North Carolina Winegrowers' Perceptions of Climate Change Impacts

by

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May, 2013

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Wine is a product of a specific region's climate and environment. Climate change is a source of increasing sensitivity. This research analyzes the perceptions of winegrape growers and climate trends, which contribute to a better understanding of climate change impacts on winegrape production and adaptation strategies. Results are compiled from 12 winegrower interviews and 34 web survey responses to questions on crop sensitivity to potential changes in climate as well as current experiences and adaptations to perceived changes to discover how climate change is affecting this sector of agriculture within North Carolina's distinct climate environments. Web survey and interview responses specify weather and climate as a very strong element of risk. Excessive rainfall, hail, severe weather and late spring frosts are among the greatest threats varying between regions and variety. Almost all respondents indicate experiencing a change in extreme high temperatures. The majority of respondents who indicated any concern for future climate change explained preparations are in place because there is no control over the weather, only adaptation. Climate patterns and trends are analyzed for the period 1982-2012, showing the southern mountain region is experiencing a slight increase in August mean maximum temperatures. Temperature trend lines suggest that the central region of the state is experiencing an overall increase in January mean minimum temperature. Boundaries suitable for specific varieties have changed as increasing temperatures expand zones of disease risk.

North Carolina Winegrowers' Perceptions of Climate Change Impacts

A Thesis

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by

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May, 2013

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CHAPTER 1: INTRODUCTION

1.1 Research Rationale

Crop production around the globe will be affected by changes in the Earth's climate system, increasing the vulnerability of many traditional agricultural systems. Viticulture and wine production are particularly susceptible to climate change because microclimates and macroclimates are vital factors for optimum production and quality (Jones et al. 2010). Wine is a geographically dependent product growing in specific regions on the earth, each with distinctive terroir, climate, culture, and harvesting practices (Razban 2009, Gladstones 2011). Climate change is a source of increasing vulnerability, and wine growers will benefit from a better understanding of how it might impact winegrape production, so that they may develop adaptation strategies.

Winegrape vines are perennial crops highly sensitive to environmental changes (Lobell et al. 2006, Cahill et al. 2007, Rosenzweig et al. 2007). Temperature defines the length of the growing season, the ripening potential, budburst dates, and especially harvesting dates (Webb et al. 2007; Jones 2006). White grape varieties favor cool, dry conditions. Extreme heat events, including temperatures above 35°C, cause vines to shut down for a number of days or even weeks (Belliveau et al. 2006). Red grape varieties require more heat to ripen the fruit and produce sugars, creating a high vulnerability to frosts and extreme decreases in temperature or unseasonal cold fronts (Belliveau et al. 2006). Precipitation is another variable that affects winegrape quality and complexity. Wind, humidity, atmospheric pressure and sunlight can also influence the viticulture of a region.

While winegrapes as a crop are not crucial to human survival, winemaking is an essential part of culture and the vine's extraordinary sensitivity to climate makes the industry a strong

early-warning system for problems that all food crops may confront as climates continue to change (Jones et al. 2010, Dougherty 2012, Rosenzweig et al. 2007).

The Intergovernmental Panel on Climate Change (IPCC) has shown there is a limited understanding of the U.S. agricultural sector's current sensitivity to climate variability and its ability to adapt to climate change (Field et al. 2007). The IPCC relies on computer models that cannot capture the complex real climates that affect agriculture over different regions (Gladstones 2011). Utilizing historical records of past climate trends on a localized scale can address some of the limitations of climate modeling.

Winegrapes have been used in Europe and North America agriculture as an indicator of observed trends (Rosenzweig et al. 2007). Climate change is likely to affect wine production in all wine regions of the world but the impacts will not be uniform over time and space (Webb et al. 2007; Jones et al. 2010). For example, many winegrowers are experiencing warmer and drier conditions throughout the late 20th century. This may prove to be beneficial for wine quality in some areas and problematic for others due to increasing water shortages (Gladstones 2011, Jones and Davis 2000). Most short-term and long-term research on viticulture and the wine industry has attempted to predict the impacts of climate change and variability through case studies using global and/or regional climate models (Holland 2010). There are many limits to studying one scale and proving the results to be useful. More valuable insight into adaptive capacity, constraints and opportunities can come from studying the regional and local context (Adger et al. 2007). In addition, little is known about climate change from the perspective of farmers, including wine producers (Alonso et al. 2011). Grape and wine producers know and understand the importance of the local environment to their crop and can benefit from the strategies to combat potential climatic impacts that directly affect their livelihood.

1.2 Research Goal and Objectives

This research documents the perceptions of winegrape growers to examine how climate change is affecting viticulture within North Carolina. In order to explore this industry this research addresses the following five questions:

1) What are winegrowers' perceptions of weather and climate risks and how do they change throughout the growing cycle in the wine industry of North Carolina?
2) How do the expressed risks vary based on region, experience, acreage, or winegrape varietal?
3) Are winegrape growers observing any significant changes in weather and climate?
4) Do current climate trends at different times throughout the growing cycle show changes that could potentially affect the wine industry and alter site suitability?
5) What are winegrowers' preparations for potential climate changes?

The resulting knowledge gained from this research is potentially useful across winegrowing regions within North Carolina and may be helpful outside of the state (Battaglini et al. 2008) or within other agricultural sectors experiencing similar conditions. Extensive financial and potential agricultural loss may be avoided if adaptation measures are put into place before potential climate change effects are felt or become more severe. The solutions to these issues will have greater benefits from long-term research methods but gathering initial information and grower perceptions of climate changes is an important start (Schultz 2010).

1.3 Thesis Structure Overview

This thesis is divided into eight chapters. The review of relevant literature in Chapter 2 discusses the current impacts, perceptions and the rationale for this body of research. Different approaches provide a model for combining social and climatological methods of research. Important geographic elements of the study area are discussed in Chapter 3. A brief summary of

North Carolina's wine history provides further justification for its importance. The geography and climatology of the region defines where specific varieties may prosper. The mixed methodology utilized in this research is outlined in Chapter 4. Chapter 5 reveals the findings from the web survey and interviews. Growers' perceptions of overall challenges, weather and climate variables, and climate change are discussed. A chosen case study area is analyzed in Chapter 6 using observed daily climate measurements between 1958 and 2012. This Chapter discusses these results in relation to the research questions and highlighting key findings. Thirty year observed daily climate trends are spatial interpolated to show climate changes and changes in viticulture suitability in North Carolina. Chapter 7 outlines how winegrowers are responding to climate changes and their capacity to adapt to future changes. Chapter 8 summarizes the results and conclusions from this research. Possible contribution opportunities, limitations, and future research are provided. This study fits into the context of a growing body of research to better understand the interaction of climate and winegrape production.

CHAPTER 2: LITERATURE REVIEW

2.1 Climate Change Influences on Agriculture

Recent trends analyzed by the IPCC show evidence of significant increases in variable and severe weather across North America, with significant differences across regions and over time. The growing season has lengthened for much of the temperate United States due to earlier spring warming and reduced frost risk (Field et al. 2007, Rosenzweig et al. 2007). This warming however, may expand pest and disease pressures, bring more frequent drought conditions, and could increase the threat of forest-fires (Rosenzweig et al. 2007).

A growing body of research in the California region indicates that the effects of climate change have been felt for a long period of time with perennial crops (Lobell et al. 2006). Lobell et al. (2006) focused on six perennial crops, including winegrapes, highlighting the most important climate change effects on each. The researchers argue that the effective integration of climate science into agricultural practice will provide future benefits and help promote adaptation strategies against climate change (Lobell et al. 2006). Agricultural sectors have the ability to successfully endure future changes, but recent temperature extremes and unexpected weather events have become sources of risk (Rosenzweig et al. 2007).

2.2 Climate Change Influence on Viticulture

Within the wine industry, climate effects may be evident in sensitive varieties and growing regions and winegrape phenology and resulting wine quality are important indicators of regional climate changes. Because winegrapes are a perennial crop, changes over time are easier to observe than with annual crops (Rosenzweig et al. 2007). Still, there are gaps in our overall

knowledge of the climate impacts on winegrapes with regard to where and when sensitivities exist (Adger et al. 2007).

Urhousen and colleagues focused on the Upper Moselle region of Germany in order to determine the climate factors (temperature, sunlight duration and amount of precipitation) that are the most important variables in the winegrape growing and maturation process (Urhausen 2011). The researchers found that increasing trends in annual spring and summer temperatures produced an earlier budburst date and flowering event (Urhausen 2011). In another study, the majority of British Columbia respondents identified conditions for an optimum growing season to include: a hot and dry summer, an early spring, and a long growing season (Belliveau et al. 2006). Although average temperatures have increased in many high-quality wine-producing regions, including California and Australia, climatic variations have the largest influence on winegrape production in cool climate regions such as Germany (Jones et al. 2005, Rosenzweig et al. 2007).

Jones et al. (2000; 2005; 2010) produced a significant series of studies examining the relation between climate, viticulture and wine quality, particularly in Oregon, Washington, and the Bordeaux region of France. Jones et al. (2005) found that a number of grape varieties are already well adapted to hot climates in southern Spain, Italy and North Africa (Jones et al., 2005; Webb et al., 2007). In contrast, regions where temperatures are currently unsuitable for grape growing may become more conducive to production with warming temperatures introducing new vineyards (Jones 2008). A number of potential negative effects of climate change on viticulture were identified by winegrape growers across France, Germany and Italy. These include the risk of ice in the spring, cold springs and hydrologic stress (Battaglini et al. 2008). The risks and climate changes need to be researched in other viticulture regions.

2.3 Perceptions of Climate Change

Much of the existing climate change research relies upon scientific modeling. Studying the perceptions and attitudes of farmers may provide further insight into what climate models show. Farmers may not have a complete understanding of climate change but a unique connection exists between farmers and the climate system. Because of constant monitoring, farmers have a heightened perception of even slightly abnormal weather and climate conditions (Gamble et al. 2010). This perception is influenced by a wide range of factors including nature, culture, education, social networks, and values, factors which also affect the ability of a grower to adapt in the face of weather and climate risks (Knebusch 2007, Adger et al. 2007). Many studies have applied qualitative techniques such as surveys, focus groups, and interviews to develop a better understanding of these different perceptions.

Although wine production is widely recognized as an industry vulnerable to the damaging effects of climate change, it has not been clearly defined using growers responses (Cahill 2009). Few studies have examined winegrowers' perceptions of how climate change might impact viticulture production (Ballaglini et al. 2008). Indeed, assessments of climate change perception in the literature are rare, even outside of the wine-growing sector. The existing research focuses on perception of and adaptation to weather extremes, such as drought (Meze-Hausken 2004) and heat waves (Flechsig et al. 2000).

Gamble et al. (2010) drew upon local-knowledge through an in-depth survey of farmers in several communities in Jamaica. Researchers found drought to be a significant climate stressor. This knowledge was then compared with trends in local precipitation and remotely sensed vegetation data (Gamble et al. 2010), an innovative balance of climate science and localized perception similar to the methods discussed later in the current thesis.

Less common are studies examining gradual seasonal changes, multiple growing season risks, critical timing of weather and climate risks and increased pests or disease. No studies have focused on wine grape growers and winery owners' perceptions of climate change and compared these to actual climate data for North Carolina.

2.4 Adaptive Capacity

Adaptive capacity is the ability for a system to respond successfully to a variable, including behavioral changes as well as how relevant resources and technology are utilized (Adger et al. 2007). Adaption is a key concept for considering the ability of farmers to manage climate change. Natural and social systems have an influence on a winegrower's capacity to adapt to climate variability. Adaption capacity is dependent on type of risk, as well as the size of the vineyard and operation, farming experience, and extension information. If there are positive effects of climate changes, adaptive capacity may be determined by the ability to harness the benefits. In the wine industry this may include a longer growing season for specific varietals or potential to expand the consumer market and promote tourism. Some studies have shown that elements of adaptation may be applied to any vineyard, while others focus on a specific location and specific impact.

Crop production in underdeveloped regions of the world is particularly sensitive to climate changes. In the Maule Region of Chile, Hadarits (2009) drew upon key informant interviews, semi-structured interviews, and focus groups to find that this region has not yet developed climate change adaption or mitigation strategies because participants saw no indication that climate changes were threatening the grape and wine industry. Researchers

concluded that the lack of climate change education and grower communication can significantly hinder adaptive capacity (Hadarits 2009).

A recent three-region study in Spain by Alonso et al. (2011) emphasizes that there is a clear need for education at all levels of the wine industry. The results of their survey revealed that operators who believe climate change to be real and evident also believe that if you cannot control the climate, you can control the vineyard. Operators who were considered non-believers refused to alter their operations or have not experienced climate changes yet (Alonso et al. 2011). In California, Cahill (2009) found that most growers respond and adapt individually but could benefit from coordinated community responses shared between the winegrape growers. Cahill's (2009) study examined wine quality using semi-structured interviews and future projections from climate models. The results emphasize the importance of involving stakeholders and returning useful knowledge to the wine community and serves as an excellent model for pairing growers' responses with projections of climate trends and variability.

The effects of climate variability will be global, but unique for each climate region. Effects must be dealt with on a local level, indicating a strong need for localized climate research (Cahill 2009). The objective of this thesis is to harness local knowledge in the wine industry of North Carolina as a lens for analyzing climate change, which could ultimately inform adaptation strategies. A holistic approach will be used in coupling farmer perceptions, observations, and responses with projections of climatic variability and trends.

2.5 Multiple Exposures

Natural elements are important variables in agriculture and forestry but there are many other factors that determine successful production. These include factors that each winegrower

will experience and respond to differently (Rozenzweig et al. 2007). Other factors include government policy, marketing to different consumers, financial resources, technology and labor (Belliveau 2005). The current study aims to identify the most important risk variables perceived by winegrowers in the context of creating a successful enterprise.

A study of the grape and apple growing sectors of Okanagan Valley, British Columbia used focus group interviews to record past and current conditions to determine the source of farm-level sensitivities as well as the ability of farmers to adapt to risks from climate change and similar factors. The findings suggest that weather is one among many factors affecting farm operation (Belliveau et al. 2006). Winegrowers make specific adaptations to positive impacts of climate change that may increase vulnerability to potential future negative impacts of climate change (Belliveau 2005, Adger et al. 2007). These researchers also found that changes in the market, costs, government, and resources impact management decisions that could increase weather and climate vulnerability.

2.6 Restating the Research Questions

This research examines the perceptions of winegrape growers to discover how climate variability is affecting this sector of agriculture across North Carolina's different climate environments. The wine industry is a significant element of the NC economy, culture and heritage. Improving our understanding of climate sensitivity can help to identify both its potential and greatest risks. To do so, this study will determine the level of sensitivity of viticulture to current and future changes in climate in different regions across the state. Results will show the extent to which winegrape growers are observing any significant changes in weather and climate variables, as well as adaptation methods they have implemented. Using a

regional case study, observed climate variable trends will provide a closer examination of conditions winegrowers perceive as risks.

