Assessment of Historical Climate Variability in Maine with Implications for Future Agricultural Productivity and Adaptation

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ASSESSMENT OF HISTORICAL CLIMATE VARIABILITY IN MAINE WITH IMPLICATIONS FOR FUTURE AGRICULTURAL PRODUCTIVITY AND ADAPTATION

By

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B.S. Purdue University, 2019

A THESIS Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science (in Quaternary and Climate Studies)

The Graduate School

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August 2022

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Climate change is a wicked problem with global impacts, one of which being the sustainability of the existing global food system. As temperatures and variability in precipitation are projected to increase, the challenges to agriculture are expected to intensify. This thesis examines the Maine historical climate record over the growing season, in combination with future projections, to assess how conditions have changed and will change with agricultural implications. In this analysis, relevant climatic variables are analyzed, and agriculture-significant measures are derived for Maine’s three climate divisions using four decades of daily and monthly gridded datasets. In addition, this thesis explores climate change risk perceptions of Maine wild blueberry growers and establishes a survey instrument which may be used to measure the risk perceptions of migrant workers in the state and within other regions of the United States, by drawing from and expanding upon the Climate Change Risk Perception Model (CCRPM). In all, this work will help inform climate adaptation and mitigation strategies for safeguarding the productivity, safety, and sustainability of food systems in Maine.
ACKNOWLEDGEMENTS

This research is supported by the National Science Foundation (NSF) Research Traineeship (NRT) program, award #1922560, entitled “NRT: One Health and the Environment (OH&E): Convergence of Social and Biological Sciences”.
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LIST OF ABBREVIATIONS

CCRPM: Climate Change Risk Perception Model
GDD: Growing Degree-Days
GSL: Growing Season Length
NCL: NCAR Command Line
RCP: Representative Concentration Pathway
SPI: Standardized Precipitation Index
SPEI: Standardized Precipitation-Evaporation Index
ET: Evapotranspiration
CMIP5: Coupled Model Intercomparison Project version 5
USCRN: United States Climate Reference Network
GHCN: Global Historical Climatology Network
NOAA: National Oceanic and Atmospheric Administration
NCLimDiv: NOAA Monthly U.S. Climate Divisional Database
PRISM: Parameter-elevation Regressions on Independent Slopes Model
NLDAS-2: Phase-2 North American Land Data Assimilation System
CHAPTER 1

INTRODUCTION

Climate change is a complex global problem affecting many systems without straightforward articulation or clear definitive solutions (Johnston et al., 2022; Rittel & Webber, 1973). As such, climate change presents significant challenges to agriculture, particularly to the sustainability of the current food system which feeds most of the world’s population and provides an income to over one billion individuals (Mase et al., 2017; Kang et al., 2009; Mbow et al., 2019a). Food security and human health are impacted by climate change in a number of ways, such as the amount of food available, directly through decreased yields, or indirectly through water availability, pests, and disease (Mbow et al., 2019a; Fanzo et al., 2017). Increasing concentration of carbon dioxide (CO$_2$) in the atmosphere can also affect the biomass and nutritional quality of crops, potentially impacting human nutrition security (Mbow et al., 2019a; Fanzo et al., 2017; Mase et al., 2017). Moreover, the health of agricultural workers can be negatively impacted by exposure to extreme temperatures (Mbow et al., 2019a; Watts et al., 2018).

The climate drivers most relevant to food systems and food security encompass temperature and precipitation related metrics, as well as joint metrics that combine these and other variables (Mbow et al., 2019a; Mbow et al., 2019b; Mase et al., 2017). These drivers include modal climate changes (i.e., shifts in plant hardiness zones), seasonal changes (i.e., longer growing seasons due to warmer temperatures), and extreme events (i.e., droughts, high temperatures), among others (Mbow et al., 2019a; Mbow et al., 2019b). The frequency of occurrence and intensity of these drivers vary with geographic location (Mbow et al., 2019a; Iizumi et al., 2018).

When the rest of the world reaches a warming of 2 degrees Celsius (°C), the Northeast region of the United States (U.S.) is projected to reach a warming of 3°C. Temperatures are increasing faster in the Northeast than in any other region in the country (Karmalkar and Bradley, 2017; Fernandez et al., 2020).
A temperature rise is found in Maine, the northernmost state on the eastern margin of the U.S. (Fig 1.1.), in which average annual temperature has risen over 1.8°C in the last 124 years (Fernandez et al., 2020). Further, precipitation across Maine is increasing in both incidence and intensity with average annual precipitation having risen about 15% during the past century. Heavy precipitation events have also become more common (Fernandez et al., 2020). In recent decades the rate of increase for both temperature and precipitation has accelerated in the state, making it an ideal study area when considering temperature and precipitation related metrics of climate change (Fernandez et al., 2020).

![Figure 1.1. Location of Maine, U.S. Source: One World - Nations Online.](image)

This thesis examines Maine’s recent historical changes in climate from an agricultural perspective. Namely, the analysis focuses on the growing season (April – October), examining changes in temperature, precipitation, evapotranspiration, and growing season length, among other variables. Future climate projections and the implications for Maine’s agriculture are addressed. In addition, this study explores climate change risk perceptions of growers in the wild blueberry industry and migrant workers in Maine’s agricultural sector through questionnaires, as well as the role of these perceptions in climate change adaptation and mitigation. The subsequent chapters are as follows:
Chapter 2 is an assessment of Maine’s historical and projected future climate, in which significant climate variables are examined and important climate indices are derived (i.e., growing season length, drought) using the NCAR Command Line (NCL). While previous work has discussed the impacts of climate change to agriculture in Maine, they often focus on a single crop, only on biotic stressors, such as pests, or fail to include specific significant climate indices (e.g., evapotranspiration) (Tasnim et al., 2021; Barai et al., 2021; Fernandez et al., 2020). In all, this chapter provides climate information that may later assist others in identifying agricultural management approaches to respond to the changing conditions in the state.

Chapter 3 is an evaluation of climate change risk perceptions held by Maine wild blueberry growers. This study updates and expands upon the extensive surveying already done with this population (Collum and Hanes, 2015a, 2015b; Files et al., 2008). Additionally, this chapter describes an instrument with the capability to gauge the working conditions and climate change risk perceptions of migrant workers, developed by expanding on the Climate Change Risk Perception Model (CCRPM) developed by van der Linden (2014). As available literature on the climate change risk perceptions of migrant workers in the U.S. is strikingly sparse, this study aimed to fill the glaring knowledge gap.

The primary findings and contributions of this thesis are summarized in Chapter 4. Suggestions for future research and the connections between Chapters 2 and 3 are also included in Chapter 4.
2.1. Introduction

In the Northeast region of the U.S., fruit and vegetable farming contributes over 70,000 jobs, almost $10 billion in direct sales, and $16 billion in economic impact (FCE, 2015). Specifically in Maine, farmers operate on 1.3 million acres of land, making up seven percent of the state’s total land area (FCE, 2015; UADA, 2020). With over 7,500 farms in the state, agriculture is fundamental to Maine’s economy and employment landscape (FCE, 2015; UADA, 2020). As climate change presents numerous challenges to agriculture in Maine, it is vital to understand the associated impacts. While increasing levels of carbon dioxide (CO₂) in the atmosphere may be advantageous to crop production, rising temperatures and greater variability of precipitation will outweigh any possible benefits of CO₂ increase (Mase et al., 2017; Walthall et al., 2013). As crop production relies on reasonably consistent weather patterns it is vulnerable to the projected rises in extreme weather events such as droughts and extreme rainfall (Mase et al., 2017; Walthall et al., 2013).

Over the last 125 years the annual average air temperature in Maine has risen by over 1.8°C (Fig 2.1), with increasing overnight low temperatures being the primary driver. Projections from the Coupled Model Intercomparison Project version 5 (CMIP5) indicate that mean annual average temperature in the state could increase by an additional 1 to 6°C by 2100, depending on future greenhouse gas emissions and societal growth (Fernandez et al., 2020; MCC STS, 2020). This warming is also associated with relatively longer summers (and growing season) and shorter winters such that the snow season is now 1-2 weeks shorter than a century ago. A similar trend is anticipated over this century. To date, most of the warm season increase has occurred during the early fall (Fernandez et al., 2020; MCC STS, 2020).
Along with air temperature, total annual precipitation statewide has increased by about 152mm over the last 125 years (Fig 2.1), with much of the surpluses coming in summer and early fall (Fernandez et al., 2020; MCC STS 2020). A study by Simonson et al. (2022), shows that the increased summer rainfall in the northeastern U.S. bears association with more frequent atmospheric blocking patterns over Greenland. Weather extremes such as heavy precipitation have also become more common since the mid-2000s. While these events have risen in frequency during all seasons, the largest increase has been seen in winter and spring (Fernandez et al., 2020; MCC STS, 2020). Climate model projections suggest that warmer temperatures will intensify the hydrological cycle in Maine bringing more extremes. Due to this, it is expected that the state will see a continued trend toward more frequent heavy precipitation events. Short-term drought is an extreme that can occasionally impact the Northeast region of the U.S. Although the most severe drought in the last two decades affected Maine during the 2020 summer, it remains unclear whether drought will become more or less common in the future (Fernandez et al., 2020; MCC STS, 2020, 2021). However, in at least one modeling study, wherein boundary conditions from the 1960s drought in combination with projected warmer temperatures, found that intensification of the hydrological cycle will bring both more extreme wet and extreme dry weather patterns in the future (Xue and Ullrich, 2021).
Figure 2.1. Maine annual average temperature from 1895-2020. Data source: NOAA’s Climate Divisional Database via the Maine Climate Office.

Figure 2.2. Maine statewide annual temperature anomalies. The black line represents observation data from the NOAA U.S. Climate Divisional Database for 1895 – 2018. The colored lines denote multi-model means for each Representative Concentration Pathway (RCP) and the corresponding spread represents the standard deviation from the mean. The gray line and shading denote the multi-model CMIP5 historical simulation. Figure from Fernandez et al. (2020).
2.1.1. Climate Setting

This study involves a climate analysis focused on the growing season in Maine, by climate division. In this study, the growing season is defined as the beginning of April to the end of October. Maine is comprised of three climate divisions: Northern, Southern Interior, and Coastal (Fig. 2.3). The Northern climate division incorporates 54 percent of the state and has a continental climate. This division is influenced most by western and northern air masses. The Southern Interior climate division spans 31 percent of the state, has the warmest summer weather, and is most affected by southern and western air masses. Lastly, the Coastal climate division includes 15 percent of the states’ total area, has a maritime climate, and is also most influenced by southern and western air masses (Whitman et al., 2013; Jacobson et al., 2009). The three climate divisions reflect the steep climatological temperature gradient from south to north (Fernandez et al., 2020; MCC STS, 2020). Based on this, different agricultural sectors and crop varieties tend to be found across these climate divisions. In the Northern climate division, the primary crop grown is potatoes, while in the Southern Interior climate division apples are key. Wild blueberries are the primary crop of concern in the Coastal division. Across all three divisions, various amounts of hay, oats, and barley are grown (USDA & NASS, 2017).
Figure 2.3. Maine’s three climate divisions: Northern, Southern Interior, and Coastal. Figure from Whitman et al. (2013).

2.1.2. Climate Change and Agriculture in Maine

This analysis of changes in Maine’s growing season climate includes both temperature-related and precipitation-related metrics, as well as joint metrics that combine these and other variables. A total of four metrics are used.

For temperature-related variables, trends in the length of the growing season and growing degree-day (GDD) accumulation were derived. In any region, the length of the growing season denotes the number of days when plant growth occurs (EPA, 2021a). Occasionally referred to as the frost-free season, the growing season length (GSL) is determined by the timing of spring and fall frosts (EPA, 2021a; Kunkel et al., 2004). The length of the growing season is important to consider as it often determines which crops can be grown in a particular area as some crops require a longer growing season, while others mature rapidly (EPA, 2021a; Kunkel et al., 2004). Changes in GSL may have both positive and negative effects on certain crop yields (IPCC, 2014). A longer growing season has the potential to allow growers to diversify or have more than one harvest from the same plot. On the other
hand, a longer growing season may limit the varieties of crops grown, encourage the growth of weeds, enhance irrigation demands, or encourage invasive species (EPA, 2021a; Fernandez et al., 2020). In kind with GSL, GDDs are based on temperature (EPA, 2021; MRCC, 2021). GDDs, defined as the number of degrees the average daily temperature is above a specified minimum temperature, are essential to consider as plants predominantly only grow above a certain temperature threshold (USA-NPN, 2017; MRCC, 2020). In general, GDDs may influence plant growth and agricultural production, as well as the distribution and impact of plant diseases and pests (EPA, 2021b). It is important to note that while GDDs may mirror cumulative conditions that support plant development, GDDs do not encompass many potentially important factors related to the structure of weather conditions, which can also have considerable effects on plant development (EPA, 2021b).

