019. Winter weather whiplash: impacts of meteorological events misaligned with natural and human systems in seasonally snow-covered regions. Earth's Future: American Geophysical Union, First published: 21 November 2019. doi.org/10.1029/2019EF001224

6: Fernandez, I.J., C.V. Schmitt, S.D. Birkel, E. Stancioff, A.J. Pershing, J.T. Kelley, J.A. Runge, G.L. Jacobson, and P.A. Mayewski. 2015. Maine's Climate Future: 2015 Update. Orono, ME: University of Maine. climatechange.umaine.edu/wp-content/uploads/sites/439/2018/08/Maines_Climate_Future_2015_UpdateFinal-1.pdf

7: Clark, J.S., L. Iverson, C.W. Woodall, C.D. Allen, D.M. Bell, D.C. Bragg, A.W. D'Amato, F.W. Davis, M.H. Hersh, I. Ibanez, S.T. Jackson, S. Matthews, N. Pederson, M. Peters, M.W. Schwartz, K.M. Waring, and N.E. Zimmermann. 2016. The impacts of increasing drought on forest dynamics, structure, and biodiversity in the United States.

8: Vose, J.M., C.F. Miniat, C.H. Luce, H. Asbjornsen, P.V. Caldwell, J.L. Campbell, G.E. Grant, D.J. Isaak, S.P. Loheide II, and G. Sunh. 2016. Ecohydrological implications of drought for forests in the United States. Forest Ecology and Management, 380:335–345. doi.org/10.1016/j.foreco.2016.03.025

9: Drummond, F, J. Smagula, S. Annis and D. Yarborough. 2009. Organic Wild Blueberry Production. University of Maine Agricul. and Forestry Exper. Stn. Tech. Bull. 852: 43 pp.

10: Vander Kloet, S. P. 1988. The genus Vaccinium in North America. Publication 1828. Ottawa: Research Branch, Agriculture Canada. 201 p.

11: Yarborough DE. 220-Wild Blueberry Culture in Maine - Cooperative Extension: Maine Wild Blueberries - University of Maine Cooperative Extension. Cooperative Extension: Maine Wild Blueberries. https://extension.umaine.edu/blueberries/factsheets/production/wild-blueberry-culture-in-maine/

12: Drummond FA, Yarborough DE. Growing Season Effects on Wild Blueberry (*Vaccinium angustifolium*) in Maine and Implications for Management. Orono, ME: University of Maine; 2014.

13: Clements et al. unpublished

14: Specialist Interview with David Yarborough - Maine Climate and Ag Network - University of Maine. Maine Climate and Ag Network. https://umaine.edu/climate-ag/projects/specialist-interview-with-david-yarborough/

15: Climate Highlights: Climate Change and Agriculture in Maine - Maine Climate News - University of Maine Cooperative Extension. Maine Climate News. 2011. https://extension.umaine.edu/maineclimatenews/archives/summer-2011/climate-change-and-agriculture-in-maine/

16: The End of Maple Syrup? Climate Change Threatens Maine's Iconic Maple Sugar Industry. Manomet. 2018 Mar 22. https://www.manomet.org/publication/the-end-of-maple-syrup-climate-change-threatens-maines-iconic-maple-sugar-industry/

17: Maple Sugar Industry Faces Unpredictability in the Face of Climate Change - Signs of the Seasons: A New England Phenology Program - University of Maine Cooperative Extension. Signs of the Seasons: A New England Phenology Program. 2017 Apr 4. https://extension.umaine.edu/signs-of-the-seasons/2017/03/26/maple-sugar-industry-faces-unpredictability-face-climate-change/

18: Sugar Maple (Rock Maple, Hard Maple) Fact Sheet - Signs of the Seasons: A New England Phenology Program - University of Maine Cooperative Extension. Signs of the Seasons: A New England Phenology Program. https://extension.umaine.edu/signs-of-the-seasons/indicator-species/sugar-maple-fact-sheet/

19: Gabe T. ECONOMIC IMPACT OF MAINE'S MAPLE INDUSTRY. Orono, ME: University of Maine; 2014.