CHAPTER 3: NORTH CAROLINA GEOGRAPHY, VITICULTURE HISTORY AND CHARACTERISTICS

3.1 North Carolina Geography

North Carolina is situated on the eastern coast of the United States, between the Appalachian Mountains and the Atlantic Ocean (Fig. 3.1). Wineries are distributed throughout the state and cluster in the central area. The state has three different winegrape growing

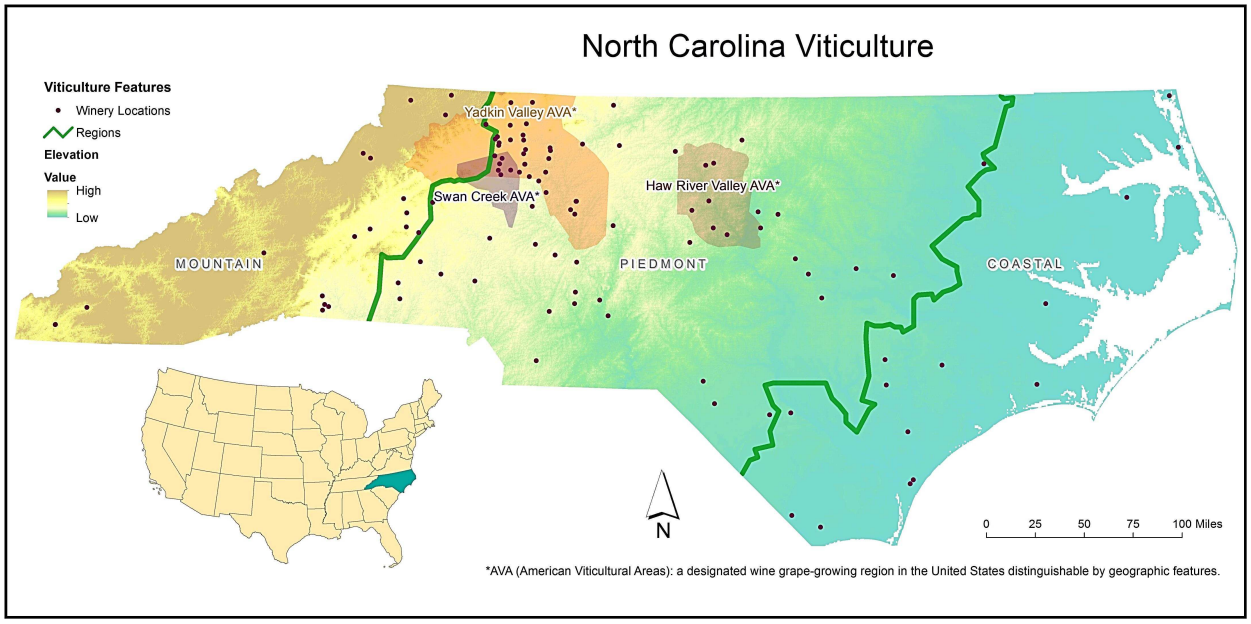

Figure 3.1: Site map, North Carolina viticulture

environments. The Mountain Region, located in the western part of the state, contains some of the highest sections of the Appalachian Mountain range with elevations reaching above 2,000 feet and many slopes well over 15 percent (Fig. 3.2). Slope is important to a vineyard to avoid cold air ponding in low areas but can be difficult to manage with large machinery and high erosion (NC Department of Commerce 2012).

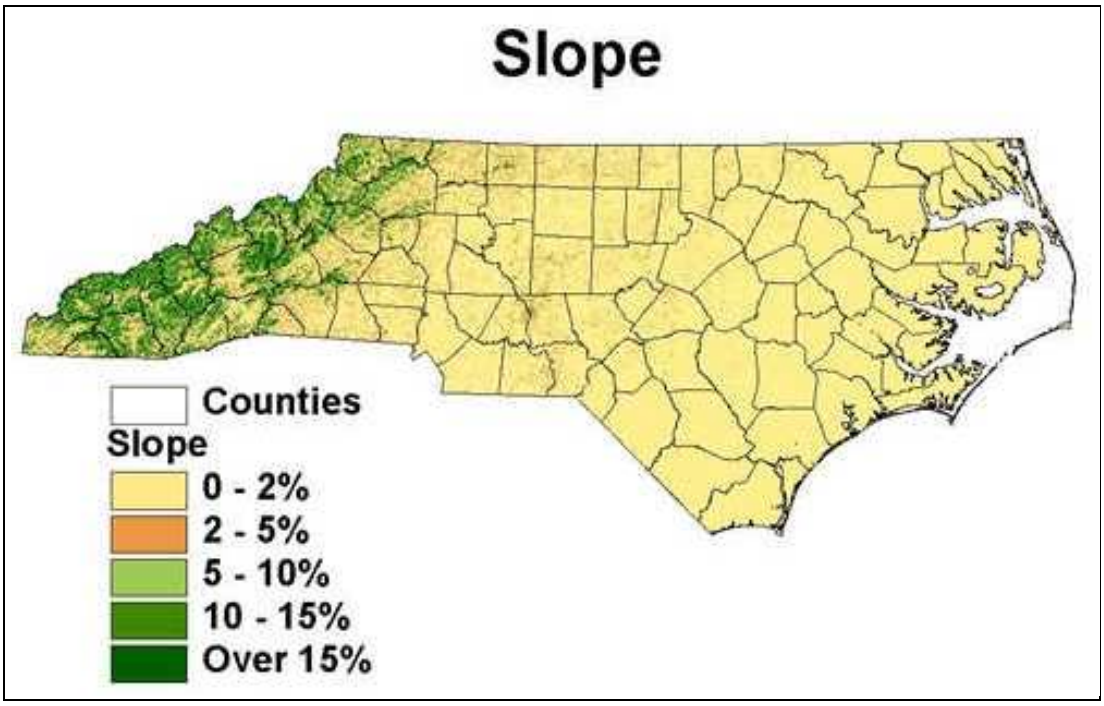

Figure 3.2: Vineyard Site Suitability (N.C. Department of Commerce 2012).

The Piedmont Region, located in the central part of the state, provides a longer growing season in some areas. Elevations in the Piedmont range from 500 to 2,000 feet above sea level. The Piedmont Region presently has three federally recognized American Viticultural Areas (AVA) including Yadkin Valley, located in the northwest Yadkin River valley and associated with 40 wineries, the highest concentration in the state; Swan Creek associated with five wineries with some overlap into the Yadkin Valley; and Haw River Valley associated with seven wineries located in the central part of the state (Fig. 3.1). These regional designations are controlled by the Federal Tax and Trade Bureau (TTB). The TTB recognizes these as AVA because of their distinctive combination of soil, climate, elevation and identifiable regional wine character (Visit NC 2012). Wineries can reveal the geographic pedigree of their wine by using a tag on their labels called an Appellation of Origin.

The Sandhills or Coastal Region, located in the eastern part of the state, largely experiences a maritime macroclimate because of its proximity to the Pamlico Sound and the Atlantic Ocean. All other bodies of water throughout the state are too small to significantly affect the regional climate (Poling & North Carolina Cooperative Extension Service 2007). The maritime climate may extend the growing season (Wolf et al. 1995). Elevations in this region are below 500 feet above sea level.

North Carolina experiences different climate conditions than those in mid-latitude regions of Europe or the western United States. Having one of the most complex climates of any eastern state, NC needs to be analyzed in more depth with regard to past and future climate variability (Boyles and Raman 2003). Each winegrowing region experiences different weather and climate risks that may include "low winter temperatures, late spring frosts, excessive summer heat and unpredictable precipitation" (Poling & North Carolina Cooperative Extension Service 2007).

A graph of North Carolina's average rainfall varies between 3.14 in to 4.73 inches per month (Fig. 3.3.1). As described by growers, the highest rainfall is received in Yadkinville, NC between March and September. Figure 3.3.1 shows the highest average monthly rainfall is in July. In comparison to North Carolina's climate, Napa, CA vineyards experience very low rainfall throughout the summer months (Fig. 3.3.2) and growers may not consider excessive rainfall to be a risk at any time of the year. A prominent viticulture region in Bordeaux, France experiences rainfall that varies over the course of the year from 2.1 inches to 3.5 inches per month (Fig. 3.3.3). On average most rain falls during the months of November (3.5 inches) and October (3.4 inches). July and August are usually the driest months. Bordeaux experiences a steady rainfall pattern throughout the year similar to North Carolina. However the amount of rain is generally less in Bordeaux. Growers in France may perceive excessive rainfall as a risk but at

different times of the year than what North Carolina growers perceive. Interestingly, North Carolina's rainfall peaks in the middle of the summer season (July) at the same time Napa and Bordeaux experience their minimum. It is difficult for North Carolina growers to learn from vineyards with a long history of success and experience with excessive rainfall outside of the state because conditions and timing are so different.

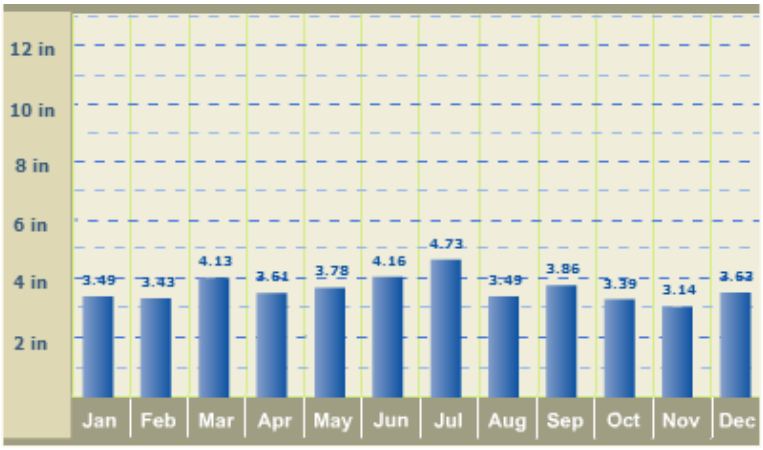

Figure 3.3.1: Monthly Averages for Yadkinville, NC (The Weather Channel, LLC 2012)

Figure 3.3.2: Monthly Averages for Napa, CA (The Weather Channel, LLC 2012)

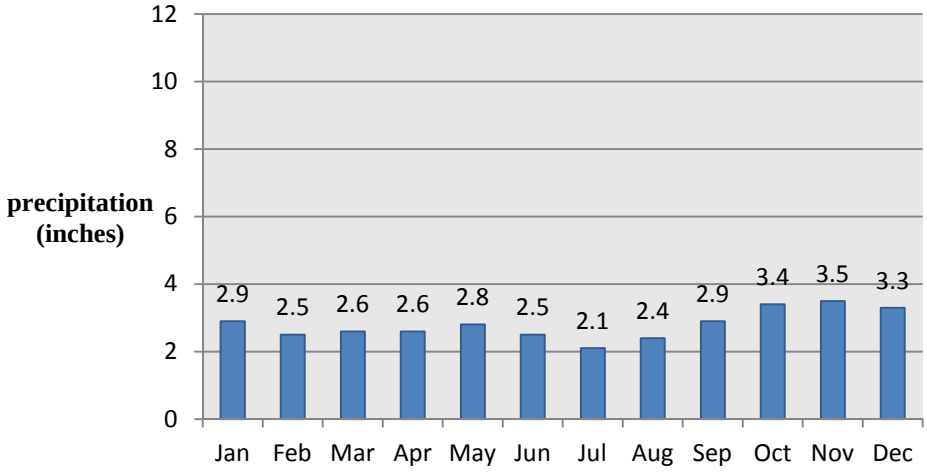

Figure 3.3.3: Weather in Bordeaux, France Average Monthly Rainfall (WeatherOnline, Ltd 2013)

The North Carolina Department of Commerce maps atmospheric variables relevant to viticulture suitability. Pierce's disease (PD) risk follows warmer climates from the south up the east coast, shown south of the red line in Figure 3.4 (Poling & North Carolina Cooperative Extension Service 2007). Higher elevations in the western part of the state offer lower winter temperatures that prevent the spread of PD. For much of NC the mean minimum temperature in January does not get below 30°F, shown in red on Figure 3.5.

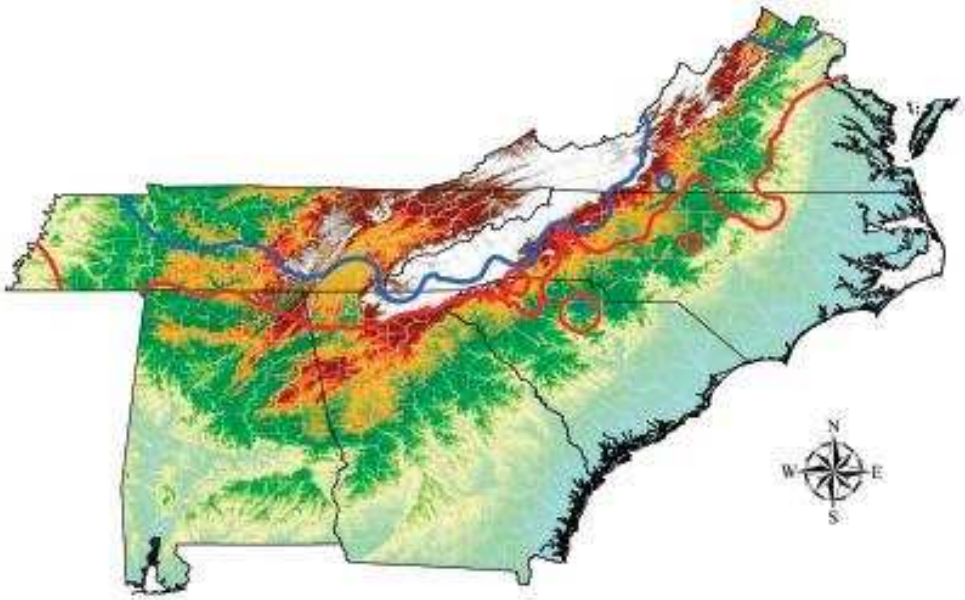

Figure 3.4: Increasing risk of Pierce's Disease south and east of red line (N.C. Department of Commerce 2012).

Figure 3.5: Pierce's Disease Potential (Poling & North Carolina Cooperative Extension Service 2007).

Coastal regions rarely experience temperatures below 0°F (Fig. 3.6). The Piedmont and some of the Mountain's minimum temperature range is between 25° and 30°F with some outliers in high elevations that can reach between 20° and 25°F.

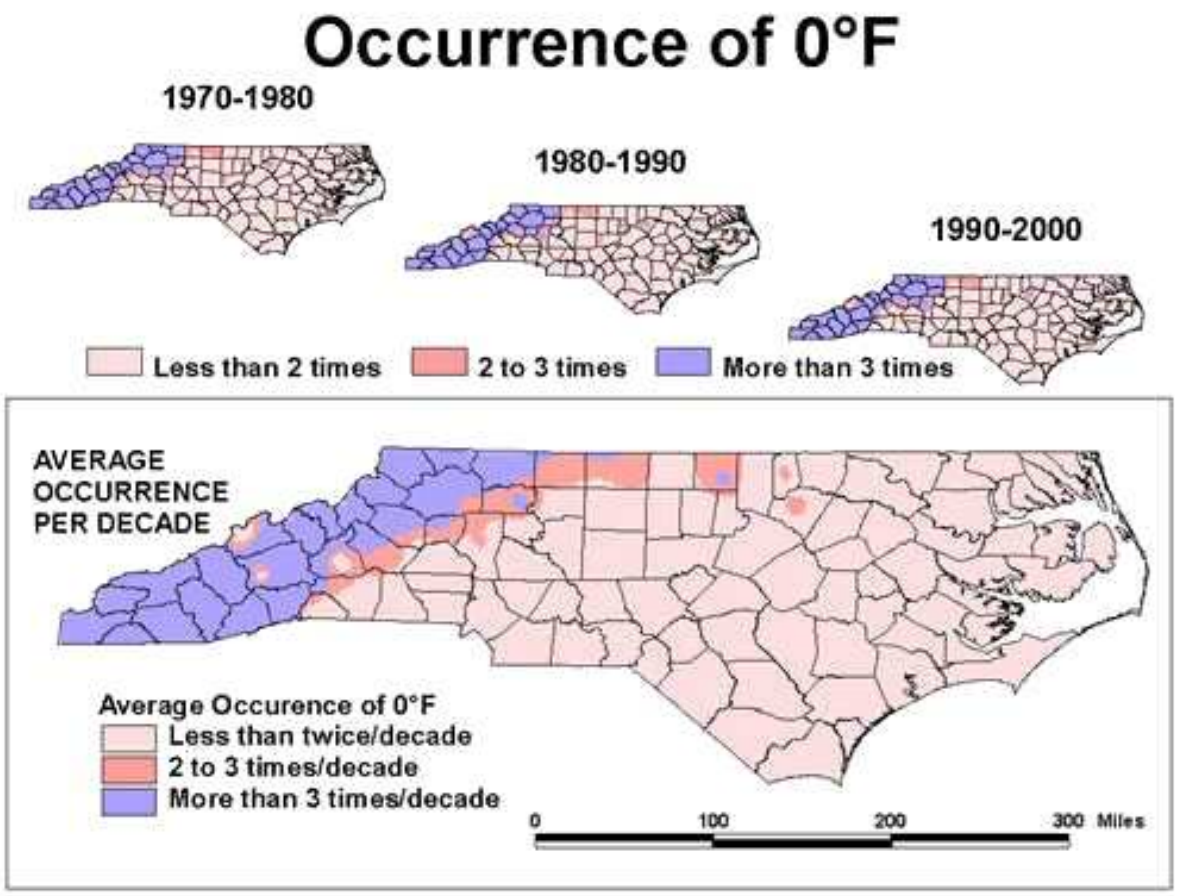

Figure 3.6: Decadal occurrence and average occurrence per decade of 0°F. Maps generated by John Boyer, a Virginia Tech geographer (N.C. Department of Commerce 2012).

The average occurrence of 0°F is more than three times per decade throughout the entire mountain region and the average occurrence of -8°F per decade shows a similar pattern (Fig. 3.7). These variables help determine the risk of frost for each vineyard.