Considering precipitation-related metrics, trends in the Standardized Precipitation Index (SPI) are analyzed. SPI is a multi-scalar drought index based upon climate data (Mckee et al., 1993; Abatzoglou et al., 2022). The SPI utilizes only monthly precipitation in its calculation and was primarily developed for two reasons. One of which being that water supply, in the form of precipitation, is often the most dominant component of the soil’s water budget and strongly influences the Palmer calculations. The Palmer Drought Severity Index (PDSI) is among the most commonly utilized methods in drought calculations, however the PDSI has a fixed temporal scale making its use an ideal for this study (Tufaner and Özbeyaz, 2020). Further, it is possible for an area to be in short-term deficit, medium-term excess, and long-term deficit of water all at the same time (Mckee et al., 1993; Abatzoglou et al., 2022). SPI is standardized to ensure all precipitation patterns are displayed using common terminology allowing for easy comparison among locations. All forms of SPI pertain to a specified time scale (i.e., 3 months) (Abatzoglou et al., 2022).

To provide a more comprehensive analysis, joint metrics that combine temperature, precipitation and other variables were needed. To this extent, the Standardized Precipitation
Evapotranspiration Index (SPEI) is included. The SPEI was developed to overcome some of the limitations of the SPI (Vicente-Serrano et al., 2010; Abatzoglou et al., 2022). Like the SPI, the SPEI is a multi-scalar drought index based upon climate data. This index is especially valuable as it can be used for establishing the onset, duration, and magnitude of drought conditions (CSIC, 2022; Abatzoglou et al., 2022). Additionally, trends in evapotranspiration (ET) across the climate divisions were explored in this study. ET contains both transpiration and soil evaporation and is a main determinant of water availability in combination with precipitation (Sadras et al., 2020; Long et al., 2014). Representing a key part of energy and water budgets, ET signifies the greatest terrestrial water outflow globally (Zhang et al., 2020; Long et al., 2014). What’s more, by moderating the surface-energy budget, ET controls land-atmosphere feedbacks. To advance the understanding of the water and energy balance, accurate quantification of ET at global and regional scales is crucial (Zhang et al., 2020; Long et al., 2014).

2.2. Methods

2.2.1. Datasets

This research utilized climate information from two station-based weather observation networks and three gridded data products: 1) United States Climate Reference Network (USCRN), 2) Global Historical Climatology Network (GHCN), 3) National Oceanic and Atmospheric Administration (NOAA) Monthly U.S. Climate Divisional Database (NClimDiv), 4) Parameter-elevation Regressions on Independent Slopes Model (PRISM), and 5) Phase-2 North American Land Data Assimilation System (NLDAS-2). As described below, these five datasets were applied based on product type (location observation record or gridded data), temporal resolution (daily or monthly), and the availability of specific weather variables. The NCAR Command Language (NCL) version 6.6.2 (NCAR, 2019) was used in combination with Microsoft Excel version 16.61.1 (Microsoft Corporation, 2018) to analyze data and generate figures.


**Station Observations**

The USCRN is a maintained, high-quality network of 139 climate monitoring stations across the continental U.S., as well as in Hawaii and Alaska (NOAA-NCEI, 2022a). The USCRN serves to provide a continuous series of climate observations, which are used to monitor national climate trends (NOAA-NCEI, 2022a; Diamond et al., 2013). Variables recorded by the stations include temperature and precipitation, among others (NOAA-NCEI, 2022a; Diamond et al., 2013). There are two USCRN stations in Maine, in Limestone and Old Town, with complete annual records starting in 2003 (NOAA-NCEI, 2022a).

Limestone is located in the Northern climate division and Old Town is located in the Southern Interior climate division. The high-quality data provided through the USCRN made its use ideal for the validation of PRISM.

The GHCN offers both daily and monthly datasets. The GHCN daily (GHCNd) is used in this research. It is a combined database made up of daily climate summaries from land surface stations around the world (NOAA-NCEI, 2022b). The GHCNd encompasses records for over 100,000 stations in 180 countries and territories across the globe, with 49 stations of those stations being in Maine (NOAA-NCEI, 2022b). Some of the daily variables recorded by these stations include minimum temperature, maximum temperature, and total precipitation (NOAA-NCEI, 2022a). GHCNd was also used in the validation of PRISM, despite being of lower quality than USCRN, as it has a much longer record, going back to the early 1900s.

**Gridded Datasets**

NClimDiv is a gridded dataset based on the GHCNd (NOAA-NCEI, 2021). NClimDiv employs climatologically supported interpolation, which aids in addressing topographic and network variability (NOAA-NCEI, 2021). In the continuous U.S., NClimDiv offers a period of record from 1895 – present (NOAA-NCEI, 2021). For the purposes of this research, NClimDiv was used based on its availability of
monthly gridded data for temperature and precipitation. The data was used in calculations of long-term temperature and precipitation trends and anomalies.

PRISM is considered a state-of-the-art, high-resolution (4km x 4km) gridded dataset for the continental United States. PRISM works by interpolating between an array of input station data in addition to using regression analysis to identify topographic influences (Daly et al., 2008; Daly et al., 1997). The model requires region specific knowledge on lapse rates and tendency for temperature inversions (Daly et al., 2008; Daly et al., 1997). PRISM was used due to its availability of 4km gridded daily data for the period of 1981 – 2020 for average temperature, minimum temperature, and maximum temperature. PRISM was specifically used for the calculation of growing season length and growing degree day accumulation.

NLDAS-2 is an offline data assimilation system composed of four uncoupled land surface models (LSMs) driven by observation-based atmospheric forcing (Xia et al., 2012a). The LSMs are executed over central North America on a 1/8th-degree grid and range from January 1979 to present (Xia et al., 2012a; NASA, 2022). The four LSMs are Noah, Mosaic, VIC, and SAC-SMA (Xia et al., 2012a). VIC operates on a one-hour computational time step, while Noah and Mosaic operate on a 15-minute time step (Xia et al., 2012a). The models are representative of different approaches to land surface modeling (Xia et al., 2012a). Only the Noah, Mosaic, and VIC LSMs were included in this study. The Noah and Mosaic models branch from the surface-vegetation-atmosphere transfer (SVAT) schemes found within the coupled climate modeling community (Xia et al., 2012a). With consideration to these models, an emphasis was placed on the accuracy of the water and energy exchanges between land surface and the atmospheric boundary; these exchanges occur via evapotranspiration, latent heat, and sensible heat (Xia et al., 2012a). On the other hand, the VIC model was created within the hydrological community as an uncoupled model with the primary goal of supporting the simulation of streamflow (Xia et al., 2012a). The VIC model has been further developed over the past decade to better account for the full energy
balance according to the SVAT concept (Xia et al., 2012a). These LSMs are compared further in section 2.3.3.4 of this thesis. NLDAS-2 data was included in this study due to its calculation of total evapotranspiration.

2.2.2. PRISM Validation

PRISM solutions were validated against daily station data (GHCN, USCRN) and NClimDiv prior to calculating growing season and degree-day accumulation trends. To validate PRISM daily data, a comparison was done with daily average temperature data from GHCN and USCRN. The sites used for this comparison were Old Town, ME and Limestone, ME. These sites were chosen as they are the only USCRN stations in Maine. Root Mean Square Error (RMSE) values were calculated using Microsoft Excel to determine the average distance between PRISM values and values from the USCRN and GHCN datasets. A lower RMSE value indicates a higher similarity. To further validate PRISM daily data, average monthly temperature and total monthly precipitation values were calculated for 1981-2021. These values were compared with data from NClimDiv on a statewide level. Linear correlation r-values were calculated using Microsoft Excel. These values may range from -1 to 1, with r=-1 indicating a perfect negative correlation, r=0 indicating no relationship, and r=1 indicating a perfect positive correlation.

2.2.3. Calculation of Significant Indices

Temperature

A historical analysis of temperatures across the three Maine climate divisions was completed for the years 1981-2020, where 1981 is the first year in the daily PRISM dataset. Daily PRISM temperature data including minimum, maximum, and average temperature, was used to analyze trends during the growing season. Specifically, historical trends in overnight low temperatures and average daily temperatures were examined.
Precipitation

A historical analysis of total precipitation during the growing season across the three Maine climate divisions was performed for the years 1981-2020 using PRISM.

Growing Season Length

The length of the growing season is defined as the number of days between the last spring frost and the first fall frost (Fernandez et al., 2020). Frost events are defined here as days in which the minimum temperature drops below 0°C (EPA, 2021a). Changes in the length of the growing season were calculated using PRISM daily minimum temperature data from 1981-2020 using NCL. Annual GSL and timing of spring and fall frosts were averaged across the state’s three climate divisions.

Growing Degree-Day Accumulation

For the calculation of GDDs, a baseline of 10°C is utilized. The 10°C is a commonly used baseline for an analysis with multiple plant species of interest (EPA, 2021b; MRCC, 2021). To expand, using this baseline, a day with an average temperature of 25°C represents 15 growing degree days. Utilizing NCL, GDDs were calculated using PRISM average daily temperature data from 1981-2020. For each climate division, daily growing degree days were calculated by subtracting the specified baseline temperature from the average daily temperature (Equation 2.1). Daily results were summed to calculate total annual GDDs for each year from 1981-2020.

\[ \text{daily GDD} = \text{average temperature (°C)} - \text{baseline temperature (°C)} \]

Equation 2.1. Calculation of daily GDD.

Drought Indices (Standard Precipitation Index & Standard Precipitation-Evapotranspiration Index)

SPI is calculated through a series of steps. First, monthly precipitation values over the specified period of months (e.g., 6 months) are summed and formed into historical series. From this historical series, a histogram or empirical distribution is created and then approximated by the incomplete beta distribution (Mckee et al., 1993; Abatzoglou et al., 2022). Following this, various points on the
distribution are mapped onto a bell-shaped curve (normal) distribution. SPI is taken as the numerical value on a normal distribution from a long-term average (McKee et al., 1993; Abatzoglou et al., 2022). No units are associated with SPI (McKee et al., 1993; Abatzoglou et al., 2022).

SPEI utilizes monthly precipitation data, in addition to average monthly temperature in its calculation (Vicente-Serrano et al., 2010; Abatzoglou et al., 2022). Using average monthly temperature, potential evapotranspiration (PET) is calculated. The SPEI uses a historical time series of the general water balance (precipitation - PET) in place of simply using the precipitation time series (Abatzoglou et al., 2022). SPEI and SPI are calculated in a similar manner. The standardization process for SPEI follows the same steps as SPI, apart from a three-parameter log-logistic theoretical distribution being used to account for negative values in the general water balance time series (Vicente-Serrano et al., 2010; Abatzoglou et al., 2022).

SPI and SPEI were obtained from the WestWide Drought Tracker (WWDT) for the time periods of 5-months (ending in September), 7-months (ending in October), and 12-months (ending in October) for the years 1950-2020 across each of the three climate divisions. These time periods were selected as the 5-month period captures the hottest period of the growing season, the 7-month period captures the entire growing season, and the 12-month period captures the water year and the winter signal. The WWDT calculated these drought indices using PRISM monthly data (Abatzoglou et al., 2022).

Evapotranspiration

Three Land Surface Models (LSMs) were included: the Noah model, Mosaic model, and the VIC model. All of the LSMs use a threshold air temperature of 0°C to characterize the precipitation inputs (Xia et al., 2012a). To this extent, if the air temperature is greater than 0°C, the precipitation is considered rainfall. Further, the LSMs included characterize ET based upon vegetation transpiration and the impacts of soil moisture stress on evaporation from the top layer of the soil profile (Long et al., 2014).
The Noah model acts as the land component in the Weather Research and Forecasting (WRF) regional atmospheric model, the Global Forecast System, and the NOAA National Centers for Environmental Prediction (NCEP) coupled Climate Forecast System (CFS) (Xia et al., 2012a; Ek et al., 2003). This LSM consists of four soil layers, with thickness of 10, 20, 60, and 100cm. The first three layers form the root zone in non-forested areas (Xia et al., 2012a). With respect to Koren et al. (1999), this model reproduces the freeze-thaw process of soil and the impact this process has on soil heating, cooling, and transpiration (Xia et al., 2012a).

The Mosaic model uses a tiling approach to account for sub-grid heterogeneity of vegetation and soil moisture (Xia et al., 2012a). Each tile has three soil layers with thickness of 10, 30, and 160 cm; the first two layers fall within the root zone (Xia et al., 2012a). Every vegetation tile calculates its unique energy and water balance, as well as its soil moisture and temperature (Xia et al., 2012a). The Mosaic model was developed to be used in NASA’s global climate model (Xia et al., 2012a; Koster and Suarez, 1994).

The VIC model also includes three soil levels and uses sub-grid vegetation tiles (Xia et al., 2012a). The VIC model has a top layer of 10 cm and spatially varying thickness for the remaining two layers (Xia et al., 2012a). The root span may span all three layers depending on the associated vegetation type (Xia et al., 2012a). This model was developed as a macroscale, hydrologic model by the University of Washington and Princeton University (Xia et al., 2012a; Liang et al., 1994).