20: March is Maple Sugar Month - Signs of the Seasons: A New England Phenology Program - University of Maine Cooperative Extension. Signs of the Seasons: A New England Phenology Program. 2020 Mar 11. https://extension.umaine.edu/signs-of-the-seasons/2017/03/24/march-maple-sugar-month/

21: The Future of Sugar Maples in Maine - Signs of the Seasons: A New England Phenology Program - University of Maine Cooperative Extension. Signs of the Seasons: A New England Phenology Program. https://extension.umaine.edu/signs-of-the-seasons/news-events/the-future-of-sugar-maples-in-maine/

22: Matthews SN, Iverson LR. Managing for delicious ecosystem service under climate change: can United States sugar maple (Acer saccharum) syrup production be maintained in a warming climate? Taylor & Francis. 2017 Feb 14. https://www.tandfonline.com/doi/full/10.1080/21513732.2017.1285815

23: Bose, Arun & Weiskittel, Aaron & Wagner, Robert. (2017). Occurrence, pattern of change, and factors associated with American beech-dominance in stands of the northeastern USA forest. Forest Ecology and Management. 392. 202-212. 10.1016/j.foreco.2017.03.003

24: Janowiak, Maria & Swanston, Christopher & Handler, Stephen & Morelli, Toni & D'Amato, Anthony & Iverson, Louis & III, Frank & Dijak, William & Peters, Matthew & Matthews, Stephen & Prasad, Anantha & Fraser, Jacob & Brandt, Leslie & Butler-Leopold, Patricia & Shannon, Danielle & Campbell, John & Emery, Marla & Fisichelli, Nicholas & Rustad, Lindsey. (2018). New England and Northern New York Forest Ecosystem Vulnerability Assessment and Synthesis: A Report from the New England Climate Change Response Framework Project. 10.2737/NRS-GTR-173.

25: Iverson LR, Peters MP, Prasad AM, Matthews SN. Analysis of Climate Change Impacts on Tree Species of the Eastern US: Results of DISTRIB-II Modeling. Forests. 2019; 10(4):302.

26: Oswald, Evan M., Pontius, Jennifer, Rayback, Shelly A., Schaberg, Paul G., Wilmot, Sandra H., Dupigny-Giroux, Lesley-Ann. 2018. The complex relationship between climate and sugar maple health: Climate change implications in Vermont for a key northern hardwood species. Elsevier. https://doi.org/10.1016/j.foreco.2018.04.014

27: Fisichelli, N.A., and K.M. Miller. 2018. Weeds, worms, and deer: positive relationships among common forest understory stressors. Biological Invasions, 20(5):1337–1348. doi.org/10.1007/s10530-017-1630-y

28: Ryan, M.G., and J.M. Vose. 2012. Effects of climatic variability and change on forest ecosystems: A comprehensive science synthesis for the U.S. forest sector (Chapter 2). U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Gen. Tech. Rep. PNW-GTR-870. fs.usda.gov/treesearch/pubs/42651

29: Thompson, J.R., J.S. Plisinski, P. Olofsson, C.E. Holden, and M.J. Duveneck. 2017. Forest loss in New England: A projection of recent trends. PLoS ONE, 12(12): e0189636. doi.org/10.1371/journal.pone.0189636

30: Adams, A.B., J. Pontius, G. Galford, and D. Gudex-Cross. 2019. Simulating forest cover change in the northeastern U.S.: decreasing forest area and increasing fragmentation. Landscape Ecology, 34:2401–2419. doi.org/10.1007/s10980-019-00896-7