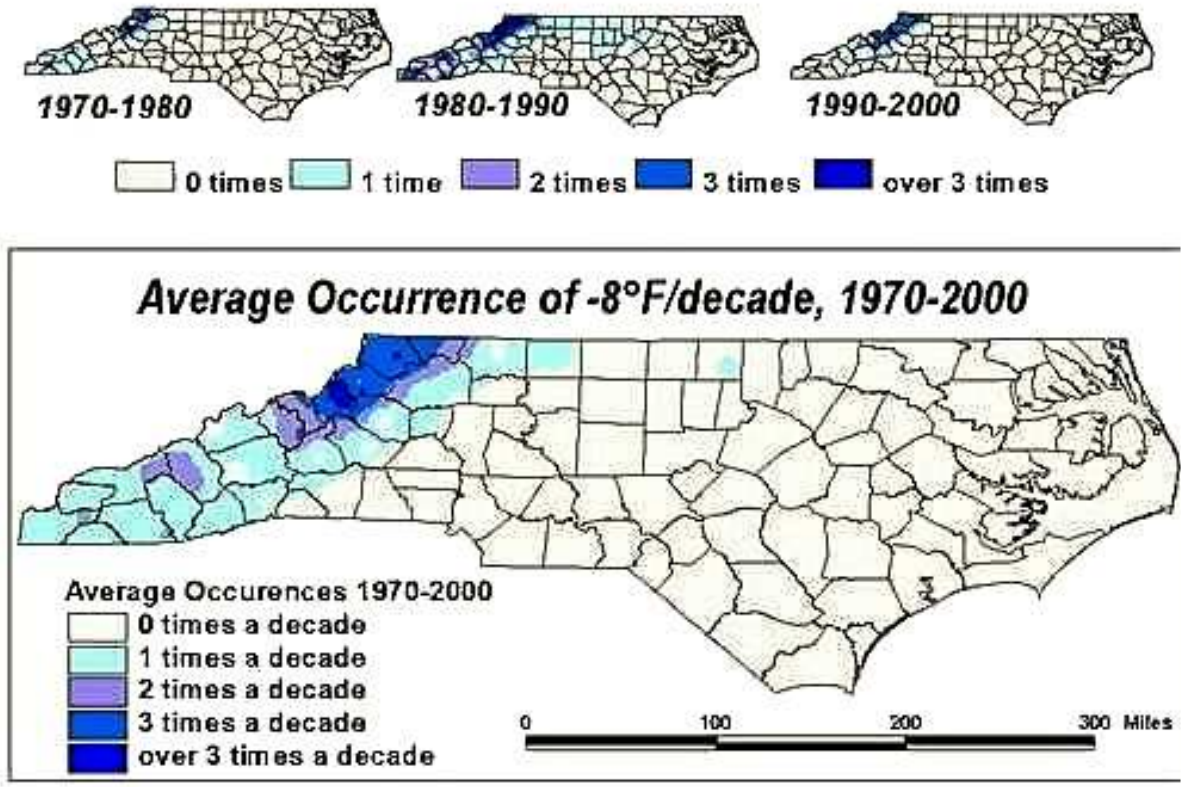

Figure 3.7: Decadal and average occurrence of -8°F (N.C. Department of Commerce 2012).

The day-night temperature differential based on average minimum and maximum temperatures for August (Fig. 3.8), is relatively uniform across the state until the Mountain region. Temperatures in the mountains can fluctuate rapidly on a day-to-day basis because of the

continental climate (Wolf et al. 1995).

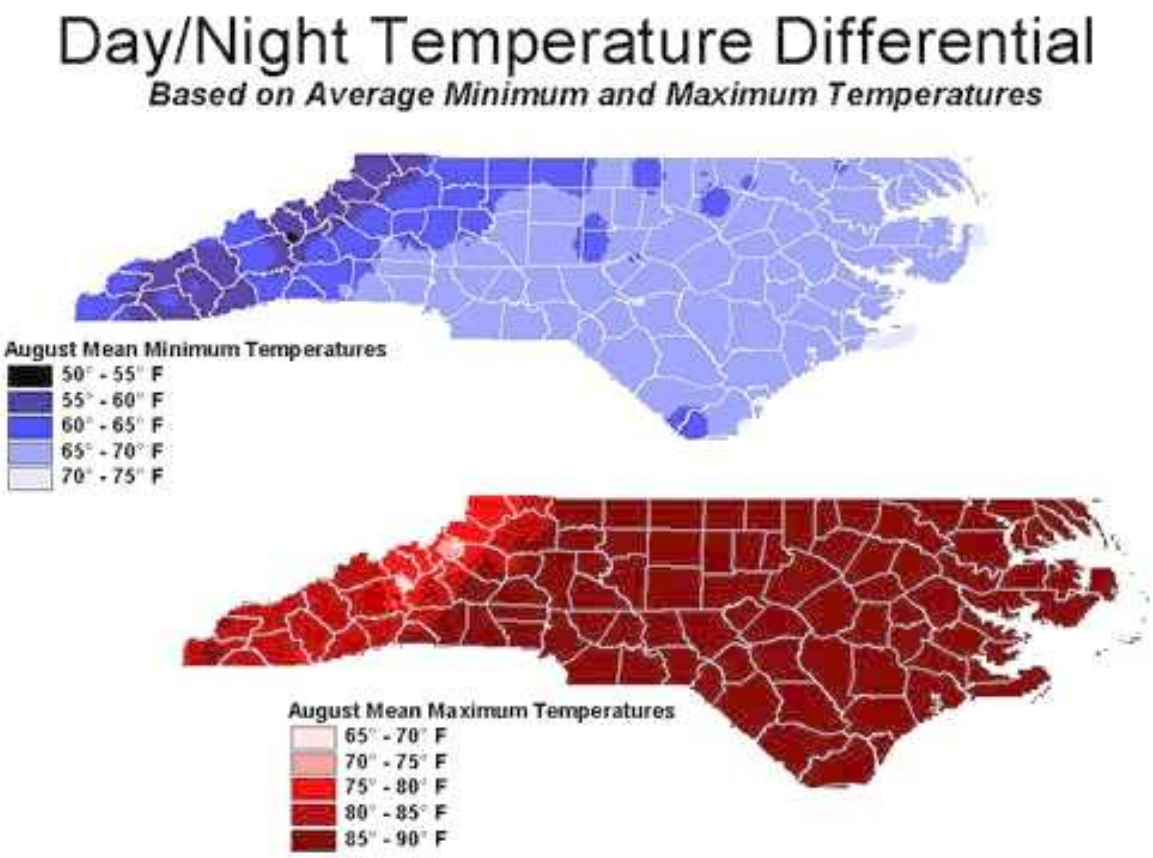

Figure 3.8: August Mean Minimum and Maximum Temperatures (N.C. Department of Commerce 2012).

In many areas of NC, the maximum summer temperatures exceed 85 to 90°F (Poling & North Carolina Cooperative Extension Service 2007). Vineyards located in higher elevations, particularly between 500 and 1,500 feet above sea level will experience slightly cooler than average summer daytime temperatures. If higher temperatures remain into the nighttime it may result in grapes with unbalanced juice due to decreased acidity and pigmentation, along with increased sugar and pH (Poling & North Carolina Cooperative Extension Service 2007).

The harvest season extends from August to October in the Northern Hemisphere and precipitation during this period can be detrimental (Fig. 3.9).

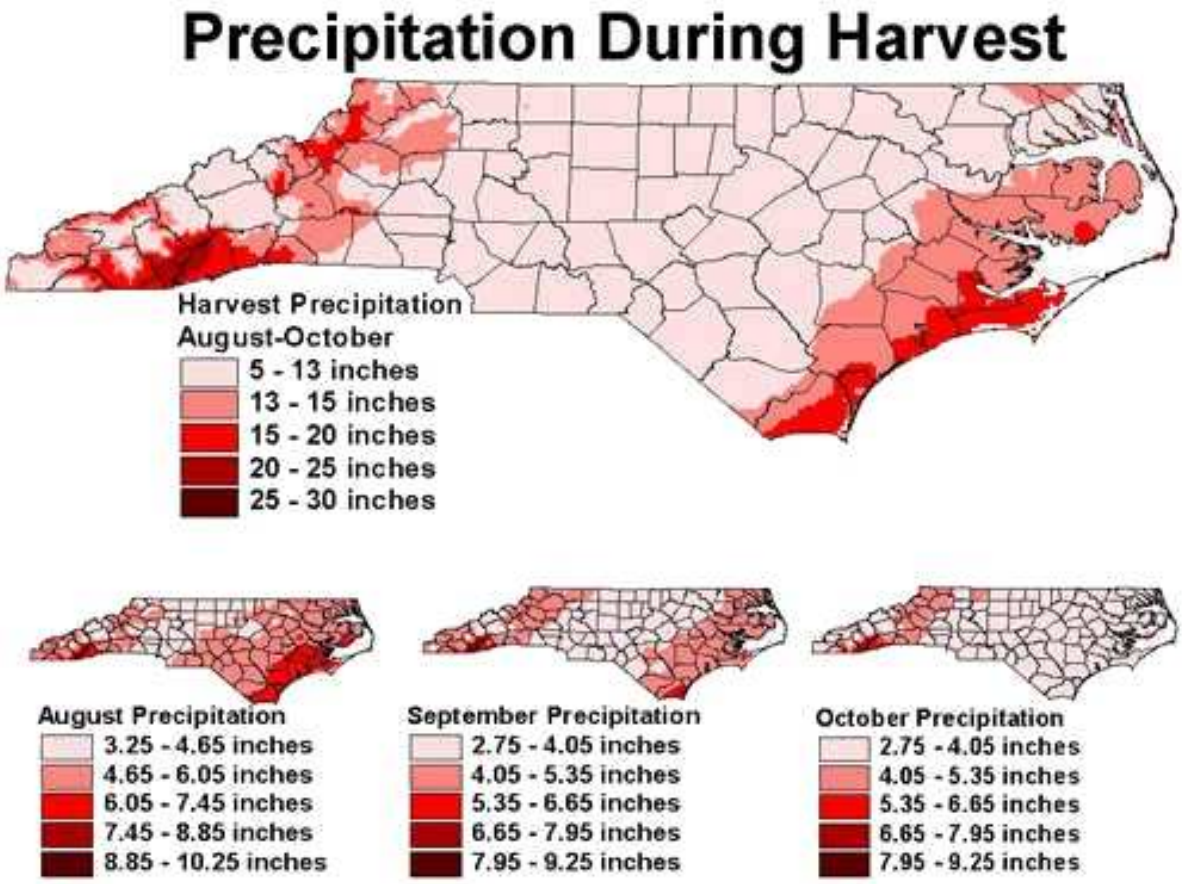

Figure 3.9: Total precipitation during harvest (N.C. Department of Commerce 2012).

The NC Wine Grape Grower's Guide notes that most of the state receives between 40 and 50 inches of precipitation each year, while adult grapevines only require between 24 and 30 inches annually (Poling & North Carolina Cooperative Extension Service 2007). The coastal region experiences the highest precipitation during August. This region may experience frequent tropical storms or hurricanes and is directly influenced by its proximity to water (Wolf et al. 1995). Excess precipitation may interrupt the harvest schedule and affect the flavors and aromas in the resulting wine. Any significant changes in summertime rainfall could alter the future of a vineyard. Figure 3.10 delineates clear zones of viticulture suitability in NC. The frequency of

0°F map (Fig. 3.6) shows a very similar pattern to the delineation between Zones 2 and 3 in the viticulture suitability map (Fig. 3.10). The 30° mean January minimum isotherm approximates the boundary between Zones 2 and 3. In summary, the boundaries of temperature variables have significant overlap with boundaries of grape variety suitability.

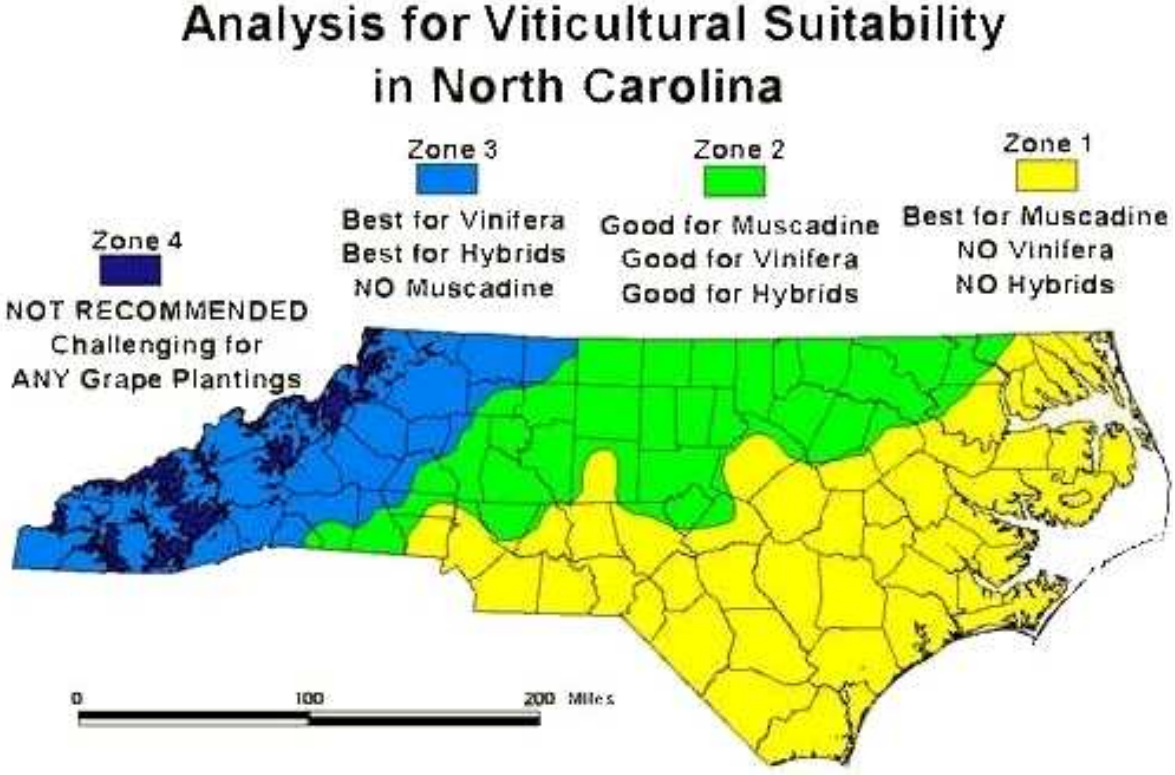

Figure 3.10: NC Viticulture Suitability (N.C. Department of Commerce 2012).

Several common winegrape varieties grown across the state are traditional European species (vitis vinifera), which mirror those grown in California and Europe to create Chardonnay, Cabernet Sauvignon, Merlot, Viognier and Cabernet Franc (Visit NC 2012; MacCracken 2011). Vinifera grapes are in high demand but are very pest and weather sensitive. The native varieties to North Carolina are the Muscadines (vitis rotundifolia) which include the grape Scuppernong (MacCracken 2011). Scuppernong was the first grape cultivated in the U.S. and is the official fruit of North Carolina (Visit NC 2012). The Labrusca-type American variety

is also common in NC which includes Catawaba, Concord, Delaware and Niagra. Native varieties have the ability to produce reliable harvests in intermittent weather and tolerate pests and diseases (Poling & North Carolina Cooperative Extension Service 2007). The Piedmont Region, delineated as Zone 2 in Figure 3.10, offers the most varied winegrape growing opportunities. The Mountain Region is considered a challenging growing site, but Vinifera and French-American hybrids can prosper here. Hybrids are a combination of disease resistant, hardy native American varieties with the quality and classic flavors of the Vitis vinifera that result in Chambourcin, Seyval Blanc, and Vidal Blanc (Visit NC 2012). Hybrids are less in demand but may tolerate most diseases, colder temperatures, and have a later initial bud break with secondary budding that follows. The secondary budding acts as a late spring frost insurance.

A crop of newly planted grape vines takes four to five years to grow before harvest for optimal production value (Belliveau et al. 2006). The average vine lifespan is around 50 years; however future climate change forecasts may severely alter this number. These forecasts create peril for the Mothervine, a 400-year old Scuppernong vine in Manteo on Roanoke Island, North Carolina, the oldest known cultivated grapevine in the nation (Visit NC 2012; Holland 2010).