While numerous variations exist between the models, such as in the seasonal cycle of the sensible heat/latent heat ratio, total precipitation is identical between them (Xia et al., 2012a). The Noah model outputs the smallest evapotranspiration values as well as the greatest total runoff among the models (Xia et al., 2012a, 2012b). Opposingly, the Mosaic model outputs the largest evapotranspiration values and the smallest runoff (Xia et al., 2012a, 2012b). The VIC model simulates the mean annual runoff and evapotranspiration values well compared to observational values (Xia et al., 2012a).
2012a, 2012b). Water storage differences among the models are the most obvious over the summer months, with the VIC model showing the largest changes (Xia et al., 2012a, 2012b). For all three models, the largest disparity for evapotranspiration occurs in the Northeastern U.S., as does the greatest disparity in the top two-meter soil moisture anomaly (Xia et al., 2012a, 2012b). Compared to the other LSMs, the Noah model is considered to perform the poorest over the Northeastern U.S. (Xia et al., 2012a, 2012b). Total ET, in kg/m², from NLDAS for the years 1971 – 2021 was obtained via the NASA Goddard Earth Sciences Data and Information Services Center (GES DISC) for each of the three climate divisions.

2.2.3. Future Projections

Future projections for temperature, growing degree-day accumulation, and growing season length were determined for the three Maine climate divisions for the years 2050 and 2100, under two Representative Concentration Pathway (RCP) scenarios, RCP4.5 and RCP8.5, acquired from the CMIP5 (Fernandez et al., 2020). RCPs are defined by their collective measure of human emissions of greenhouse gases (GHGs) from all sources, or their total radiative forcing (CIESIN, 2019). RCP4.5 comprises a stabilization of radiative forcing at 4.5 W/m² after 2100 and RCP8.5 involves increasing radiative forcing resulting in an 8.5 W/m² in 2100 (CIESIN, 2019).

Projected changes in growing season length and degree-day accumulation were determined by adding the projected change in temperature, from each of the included RCPs for 2050 and 2100, to the average and minimum temperature over the last three decades. To explain further, if CMIP5, under an RCP4.5 scenario, predicted a warming of 2°C, that amount was added to every day of the historical record and climate indices calculated.
2.3. Results

2.3.1. PRISM Validation

Upon visual inspection, the trend of PRISM daily temperature data appears to be nearly identical in comparison to that of daily temperature data from USCRN and GHCN for the period 2003-2020 at both Limestone and Old Town (Fig. 2.4). However, there is a smaller diurnal temperature range in PRISM compared to USCRN. The lowest correlation coefficient is 0.947, indicating a nearly perfect positive correlation between PRISM daily temperature data and USCRN, as well as GHCN at both locations. The RSME indicates an error of just below 4°C at Limestone, and an error of about 3°C and 3.5°C at Old Town, for USCRN and GHCN, respectively (Table 2.1).

The linear correlation ($r$) between PRISM daily temperature data and N ClimDiv monthly temperature data for the 1981-2021 period is 0.996, indicating a near perfect positive correlation (Fig 2.5). However, there is a systemic warm bias in PRISM of about 0.5°C relative to N ClimDiv for the entire record. PRISM daily precipitation data and N ClimDiv monthly precipitation data were also compared over the 1981-2021 period (Fig 2.6). Linear correlation was calculated at 0.9891, indicating a strong positive correlation. In comparison to N ClimDiv, PRISM total annual precipitation values are dramatically greater. In fact, PRISM total annual precipitation values are roughly three times greater in most years compared to N ClimDiv. The total annual precipitation values produced for each Maine climate division by PRISM fall much closer to those produced for the entire state by N ClimDiv (Fig A.1).
Figure 2.4. Comparison of daily average temperature data from PRISM, USCRN, and GHCN for the period of 2003 – 2020. PRISM, USCRN, and GHCN are represented by blue, orange, and gray respectively. Trend lines are shown by dashed lines in the corresponding colors.

<table>
<thead>
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<th>Location</th>
<th>Linear Correlation</th>
<th>RMSE</th>
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</tr>
<tr>
<td>PRISM-GHCN</td>
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<tr>
<td>PRISM-GHCN</td>
<td>0.964</td>
<td>3.114</td>
</tr>
</tbody>
</table>

Table 2.1. Linear correlation coefficients and Root Mean Square Error between PRISM and USCRN, as well as PRISM and GHCN at the station locations of Limestone, ME and Old Town, ME.
Figure 2.5. Comparison of temperature between PRISM daily data and NClimDiv monthly data for the period of 1981-2021. PRISM is represented by the blue line and NClimDiv by the gray line. Trend lines are shown by dashed lines in the corresponding colors. The linear correlation between the time series is 0.996.

Figure 2.6. Comparison of total annual precipitation between PRISM daily data and NClimDiv monthly data for the period of 1981-2021. PRISM is represented by the blue line and NClimDiv by the gray line. Trend lines are shown by dashed lines in the corresponding colors. The linear correlation between the time series is 0.989.
2.3.2. Historical Analyses

Average temperature has risen during the growing season in each of the three climate divisions since 1895 (Fig A.2). According to the analysis, average temperatures have increased the most in the Coastal climate division, rising ~1.6°C over the last 125 years, while temperatures have increased the least in the Northern division, rising ~1.2°C over the same period. Like average temperature, minimum temperatures have increased during the growing season in all three climate divisions over the last 125 years (Fig. 2.7). Also, in kind with average temperature, minimum temperatures have increased the greatest amount in the Coastal climate division, ~2.2°C, and risen the least amount in the Northern climate division, ~1.4°C. Partially continuing this trend, maximum temperatures have increased the highest amount in the Coastal climate division, rising ~1.2°C over the last 125 years, while maximum temperatures have increased the least amount in the Southern Interior division, rising ~1.0°C (Fig 2.8).

Additionally, while precipitation has increased in all Maine climate divisions, the Coastal climate division experienced the greatest trend rate of precipitation increase over the period of 1895-2020 compared to the Northern and Southern Interior climate divisions, which had a near identical trend rates of increase (Fig. 2.9). Likewise, precipitation increased the greatest amount in the Coastal climate division, with an increase of about 20mm. Abnormally dry periods were observed around 1955, 1965, 2000, 2016, and 2020.
Figure 2.7. Annual minimum temperature in Maine by climate division during the growing season (Apr. – Oct.) for the period 1895-2020. The Northern, Southern Interior and Coastal climate divisions are represented by the blue, orange, and gray lines respectively. Linear correlation lines are shown by dashed lines in the corresponding color. The slope for each climate division is 0.012, 0.014, and 0.165 respectively. The total change over the 125 period for each climate division is ~1.4°C, ~1.6°C, and ~2.2°C respectively. Data source: NOAA’s NClimDiv via the Maine climate office.

Figure 2.8. Annual maximum temperature in Maine by climate division during the growing season (Apr. – Oct.) for the period 1895-2020. The Northern, Southern Interior and Coastal climate divisions are represented by the blue, orange, and gray lines respectively. Linear correlation lines are shown by
dashed lines in the corresponding color. The slope for each climate division is 0.008, 0.009, and 0.010 respectively. The total change over the 125 period for each climate division is ~1.1°C, ~1.0°C, and ~1.2°C respectively. Data source: NOAA’s NClimDiv via the Maine climate office.

Figure 2.9. Annual total precipitation in Maine by climate division during the growing season (Apr. – Oct.) for the period 1895-2020. The Northern, Southern Interior and Coastal climate divisions are represented by the blue, orange, and gray lines respectively. Linear correlation lines are shown by dashed lines in the corresponding color. The slope for each climate division is 0.138, 0.136, and 0.166 respectively. The total change over the 125 period for each climate division is ~17mm, ~17mm, and ~20mm respectively. Data source: NOAA’s NClimDiv via the Maine climate office.

According to the analysis, an increase in growing degree-day accumulation has occurred across the state, visible in each climate division (Fig 2.10). Interestingly, the Southern Interior and Coastal climate divisions follow a very similar trend, both with an increase of about 190 degree-days, or 19%, over the last 125 years. GDD accumulation has seen the greatest increase in the Northern climate division, at about 200 degree-days or 27%. Contrastingly, while GSL has increased in every climate division, the largest increase in GSL has occurred in the Southern Interior division, with an addition of approximately 25 days since 1981 (Fig 2.11). The Northern climate division has experienced the lowest increase in GSL, with an addition of about seven days since 1981.
Figure 2.10. Maine growing degree-day accumulation by climate division from 1981-2020. The Northern, Southern Interior, and Coastal climate divisions are represented by the blue, orange, and gray lines respectively. The dashed lines represent linear correlation in the corresponding colors. The slope for each climate division is 5.151, 4.803, and 4.629.

Figure 2.11. Maine growing season length by climate division from 1981-2020. The Northern, Southern Interior, and Coastal climate divisions are represented by the blue, orange, and gray lines respectively. The dashed lines represent linear correlation in the corresponding colors. The slope for each climate division is 0.178, 0.616, and 0.546.
SPI over a five-month timescale (capturing the period of May-September) (5-SPI), over a seven-month timescale (capturing the period of April-October) (7-SPI), and over a 12-month timescale (12-SPI) all show the abnormally wet period which occurred in Maine between 2004-2014 (Fig. 2.12). The same is true for SPEI (Fig. 2.13). According to 5-SPI, the Northern climate division, Southern Interior climate division, and Coastal climate division experienced 30, 33, and 35 abnormally dry years respectively, since 1895. Comparatively, according to 7-SPI (ending in October and encompassing the growing season), the Northern climate division, Southern Interior climate division, and Coastal climate division experienced 26, 28, and 26 abnormally dry years respectively, since 1895. The 12-SPI shows the climate divisions experienced 27, 31, and 31 abnormally dry years, falling between the numbers produced by the SPIs on the five- and seven-month timescales.

Based on the five-month SPEI (5-SPEI), capturing the same period as 5-SPI, over the last 125 years, the Northern climate division, Southern Interior climate division, and Coastal climate division experienced 32, 35, and 34 abnormally dry years respectively. In comparison, based on the seven-month SPEI (7-SPEI), capturing the same period as 7-SPI, the Northern climate division, Southern Interior climate division, and Coastal climate division experienced 28, 30, and 29 abnormally dry years respectively, since 1895. SPEI over a 12-month timescale (12-SPEI) shows 28, 29, and 28 abnormally dry years occurring in the Northern, Southern Interior, and coastal divisions since 1895. Unlike 12-SPI, where the number of abnormally dry years fell between 5- and 7-SPI, 12-SPEI displays an equal or lower number of dry years for each climate division. 5-SPI and 5-SPEI more clearly show the shift to a dry period, beginning in 2016.

While it is clear the number of abnormally dry years vary by timescale, the years over which droughts fall also varies. In the Northern climate division, the drought known to have occurred in the early 2000s is shown to fall over the years 1999-2003 in 5-SPI. However, in 7-SPI the drought only includes 2000-2002, and in 12-SPI the drought includes 2000-2003. Considering SPEI, in the Northern
climate division, 5-, 7-, and 12-SPEI all show the drought of the early 2000s occurring over the same years as SPI over the corresponding timescales. Additionally, the severity of dry conditions varies between timescales. For the year 2019, in the Coastal climate division 5-SPI has the value of about -1.3, 7-SPI shows the value about -0.4, and 12-SPI shows the value of approximately -0.2. Still considering the Coastal division in 2019, 5-SPEI has the value of about -1.5, 7-SPEI shows the value about -0.6, and 12-SPEI shows the value of approximately -0.3.

Total evapotranspiration does not appear to have changed dramatically since 1979 in any of the three climate divisions, regardless of the LSM (Fig. 2.14). However, the Noah and VIC models do note a positive rate of increase in ET for the Northern, Southern Interior, and Coastal climate divisions. Opposingly, while the Mosaic model records a positive rate of increase in ET in the Southern Interior climate division, a decreasing rate of ET is shown for the Northern and Coastal climate divisions. For all climate divisions, the Noah model consistently recorded the lowest ET values while the Mosaic model recorded the greatest.