31: Rapp JM, Lutz DA, Huish RD, Dufour B, Ahmed S, Morelli TL, Stinson KA. Finding the sweet spot: Shifting optimal climate for maple syrup production in North America. Forest Ecology and Management. 2019 Jun 13. https://www.sciencedirect.com/science/article/pii/S0378112719303019

32: Wolfe, D.W., A.T. DeGaetano, G.M. Peck, M. Carey, L.H. Ziska, J. Lea-Cox, A.R. Kemanian, M.P. Hoffmann, and D.Y. Hollinger. 2018. Unique challenges and opportunities for Northeastern U.S. crop production in a changing climate. Climatic Change, 146:231. doi.org/10.1007/s10584-017-2109-7

33: McKenzie M. March maple madness in N.H. The Conway Daily Sun. 2017 Aug 4. https://www.conwaydailysun.com/news/march-maple-madness-in-n-h/article_dcd85fb9-93ce-5ef1-a404-c23fa62c365d.html

34: Climate Change. United Nations. https://www.un.org/en/sections/issues-depth/climate-change/

35: 1924-1989 Maine Department of Agriculture (1924 to 1928 includes imported berries), 1990 to 2014 New England Agricultural Statistics Service.

36: Whetstone K, Keough G, Smith B. UNITED STATES MAPLE SYRUP PRODUCTION. Washington, D.C: United States Department of Agriculture; 2014.

37: Proctor Maple Research and Facilities. (n.d.). https://www.uvm.edu/cals/proctor-maple-research-and-facilities

38: A systems biology approach to explore the impact of maple tree dormancy release on sap variation and maple syrup quality. (n.d.). https://mapleresearch.org/pub/018-40-y-2-2/

39: Handwerk, B. 2011 October 5. Little Ice Age Shrank Europeans, Sparked Wars. https://www.nationalgeographic.com/news/2011/10/111003-science-climate-change-little-ice-age/

40: Blueberries. (n.d.). https://www.agmrc.org/commodities-products/fruits/blueberries

41: USDA Specialty Crop Block Grants Create New Economic Opportunities and Grow Markets for Local Producers. 2014 October 9. https://www.maine.gov/dacf/about/news/news.shtml?id=629341

42: The Story of Wild Blueberries – 10,000 Years in the Making. 2017. https://www.wildblueberries.com/wp-content/uploads/2017/04/Wild-Blueberry-Fact-Sheets.pdf

43: Matalon, L. 2018 March 8. Québec's Legal Maple Syrup Cartel Dictates Prices For Vermont Maple Producers. https://www.vpr.org/post/qu-becs-legal-maple-syrup-cartel-dictates-prices-vermont-maple-producers#stream/0

44: Carylsue. 2018 April 4. Iceland Is Growing New Forests for the First Time in 1,000 Years. https://blog.education.nationalgeographic.org/2018/04/04/iceland-is-growing-new-forests-for-the-first-time-in-1000-years/

45: Spotted Wing Drosophila-Drosophila suzukii. (n.d.). https://www.maine.gov/dacf/php/gotpests/bugs/spotted-wing-drosophila.htm#:~:text=Spotted Wing Drosophila

46: Genetic diversity helps protect against disease. 2018 May 23. https://www.sciencedaily.com/releases/2018/05/180523133324.htm

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Ashley Kayser was born in California; while moving to Kennebunk, Maine at the age of two, her parents raised her with the environmentally-forward attitude they had developed in the Golden State. Growing up with fresh produce from the family gardens, Ashley became interested in the environment at a young age; throughout her schooling this passion developed and matured. Graduating from Kennebunk High School in 2016, Ashley entered the University of Maine's Honors College & Ecology and Environmental Sciences Program that fall.

Working as a Maine Learning Assistant and Tutor for Biology and Chemistry during the school year, Ashley completed seasonal internships with NOAA Fisheries and Environment Maine. She spent two semesters abroad, in Italy and South Korea, before returning for her final year.

Ashley aims for a career that will enable her to maintain her passion for the sciences while providing tangible results for herself and others.