3.2 History and Characteristics of North Carolina Viticulture

The number of wineries in North Carolina has grown immensely since the end of prohibition. Particularly in the past decade the number increased from 21 wineries in 2000 to over 100 wineries and 400 vineyards today (VisitNC 2012). Vineyards are not new to North Carolina; in 1840 it was the leading wine state producing more than every U.S. state combined (Poling & North Carolina Cooperative Extension Service 2007). According to the NC

Department of Commerce, there were 109 wineries formally established in 2011; each with varying acreage and profitability across the state.

The growth in the industry is continuing and every vineyard or winery is making a long term commitment and contribution to the local community. “The grape and wine industry in North Carolina is now worth in excess of $30 million dollars” (NC State University). Governor Bev Perdue stated that “the industry supported 7,600 jobs across the state, adding 1,900 jobs since 2005” (Rimerman & Co. 2011). The mountain region is presently home to Ashville’s Biltmore Estate Winery, which receives more than one million visitors annually and is ranked as the United States’ most visited winery (Rimerman & Co. 2011). The world’s largest Muscadine wine producer is located in the coastal region of North Carolina. Today, NC ranks ninth in wine and grape production in the United States and ranks sixth in tourism (Visit NC 2012). “Statistics alone do not adequately measure the intangible value the wine industry brings in terms of overall enhanced quality of life, limitation of urban sprawl and greater visibility for the state of North Carolina” (Rimerman & Co. 2011). It is clear that the NC wine industry is significant to the state’s overall identity.

CHAPTER 4: METHODOLOGY

This study utilized multiple methods to better understand winegrowers' sensitivity to potential climate changes in North Carolina. Exposure and sensitivity play a vital part in the degree of vulnerability. Different exposures determine a degree of sensitivity and sensitivity is the manner in which a system is impacted by a variable whether it is climatic or non-climatic and the system's responsiveness (Adger et al. 2007, Belliveau 2005). Qualitative methods, including web surveying and semi-structured interviews, can discover winegrowers' perceptions of risk. Research utilizing qualitative methods is the most effective way to investigate real world responses and lived experiences.

The analysis that follows, examined what factors influence a vineyard's vulnerabilities and the individual characteristics or experiences that shape each farmer's perceptions and ultimate decisions. A spatial analysis of winegrowers' responses can identify regional similarities or differences. To parallel qualitative responses, observed daily climate data are analyzed for the actual climate record. Physical measurements were used to parallel perceived risks and project trends into the future.

Using mixed methodology can develop a holistic understanding of the North Carolina Wine industry. It cannot represent the perceptions and experiences of all North Carolina wineries, but impacts, strategies and experiences from this representative sample could apply to other winegrowing regions.

4.1 Development of Web Survey

Potential web survey participants were recruited through convenience sampling. Many wineries were confronted initially at the largest multiregional North Carolina Wine Festival,

Saturday, May 26th, 2012 at Tanglewood Park, Clemmons, NC. Other potential participant emails were collected from NCwine.com. Other initial preprocessing included collecting basic information about each vineyard from the official website of each winery or vineyard registered with the state. Basic information consisted of the winery's address, vineyard acreage, the year of vineyard establishment, and contact information. The winery's address was used to geolocate its position in order to create a map of all 109 wineries in the state.

The web survey was created using Qualtrics survey software through East Carolina University and was distributed through email to 109 winery contacts. Wineries that outsource all of their winegrapes for production from somewhere outside of North Carolina or do not operate a vineyard were asked not to participate. The survey questions are multiple choice, check boxes, five-level importance scale questions, and very few open format questions to make it quick and easy to comprehend while providing insightful information. This format is easy and convenient for each grower to complete at his or her own pace. Growers were given two months to finish the survey and reminder emails were sent every two weeks. The completed surveys were stored in Qualtrics where basic statistics and question by question analysis is possible.

Producers were asked to describe basic characteristics including their role at the winery, number of years of experience in the wine industry, what year the current vineyard was established, number of acres, which winegrape varieties are currently grown, and the overall crop yield. Questions about production prompt growers to rank the importance of variables that impact a successful year. Questions about weather and climate express the level of risk that specific weather events and climate conditions pose to their vineyard. For this study, it is also important to ask if there are particular times throughout the growing cycle more at risk to each condition or event. Questions about climate change focus on experiences with changes in each

weather event or climate condition over the last 5 to 10 years. If a change is perceived, a follow-up question determines if growers experienced a change in frequency or intensity in each event or condition. Again, growers were asked to indicate particularly sensitive times in the growing cycle to changes in climate conditions or weather events. Finally, growers were asked to express their level of concern that climate changes will impact their vineyard in the future and if any preparations or adaptations have been made for potential impacts of climate change.

4.2 Interview Process

Interview participants were collected by cold calling and emailing owners and operators. Also, survey participants that agree to be contacted for further questioning were included in this database. A recorded, semi-structured interview was conducted with each participant for a period of one to two hours. All interview participants were asked to sign an informed consent document to ensure that participation is voluntary and any responses will be used for research purposes only.

Interviews investigated topics addressed on the web survey in greater detail. Interview questions focused on the objective to better understand the impact climate change presently has on viticulture in North Carolina. Growers were asked to describe their experiences with wine production and vineyard operations. Important aspects include history of the vineyard, characterization of successful and unsuccessful growing years, management practices and responses, external influences and concerns for the future. Growers were also asked to describe interactions with the NC government, other winegrowers and the market. An interview guide poses these topics as triggers for discussion of exposures and sensitivities and gradually incorporates weather and climate variables, as opposed to a biased and narrow discussion. This

method reveals the role of weather and climate in the context of the overall enterprise (Belliveau 2005).

The seasonal component of the wine process was taken into account when scheduling interviews. The summer growing season, May through August, and post-harvest season, October through December provided the greatest opportunity to arrange face-to-face interviews with each vineyard operator. Conducting each interview at each participating winery or vineyard location allowed for participant comfort, convenience and offered the possibility to learn more about the vineyard by observing the participant in their own environment (Flowerdew 2005).

Twelve interviews were conducted, including three from each growing region: mountain, western piedmont, eastern piedmont and coast. There is often criticism with research using small sample sizes. A common concern is the validity of the study and whether it is representative of the population. The logic behind interviews as a research method is not to be representative, but to understand the perceptions and experiences of individual winegrowers (Flowerdew 2005). Each participating vineyard has the opportunity to contribute valuable local knowledge that is only held by a few key individuals in the industry that no other observation or census data could provide (Hay 2005). Large questionnaires can reach a significant portion of the population but can sometimes have extremely limited explanatory power (Flowerdew 2005).

4.3 Data Analysis

Qualitative analysis focuses on winegrowers' beliefs, experiences and responses. The web survey results provide an understanding of important growing variables, weather and climate risks, experiences and spatial distribution of similar and contrasting responses. This

method sparks interest in the overall study and gathers basic perceptions to shape further interview questions (Flowerdew 2005).

To analyze the web survey results, each question is considered individually by defining the frequency of each response and calculating basic statistics. The characteristics of each owner, operator or vineyard may have an influence on responses to variables of risk or experiences with past climate changes. The t-test can assess whether the means of two groups, such as responses from experienced versus inexperienced growers, are statistically different from each other. The tested groups consisted of small wineries less than 10 acres and large wineries more than 10.5 acres as well as experienced growers involved in the industry more than 10 years and inexperienced growers involved in the industry for less than 10 years. P-values less than 0.05 (95% confidence level) were considered significant. An analysis of variance (ANOVA) represents an extension of the two-sample t-test for differences of means between more than two groups (Rogerson 2010). Three groups were analyzed using ANOVA. The first groups consisted of vineyards growing only vinifera winegrape varietals, only muscadine winegrape varietals, or a mixture of winegrape varietals. The second groups consisted of three viticulture suitability zones discussed further in Chapter 6. Again, any P-values less than 0.05 (95% confidence level) were considered significant.

For analyzing winegrowers' interview responses, each recording was carefully transcribed. Analysis of the transcribed passages followed methods of coding to make dialog organized and easily accessible. Sections of each transcribed response were organized by search terms or categories. These terms are based around key themes of exposure to which growers are sensitive, and factors that impact production strategies and adaptation. Descriptive coding based on themes reduces the amount of data by following along patterns stated directly by research and

those that emerge throughout the analysis (Hay 2010). An electronic codebook was formed around key words that jump-out of each passage, including: vineyard characteristics, weather variables, climate variables, pests and disease, practices and interactions, as well as future thoughts. Initial codes identify conditions, actions and categories, which come from research questions and the review of literature. This leads to interpretive codes, such as patterns, commonalities, relationships and variability in responses within region and between regions of North Carolina (Hay 2010). Other patterns and themes that develop from a winegrower's passage allow for an analysis of processes and the context of phrases, as opposed to discovering theory, meaning or the language behind each phrase. Typically, the objective of descriptive coding is to answer questions that begin with 'who, what, where, when and how' (Hay 2010). Coding is an analysis in itself and could ideally continue without limits to find every pattern from every angle. However the current scope provides an opportunity for future coding analysis and further research to take place.

4.4 Historical Climate Records

It is challenging to interpret the impact of climate changes through climate records alone. The qualitative results guide the selection and interpretation of climate data in this study. Climatic data of interest includes variables that survey and interview respondents indicate as high risk during particularly sensitive time periods. Annual mean minimum temperatures and annual mean maximum temperatures during months that growers specified were calculated.

Observed daily records were acquired from the State Climate Office (SCO) of North Carolina out of North Carolina State University. In order to examine a historical record for monthly and decadal change, a minimum of 30 years is climatologically acceptable. A linear

trend line is fit to the data to determine if climate variables show changes that winegrape growers are experiencing or not experiencing. One of the problems with using linear trends is climate changes will most likely be non-linear.

4.5 Mapping

The results of survey responses to specific questions of weather and climate risk were mapped using Geographic Information Systems (GIS) to show any clustering. GIS was also used to perform the proximity and spatial analysis. Ideally, a weather station located directly on each vineyard would provide a more accurate depiction of the microclimate and localized climate change but is not feasible within this study. Because there are no weather stations actually located on any winery's property having at least a 30 year record, the station closest to wineries involved in the survey or interviews was found using a proximity analysis. The near tool determined the distance from each winery to the nearest weather station, within a 10 mile search radius. All wineries that completed a survey or interview were considered in this analysis.

All NC weather stations with sufficient 30 year historical data were used to interpolate surfaces for interpretation. Interpolation is a method of representing the values of a function for a limited number of observations. Analyzing specific monthly observations from weather stations can provide insight into temperature trends for those specific locations, but cannot represent a region (Boyles and Raman 2003). Interpolation can estimate the surface values at unsampled points based on known values calculated from each surrounding weather station. Empirical Bayesian Kriging (EBK) method was used for spatial interpolation. Kriging is an interpolation technique in which the surrounding measured values are weighted to derive a predicted value for an unmeasured location. Weights are based on the distance between the measured points, the

prediction locations, and the overall spatial arrangement among the measured points. EBK differs from other kriging methods by accounting for the error in estimating the underlying semivariogram through repeated simulations (Pilz and Spöck 2007). The output surface is a smooth raster layer. This method is commonly used for irregularly spaced climate data (Boyles and Raman 2003). Other methods, including Inverse Distance Weighting, Global Polynomial, did not produce a surface similar to the previous viticulture suitability mapping.

In order to create the appropriate surface for interpretation, while avoiding a long processing time, the overlap factor was set to 1, the maximum number of points in each local station model was set to 100, and the number of simulated semivariograms was set to 100. Each surface was clipped to the shape of North Carolina. Trend values were interpolated to discover locations of decreasing or increasing temperatures. Recreations of climate maps (Fig. 3.4 and Fig. 3.5) were used to create viticulture suitability boundaries.

4.6 Dissemination of Results

A written and visual product will be provided for each participant in order to disseminate results. Again, no vineyard names will be used, only the size of vineyard and region or wine trail name will indicate connections to responses and strategies. A possible platform for sharing results is the North Carolina Wine Growers Association's webpage. This will provide an opportunity for winegrowers to share opinions, experiences, strategies, and hopefully improve future climate change defenses and overall vineyard production. The end results can be used to formulate action plans used by agricultural education professionals to help the producers adjust to potential climatic changes.

CHAPTER 5: SURVEY AND INTERVIEW FINDINGS

This chapter will present the results from both the web survey and semi-structured interviews. In order to preserve anonymity, specific participant or vineyard names will not be used; instead vineyards will be characterized according to their size and or growing region. The survey responses emerged out of a specific set of questions to better understand winegrowers' perceptions of risks and how they change throughout the growing cycle. Responses also reveal any significant changes observed by growers and their concern for potential future changes. Expressed risks and significant changes were analyzed based region, experience, acreage, and winegrape varietal to study any significant differences. Out of 109 wineries in the state, 95 own and operate a vineyard. Thirty-four respondents started the web survey emailed to these wineries. Of those that responded, the Coastal, Piedmont, and Western regions were each represented. Interview responses were an extension of the survey responses to further develop an understanding of winegrowers' perceptions, decision making and reasoning behind seasonality risks. 5 of the 12 interviewees also completed the web survey. The total sample consists of 41 responses from 34 survey respondents and 7 interviewees that did not take the survey.

5.1 Characteristics of Participants and Vineyards

5.1.1 Experience and Establishment

Many wineries in North Carolina are family businesses, passed down through each generation. A coastal grower proudly remarked, "I was taught by my father. He made wine, he made whiskey, he made beer." It is common to find lifelong farmers in the wine industry who had experience with other crops before planting vines. Some owners started vineyards in the backyard as a hobby and gradually elevated their production. An eastern piedmont producer said,

"I planted my first vineyard behind my house back." A few growers began their vineyard with no previous experience in the wine industry, starting with a business background and then seeking information about viticulture from literature, official resources, and the advice of other winegrowers.

Some winegrowers have earned their enology or winemaking bachelor's degree. There is currently a popular Viticulture and Enology program within NC at Appalachian State University. Others have received certificates related to vineyard operation and winemaking from NC's Surry Community College, Virginia Polytechnic Institute and State University (Virginia Tech) and University of California Davis (Cal Davis). Many use these programs as resources as well. Several owners also mentioned taking business classes or completing a business degree.

Producers either inherited or purchased a site that was open, previously cultivated, or required removing timber. Vineyards range in establishment from one to 43 years. The majority (53%) of the growers that responded to the web survey established a vineyard one to ten years ago (Fig. 5.1).

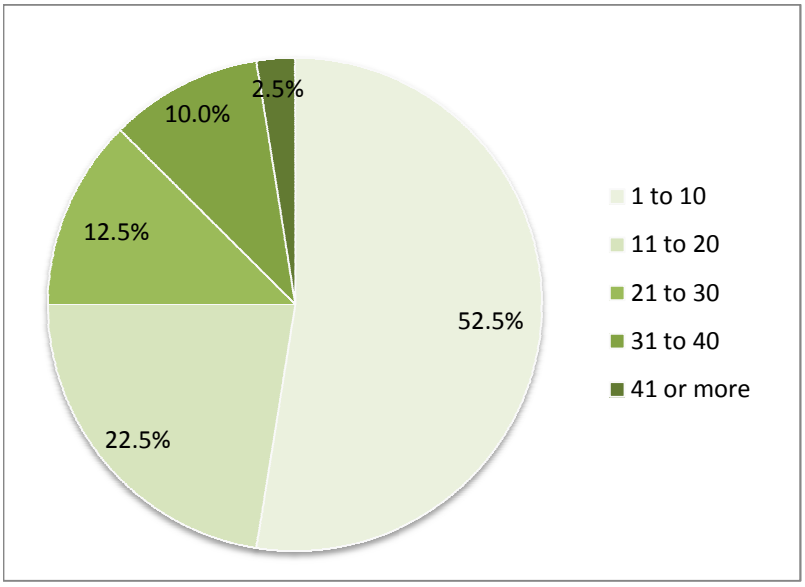

Figure 5.1: Number of years since vineyard was established (n = 41, consisting of 34 survey respondents, 7 interviewees not in survey)

The survey responses show that a cluster of vineyards, 78 percent, were established between 1999 and 2006. The pattern may be attributed to the Tobacco Transition Program Payments (TTPP), legislated in 2004, which provided annual installment payments or a lump sum to farmers who no longer desired to grow tobacco. The North Carolina Muscadine Guide indicates that, "Generally speaking, if tobacco has done well on the site, muscadine grapes should also do well" (Muscadine Guide 2003). One interviewee continues to produce a little tobacco in addition to winegrapes, corn, wheat, and soybeans.