Based on the Noah model, the greatest increase in ET (~25kg/m²) since 1979 has occurred in the Coastal climate division. In contrast, based on the VIC model the greatest increase in ET (~20kg/m²) since 1979 has occurred in the Southern Interior climate division. While the Mosaic model shows the greatest trend as a decline in ET in the Coastal division. According to the Mosaic model, over roughly the last 40 years ET in the Coastal climate division has decreased by ~15kg/m².
Figure 2.12. SPI by Maine climate division for 1950-2020. The light blue bars represent wetter than normal years while the brown bars represent drier than normal years. The top figure shows SPI over a 5-month period ending in September, the middle figure shows SPI over a 7-month period ending in October, and the bottom figure shows SPI over a 12-month period ending in October.
Figure 2.13. SPEI by Maine climate division for 1950-2020. The light blue bars represent wetter than normal years while the brown bars represent drier than normal years. The top figure shows SPEI over a 5-month period ending in September, the middle figure shows SPI over a 7-month period ending in October, and the bottom figure shows SPI over a 12-month period ending in October.
Figure 2.14. Maine total evapotranspiration in kg/m² from 1979-2020 for the three climate divisions. The divisions are represented top-bottom as Northern, Southern Interior, and Coastal. Calculations from three LSMs are represented. The Mosaic, Noah, and VIC models are represented by the black, green, and gray lines respectively. Linear correlation lines are shown by dashed lines in the corresponding color.
2.3.3. Future Projections

According to CMIP5, under an RCP4.5 scenario annual average temperature in Maine will increase by about 2°C by 2050, and 3°C by 2100. Additionally, under an RCP8.5 scenario annual average temperature in Maine will increase by about 2.75°C by 2050, and 6°C by 2100 (Fig 2.15). The projected increases in temperature result in an increase of GDD accumulation and GSL across each climate division (Table 2.2). Under the RCP4.5 scenario, GDD accumulation is greatest in the Northern climate division with an increase of approximately 34% by 2050 and 53% by 2100. Although not by a substantial margin, GDD accumulation is lowest in the Southern Interior climate division with an increase of about 30% by 2050 and 47% by 2100. The Northern climate division also experiences the largest increase in GSL, with an increase of approximately 17% by 2050 and 27% by 2100, under the RCP4.5 scenario. Similarly, under the RCP8.5 scenario, the increase in GDD accumulation and GSL are greatest in the Northern climate division with an increase of approximately 53% and 27% by 2050, and 115% and 53% by 2100, respectively. The increase in GDD accumulation and GSL are lowest in the Southern Interior climate division.

Figure 2.15. Projected Maine annual average temperature through the year 2100 under RCP4.5 and RCP8.5 scenarios. RCP4.5 and RCP8.5 are shown by the blue and black lines respectively. The dashed lines represent linear correlation. Data source: CMIP5 via Climate Reanalyzer through the University of Maine Climate Change Institute.
<table>
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<th>GSL</th>
<th>% Increase</th>
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Table 2.2. Projected change in growing degree-day accumulation and growing season length, to the nearest day, in Maine, by climate division, under RCP4.5 and RCP8.5 scenarios for the years 2050 and 2100.

2.4. Discussion

The validation of PRISM shows that the dataset can be used, but several caveats must be considered. In comparison to USCRN at both Limestone and Old Town, the PRISM record commonly exhibits a smaller amplitude diurnal temperature range (higher minimum and lower maximum daily temperature values). This is particularly visible between 2014 and 2015. In comparison to USCRN, PRISM and GHCN values appear muted. However, at Old Town, PRISM displays greater highs than USCRN and GHCN, especially prior to 2011. This suggests a systematic warm bias in PRISM, at least relative to the observational records considered here. A PRISM warm bias is further supported by temperature
overestimates in comparison to NClimDiv for the entire record. Therefore, PRISM temperatures may lend to at least small overestimates for both GDD accumulation and GSL calculations.

It should be noted that inter-annual climate variability is occurring. Temperature, precipitation, GDDs, and GSL are not increasing at a uniform annual rate. Exemplifying this, following 2009 a distinct jump, ~30%, in growing degree-day accumulation is seen (Fig. 2.10). While all three climate divisions show near equal trends in GDD accumulation, the Northern climate division shows very little change in growing season length. This can be attributed to GSL being based upon frost dates. Killing frost events in the spring undermine any early starts to the growing season; in fact, warm temperatures prior to a killing frost is lethal for many perennial crops (Winkler et al., 2013; Hatfield and Walthall, 2014). One possible interpretation is that the likelihood of killing frost occurrence is greatest in the Northern climate division due to the influence of Arctic air masses moving into Maine from Canada. In contrast, early or late season killing frost may be less likely in the Southern Interior and Coastal climate divisions because of proximity to the warming Gulf of Maine and North Atlantic. The Gulf of Maine is reported to be one of the fastest-warming regions of the global ocean (Seidov et al., 2021; Fernandez et al., 2020; Pershing et al., 2015). The warming of the Gulf of Maine is most commonly attributed to a weakening of the Atlantic Meridional Overturning Circulation (AMOC) and subsequent changes in the Gulf Stream that increase the flux of warm water into the basin (Seidov et al., 2021, Pershing et al., 2015). However, the Gulf Stream is a wind-driven surface current, and changes in large-scale atmospheric circulation also play a role in the Gulf of Maine (Birkel and Mayewski, 2018; Bricknell et al., 2020).

Consistent with the findings of Maine’s Climate Future (2020) and Maine Climate Council’s Scientific and Technical Subcommittee (2020), the historically wet period of 2005-2014 is evident in this analysis of the growing season. Previous work has shown that summer precipitation surpluses Maine and the northeastern U.S. during this interval have some association with persistent blocking high pressure patterns over Greenland, which is in turn associated with the negative phase of the North Atlantic
Oscillation (Simonson et al., 2022). Since 2016, summer precipitation has shifted towards more dryness, and some years brought impactful drought across Maine, such as in 2016/17 and 2020 (Lombard et al., 2021). This overall change in the summer precipitation regime follows the 2015-2016 mega El Niño event, which ranks among the top three in intensity since 1950 (NOAA, 2017). Distinct, differing circulation patterns prior to and following the El Niño suggest possible association to the observed summer precipitation declines in Maine (and in the broader Northeast region of the U.S.) (Xue and Kumar, 2017). However, investigation of such a link is beyond the scope of this study.

Although some uncertainty still surrounds evapotranspiration estimates, numerous studies show that historically in the Eastern region of the U.S. ET has been increasing (Kramer et al., 2015; Walter et al., 2004). The results of this study do not appear to support this, with the Noah and VIC LSMs showing only a slight historical increase statewide, and the Mosaic LSM showing a decrease in two climate divisions. Furthermore, while the Mosaic model has been shown to be more accurate than the Noah model considering the Northeastern region of the U.S, all three LSMs are known to display the largest disparity for evapotranspiration in this region (Xia et al., 2012a, 2012b). The lack of a greater increasing trend, despite warming temperatures, may be associated with the rise in overall humidity in the state over the last two decades (MCC STS, 2020; Birkel and Mayewski, 2018).

Under both RCP4.5 and RCP8.5 temperatures, and as a result GDD accumulation and GSL, are projected to follow an increasing trend through 2100. However, the scenarios diverge following 2050 with RCP4.5 beginning to stabilize, while RCP8.5 continues to warm (Fig 2.15), consistent with the findings of MCC STS (2020). It is important to note that RCP8.5 may overpredict future climate warming based on overestimates in carbon intensity and an excessively aggressive use of coal over other energy sources (Schwalm et al., 2020; Burgess et al., 2020; MCC STS, 2020). The scenario is included despite this to explore the risk of the extreme, but also because it persists as a somewhat plausible outcome (Schwalm et al., 2020; MCC STS, 2020).
2.4.1. Implications for Agriculture

As crops are susceptible to changes in climatic conditions, the potential impacts to and implications for agriculture are numerous. The warming temperature trends observed in each of Maine’s climate divisions through the historical analysis are projected to continue through 2100. Rising temperatures offer both potential benefits and damages (Fernandez et al., 2020; Ziska et al., 2016). For example, increased temperatures resulting in an extended and warmer growing season, as well as increased GDD accumulation, have the potential to allow for greater crop yields due to more than one successful harvest of a specific crop in a single growing season, larger variety of crops to be grown, and multiple crops to be planted within a season. However, warming temperatures also increase the risk of heat stress to crops which may lead to decreased plant growth, crop yield, and changes in nutritional composition (Fernandez et al., 2020; Myers et al., 2014; Mariem et al., 2021). Warming spring temperatures lend to earlier planting, however annual crops planted in this period are vulnerable to late spring frosts (Silvestro et al., 2019). Warming temperatures both negatively affect plant growing cycles, and also coincide with greater incidence and spread of some insect pests (Fernandez et al., 2020; MCC STS, 2020). For example, the blueberry gall midge is now appearing in southern Maine causing damage to crop yields (MRCM, 2022). Insect pests are likely to become an increasing problem for farmers as minimum temperatures rise. For one, rising minimum temperatures create the potential for insect species with short reproductive cycles to have more generations within a single growing season, resulting in exponential population growth (Halsch et al., 2020). Moreover, earlier colonization of cropping areas may occur by insects with annual migration patterns (Halsch et al., 2020; Guo et al., 2020). Increasing temperatures may also serve to exacerbate drought stress. This is especially concerning in Maine as the majority of wild blueberry farms and apple orchards do not currently use irrigation (MCC STS, 2020; Scattman et al., 2020).
Despite the historical and projected trends toward a wetter climate in Maine, periods of dryness and drought that may be impactful to agriculture can and will emerge as a result of variability and in association with intensification of the hydrologic cycle. Drought stress, resulting from an inadequate supply of water, negatively impacts the growth and development of crops and is the dominant environmental factor limiting crop yield and productivity (Basu et al., 2016; Iqbal et al., 2020; Tasnim et al., 2020). For example, in 2016 severe drought conditions were observed in certain areas of northern and southern Maine resulting in reduced potato crop productivity (Sharma et al., 2017). While this study does not examine changes in the frequency of extreme precipitation events, other studies have shown an increasing trend in the occurrence of these events (NCA, 2014; MCF, 2020; MCC STS, 2020). Heavy precipitation events can result in direct crop damage, as well as delayed planting and harvesting, reducing yields (NCA, 2014). Greater incidence of heavy rainfall events and wet soil conditions may favor select root pathogens and increase the spread of foliar diseases (Wolfe et al., 2018). For example, wet conditions are advantageous to late blight, which threatens all Solanaceae crops, but potato and tomato production in particular, in the Northeast U.S. (Sparks et al., 2014; Wolfe et al., 2018).

There are several limitations of this study that influence the extent to which agricultural impacts may be quantified. A 10°C base is utilized for the calculation of GDD accumulation, however the base air temperature for degree-day accumulation varies by crop species. Using a base temperature that is too low for a specific crop species will result in an overestimation of GDDs and vice versa. Along the same lines, some crop varieties have a greater tolerance to frost. As such, using a value of 0°C to indicate frost occurrence, and therefore the start/stop of the growing season may not be accurate for all crop species. A species that can withstand temperatures of -1°C should have a longer growing season length than crops who are only able to withstand temperatures of 1°C base. Based on this, GSL may be over or underestimated in this study depending on the crop variety of interest.
2.5. Summary and Conclusions

This study explores the Maine historical climate record over the growing season. Utilizing approximately four decades of gridded daily and monthly climate data, annual changes in certain climatic variables and agricultural measures across the state are identified. These include temperature, precipitation, accumulated degree-days, growing season length, drought occurrence, and evapotranspiration. Of these, temperature, precipitation, GDD accumulation and GSL are determined to have an overall increasing trend since 1981. Further, the results indicate that following 2016 precipitation has decreased and been more variable during the summer, leading to the development of impactful drought across the state. It should be noted that the results suggest a systematic warm bias in PRISM, which may lead the GDD and GSL overestimations, concerning the study area examined here. This study does not yield any clear results regarding evapotranspiration; however, this may be due to uncertainty of LSMs and increased humidity in the state. Future temperature projections from CMIP5 are used to quantify growing degree-day accumulation and growing season length under two possible emission scenarios, RCP4.5 and RCP8.5, through the year 2100. Projected increases in GDDs and lengthening of the growing season may allow for a greater variety of crop species to be grown, additional harvests, and multiple crops to be planted within a season, but also increase the risk of heat and drought stress, insect pests, and disease, threatening crop productivity.

To overcome the limitations of and expand upon this study future work should quantify GDD accumulation using base air temperatures of crop species specific and important to Maine, such as potatoes and blueberries, allowing for a more accurate quantification of agricultural impacts. Similarly, the frost value should be modified in the calculation of growing season length to account for frost tolerance of relevant crop species. The inclusion of additional agricultural measures, such as high-heat index and shifts in plant hardiness zones, would also be advantageous to creating a more holistic view of potential implications for the food system. Lastly, the inclusion of potential adaptation responses (e.g.,
cover and companion crops, resistant crop varieties) and their effectiveness, would help to inform stakeholders and in turn serve to preserve the productivity of food systems in Maine.
CHAPTER 3
AN ANALYSIS OF CLIMATE CHANGE RISK PERCEPTIONS IN MAINE’S AGRICULTURAL SECTOR

3.1. Introduction

Climate change presents numerous challenges to agriculture globally, particularly to the sustainability of food systems (Mase et al., 2017; Kang et al., 2009). Any potential advantages of rising atmospheric CO₂ to crop production will likely be outweighed by warming temperatures and greater precipitation variability (Mase et al., 2017; Walthall et al., 2013). Annual crop production is vulnerable to projected rises in extreme weather events, such as drought conditions and high heat, as it relies on relatively consistent weather patterns (Motha, 2011; Powell and Reinhard, 2016; Mase et al., 2017).