Fifty-three percent of survey respondents have ten years or less experience in the industry and 47% of the respondents have more than ten years of experience (Fig. 5.2). North Carolina

continues to be considered a young industry, from a national perspective.

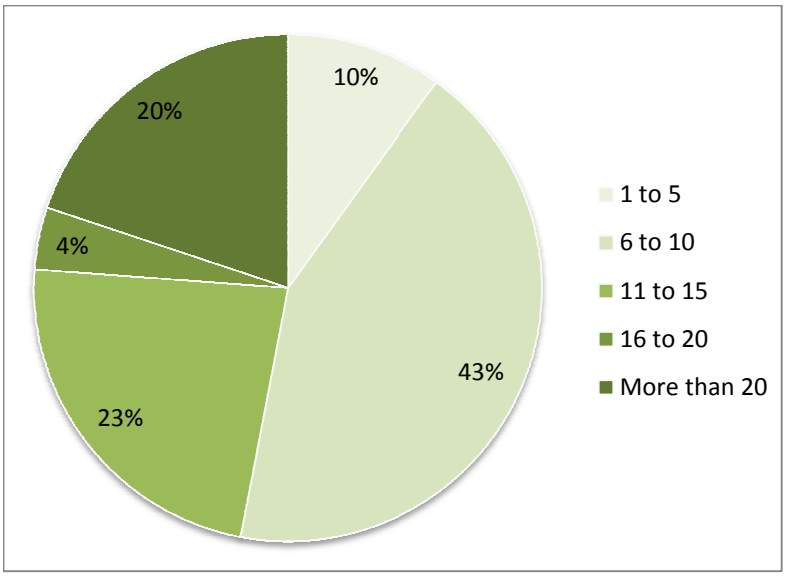

Figure 5.2: Number of years respondents have been involved in the wine industry (n = 41, consisting of 34 survey respondents, 7 interviewees not in survey)

5.1.2 Vineyard Acreage and Varieties

An acre of vines can potentially yield about one ton of winegrapes, starting three years after planting (Weber et al. 2003). One ton will go on to produce around 60 to 63 cases, or 720 bottles, of wine. After the fifth or sixth year, yield maturity is reached and the potential yield can be between three and six tons per acre (Weber et al. 2003). The majority of winegrape growers who responded to the web survey operate a vineyard smaller than 20 acres (Fig. 5.3). In this study, a small vineyard is considered between three and ten acres. Forty-four percent of survey respondents support grapevines on land less than ten acres. A medium size vineyard is between 11 and 30 and the larger vineyards can be well above 20 acres. Seventeen percent of respondents support a farm between 11 and 20 acres, while 39% support over 20 acres of grapevines.

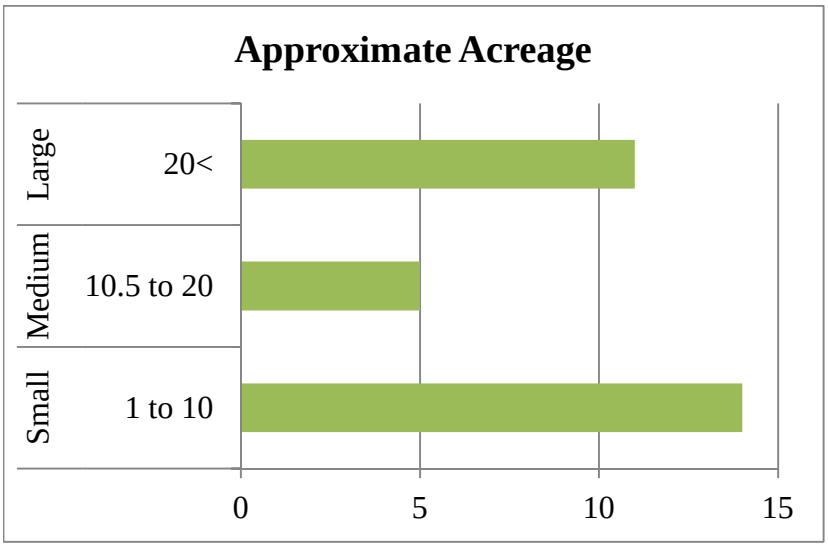

Figure 5.3: Acreage of vineyards in study

Some growers have slowly built up to the vineyards they have today. A small, eastern piedmont farmer struggled, "We worked up to it. I couldn't plant all that much at one time and take care of it. I would plant like one or two rows every spring" and another mentioned spending two years to plant 50 acres of grapes. Others began harvesting grapes commercially as soon as possible and as many as possible.

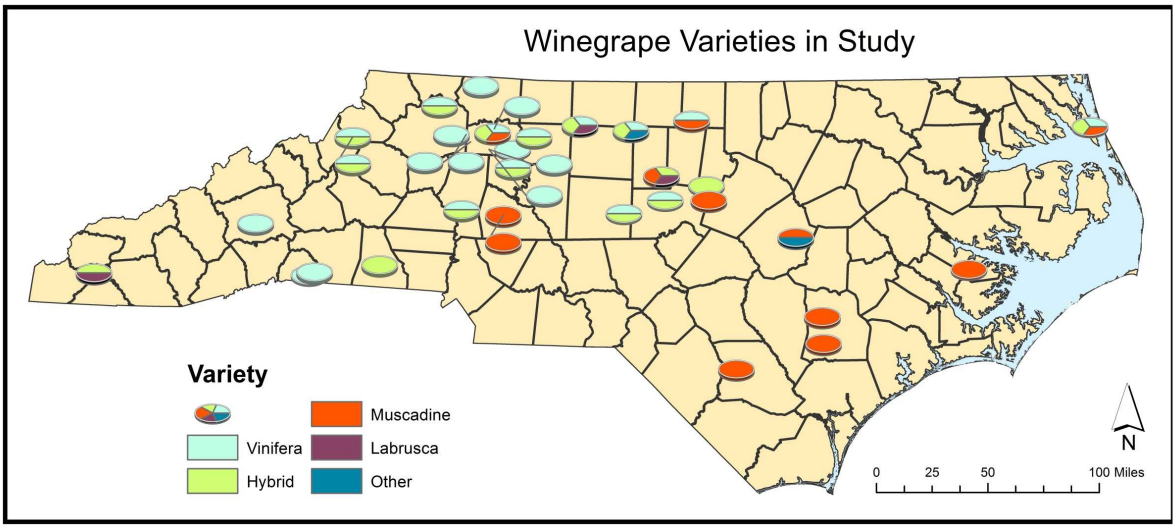

Figure 5.4: Winegrape varieties produced at each vineyard in the study

The web survey results indicate that muscadine varietals are grown closer to the eastern piedmont and coastal regions (Fig. 5.4). The classic Vitis vinifera winegrapes are consistently grown throughout the piedmont regions and sparsely throughout the mountain region. This pattern is consistent with the suitability map (Fig. 3.4). One brave coastal grower supports acreage of each variety on a medium sized vineyard, shown in the north eastern part of the state in Figure 5.4. This farmer said he chose to grow the sensitive viniferous grape simply because, "they're more valuable."

The most common variety grown among the survey respondents was one to five acres of French-American hybrids (Fig. 5.3). Interviewees were divided on feelings towards growing hybrid varieties. One mountain grower says, "Hybrids are cold hardy. Hybrids are insurance." Other growers avoid hybrids because they are perceived to have a lower quality. A very large mountain vineyard said:

> In the early 80's, we had hybrids like Savon Blanc, Vidal Blanc, and they were great producers. But the problem is our winemaker didn't like them, they're real acidic. You know, Yadkin valley and [here in the mountain] all we do is vinifera. It's so much smoother. Some of them do mess with hybrids a little bit, in case vinifera gets fried.

The wine market can be a major influence on the selection of a winegrape variety. For example, one grower said Pinot grigio, a vinifera varietal, is difficult to grow in this climate, "but we have it because we're Italian, you know pino grigio is the number one selling wine on the planet." Other growers told me some grape varieties were chosen for a vineyard simply because they are not very well-known, or because they cannot be purchased locally. The winegrape varietals chosen by each winery act as their identity and the number of acres dedicated to each variety determines the amount of labor and costs required. Each variety comes with a different set of challenges.

5.2 Overall Challenges

The first research question that this thesis sought to address is the extent to which farmers consider weather and climate issues to have an impact on their success. The wine industry is a unique agribusiness with risks associated with costs of inputs, the growing environment, the wine market and economy, technology, pest and disease control, and government policies. Survey takers were asked to rank specific variables by their importance to a successful year (Fig. 5.5). Each interviewee was also asked to discuss all aspects of a growing year including key challenges or variables that cause stress on their vineyard.

Survey respondents rank weather and climate, pest and disease control, and the growing environment as significantly important variables to a successful yearly enterprise. Every respondent indicated that weather and climate was either very or somewhat important. It received the highest percentage of very important, making it the most significant factor, discussed further in Section 5.3.

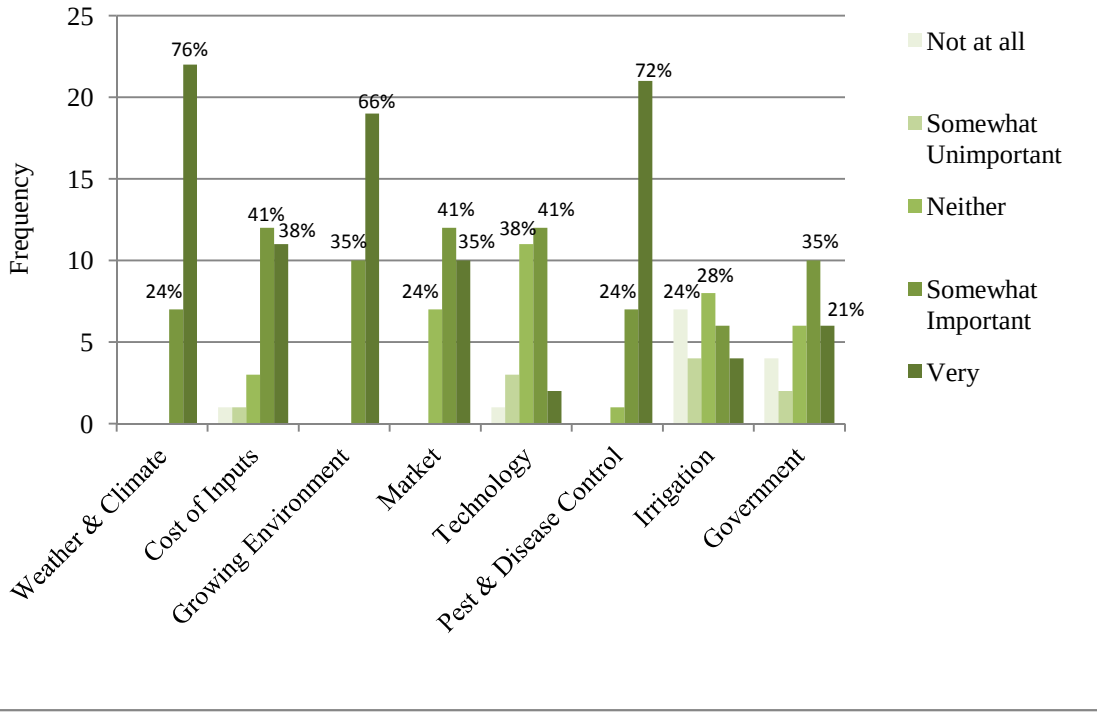

Figure 5.5: Growers' rank importance of variables on a successful year

5.2.1 Pests and Disease

Almost every grower considers pest and disease to be a very or somewhat important factor in their success. Seventy-two percent consider this to be very important, second only to weather and climate (Fig. 5.5). When talking with a very large mountain vineyard director, who deals primarily with the winegrape crop, about major challenges he said, "It's really weather and pests. The market is always going to be good. Every grape we get goes to [the winery] so we don't have to worry about the market." Another large grower in the western piedmont with a strong passion for farming believes, "The biggest challenge in North Carolina is the spray program [for powdered mildew] because we have such incredible humidity."

The timing of humidity conditions throughout the year determines the type of necessary disease prevention. A large piedmont grower's, "biggest concern in the vineyard, earlier in the

season is betryus, powdery and downy mildew, and then later on our main concern shifts to bud drops versus folio issues." As grape clusters grow larger, the space between each grape decreases and any moisture caught in-between is a potential breeding ground for mildew. "That becomes our priority to protect and anywhere that you have fruit that is not exposed to sunlight and air flow then that makes it easier for the mold to get in there and establish themselves" a producer indicated. Once you find mildew, it is too late; it will defoliate the vines. Often confused with powdered mildew is another disease called white rot that may result from hail storms. This shows up later in the season causing damage to the grape cluster.

Prevention is the best way to manage winegrape diseases. "We spray roughly every 10-12 days pretty much regardless, just because if you don't spray around here, even if you don't see it, you're going to have a problem," a western piedmont grower commented. Another piedmont grower with a significant history explained:

> One of the big challenges was chemicals, finding what to use right. When I started there was nobody in the business much in North Carolina. Nobody knew what to spray with. I got a lot of advice from the start up Surry Community College and the North Carolina Wine Growers Association helped me a lot because they suggested chemicals to me.

There may be a recipe for the right chemicals to use, but there is no recipe for when to spray. "You do not have a spray regimen but you have to stay on top of it," a western piedmont grower summarizes. This stressor requires a lot of farmers to be out in the field just about every day to check the vines, foliage and fruit.

Pest pressures include deer, birds and insects, which can spread Pierce's disease (PD). A small, eastern piedmont grower elaborates on PD pressures:

> From [the center of NC] over, you have a tremendous amount of pierce's disease. So, with a disease like pierces, there is no cure for it, and the only way it goes away is if there is a very cold period so the coldness will kill the bacteria. Which, from here east, it doesn't snow, it doesn't get cold. So that disease won't go away and it will affect the viniferas or the classical grapes.

Another frustrated farmer battling deer says, “one year they just ravaged it. In three days they can just clear out the entire vineyard.” He continues, “This year we put the netting up and now the birds are going at it. So we’ve lost just about half of the fruit out there with bird damage. I’ve got to use different netting next year.” In many vineyards, special netting is required on vines as fruit matures to sweetness, and it can become costly and labor intensive to install and move netting. One very large mountain vineyard invested in an eight-foot high electric deer fence around the entire property. A coastal grower has an opposing view on netting and simply takes the risk of pest problems:

> Some people in the mountains have fencing like a hard plastic mesh, but for our vineyard it doesn’t look good. We have to be aesthetically pleasing as well as functional because we have really good traffic off the highway. 60-70 mph traffic going past they want to see like a pretty vineyard rolling and to think I’d like to stop. They want to see something that looks good.

The birds and the bees can become a stressor when sour rot sets in and rotten berries become an attraction. An overwhelmed mountain grower experiencing a little rot said, “It’s always a chain reaction of stuff and once it starts you can’t hardly control it.”

Contrary to these responses, one interviewee that grows muscadine grapes believed, “We don’t have a disease problem here and the only pest that bothers us is Japanese beetles.” Another muscadine producer added that the native grape is thick skinned and produces antioxidants that act as a good immunity to many diseases that vinifera producers face.

5.2.2 Growing Environment and Irrigation

Most growers (66%) ranked the growing environment as a very important factor, with the remaining farmers ranking it as a somewhat important variable (Fig. 5.5). The growing environment consists of the vineyard’s physical microenvironment, including location, soil type, water table, slope, and elevation. One of the biggest stressors for coastal growers in this study is

the soil type. These growers prefer higher sandy soils at 18 feet above sea level over lower, black loam or silt-like areas at 10 feet above sea level. Piedmont and mountain growers worry more about selecting growing environments with North to South oriented slopes with open sun coming in and elevated areas to protect from frost.

Survey respondents were closely divided (Fig. 5.5) on the importance of irrigation or sources of water. Some growers have invested in an irrigation system on site as a backup. One large, coastal grower, with a large water tank on site, told me he has never needed to use it. Grapes thrive on hot, dry conditions and growers in North Carolina do not experience these conditions often. Drip irrigation or water reserves are used during dry periods.

5.2.3 Market and Economy

Seventy-seven percent of survey respondents believe the wine market is somewhat or very important to a successful growing year (Fig. 5.5). Interviewees who take part in every role in the enterprise are mainly concerned about the market and economy. A small, eastern piedmont grower points out,

> One of the things I learned early on is don't put all of my eggs in one basket. This is a tough economy. I'll tell you right now a lot of wineries are like every other small business, trying to stay on top of it, get creative to get customers through the door and spend a little bit of that disposable income.

Some businesses are not going to survive the current economic challenges. Farming is a business that is constantly changing. The market can switch to something new every day, and if growers do something right to the enterprise one year, it may be inconsequential the next year.

5.2.4 Costs of Inputs and Technology

Thirty-nine percent of growers indicated their costs of inputs, consisting of the cost of direct material, labor, and other overhead items devoted to wine production, are very important (Fig. 5.5). Twelve growers (41%) indicated these factors are somewhat important. Starting and maintaining a vineyard requires a significant capital investment. If a winery stays below a 10,000 case volume, inputs are usually more reasonable. One grower specifies, “Grape costs are pretty reasonable in North Carolina so if I do buy outside grapes I can get them at a price that offers me good value and doesn’t force me to pass along that cost to my customers.” Large vineyards that produce an optimum yield in a year may allow growers to increase profits by selling extra grapes.

The facilities associated with a vineyard range from cheaper Quonset huts or barns to expensive, extravagant villas, and tasting rooms. Tourism advertising is an important aspect of the costs of inputs for a winery. Several growers informed me that, “Those advertising signs you see on the highway cost anywhere from $20-30,000 for two signs in one spot; One going one way and one going the other.” Several producers choose to invest a significant amount of money into manicured and landscaped properties to cater to the tourist’s expectations.

Forty-one percent believe technology has somewhat of an importance to the success of the enterprise, while 37% of respondents have neutral views (Fig. 5.5). Technology may include tools for winemaking, pest and disease prevention, harvesting or general maintenance. Many of those interviewed do everything by hand and do not utilize large machinery; this includes harvesting and pruning, considered the most labor intensive tasks. Farms, especially larger acreage farms, with little technology will need to bring in more laborers during specific times of the year. Another winegrower said, “In the beginning I had to pay hand labor, I’d hire 10-15

Mexicans, hand pickers. My labor was running me $7-8,000 a week. That was taking all my money. So, I bought a grape picker for $150,000." Producers that utilize technology mentioned using bladder presses that can press tons of grapes. An interviewee recently purchased a mechanical pruner:

> Now we're all excited because they invented a little sleeve that follows up behind the grapevine [and] shoots the clippings to the middle of the vineyard. Instead of letting it fall down, and we would have to try and rake it, they mulch it and put it back in the vineyard after. So now we've saved some money because we have less labor there.

Every winery experiences business risks that parallel the vineyard risks. For example if a frost kills the buds, a western piedmont grower ranted, "we won't see that in the bottle and one thing people don't think about is that's money that was supposed to be for buying new equipment or being able to pay someone for 8 months." If the winegrapes are primarily impacted by an event or condition, the business will suffer secondary impacts.

5.2.5 Government

Thirty-five percent of growers (21) indicate the government is either very or somewhat important to success (Fig. 5.5).Those who do strongly express their opinion that government bureaucracy is a hindrance to their operation. One grower complained about, "way too much, useless and mostly unnecessary government involvement." Another grower said, "(government) increases cost to the consumer" and another strongly opinionated coastal producer informed me, "Agriculture is the crookedest bureaucracy in America and that's why I can't get any help from agricultural laws. I'll tell you how crooked it is, they have two[federal] offices in Las Vegas." Another large muscadine grower has experienced a long struggle with Federal tax fluctuations over time:

> Major risks are the same for any company right now, the taxation issues that we're unsure about. But for a company our size, most people think we don't mind paying a little extra but on the flip side we need to cut this waste out. So there's a lot of uncertainty for us financially so that's the biggest risk.

Changes in policy and permitting have hindered interviewees in the past. A small, eastern piedmont grower complained, "It took me over a year, eleven months actually, and I worked on it some everyday trying to get a permit. Yea there are plenty of taxes on everything and you have to have a lot of different permits and that costs money. The government wants to know everything." Another piedmont grower strongly said:

> I was the first winery they wanted to regulate under their jurisdiction and they wanted to throw all these zoning things at me, safety and AVA things that weren't necessarily required.
>
> They just wanted to make it more difficult, (saying) 'you're going to do it the way I want you to do it.' This is my second winery, don't tell me how to run a winery. We went back five times to get a building permit and they kept denying us.

Winemaking is a federally monitored agribusiness and each state has individual laws. Many producers accept that alcohol will always be closely regulated and taxed. Large vineyards may even face higher taxes and annual audits. Commercial wineries are required to license all laborers and renew certification every five years. These growers accept government monitoring as a part of the business but one complains:

> If five bottles go missing out of 10 million then they won't leave. Then they'll probably fine you so that's how crazy it can get if you don't write everything down. We keep records of everything we spray, everything we buy, and when we do it. It's probably going to get worse too. It really tightened up after 9/11.

Other producers view the government as an important necessity referring specifically to extension agents and local agriculture agencies that help with marketing. "That helps out because you have a lot of people who can't afford to be out doing marketing themselves. It's a communal marketing sales effort so everybody pools their money so they can get more done than trying to

market their individual brands," a grower informed me. As the NC wine industry grows in size and recognition, perceptions of government importance may change.

5.3 Weather and Climate Variables

All respondents perceive weather and climate as somewhat or very important to a successful growing year (Fig. 5.5). To identify specific weather and climate risks, growers were asked to rate their vineyard's level of risk to excessive rainfall, insufficient rainfall, high temperatures, low temperatures, high humidity, high wind, hail, and severe weather. Variables that respondents ranked as high risk factors are analyzed further through localized case studies in Chapter 6.

At least, 35% of respondents identified each of the weather events or conditions as a strong or very strong risk, showing that all are significant stressors for the NC viticulture industry. According to the respondents, the weather event presenting the greatest risk is excessive rainfall with 22 respondents ranking it as strong or very strong. This was closely followed by hail (19) and severe weather (18). Three additional weather events were viewed by respondents as fairly strong risks; low temperatures (15), high temperatures (13), and humidity (13). The lowest risks were perceived to be insufficient rainfall (11) and high winds (10).

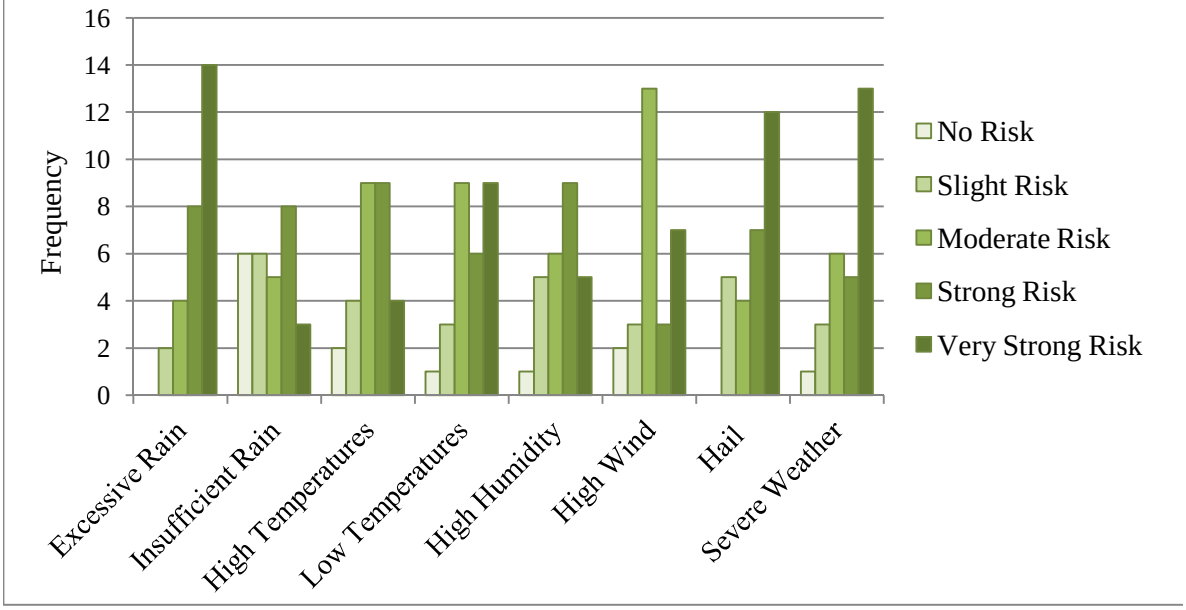

Figure 5.6: Growers' Perceptions of Weather and Climate Risks

5.3.1 Factors Influencing Risk Perceptions

Perceptions of risk were examined for differences based on the location and characteristics of vineyards. First, a t-test assessment was used to compare both vineyard acreage and grower experience to the survey responses for each risk factor. Therefore, for this group of winegrowers there is no correlation between the vineyard size and perceived weather risks or between length of experience in the industry and perceived weather risks.

Next, an ANOVA test was used to examine both location and grape varietals. Variation based on location was assessed by dividing growers into Zone 1, Zone 2 and a combination of Zone 3 and 4 (based on an updated suitability map to be discussed in Chapter 6: see Fig. 6.17.2). The variation between survey responses to weather risk and winegrape varietals, consisting of 100% vinifera growers, 100% muscadine growers, and mixed grape growers, was also assessed. Resulting p-values for both assessments are not significant based on a 95% confidence level,

with one exception. This means that in general there are not significant differences according to winegrape varietal or suitability zones.

Responses to insufficient rainfall risk do show significant differences, both by region and varietal ($p = 0.01$). Many growers in Zone 1 produce 100% muscadine winegrapes. The mean response from both groups indicates these growers perceive lack of rainfall as a strong risk. The majority of respondents in Zone 2 produce mixed varietals. The mean response from these groups indicates insufficient rainfall is perceived as a moderate risk. Almost every grower in Zones 3 and 4 produces 100% vinifera and the mean response suggests lack of rainfall is a slight risk. In other words, insufficient rainfall risk decreases as you move from East to West across NC. Eastern growers may perceive drought as a higher risk because, since rainfall is regularly received, there may not be an irrigation method in place to combat drought. Several survey respondents from Zone 2 and 3 specify that irrigation is established, leading to lower risk.

5.3.2 Seasonality of Risks

Growers were asked in the web survey to specify particular times throughout the growing season where they believe their vineyard is more at risk to weather and climate events and conditions. The most commonly identified seasonal risk was excessive rain in August and September (Table 5.1). There are also seasonal differences in temperature risks. Winegrowers in NC want rainfall in the beginning stages of growth during spring months and very little rainfall as grapes reach maturation. Hail during the growing season is also a risk especially June through September. Interviewees explain that high temperatures are more risky throughout the summer, particularly during August. High humidity is also viewed as a significant risk from May through September. Low temperatures are perceived as a risk January through April. Thirty-two percent

expressed that throughout the entire year their vineyards are at risk to severe weather. Precipitation, high temperatures and low temperatures are examined further in a monthly case study in Chapter 6.

	Percentage												
	All Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Excessive Rain	9%	3%	3%	9%	15%	21%	12%	18%	62%	56%	24%	3%	3%
Insufficient Rain	9%	0%	0%	6%	24%	27%	29%	15%	12%	3%	0%	0%	0%
High Temperatures	6%	9%	12%	9%	6%	9%	21%	32%	38%	21%	3%	0%	0%
Low Temperatures	12%	32%	27%	38%	35%	12%	0%	0%	0%	0%	0%	9%	21%
High Humidity	3%	3%	3%	0%	24%	38%	41%	47%	50%	41%	18%	3%	3%
High Wind	15%	3%	3%	3%	12%	12%	24%	29%	38%	38%	18%	0%	0%
Hail	15%	3%	3%	6%	29%	35%	41%	47%	47%	41%	12%	3%	3%
Severe Weather	32%	0%	0%	9%	9%	12%	27%	32%	35%	27%	15%	3%	3%

Table 5.1: Percentage of responses to survey question: Any particular time(s) in the growth cycle more at risk to weather and climate events and conditions?

Responses to seasonality of risks show some variation according to principle grape varietal. Vinifera and mixed winegrape growers have a much higher concern for high humidity and high temperatures throughout the summer than muscadine growers (Table 5.2.1-5.2.2). Muscadine grapes are more heat and disease tolerant. Muscadine and mixed grape growers perceive high wind in August and September as a higher risk than vinifera growers (Table 5.2.3). A higher percentage of muscadine producers indicated the entire year as a concern for severe weather, whereas vinifera growers have more concern only in August and September (Table 5.2.4). Muscadines are grown along the coast where severe weather and high winds are more frequent. Muscadine growers are also more concerned about receiving little rainfall in April, May and June, than vinifera or mixed winegrape producers due to the lack of irrigation use (Table 5.2.5).

Percentage													
	All Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
100% Muscadine	0%	0%	0%	0%	14%	14%	14%	29%	14%	14%	0%	0%	0%
100% Vinifera	0%	0%	0%	0%	33%	56%	56%	67%	78%	67%	22%	0%	0%
Mixed	8%	8%	8%	0%	31%	54%	62%	62%	69%	54%	31%	8%	8%

Table 5.2.1 Seasonality of High Humidity

Percentage													
	All Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
100% Muscadine	14%	0%	0%	0%	0%	14%	14%	0%	14%	14%	0%	0%	0%
100% Vinifera	0%	11%	11%	0%	0%	0%	22%	56%	56%	22%	0%	0%	0%
Mixed	8%	15%	23%	23%	15%	15%	31%	46%	54%	31%	8%	0%	0%

Table 5.2.2 Seasonality of High Temperatures

Percentage													
	All Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
100% Muscadine	0%	0%	0%	0%	0%	0%	0%	43%	71%	71%	29%	0%	0%
100% Vinifera	33%	0%	0%	0%	11%	22%	33%	22%	11%	11%	11%	0%	0%
Mixed	15%	8%	8%	8%	23%	15%	38%	38%	54%	54%	23%	0%	0%

Table 5.2.3 Seasonality of High Wind

Percentage													
	All Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
100% Muscadine	57%	0%	0%	14%	14%	29%	29%	29%	29%	29%	29%	0%	0%
100% Vinifera	22%	0%	0%	11%	11%	11%	33%	56%	56%	33%	11%	0%	0%
Mixed	38%	0%	0%	8%	8%	8%	31%	31%	38%	31%	15%	8%	8%

Table 5.2.4 Seasonality of Severe Weather

Percentage													
	All Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
100% Muscadine	14%	0%	0%	29%	57%	57%	57%	29%	29%	0%	0%	0%	0%
100% Vinifera	0%	0%	0%	0%	11%	22%	33%	22%	22%	11%	0%	0%	0%
Mixed	15%	0%	0%	0%	23%	23%	23%	8%	0%	0%	0%	0%	0%

Table 5.2.5 Seasonality of Insufficient Rainfall

Over the course of a growing season, it may be difficult identify the impact of any particular weather event. A large producer remembers a bad year: “You have to wait until you

pick it. Your grapes can look wonderful and you start harvesting them, because we've got 60 acres, especially in our vineyard you'll [find one] section did better than [another] section." In addition, each grower may perceive the meaning of each weather and climate risk differently. For example, excessive rain may be perceived as excessive rain amounts or excessive rain days. High wind, hail and severe weather may have some overlap in meaning to respondents.

5.3.3 Rainfall

Precipitation is an essential part of any crop but too much rainfall at the wrong time can significantly affect quality and crop yield. Excessive rainfall is perceived by survey respondents as the highest vineyard risk indicated by survey respondents (Fig. 5.6). One grower told me, "The most critical part about rain is it doesn't matter so much that it rains, it's the timing of the rain in relation to fruit maturity." Excess water during pre-bloom through blooming will produce excessive shoot growth and leaf canopy, resulting in poor fruit set or delayed ripening (Poling & North Carolina Cooperative Extension Service 2007). Winegrapes are particularly sensitive to rainfall during verasion and harvest. Again, survey respondents specify August and September as a particular time in the growth cycle more at risk to excessive rainfall (Table 5.1), when verasion usually occurs and harvesting practices begin. A large, coastal grower who described how detrimental excessive rainfall can be during this time period said, "Too much rain is bad because the grapes will just about fatten up and split and their sugar content will drop, [juices will be] watered down. He continued, "But it's really an issue of the excess rain will plump up the clusters and rub up against each other and then they rot. Then we get sour rot and then once you have sour rot it just keeps going because it's an opportunist infection. Turns the grape into

vinegar and drips down and takes over." A small, eastern piedmont grower expresses his frustration:

> You can deal with a rolling thunderstorm, but when you have these large geographical climate changes, there's not much you can do about it. So, you're fighting that and it's a timing issue. [If] you get an inch of rain, you're going to set yourself back a week and then [if] another storm comes in and gives you another inch of rain, it's going to set you back another week. So, you just lost three weeks right there, almost a one month delay. [The grapes] need that third week just to make up for [too much rain].