In the northeast region of the U.S. fruit and vegetable farming contributes over 70,000 jobs, almost $10 billion in direct sales, and $16 billion in economic impact (FCE, 2015). In Maine farmers operate 1.3 million acres of land, comprising seven percent of the total land area in the state (FCE, 2015; UADA, 2020). With over 7,500 farms in the state, agriculture is vital to Maine’s economy and employment landscape (FCE, 2015; UADA, 2020). In addition, Maine boasts a diverse agricultural industry and is the largest producer of wild blueberries in the world (FCE, 2015; UADA, 2020; Yarborough, 2015). The economic impact of wild blueberries benefits Maine as a whole, but especially some of the most economically challenged areas of the state (Wild Blueberry Commission of Maine, 2014).

The vulnerability of crop production to climate change is dependent on both the biophysical impacts of climate change and by the human responses to moderate or mitigate those impacts (Walthall et al., 2013; Mase et al., 2017). Understanding how farmers consider and act upon the impacts of a changing climate is essential for learning how to work with producers to prevent the occurrence of crop failure (Mase et al., 2017; Jemison et al., 2014). Many previous studies have examined climate change risk perceptions relating to agriculture, including blueberries, in the U.S. (Ardbuckle et al., 2013;
Chatrchyan et al., 2017; Lane et al., 2018; Linder and Campbell-Arvai, 2021) and in the state of Maine (Jemison et al., 2014; Schattman et al., 2020; Clements et al., 2021; Tasnim et al., 2022). These studies have shown that farmers hold a wide range of beliefs relating to climate change, from thoughts that it will be beneficial to those that express a high degree of concern (Jemison et al., 2014; Ardbuckle et al., 2013). Additionally, previous studies have determined factors found to influence the belief in or skepticism towards climate change include an individual’s gender, environmental values, age, level of education or socio-economic status, and political affiliation (Mase et al., 2015; van der Linden, 2015; Soucy, 2020). This study sought to build upon previous findings of Maine wild blueberry farmer climate change risk perceptions (Jemison et al., 2014; Schattman et al., 2020).

Furthermore, despite countless studies being conducted on farmers’ views on and responses to climate change in the U.S., United Kingdom (U.K.), and Australia, very little research has examined the climate change risk perceptions of migrant workers (Mase et al., 2017; Fleming and Vanclay, 2010; Islam et al., 2013). The term *migrant worker* refers to an individual who migrates from one country to another with the intent of being employed other than by their own account (Ethical Trading Initiative, 2022). According to data in the 2017 Census of Agriculture conducted by the U.S. Department of Agriculture (USDA) National Agricultural Statistics Service (NASS), over 350,000 migrant workers were hired in Maine for agricultural labor (excluding contract workers), with a large portion being from Latin America. Based on this, migrant workers effectively comprise about 15% of paid hired farmworkers reported by the state (USDA NASS, 2017). This number is likely an underestimation as it fails to account for workers who may not be in the U.S. legally. In addition, while some research has been conducted into working conditions for migrant farm workers in the Northeast region of the U.S., it is limited and does not account for conditions likely to be exacerbated by climate change (Acury and Mora, 2020; Acury et al., 2015; Schell, 2002). This study sought to fill the gap in research relating to migrant workers’ climate
change risk perceptions and working conditions by using an established conceptual framework (van der Linden, 2015) to develop a survey instrument to be implemented in Maine.

### 3.2. Conceptual Foundation

*Risk perceptions* are defined as beliefs held by individuals concerning potential harm or the probability of a loss (Darker, 2013). The level to which an individual perceives a risk is subjective to judgments made regarding the characteristics and severity of the risk (Darker, 2013). In this study the Climate Change Risk Perception Model (CCRPM) is drawn upon to measure climate change risk perceptions among two populations (van der Linden, 2015). While the use of the Social Amplification of Risk Framework (SARF) was also strongly considered, ultimately a clear path does not exist on how to apply relevant concepts to an individual level rather than the level of society (Mase et al., 2015; van der Linden, 2015). Additionally, the CCRPM was selected as the influence of social factors on individual climate change risk perceptions are of interest and the CCRPM is one of few models that accounts for the role of social norms (van der Linden, 2015). Moreover, the CCRPM emphasizes the importance of social-psychological determinants that influence public risk perceptions of climate change (van der Linden, 2015). This is especially advantageous as numerous studies have indicated that risk perception is a key predictor of willingness to help mitigate climate change (van der Linden, 2015; Leiserowitz, 2006; Tobler et al., 2012).

Three primary dimensions are included in the CCRPM (Fig. 3.1) with socio-demographics essentially acting as control variables (van der Linden, 2015). Socio-demographics are the characteristics that define people of a specific group or population and include gender, age, education level, and location, among others (van der Linden, 2015). It is recognized that females often hold higher risk perceptions, compared to males, for a large variety of hazards, including climate change (Pearson et al., 2017; van der Linden, 2015). What’s more, individuals with a more liberal, compared to conservative, political leaning tend to perceive climate change with a higher degree of risk (Gregerson et al., 2020; van
The majority of studies find almost no or no correlation between climate change risk perceptions and age, education level, and income (Brody et al., 2008; van der Linden, 2015; Milfont, 2012). The decision to use socio-demographics as control variables is based on their relatively unimportant and often-variable influence on risk perceptions (van der Linden, 2015; Brody et al., 2008; Sundblad et al., 2007). The three main dimensions included in this framework are cognitive factors, experiential factors, and socio-cultural influences, which are expanded upon in the following sections.

**Figure 3.1.** van der Linden Climate Change Risk Perception Model; adapted from van der Linden (2015).

While the CCRPM has been proven to be an accurate tool in the measurement of climate change risk perceptions, especially in the U.K. (van der Linden, 2015), expanding the model was necessary to capture the risk perceptions of migrant workers more holistically (Leiserowitz, 2006; Schipper, 2010). According to Fountain et al. (2004), numerous societies around the world believe a divine explanation exists for the occurrence of natural hazards (i.e., flooding, drought) and the consequences that result. This is particularly true for societies living in poor, rural areas; many migrant workers in Maine’s agricultural sector come from these groups. Throughout history and within specific cultures, natural disasters have been thought to be a result of transgression of moral codes (Fountain et al., 2004). To this
extent, Religion was added to the CCRPM as an additional dimension for the purposes of this study. The original three main dimensions of the CCRPM (cognitive factors, experimental factors, and socio-cultural influences), as well as Religion, are described in the following sections.

3.2.1. Cognitive Factors

Numerous studies have found that risk perception of a hazard is often shaped by an individual’s knowledge of that risk (Tenkorang, 2018; Ning et al., 2020; Ao et al., 2020). Three types of knowledge are distinguished between in the CCRPM (van der linden, 2015). These include knowledge about the causes, impacts, and responses to climate change, all of which were found to have a positive and significant relationship to holistic climate change risk perception (van der linden, 2015). Each of these three types of knowledge have been confirmed to influence risk perceptions of climate change, either individually or in combination, through previous research (O’Conner et al., 1999; Sundblad et al., 2007; Tobler et al., 2012). To expand, this means individuals holding a greater knowledge about the causes of climate change, greater knowledge of the impacts resulting from climate change, and greater knowledge of effective response behaviors tend to perceive climate change as having a higher risk (van der linden, 2015; Sundblad et al., 2007; Tobler et al., 2012). It is crucial to note that knowledge has been found to be influential to risk perception predominantly when considering societal risk, but the same cannot be stated for personal risk (van der linden, 2015; Tolber et al., 2012). Societal risks are those which may affect a group of people (GRESB, 2021), while personal risk is that which only affects an individual or their immediate family (Rejda and McNamara, 2022).

3.2.2. Experiential Factors

Experiential factors are broken down into affect and personal experience. Affect, as it is used within the CCRPM, refers to a positive or negative evaluative feelings driven by an external stimulus; affect may be thought of as a subtle form of emotion (van der Linden, 2015; Slovic et al., 2007). The CCRPM specifically includes holistic affect, which considers the affect as a whole instead of breaking it
into individual pieces, and was found to be the supreme predictor of societal and personal risk perceptions of climate change (van der Linden, 2015, 2017; Leiserowitz, 2006).

While as a risk object climate change cannot be experienced directly, individuals may indirectly experience climate change via its impacts (van der Linden, 2015; Weber, 2010). In example, these impacts include extreme weather events such as flooding and heatwaves. An expanding body of evidence proposes that personal experience with extreme weather events influences risk perceptions of climate change (van der Linden, 2015; Brody et al., 2008; Akerlof et al., 2013).

### 3.2.3. Socio-cultural influences

Both broad value orientations and social norms fall under socio-cultural influences. Three broad value orientations, comprising the environmental domain, are incorporated in the CCRPM (van der Linden, 2015; Stern et al., 1993). These include egoistic values (i.e., maximizing personal outcomes), biospheric values (i.e., concern for other species and nature), and socio-altruistic values (i.e., desire to protect other humans) (van der Linden, 2015; Stern et al., 1993). The construct validity for the three mentioned broad value orientations has been proven through extensive studies occurring across various cultures and contexts (van der Linden, 2015; De Groot and Steg, 2007; De Groot et al., 2013).

Also included in the CCRPM are social norms, used to denote how individuals are expected to think, feel, or act in specific instances (van der Linden, 2015). The CCRPM more specifically categorized social norms in terms of descriptive social norms and prescriptive social norms. Descriptive social norms refer to what a group’s majority thinks, feels or does (e.g., extent to which a group is working to mitigate climate change impacts) (van der Linden, 2015; Baumeister & Vohs, 2007). On the other hand, prescriptive social norms refer to what the group’s majority approves of (e.g., degree to which a person feels socially compelled to consider climate change a risk) (van der Linden, 2015; Baumeister & Vohs, 2007). The influence of social norms on risk perceptions of climate change has been exemplified by van der Linden (2015) and Sattler et al. (2017).
3.2.3. Religion

As it is used in this study, religion is defined as all forms of belief systems which are based on faith in a god or gods, preserved in formal institutions, and conveyed through superstitions and folklore (Schipper, 2010). In recent years, numerous studies have stated the significance of religion in regard to climate change (Hulme, 2017; Jenkins et al., 2018; Ives and Kidwell, 2019). While the influences of religion may be noticeable through the CCRPM’s existing dimensions, religion cannot be evaluated in the same way. Evaluating religion on a scale that is either right or wrong leaves too much room for both an ethical dilemma and academic debate, and thus a separate dimension was required (Geertz and Markússon, 2011; Smart, 1973).

3.3. Survey of Wild Blueberry Growers in Maine

Study Population

The majority of wild blueberry growers in the state of Maine are over the age of 55, have at least 20 years of experience growing wild blueberries, and hold a college degree. Wild blueberry growers in the state are predominantly male (University of Maine Cooperative Extension, 2015a, 2015b). The wild blueberry growers who attend the Annual Blueberry Hill Farm Day, organized by the University of Maine Cooperative Extension, were specifically targeted for this study. Due to this, all individuals in the study population had some degree of familiarity with the University of Maine Cooperative Extension. The majority of growers are located in coastal regions, which was expected as wild blueberries are almost exclusively grown in the coastal climate division of Maine (USDA-NASS, 2019).

Survey Design and Implementation

In an attempt to overcome the persistent and growing survey fatigue among Maine wild blueberry growers, the survey instrument was restricted to the length of one single page. The questionnaire (Appendix A) included a total of ten questions which aimed to gauge grower risk
perception of climate change and were influenced by the works of van der Linden (2015) and Soucy (2020). The socio-demographic variables of age, gender, zip code, and race were included, as well as years of experience working in the Maine wild blueberry sector. In addition, participants were asked on a five-point scale, from never to very frequently, the extent to which they noticed six climatic conditions in the state over the past five years, modified from Soucy (2020). Using the same six items (changes in growing season length, changes in seasonal temperature, uncertainty in weather patterns, seasonal drought conditions, heavy rainfall events, killing frost), participants were asked to describe the impact of the items on the wild blueberry sector in Maine, on a four-point scale (no impact, negative impact, positive impact, both a positive and negative impact). Participants were also asked which of those six items they would attribute (at least in part) to a changing climate, selecting all that applied (adapted from Soucy, 2020). Further, respondents were requested to indicate, on a five-point scale from strongly disagree to strongly agree, the extent to which they agreed or disagreed with eight statements relating to the cause(s) and occurrence of climate change (“climate change is currently occurring”, “climate change is primarily caused by natural forces”, “climate change is primarily caused by human activities”, “climate change is equally caused by natural forces and human activities”, “climate change is occurring but I am unsure of its causes”, “I am unsure whether or not climate change is occurring”, “overall, I feel that climate change is favorable”, “overall, I feel that climate change is unfavorable”) (adapted from Soucy, 2020). Participants were additionally asked to select from a list of five items regarding barriers to their ability to implement adaptation strategies (complexity of information, lack of access to information, environmental and climate regulations, lack of financial capacity, uncertainty about climate change impacts) (adapted from Soucy, 2020).