To ensure better quality, winegrowers do not want to pick unless the fruit is as ripe as it needs to be, considering all factors. Growers must maintain a balancing act to avoid damage; keeping a close watch on the weather and forecasts to decide when to pick and when to leave fruit on the vine. A frustrated piedmont grower said, "Every time we've thought about waiting another day [to pick], we've been bit in the ass, but with the short crop that we had we couldn't afford to take that chance." He added, "We could literally get 5 inches of rain in an hour or two that could ruin the entire crop. Makes me want to put up a 42 acre tent!" Often, periods of constant cloud cover, can be just as detrimental as rainfall by preventing the normal photosynthetic generation of vines.

Mapping responses by the participant's location provides an opportunity to discover spatial patterns (Fig. 5.7). The cluster of respondents in the Yadkin Valley, shown in the area of detail, are divided between those considering rainfall a moderate to high risk and those considering it a slight to non-risk. This emphasizes the micro scale features of each vineyard site that increases or decreases vulnerability during excessive rainfall conditions.

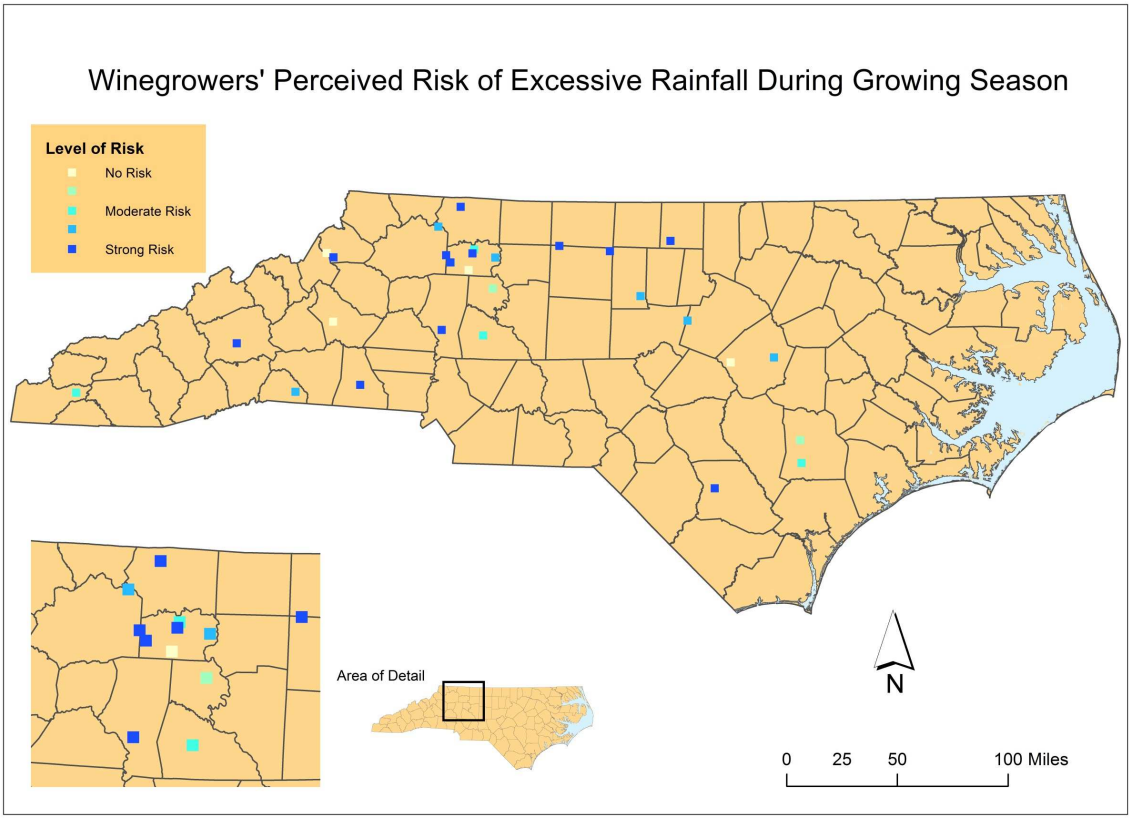

Figure 5.7: Visualizing survey responses to excessive rainfall risk

Overall, survey respondents believe insufficient rainfall is a lower risk factor. Ideal conditions include very little rainfall on a vineyard in NC. A small, mountain grower says, "There's no doubt in my mind that we don't need irrigation. A lot of rain is not good." Drought is positively received by all North Carolina wine producers in this study and one producer even says, "We love droughts. And we tell people in California, [who] get almost no rain." Many mention years of drought are associated with some of their best wines. Backup drip irrigation or retaining ponds continue to be necessary on NC vineyards because "the grapes will just shut down if it's too dry and the crop or fruit that you have won't materialize," one grower informs me. Again, timing of insufficient rainfall is important, a coastal grower points out, "Drought can be a problem. You want a dry August. We've had issues, your berry size is smaller, sugar levels are great but you don't have a lot of your yield, juice yield is way down." Young vines also

require more irrigation than mature vines but most growers believe it is usually provided for naturally. Most survey respondents indicated higher insufficient rainfall risk throughout the growing season but particularly in April through July (Table 5.1).

5.3.4 Severe Storms and High Wind

Forty-five percent of survey respondents perceive severe weather events as a very strong risk to their vineyard, and the majority of survey respondents perceive wind as a moderate risk factor (Fig. 5.6). Row orientation and the time of the growing season can increase or decrease risk. A coastal grower mentions, “When the hurricane comes through, it doesn’t blow so many vines down, especially if it’s early in the season.” After foliage comes out, strong winds “just break the post and the vine creates a canopy so the wind hits it and pushes it over and then it hits another one.” This farmer remembered rows and rows of grapes lying down, which he had to raise up in a week’s time or the ground would rot the grapevine.

A large, coastal grower who had a devastating experience with strong storms said, “Hurricanes and all of that destroyed the winery and the vineyard at one time. This past year [storms] took 80% of my crops. But a few years before that [storms] almost completely destroyed my whole vineyard.” He told me just over 60 acres were flat on the ground. He continued, “These [muscadine] grapes will come back if you have hurricane damage even though you lost everything last year, that’s just tough turkey.” Storm and hurricane damage may result in the decision to purchase grapes or juice from an unaffected area. Severe weather can affect the entire state, a region, one vineyard and not another, or even a part of the vineyard. Tracking these systems can be a major stressor for farmers.

5.3.5 Hail

Hail can have a detrimental effect on winegrapes and can be a risk factor throughout the entire growing season. Forty-two percent of respondents perceive hail as a very strong risk (Fig. 5.6). The coastal respondents believe hail to be a strong risk but may not experience hail problems as often as vineyards in the piedmont and mountain region. A large, mountain grower with very strong hail risk commented:

> Nothing you can do about hail. The hail storms are so scattered. This year we got hit by that hail storm and then we had frost before that. I've never seen a hail storm this bad my whole life. It's been a tough year so now last year we had about 250 tons, now we're going to have about 50. It knocked shoots off, knocked clusters off, just a disaster. We lost like 90%.

Hail storms and their severity are very difficult to forecast and farmers often feel powerless.

5.3.6 High Temperatures and Humidity

Overall survey respondents (64%) perceive high temperatures as a moderate or strong risk factor (Fig. 5.6). Growers indicated that risks are greater in July and August (Table 5.1), when extreme high temperatures can produce high sugar levels or grapes will fall off. One grower expresses what he has experienced recently with the rapid onset of very high temperatures and dry conditions: "The grapes get really dried out. I had no problem sweating the heat or any kind of weather until it got so hot this summer and it did it quickly that it dried the ground out real quickly and I happen to have water problems at the same time." He continues to discuss how lacking an irrigation system or a properly working system during extreme heat is very stressful. Hot and dry conditions are ideal for the month of August in NC, but without some form of irrigation berry size will be smaller and yield will decrease.

As discussed in Chapter 3, the diurnal temperature shift is important to a resulting wine's quality and complexity. A coastal producer struggles with, "a lot of nights [remaining above] 75°F. During the day if it's 85 or 90°F, [I] wish it could be like 65°F at night." Vineyards at higher elevations do not experience this problem because there is a large day to night temperature differential (Fig. 3.7).

The responses to high humidity are very scattered between slight and strong risk. As previously discussed, the timing of humidity conditions throughout the growing season determines the type of risks involved. Fifty percent of survey respondents believe August is a particularly sensitive time in the vineyard to experience high humidity conditions (Table 5.1). One coastal grower comments:

> Our biggest issue is the humidity. It gets down into the high 70's at night [in July and August] and the humidity is through the roof and then we get a heavy dew and you walk around in the vineyard at 2 o'clock in the afternoon the next day and there's still dew on the ground. That's just nothing but a breeding ground for mold and mildew.

Humidity is one of the biggest challenges for many growers and can increase costs and labor as more frequent spraying is required. This is a factor unique to the eastern United States that the west coast, including California vineyards, does not have to consider during the growing season.

5.3.7 Low Temperatures

Survey respondents (54%) perceive low temperatures as a strong or very strong risk. Thirty-two percent consider low temperatures a moderate risk (Fig. 5.6). Rapid drops in winter temperatures or extreme low temperatures could injure vines, particularly Vitis vinifera varieties. Interviewees welcome cold winter temperatures to prevent pierce's disease.

If a mild winter is followed by late spring frost in May with several days of low temperatures in the teens, one grower says, “nothing that sensitive is going to survive. The whole place turn(s) brown. And that happens.” Frost susceptibility across the state is varietally dependent based on budbreak, more so than anything else. If a varietal has an early bud break and late frost occurs in May, there will be problems. A small, eastern piedmont grower elaborates:

> My concern is when the threat of frost has gone away. So that’s a major concern for this far east and this far south. We had bud swell and we had some shoots coming out and we got a frost at night and some of the fruit over there shows frost damage on it. I mean I had foot and a half growth by then. Once it gets below 28°F, there’s not much anyone can do.
>
> Hopefully the damage isn’t going to be that bad or you can recover over the next year or so. But yea we lost about 3,000 vines then, slowly back planting now. We’re buying a lot of grapes from growers right now because we’ve had a lot of issues with growing and the late freeze.

The mountain region regularly experiences frost, usually at the beginning of April and sometimes as late as mid-May. A large mountain grower said, “I’ve been here 31 years and we’ve had a frost every year, guarantee.” For this reason, mountain producers try to choose varietals with later bud breaks. For varietals that do break in April, wind machines or water spraying can be used to decrease frost vulnerability. If shoots are too long, spraying water may cause them to freeze and break off but the buds will die if no preventative measures are taken. Most vines have a primary bud, secondary bud, and tertiary bud. When the primary bud dies, there will still be bud growth but will not provide as high of a yield.

5.4 Perceptions of Climate Change

Near the end of each survey, respondents were asked if they had experienced any changes in weather and climate events or conditions over the past 5 to 10 years. Figure 5.8 shows that

most growers indicate changes in high temperatures. Interviewees were asked what specific changes in events or conditions have impacted the vineyard since establishment.

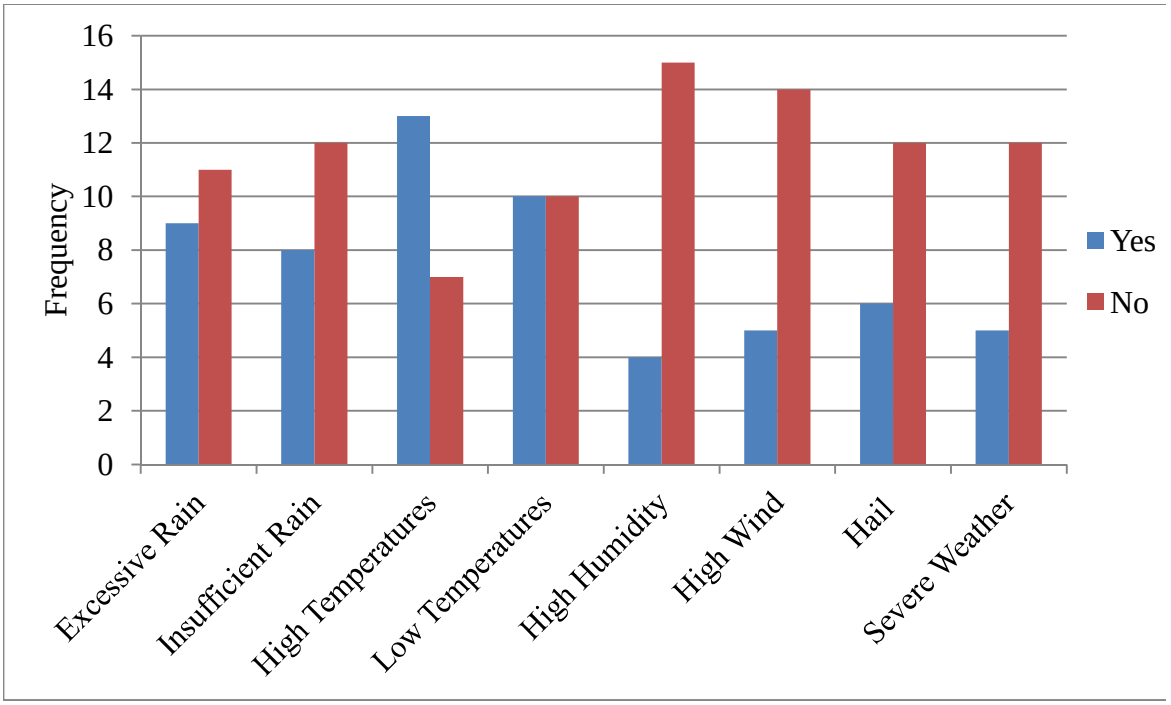

Figure 5.8: Growers experiencing changes in weather events and climate conditions

Forty-four percent of smaller vineyards have experienced changes in any weather and climate variable and 38% of larger vineyards indicated they have experienced changes. Thirteen respondents (65%) believe to have experienced changes in high temperatures and 73% of the more experienced winegrowers have experienced changes in high temperatures. A grower from the mountain region said, “Now we’re getting warmer in the summers. This year we were up to 97°F. And I was born and raised here. In the 80’s, 60’s and 70’s we never got above mid 80’s. It’s increased at least 10 degrees.”

Responses are split on experiences with changes in low temperatures. Most interviewees mention low temperatures are changing. A large, mountain producer recalls:

> In the winter, most of them it gets down below 5 degrees Fahrenheit which years ago we were always cold and winters started warming up. Three years ago we had 48 inches of snow. Two

years ago we had 36. Last year we had 2 inches total so that's how much difference. In the 60's we always had snow. We had tons. We would have a foot of snow and it would get down to zero, we'd get another foot of snow, down to zero.

Overall, there have been fewer experiences with changes in high humidity, high wind, hail and severe weather. Consistently large vineyards (acreage > 20) have not experienced changes in high humidity. These weather factors are difficult to measure and record over time. The majority of survey respondents believe rainfall conditions have maintained a constant intensity or a higher intensity. Respondents are the most concerned about changes in excessive rainfall throughout the summer months. Table 5.2 shows that August continues to be perceived by survey respondents and interviewees as a sensitive time in the growth cycle to any changes in excessive rainfall.

	Percentage												
	All Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Excessive Rain	0%	0%	0%	0%	3%	6%	6%	24%	41%	24%	10%	0%	0%
Insufficient Rain	6%	0%	0%	0%	3%	6%	24%	10%	3%	0%	0%	0%	0%
High Temperatures	0%	6%	6%	10%	3%	6%	24%	17%	21%	10%	3%	3%	3%
Low Temperatures	3%	24%	6%	14%	24%	6%	0%	0%	0%	0%	0%	3%	14%
High Humidity	0%	0%	0%	0%	0%	10%	14%	10%	10%	0%	0%	0%	0%
High Wind	3%	0%	0%	6%	3%	3%	3%	10%	14%	10%	3%	0%	0%
Hail	0%	0%	0%	6%	10%	17%	24%	17%	10%	10%	6%	0%	0%
Severe Weather	6%	0%	0%	0%	0%	3%	10%	6%	3%	3%	0%	0%	0%

Table 5.3: Percentage of responses to survey question: Any particular sensitive time(s) in the growth cycle to changes in weather and climate events and conditions?