Following approval from the Institutional Review Board for Protection of Human Subjects (IRB) (Appendix B), the printed questionnaire, accompanied by a detailed consent form (Appendix C), was
made available at the Annual Blueberry Hill Farm Field Day in July of 2021. The questionnaire was anonymous.

**Results**

A total of 12 Maine wild blueberry growers completed the wild blueberry survey, of which over 80 percent were male. Participants’ ages ranged from 43 – 71 years old (one participant did not include their age), and of the seven respondents that listed their race, all were White. A total of 75 percent of respondents reside in Washington County, ME, about 17 percent in Knox County, ME, and roughly eight percent in Penobscot County, ME.

In the last five years in Maine, respondents noticed the greatest occurrence of seasonal drought conditions, followed by changes in seasonal temperature (Fig. 3.2). These results were not unexpected as the 2016 and 2020 droughts (Fig 2.13), noted in section 2.3, resulted in significant impacts to agriculture. Killing frost was noticed least frequently by the respondents. However, one respondent noted a very frequent occurrence of killing frost specifically included that they suffered a 100% yield loss in 2020 as a result. Moreover, referring to the six climatic conditions included in the survey, most respondents associated killing frost and seasonal drought conditions with negative impacts (Fig, 3.3). Changes in growing season length was considered to have the greatest positive impact, while uncertainty in weather patterns was considered to have the greatest number of both positive and negative impacts by participants. Overall, the majority of the climatic conditions were more likely to be associated with negative impacts.
Figure 3.2. Results of survey question “To what extent have you noticed the following conditions in the last 5 years in Maine?”. Dark green represents the response of “very frequently”, light green represents “frequently”, light gray represents “occasionally”, dark gray represents “rarely”, and black represents “never”.

Figure 3.3. Results of survey question “Of the conditions that you’ve noticed, how would you describe their impact on the wild blueberry sector in Maine?”. Dark gray represents the response of “no impact”, light gray represents “negative impact”, dark green represents “positive impact”, and light green represents “both a positive and negative impact”.

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Additionally, most respondents agree that climate change is currently occurring (~67%). Despite this, there is not a clear consensus as to the cause of climate change among the survey participants (Fig. 3.4), with only 25% of growers indicating that they believe climate change is primarily human-caused.

Concerning barriers to the implementation of adaptation strategies to address climate change, respondents noted a lack of financial capacity as the greatest obstacle (Fig. 3.5). In this study uncertainty of climate change impacts was found to be the second greatest barrier to Maine wild blueberry growers implementing adaptation strategies (Fig. 3.5).

![Figure 3.4](image)

**Figure 3.4.** Results of survey questions asking participants to indicate the extent to which they agreed or disagreed with six statements. Dark green represents the response of “strongly agree”, light green represents “agree”, light gray represents “neutral”, dark gray represents “disagree”, and black represents “strongly disagree”.


Figure 3.5. Results of survey question asking about barriers to respondents’ ability to implement adaptation strategies to address climate change.

Discussion and Future Work

The low response rate of the survey may be attributed, at least in part, to survey fatigue known to be occurring amongst this population. Moreover, the low response rate may be linked with the questionnaire being distributed during the COVID-19 pandemic, leading to fewer individuals attending the 2021 Annual Blueberry Hill Farm Field Day, as well as individuals taking additional safety precautions (i.e., not touching pens, being within six-feet). The COVID-19 pandemic may have also contributed to survey fatigue at the time of the questionnaire’s distribution (Koning et al., 2021; Grandstaff and Webber, 2021).

The written in response of a respondent who indicated suffering a 100% yield loss in 2020 as a result of killing frost is of particular interest. This personal experience with killing frost, which resulted in negative personal impacts, likely influenced the individual’s higher perceived risk of climate change (Lujala et al., 2014; van der Linden, 2014). The devastating impacts of killing frost in recent years has also been observed by others in the community (Atwell, 2021; Whittle, 2020). As individuals continue to
experience climate change impacts, it may be expected that higher climate change risk perceptions will also be observed, as experience has shown to be a predictor of risk perception among various populations (van der Linden, 2015; Soucy et al., 2020). However, this cannot be stated definitively as some studies suggest the relationship may be more complicated than currently understood (Whitmarsh, 2008; Wachinger et al., 2012). Moreover, the finding that most respondents agree that climate change is currently occurring (~67%) is in line with research conducted by Ballew et al. (2019), which found that 71% of U.S. citizens believe climate change is occurring as of 2017. Despite this, the lack of belief in climate change being caused by human activities (~25%) among the survey participants differs from the study done by Ballew et al. (2019), in which 56% of respondents said climate change is human caused. This discrepancy may be the result of wild blueberry growers in Maine predominately residing in rural areas (Marlon et al., 2021).

In regard to barriers to the implementation of adaptation strategies to address climate change, a lack of financial capacity being noted as the greatest obstacle is consistent with the findings of Masud et al. (2017) and Esham and Garforth (2012). While uncertainty of climate change impacts was found to be the second greatest barrier to Maine wild blueberry growers implementing adaptation strategies, however other studies found perception of adaptation effectiveness to be a stronger obstacle compared to uncertainty of climate change impacts (Masud et al., 2017; Esham and Garforth, 2012).

The results of the wild blueberry grower survey can serve to inform the direction of future work. As a clear consensus among the causes and occurrence of climate change was not shown, and uncertainty regarding climate change impacts was noted as a substantial barrier to the implementation of adaptation strategies, it is reasonable to suggest future work place a greater focus on the education of growers relating to climate change and its impacts (Arbuckle et al., 2014; Mase et al., 2017). To elaborate, the figures included in Chapter 2 could be shared with wild blueberry growers in Maine, to provide further information on the changes in climatic conditions occurring and expected to occur. Further, by
sharing data about changes in climatic conditions (i.e., temperature, precipitation) that are directly linked to yield loss, and therefore profits, growers may seek to take adaptive action, while also anticipating changes in insect and pest presence.

3.4. Survey of Migrant Workers in Maine’s Agricultural Sector

Study Population

Migrant and seasonal workers in Maine’s agricultural sector are predominantly from the countries of Mexico, Haiti, and Canada (MDOL, 2015). This population has a wide age distribution with workers ranging from teenagers to senior citizens and consists of both males and females (MDOL, 2015). The average level of formal schooling completed by migrant workers in the U.S. agricultural sector is eighth grade (NFWM, 2022). Levels of English literacy, defined as the understanding, use, and engagement with written text to interact with society, reach personal goals, and build knowledge, among migrant workers varies primarily by country of origin (Arcury et al., 2010; Richwine, 2017). According to research by Batalova and Fix (2015), Hispanic immigrants in the U.S. struggle the most with English literacy. However, many agricultural workers speak little to no English, with the most commonly known language among these workers being Spanish (Arcury et al., 2010; Carrol et al., 2005). Haitian Creole is also widely spoken, and for over a fourth of agricultural workers from Latin America the primary native language is an indigenous of Native American Language (Arcury et al., 2010; Farquhar et al., 2009). This is particularly relevant as many of these indigenous languages are only spoken, not written (Arcury et al., 2010; Farquhar et al., 2009). The number of years the workers have worked in the U.S varies from a single year to over three decades (MDOL, 2015).

Survey Design and Implementation

The questionnaire (Appendix D) was developed to measure climate change risk perceptions of migrant workers drawing heavily from, but also expanding upon the CCRPM through the additions of
religion and working conditions as constructs. The questionnaire was created in Qualtrics (Qualtrics, Provo, UT) and incorporates a total of nine constructs:

(1) Knowledge about climate change is measured by four questions. Three of these draw on items developed by van der Linden (2014), and present nine items (average global temperature, drought occurrence, biodiversity, sea level, melting of glaciers and ice caps, ocean acidification, extreme weather events, spread of infectious disease, crop yields) in a randomized order with five of the items being correct and four being incorrect. Responses may only be right or wrong, with correctness supported by strong scientific agreement in literature. The method is adopted from van der Linden (2014) and Leiserowitz et al. (2010). A higher number of correct responses denotes a greater knowledge of climate change (van der Linden, 2015; Leiserowitz et al., 2010). Despite the number of items being decreased from van der Linden (2014), construct reliability should not be impacted (Kost and da Rosa, 2018). The fourth question included to measure knowledge was adapted from Soucy (2020). This question asks respondents to agree or disagree with five statements regarding the occurrence of (currently occurring or not occurring) and cause of climate change (human activities, natural forces, or a combination of the two) on a five-point scale (from strongly disagree to strongly agree).

(2) Affect is assessed through five questions, three of which target generalized affect while the remaining two seek to measure associated affect. Drawing on previous work by van der Linden (2014) and Poortinga et al. (2011), generalized affect is measured using two seven-point scales (i.e., “To me, climate change is something...”) (unfavorable-favorable, negative-positive). Following work done by Soucy (2020) and Slovic and Peters (2006), associated affect, relating to observed extreme weather events, is evaluated by two questions i.e., “Of those that you’ve noticed, how would you describe their impact on the agricultural sector in Maine”), using a seven-point scale (unfavorable-favorable).
(3) Personal experience is measured following the work of van der Linden (2014) and Soucy (2020). Three questions are included, each asking participants to note the frequency, on a five-point scale (from never to very frequently), they’ve noticed seven weather items (changes in growing season length, changes in seasonal temperature, uncertainty in weather patterns, seasonal drought conditions, heavy rainfall events, killing frost, frequency of heatwaves) over the last five years in their community, Maine, and the U.S.

(4) Broad value orientations are measured following the standardized value scale developed by De Groot and Steg (2007) and used by van der Linden (2014). 12 items (four egoistic, four altruistic, and four biospheric items) are randomly spread over three questions. On a seven-point scale, participants are asked to specify the level of importance of each item as a guiding principle in their lives (from not important at all to very important) (van der Linden, 2014; Soucy, 2020; De Groot et al., 2013).

(5) Social norms, broken into descriptive and prescriptive norms, are assessed through two questions, similar to van der Linden (2014). To measure descriptive social norms, participants are asked to indicate the extent to which they agree with five statements (i.e., “individuals in my community are doing something to help reduce the risk of climate change”), on a seven-point scale (from strongly disagree to strongly agree) (Soucy, 2020; van der Linden, 2015; Sparkman et al., 2020). Similarly, to measure prescriptive social norms, participants are asked to indicate the extent to which they agree with three statements (i.e., “I feel that helping to tackle climate change is expected of me”), on a seven-point scale (from strongly disagree to strongly agree) (van der Linden, 2015; Sparkman et al., 2020)

(6) Risk perceptions are measured using a total of six items, drawing upon items used by van der Linden (2014) and Leiserowitz (2006). The six items included encompass both spatial (e.g., “how serious would you rate current impacts of climate change around the world?”) and time-based
(e.g., “how likely are you to experience serious threats to your health, or overall well-being as a result of climate change during your lifetime?”) dimensions and are measured using either of two seven-point scales (from not serious to serious or from unlikely to likely).

(7) The socio-demographic variables included are age, gender, race, ethnicity, political leaning, level of education and religious affiliation (if any), as well as geographic area(s) of work, years worked in the U.S., and geographic location of community.

(8) Drawing upon Schipper (2010), Fountain et al. (2004), and Sparkman et al. (2020), religion is measured through four questions. Three of the questions ask participants to indicate the extent to which they agree or disagree with statements on a seven-point scale (from strongly disagree to strongly agree). The questions contain three items relating to personal and community feelings towards religion (i.e., “My faith is central to my identity”), three items relating to the nature of disasters (i.e., “Hazards and disasters cannot be controlled”), and seven items relating to the cause(s) of climate change and the appropriate response (i.e., “Climate change is a result of transgression of moral codes”, “individuals should not interfere with the impacts of climate change). The fourth question is open-ended and asks participants to state what they believe they could personally do to reduce the risk of climate change.

(9) Working conditions are assessed through nine items. Respondents are asked to indicate the extent to which they agree or disagree with the items on a seven-point scale (from strongly disagree to strongly agree). Items include having basic needs met (i.e., “I have adequate access to water throughout the day”), as well as employer relations (i.e., “My employer cares about my safety”).

Due to complications resulting from the COVID-19 pandemic, as well as researcher time constraints, the survey has not yet been implemented. These complications include University restraints on travel.
and on in-person survey distribution, travel restrictions impacting migrant workers reaching Maine, expanded safety protocols, among others.

**Discussion and Future Work**

As the survey developed to measure the climate change risk perceptions of migrant workers in Maine agriculture did not reach the stage of implementation, a plethora of future work is required. Relating the survey instrument itself, it is advisable that the wording of several questions be revisited. This is particularly true for the questions relating to working conditions. In these questions the term ‘adequate’ is used to quantify conditions such as access to water and shade, however as adequate does not signify a universally understood amount, a clear definition will need to be included or the question rephrased to include specific time durations and quantities. Further, as religion is not experienced the same way between geographical areas uniformly (i.e., developed/undeveloped areas, rural/urban areas), discussions should be had with individuals native to the areas of interest and a deeper literature review conducted (Nikkhah et al., 2015; Deneulin and Rakodi, 2011).

The questionnaire will need to be translated into both Spanish and Haitian Creole as these are the primary languages spoken by migrant workers in Maine’s agricultural sector (MDOL, 2015). Translation is not always straightforward (Martinez et al., 2006). As an example of how wording can be interpreted based on a prior study, the question ‘do you let animals into your home?’ asked of an adult living in urban Maine would likely be interpreted correctly, with a response relating to if the individual had pets. In contrast, if the same question was asked of an adult living in certain areas of rural Guatemala the question may not be interpreted as intended due to the word ‘let’; animals may wander into the home with being let in by the individual due to differences in home and societal structure. In addition, varying levels of literacy exist among the migrant workers in Maine’s agricultural sector. Based on this, the questionnaire may have to be read to the respondents requiring additional resources and personnel. It is recommended that the survey be distributed by or in collaboration with an organization
that holds a high degree of trust among this population, such as Mano en Mano or Maine Mobile Health Program and can orally deliver the survey instrument.

3.5. Summary and Conclusions

Wild blueberry growers were surveyed to enhance our understanding of how this population perceives the occurrence of climate change, climate change risks and impacts to the wild blueberry sector in the state, and barriers that are affecting individuals’ ability to implement adaptation strategies to address these impacts. The results indicate that wild blueberry growers who answered the survey are not in agreement regarding the primary cause of climate change, but all note observing impacts of climate change. It is important to note that due to the low response rate, this sample may not be an accurate representation of the population. To overcome the uncertainty in climate change causes and impacts, as well as additional barriers such as financial assistance opportunities in the state, education and outreach programs are recommended.

The survey instrument designed to measure climate change risk perceptions of migrant workers in Maine’s agricultural sector, by expanding on the CCRPM, did not reach implementation due to time constraints and complications of the COVID-19 pandemic. While future work is required and additional resources may be needed, the distribution of the migrant worker survey would serve to fill a long-standing knowledge gap regarding the risk perceptions of migrant workers on climate change. What’s more, the survey would quantify the working conditions of migrant workers in Maine, which could in turn lead to the improvement of these conditions if needed. As the push for greater diversity, equity, and inclusion in research is more prevalent than ever before, now is an ideal time to include the views of a population previously overlooked.
CHAPTER 4

CONCLUSION

Global agriculture and the sustainability of food systems face numerous challenges from climate change. While potential advantages of climate change to agriculture exist, any advantages to crop production will be overshadowed by the threats posed to crop productivity. From an agricultural viewpoint, this thesis examines Maine’s historical climate record and projected future conditions. Additionally, this thesis investigates climate change risk perceptions of wild blueberry growers and migrant workers in Maine’s agricultural sector through survey instruments, as well as the influence of these perceptions in implementation of climate change adaptation strategies.

In Chapter 2, Maine’s recent historical climate record is explored from an agricultural perspective, by utilizing daily and monthly gridded data from the last four decades. Future climate projections and the implications for agriculture in Maine are also examined. The results show that temperature, precipitation, accumulation of degree-days, and the length of the growing season have increased since 1981 and this trend is expected to continue in the future. A systematic warm bias in PRISM is suggested by the results, having the potential to cause overestimations of temperature rise, GDD accumulation and GSL. In addition, the results show that after 2016 precipitation has become more variable and declined over the summer months, resulting in the development of impactful drought in regions of the state. This decline may be linked to the 2015-2016 mega El Niño event, but more research is needed. Potentially due to the uncertainty of LSMs, particularly over the Northeastern region of the U.S., and increased overall humidity in Maine, the results do not show any clear trend in ET across the state over the given period. Both GDDs and the length of the growing season are projected to increase in all Maine climate divisions. This may prove advantageous allowing for more than one harvest, a greater variety of crop species to be planted, and multiple crops to be planted in a single season,
however, the risk of heat and drought stress, and the spread and incidence of pests and disease will also be amplified, threatening crop productivity.

In Chapter 3, risk perceptions of climate change held by wild blueberry growers are measured to build upon current the understanding of how this population perceives the occurrence of climate change, connected impacts to the Maine wild blueberry sector, and obstacles affecting individuals’ ability to implement adaptation strategies to offset these impacts. The results of observed climatic conditions in the state were expected based on the modeling seen in Chapter 2. The results indicate that outreach and education of growers into the causes and impacts of climate change, potentially using figures within Chapter 2 as visual aids, would be of the greatest benefit. Additionally, in this chapter, a survey instrument, which expands upon the current CCRPM to include religion and working conditions, capable of quantifying the climate change risk perceptions of migrant workers is created. Recommendations are made for the future distribution of the instrument as it could not be disseminated due to conditions resulting from the COVID-19 pandemic and researcher time constraints.

The results of this thesis highlight the complexity involved with addressing climate change, as well as the need for integrated research. The agricultural implications of climate change cannot be accurately quantified without the inclusion of both biophysical and social factors. As such, successful adaptation strategies and solutions to this pressing global problem cannot hope to be achieved without a more holistic understanding of the challenge at hand. Future work should expand upon the climatic conditions included in this study, while also exploring the interconnections shared with other disciplines.
REFERENCES


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United States Environmental Protection Agency (EPA). (2021b). Climate change indicators: growing degree days [Reports and Assessments]. https://www.epa.gov/climate-indicators/climate-change-indicators-growing-degree-days


Figure A.1. Comparison of total annual precipitation (mm) between PRISM daily data, by climate division, and NClimDiv monthly data for the period of 1981-2021. NClimDiv, showing total annual precipitation for the entire state of Maine is represented by the gray line. Total annual precipitation for the Northern, Southern interior, and Coastal climate divisions, calculated using PRISM data are shown by the blue, orange, and red lines respectively.
Figure A.2. Annual average temperature in Maine by climate division during the growing season (Apr. – Oct.) for the period 1895-2020. The Northern, Southern Interior and Coastal climate divisions are represented by the blue, orange, and gray lines respectively. Linear correlation lines are shown by dashed lines in the corresponding color. The slope for each climate division is 0.01, 0.011, and 0.132 respectively. Data source: NOAA’s NCLimDiv via the Maine climate office.
# APPENDIX B: WILD BLUEBERRY GROWER SURVEY INSTRUMENT

How many years of experience do you have working in the Maine wild blueberry sector? __________

To what extent have you noticed the following conditions in the last 5 years in Maine?

<table>
<thead>
<tr>
<th>Condition</th>
<th>Never</th>
<th>Rarely</th>
<th>Occasionally</th>
<th>Frequently</th>
<th>Very Frequently</th>
</tr>
</thead>
<tbody>
<tr>
<td>Changes in growing season length</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Changes in seasonal temperature</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Uncertainty in weather patterns</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Seasonal drought conditions</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Heavy rainfall events</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Killing frost</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

Of those that you've noticed, how would you describe their impact on the wild blueberry sector in Maine?

<table>
<thead>
<tr>
<th>Condition</th>
<th>Negative Impact</th>
<th>Positive Impact</th>
<th>Both a Negative and Positive Impact</th>
<th>No Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Changes in growing season length</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Changes in seasonal temperature</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Uncertainty in weather patterns</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Seasonal drought conditions</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Heavy rainfall events</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Killing frost</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

Of the events that you’ve observed, which ones do you attribute (at least in part) to a changing climate? (select all that apply)

- ☐ Changes in growing season length
- ☐ Changes in seasonal temperature
- ☐ Uncertainty in weather patterns
- ☐ Seasonal drought conditions
- ☐ Heavy rainfall events
- ☐ Killing frost

Which of the following would you consider to be obstacles to your ability to implement adaptation strategies to address climate change? (select all that apply)

- ☐ Complexity of information
- ☐ Lack of access to information
- ☐ Environmental and climate regulations
- ☐ Lack of financial capacity
- ☐ Uncertainty about climate change impacts

Please indicate the extent to which you agree or disagree with the following statements.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate change is currently occurring</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Climate change is primarily caused by natural forces</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Climate change is primarily caused by human activities</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Climate change is caused equally by natural forces and human activities</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Climate change is currently occurring, but I am unsure of its causes</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>I am unsure whether or not climate change is currently occurring</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Overall, I feel that climate change is favorable</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Overall, I feel that climate change is unfavorable</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

What is your gender?
- ☐ Female
- ☐ Male
- ☐ Other (please specify) __________

What is your age? __________

What is your race? __________

Please specify your 5-digit ZIP code: __________

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APPENDIX B: IRB APPROVAL

1. Funding:
This project is funded by the National Science Foundation under Grant No. 1922560 and the USDA National Institute of Food and Agriculture, McIntire Stennis project number #ME0-42017 through the Maine Agricultural & Forest Experiment Station.

2. Summary:
Climate change presents numerous challenges to agriculture globally, particularly to crop production. While increasing levels of carbon dioxide (CO2) in the atmosphere may be advantageous to crop production, increasing temperatures and increased variability of precipitation will outweigh the benefits of CO2 increase (Walthall et al., 2013). Annual crop production relies on relatively consistent weather patterns, including predictable temperatures as well as amount of precipitation. Due to this, crop production is vulnerable to changes in seasonality and projected rises in extreme weather events, such as drought and extreme heat. Some negative impacts which have been linked to changes in climate include stunted plant growth, damage to fruit, and decreases in yield (Mase et al., 2017; Walthall et al., 2013; Prasad et al., 2008). Temperatures are increasing faster within the northeast region of the United States compared to any other region in the country (Karmalkar & Bradley 2017). In northern latitudes, studies have indicated that increased warming has led to an increased growing season length and an earlier occurring spring (Badeck et al., 2004; Linderholm, 2006).

Wild blueberry production, which is essential to both the state of Maine and the United States food system, is vulnerable to climate change (Chen et al., 2012; Lobos & Hancock 2015). Maine is the largest producer of wild blueberries in the world, and every year the wild blueberry industry makes a significant contribution to Maine’s economy. The economic impact of wild blueberries benefits the state of Maine as a whole, but especially some of the most economically challenged rural areas of the state (Wild Blueberry Commission of Maine). As climate change impacts are expected to increase and intensify, it becomes increasingly important for farmers to have the knowledge and ability to adapt to these changes. Additionally, having an understanding of how farmers consider and experience the impacts of a changing climate is essential for learning to work with farmers to prevent crop failure (Mase et al., 2017; Jemison et al., 2014).

The objective of this study is to understand Maine wild blueberry farmer perceptions of climate change. We are interested in gaining a better understanding of the extent to which wild blueberry farmers have experienced climate change impacts over the past five years, their knowledge of climate change cause, and obstacles to implementation of adaptation strategies. This study will provide insight on how wild blueberry farmers understand the link between changes in climate and the impacts on crop production.

3. Methods
A physical, paper, anonymous questionnaire (5 minutes) will be used to better understand the climate change risk perceptions of wild blueberry farmers in Maine. The target population will be Maine wild blueberry farmers who attend the Annual Blueberry Hill Farm Field Day, organized by Maine Cooperative Extension. This year the event will be held over two sessions with no more than 50 individuals at a session and will be entirely outdoors. Individuals will be six feet apart and masked. The questionnaire will be pre-tested prior to implementation to reduce measurement error and participant exhaustion. The questionnaire will be administered July 8-9, 2021. Data will be uploaded to and saved in a password protected computer. The physical surveys will be stored in a locked cabinet and destroyed in August 2022.

4. Participant recruitment:
All participants will be adults (18 years of age and older) of undiminished autonomy, capable of making a truly voluntary decision whether to participate. The population targeted in this study includes Maine blueberry farmers. We plan to hand out the survey to farmers attending the Annual Blueberry Hill Farm Field Day, which will occur in early July. A total of 100 people typically attend the event, with 85% of the audience being farmers. The aim is to have 50% of the farmers complete the survey. An oral recruitment script will be read prior to any surveys being distributed. The survey will be completed on paper. The survey will be distributed and collected by the primary investigator and faculty mentor.

5. Informed consent:
A consent form will be included at the beginning of the questionnaire. Participation in the written survey indicates consent.

6. Confidentiality:
The questionnaire will be anonymous. The following precautions will be addressed to ensure privacy of the participants:
- Respondents will NOT be asked personal information outside of demographics.
• Surveys will be deposited in a box once completed.
• Raw data collected via the questionnaire will only be accessed by the PI and faculty sponsor.
• Responses to the questionnaire will be uploaded and kept in a password protected computer indefinitely. The physical surveys will be kept in a locked cabinet and destroyed in August 2022.

7. Risks to participants:

This questionnaire entails no more than minimal risk or harm to participants. The potential risks to participant may include time investment and inconvenience in answering some of the questions. Participants will be instructed that they do not have to respond to any question they do not wish to.

8. Benefits:

This questionnaire will offer no direct benefit to the participants. The information collected from this questionnaire will possibly lead to an improved understanding of blueberry farmer risk perceptions of climate change impacts on crop production. The data could inform farmer and researcher climate change mitigation and adaptation efforts.

9. Compensation:

There will be no compensation offered for the participation in this questionnaire.
APPENDIX C: CONSENT FORM

You are invited to participate in a research project conducted by Carly Frank, a master’s student in the Climate Change Institute at the University of Maine, Dr. Sandra De Urioste-Stone, an associate professor in the School of Forest Resources at the University of Maine, and Dr. Lily Calderwood, an assistant professor in the School of Food and Agriculture at the University of Maine. The purpose of this study is to gain a better understanding of farmer views of climate change impacts on crop production within Maine. You must be a blueberry farmer and at least 18 years of age to participate.

Before you consider the research, you should be aware of the following information:

- The study is voluntary. You do not have to be in this study.
- You will complete a questionnaire about climate change impacts that will take approximately 5 minutes to complete.
- If you think you want to be in the study, you should read the rest of this document.

What will you be asked to do?

If you decide to participate, you will be asked to fill out the following anonymous questionnaire, which will take approximately 5 minutes to complete. Upon completion, please deposit the survey in the marked box.

Voluntary

Participation in this questionnaire is voluntary. You may stop or skip questions at any time. Submission of the questionnaire implies consent to participate.

Risks

Except for your time and inconvenience, there are no risks to you from participating in this study.

Benefits

There are no direct benefits to you. The overall benefit of the research includes:

- Identified farmer perceptions of changing climatic conditions related to agriculture in Maine.
- Improved understanding of needs for future climate change mitigation and adaptation planning.

Confidentiality

Your responses for this questionnaire will be anonymous. Please do not write your name on your survey. The data will be uploaded and stored in a secure electronic database. All survey data will be kept indefinitely on a password protected computer, only accessible by the investigators. The physical surveys will be stored in a locked cabinet and destroyed in August 2022.

Contact Information

If you have any questions about this study, please contact Carly Frank at carly.frank@maine.edu. You may also contact the faculty advisor on this study, Dr. Sandra De Urioste-Stone at...
sandra.de@maine.edu. If you have any questions about your rights as a research participant, please contact the Office of Research Compliance, University of Maine, (207) 581-2657, or email umric@maine.edu.

Thank you for taking the time to complete this questionnaire!
APPENDIX D: MIGRANT WORKER SURVEY INSTRUMENT

Indicate, to the best extent of your knowledge, how much you believe that each of the following items contribute to climate change...

<table>
<thead>
<tr>
<th>Item</th>
<th>I don't know</th>
<th>No contribution</th>
<th>Minor contribution</th>
<th>Major contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burning fossil fuels for electricity and heat</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Steadily rising CO2 (carbon dioxide) emissions</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Driving a car</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Flying/Commercial air travel</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Deforestation</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Nuclear power plants</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>The sun</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Earthquakes</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Phases of the moon</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

Indicate the extent to which you agree or disagree with the following statements...

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate change is currently occurring</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Climate change is primarily caused by natural forces</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Climate change is primarily caused by human activities</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Climate change is occurring but I am unsure of its causes</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>I am unsure whether or not climate change is occurring</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>
For each of the following items, indicate whether you believe that they are likely to stay constant, decrease or increase as a result of climate change...

<table>
<thead>
<tr>
<th>Item</th>
<th>I don't know</th>
<th>No Change</th>
<th>Likely to increase</th>
<th>Likely to decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average global temperature</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drought occurrence</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biodiversity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sea level</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Melting of glaciers and ice caps</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ocean acidification</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extreme weather events</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spread of infectious disease</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crop yields</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

How much do you think each of the following actions would reduce climate change if they were done worldwide?

<table>
<thead>
<tr>
<th>Action</th>
<th>I don't know</th>
<th>Not at all</th>
<th>A little bit</th>
<th>A lot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recycling glass, plastic, and paper</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Switching from fossil fuels to renewable energy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planting more trees</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eating less meat</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Using more public transportation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reducing tropical deforestation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limiting the number of children per family</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Placing a large tax on all fossil fuels</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduce space travel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Please answer the following questions to the best of your ability.

<table>
<thead>
<tr>
<th>To me, climate change is something...</th>
<th>Very negative</th>
<th>Negative</th>
<th>Somewhat negative</th>
<th>Neutral</th>
<th>Somewhat positive</th>
<th>Positive</th>
<th>Very positive</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

Please answer the following questions to the best of your ability.

<table>
<thead>
<tr>
<th>Overall, I feel that climate change is...</th>
<th>Very unfavorable</th>
<th>Unfavorable</th>
<th>Somewhat unfavorable</th>
<th>Neutral</th>
<th>Somewhat favorable</th>
<th>Favorable</th>
<th>Very favorable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Regarding agriculture, I feel that climate change is...</th>
<th>Very unfavorable</th>
<th>Unfavorable</th>
<th>Somewhat unfavorable</th>
<th>Neutral</th>
<th>Somewhat favorable</th>
<th>Favorable</th>
<th>Very favorable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>
In the last 5 years, how often have you personally noticed the following conditions in your community?

<table>
<thead>
<tr>
<th>Condition</th>
<th>Never</th>
<th>Rarely</th>
<th>Occasionally</th>
<th>Frequently</th>
<th>Very frequently</th>
</tr>
</thead>
<tbody>
<tr>
<td>Changes in growing season length</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Changes in seasonal temperature</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Uncertainty in weather patterns</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Seasonal drought conditions</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Heavy rainfall events</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Killing frost</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Frequency of heatwaves</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

In the last 5 years, how often have you personally noticed the following conditions in Maine?

<table>
<thead>
<tr>
<th>Condition</th>
<th>Never</th>
<th>Rarely</th>
<th>Occasionally</th>
<th>Frequently</th>
<th>Very frequently</th>
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<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>
In the last 5 years, how often have you personally noticed the following conditions in the United States?

<table>
<thead>
<tr>
<th>Condition</th>
<th>Never</th>
<th>Rarely</th>
<th>Occasionally</th>
<th>Frequently</th>
<th>Very frequently</th>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Of those that you've noticed, how would you describe their impact on the agricultural sector in Maine?

<table>
<thead>
<tr>
<th>Condition</th>
<th>Very unfavorable</th>
<th>Unfavorable</th>
<th>Somewhat unfavorable</th>
<th>Neutral</th>
<th>Somewhat favorable</th>
<th>Favorable</th>
<th>Very favorable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in growing season length</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Of those that you've noticed, how would you describe their impact on working conditions in the agricultural sector in Maine?

<table>
<thead>
<tr>
<th>Change in growing season length</th>
<th>Very unfavorable</th>
<th>Unfavorable</th>
<th>Somewhat unfavorable</th>
<th>Neutral</th>
<th>Somewhat favorable</th>
<th>Favorable</th>
<th>Very favorable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Changes in seasonal temperature</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
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<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
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<td>○</td>
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<td>○</td>
<td>○</td>
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<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Frequency of heatwaves</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

For each value listed, please indicate the extent to which you consider it to be a guiding principle in your life...

<table>
<thead>
<tr>
<th>Social power (control over others, dominance)</th>
<th>Not important at all</th>
<th>Of little importance</th>
<th>Somewhat important</th>
<th>Important</th>
<th>Very important</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wealth (material possessions, money)</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Authority (right to lead or command)</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Influential (having an impact on people or events)</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Value</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Equality (equal opportunity for all)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A world at peace (free of war and conflict)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Social justice (correcting injustice, caring for the 'weak')</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Helpful (working for the welfare of others)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preventing pollution</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respecting the Earth (harmony with other species)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unity with nature</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protecting the environment (preserving nature)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
To the best of your ability, please indicate the extent to which you agree or disagree with the following statements...

<table>
<thead>
<tr>
<th></th>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>Somewhat disagree</th>
<th>Neither agree nor disagree</th>
<th>Somewhat agree</th>
<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most people who are important to me are personally doing something to help reduce the risk of climate change</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Individuals in my community are doing something to help reduce the risk of climate change</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Most people I care about believe in climate change</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>The company/organization I work for believes in climate change</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>The company/organization I work for are doing something to reduce the risks of climate change</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>
To the best of your ability, please indicate the extent to which you agree or disagree with the following statements...

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>Somewhat disagree</th>
<th>Neither agree nor disagree</th>
<th>Somewhat agree</th>
<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>I feel that helping to tackle climate change is expected of me</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>People who are important to me would support me if I decided to change my behavior to help reduce climate change</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>People whose opinions I value think I should act to reduce the risk of climate change</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Please answer the following questions to the best of your ability

<table>
<thead>
<tr>
<th>Question</th>
<th>Not serious</th>
<th>Not very serious</th>
<th>Neutral</th>
<th>Somewhat serious</th>
<th>Serious</th>
</tr>
</thead>
<tbody>
<tr>
<td>How serious would you rate current impacts of climate change around the world?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>How serious would you estimate impacts of climate change in society?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>How serious of a threat do you think climate change is to you?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>How serious of a threat do you think climate change is to the natural environment?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Please answer the following question to the best of your ability

<table>
<thead>
<tr>
<th>How likely do you think it is that climate change will have significant harmful, negative impacts on society?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very unlikely</td>
</tr>
<tr>
<td>○</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>How likely are you to experience serious threats to your health, or overall well-being as a result of climate change during your lifetime?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very unlikely</td>
</tr>
<tr>
<td>○</td>
</tr>
</tbody>
</table>

To the best of your ability, please indicate the extent to which you agree or disagree with the following statements...

<table>
<thead>
<tr>
<th>Religion is important to me</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly disagree</td>
</tr>
<tr>
<td>○</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Religion is important to those in my community</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly disagree</td>
</tr>
<tr>
<td>○</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>My faith is central to my identity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly disagree</td>
</tr>
<tr>
<td>○</td>
</tr>
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To the best of your ability, please indicate the extent to which you agree or disagree with the following statements...

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<th>Somewhat agree</th>
<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazards and disasters cannot be controlled</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>People are victims</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Disasters are not natural</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
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<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>A divine explanation exists for climate change (i.e. sent by God)</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Climate change is a result of transgressions of moral codes</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Individuals should not interfere with the impacts of climate change</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>God will protect me from the impacts of climate change</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Droughts/floods are signals from God</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Climate change is part of God's plan</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Individuals should care for the environment</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>
What do you think you could personally do to reduce the risk of climate change?

To the best of your ability, please indicate the extent to which you agree or disagree with the following statements...

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>Somewhat disagree</th>
<th>Neither agree nor disagree</th>
<th>Somewhat agree</th>
<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>I have adequate access to clean drinking water throughout the day</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>I have adequate access to shade throughout the day</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>I have adequate time to eat throughout the day</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>I am reasonably compensated for my work</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>I have somewhere to go/someone that I feel comfortable reporting an issue to</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
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</table>
To the best of your ability, please indicate the extent to which you agree or disagree with the following statements...

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<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>My employer cares about my safety</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>My employer cares about my well-being</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>I trust my employer</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>My employer respects me as a person</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

What is your current geographic area of work?

- Androscoggin
- Aroostook
- Cumberland
- Franklin
- Hancock
- Kennebec
- Knox
- Lincoln
- Oxford
- Penobscot
- Piscataquis
- Sagadahoc
- Somerset
- Waldo
- Washington
- York
Please indicate how many years have you worked in the US

- <1
- 1-4
- 5-9
- 10-14
- 15-19
- 20-29
- 30-39
- 40+

Please indicate your gender

- Male
- Female
- Non-binary
- Other
- Prefer not to say

Please indicate your religion (if any)

- Christianity
- Judaism
- Islam
- Catholicism
- Hinduism
- Buddhism
- Sikhism
- Other
Please indicate the highest level of school you have completed

○ Less than high school  
○ High school graduate  
○ Some college  
○ 2 year degree  
○ 4 year degree

When it comes to politics, I consider myself to be...

○ Very conservative  
○ Conservative  
○ Neutral  
○ Liberal  
○ Very liberal

In which country would you consider your community to be in?

Please indicate your age

○ 18-24  
○ 25-34  
○ 35-44  
○ 45-54  
○ 55-64  
○ Over 65
Please indicate your race

☐ American Indian
☐ Black or African American
☐ Asian
☐ White
☐ Native Hawaiian or other Pacific Islander

Please indicate your ethnicity

☐ Hispanic or Latino
☐ Not Hispanic or Latino
BIOGRAPHY OF THE AUTHOR

Carly Frank was born in Wynnewood, Pennsylvania on December 13, 1996. She was raised in Phoenixville, PA and graduated from Spring-Ford High School in 2015. She attended Purdue University and graduated in 2019 with a Bachelor’s degree in Natural Resources and Environmental Science. She entered the Quaternary and Climate Studies graduate program at The University of Maine in the fall of 2020. After receiving her degree, Carly will be returning to Purdue University to pursue a Doctor of Philosophy degree in Ecological Sciences and Engineering. Carly is a candidate for the Master of Science degree in Quaternary and Climate Studies from the University of Maine in August 2022.