Figure 5.9 shows the number of responses to questions about experiences in changes of frequency with each weather and climate event or condition. Growers considerably agree that they have experienced more frequent high temperature conditions and 60% of survey respondents have experienced more frequent insufficient rainfall conditions. Survey respondents have almost evenly divided beliefs that rainfall conditions have changed in frequency. An

interviewee informed me that his vineyard experiences the "same pattern. [Every] ten years, you have three heavy rain years, three drought years and four perfect years maybe."

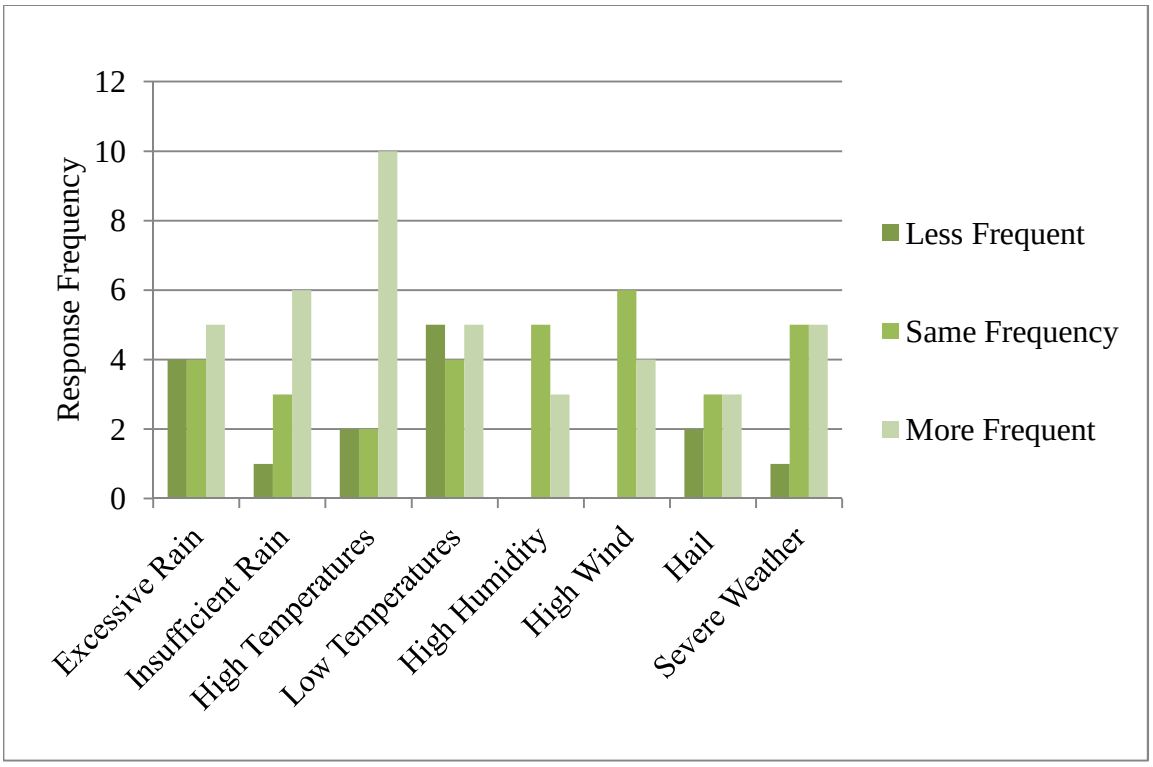

Figure 5.9: Growers' perceptions of changes in frequency of weather events and climate conditions

Fewer respondents have experienced changes in the intensity of weather and climate events or conditions (Fig. 5.10). 63% of growers have experienced more intense severe weather over the past 5 to 10 years. Almost all survey respondents that answered the question on climate changes indicate high temperatures becoming more frequent and responses vary between the intensity of high temperatures staying the same or increasing. This may suggest a change in the growing cycle as one grower mentioned, "I feel like obviously we're getting warmer. I do know that because our harvest season has moved up."

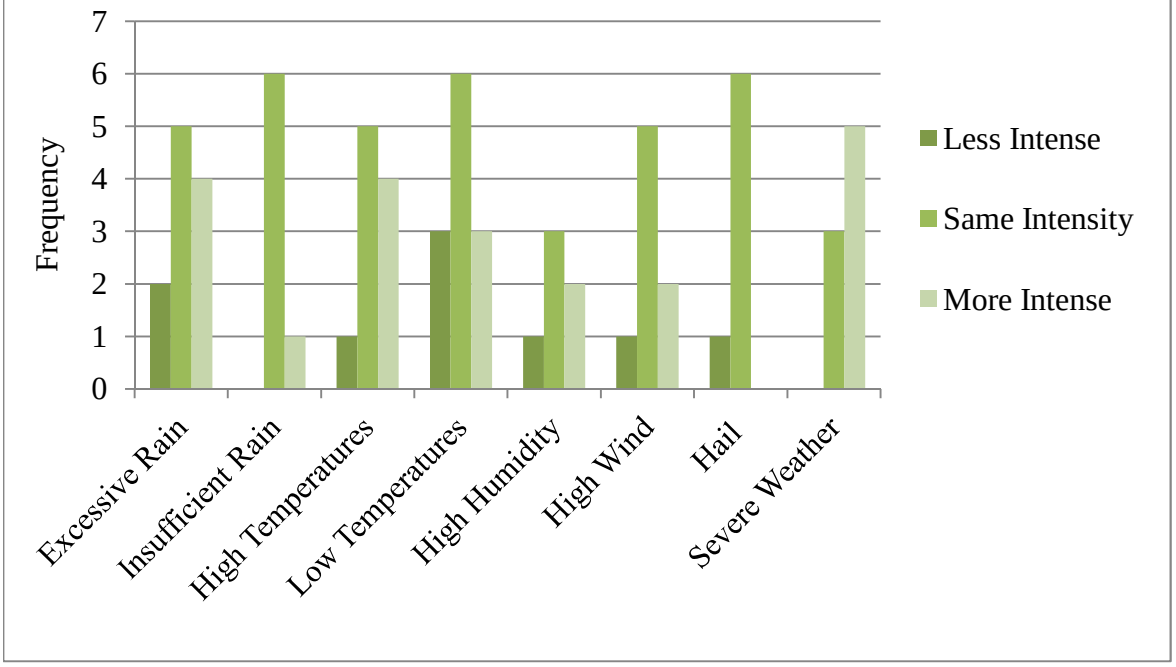

Figure 5.10: Growers' perceptions of changes in intensity of weather events and climate conditions

Finally, surveyed growers were asked the level of concern they have that climate change will impact their vineyard in the future. Twenty percent of winegrowers are very concerned about potential climate change impacts (Fig. 5.11). Twenty-four percent are somewhat concerned, 32% are slightly concerned, and 24% are not at all concerned that climate change may impact their vineyard in the future. A mountain producer said, "Normality wise this is a good place climate wise." But events and conditions do not always follow the norm. If potential future climate changes produce further challenges, a survey respondent emphasizes that, "We must adapt. We have no control of the weather." The reason most growers are not very concerned is because most did not express having experienced any changes in weather variables except for high temperatures.

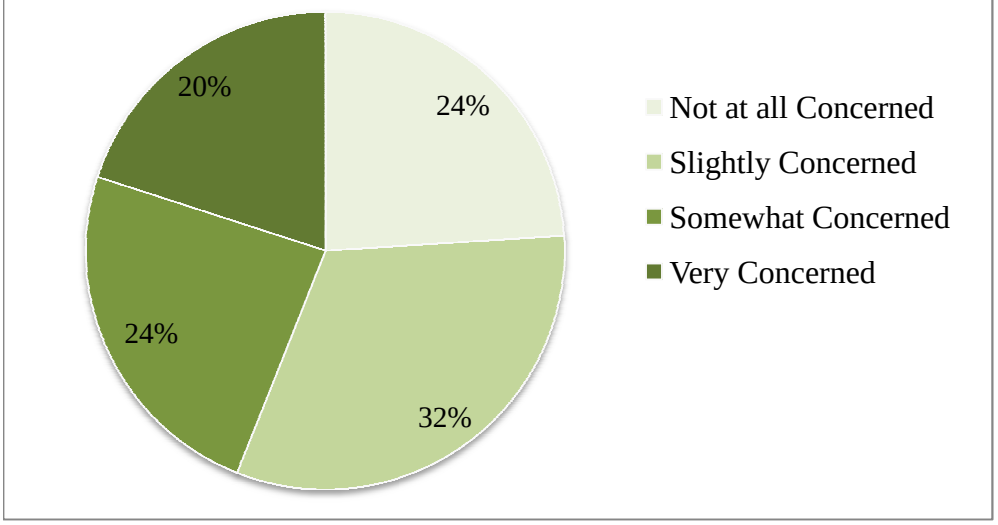

Figure 5.11: Growers' level of concern for future climate change impacting their vineyard

Growers recognize that climate changes may not be quick and dramatic. A coastal grower lightly commented: "Eventually if the heat keeps building up, all this area will be under water again up as far as Greenville and we'll have waterfront property." In a generally sense, "no year is ever the same," a large, western piedmont grower believes. Many survey respondents commented on what specific preparations and adaptations they have developed, discussed further in Chapter 7.

Many interviewees were skeptical about climate change and global warming. An experienced coastal producer believes, "everything goes in cycles and we're not getting anything different that hasn't been here before. Some idiots like Al Gore say we're having a global warming. It's happened before." Another grower from the piedmont region agrees, "That's a bunch of baloney. It's political, that's exactly what it is." He is not at all concerned with climate change and believes, "that the good lord is going to give us what we need. I know what I should be doing with the wine if things change for the worst." From the mountain region, a large mountain vigneron adds, "Everyone says it's global warming. I think it's just weather change.

It's always been changing." These perceptions are coming from vineyard operators and owners that have been involved in the industry well over 30 years. Most of the producers I talked to are very reluctant to believe the media hype and recent studies. One grower elaborates:

> I believe that there have been statistically significant changes in climatic recordings over the last 50 years. But I don't know if those changes would be significant over the last 200 years. Certainly not over the last 1,000 years that humans have been around. We are here trying to make a decision that will have far reaching effects based on 2% knowledge.
>
> To me, that is putting the cart before the horse. I don't know a scientist anywhere who would be willing to make a decision that would have such far reaching effects based on such a limited data pool. Obviously there's more out there that we don't know than we do.

Clearly, there are strong opinions and similar thinking within this group of winegrowers. The survey and interview respondents weighed their experiences against what they hear to make decisions. If a producer has a strong concern for future climate changes, this does not necessarily mean that changes on the vineyard will take place. Conversely, unconcerned growers, who believe climate change and global warming are simply politically charged notions, may already be making adjustments to their growing practices.

CHAPTER 6: CASE STUDIES AND SPATIAL ANALYSIS

NC winegrowers in this study identify weather and climate as the most important variables to consider. Based on survey and interview findings, precipitation and temperature are strong determinants of a successful or unsuccessful season. Timing of specific rain and temperature conditions within the growing cycle is crucial. Analyzing current climate trends for variables expressed by growers as strong or very strong risks at important times in the growing cycle may reveal changes that could potentially affect the NC wine industry and alter site suitability.

Daily observations of precipitation, maximum temperature, and minimum temperature were collected for a 30 year time scale, January 1982 to December 2012, from the National Weather Service Cooperative Observer Network (COOP). There is a COOP station for almost every county in North Carolina. The proximity analysis narrowed down which COOP stations are closest to the wineries involved in this study (Fig. 6.1). Stations with incomplete data for the time scale had to be eliminated from the case study.

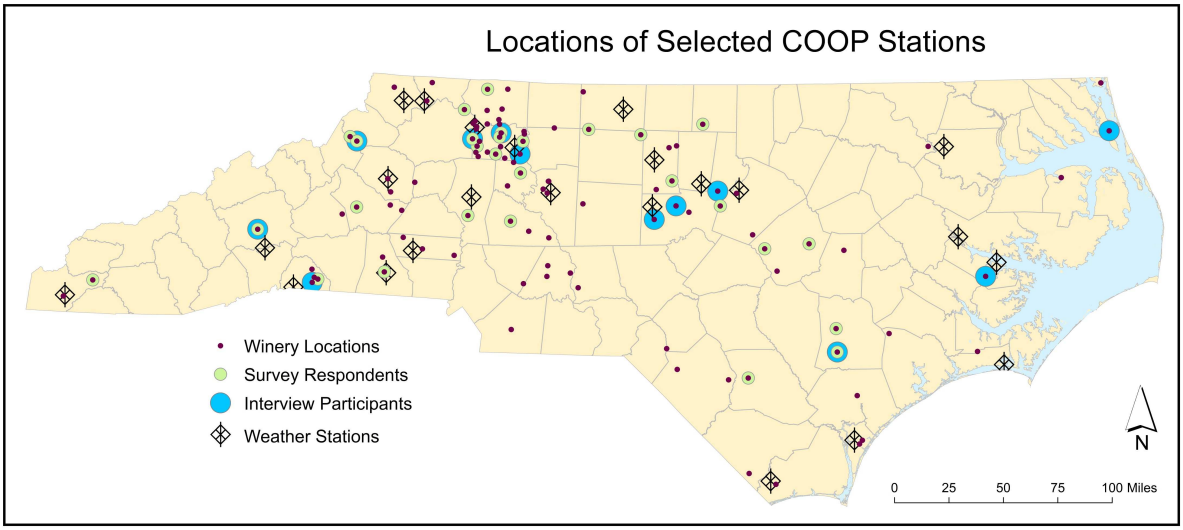

Figure 6.1: Locations of COOP stations resulting from proximity analysis

The largest cluster of wineries in the Yadkin Valley may be represented by the Yadkinville station located in Yadkin County and the Elkin station located in Surry County for each case study (Fig. 6.2). For these two stations, an extended historical time scale was collected. While the Yadkinville station recorded temperature and precipitation from January 1958 to December 2012, the Elkin station recorded only precipitation for this time scale. Ten wineries are within a ten mile buffer of either of the two weather stations. Four of the ten wineries within the ten mile buffer surrounding the Yadkinville station were survey participants and two were interviewed. Within the Elkin station buffer area, one winery was interviewed and three were surveyed.

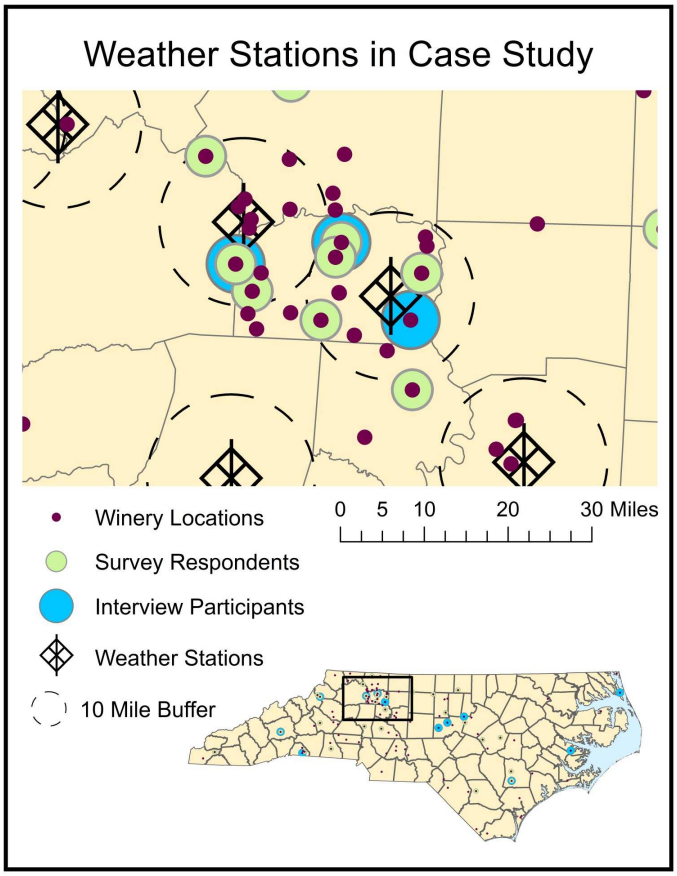

Figure 6.2: Location of weather stations in case study in relation to surveyed and interview participants

Monthly time series were created for precipitation, maximum temperatures and minimum temperatures to provide insight into the climatic conditions that growers are experiencing. Each series was fitted with a linear trend line and analyzed by slope value.

6.1 Excessive Rainfall Case Study

Based on the results of the survey and interviews this case study investigated excessive rainfall because it is a strong or very strong risk to NC vineyards. A case study of rainfall during August reflects a time in the growing season that piedmont growers in this study have expressed as sensitive to very wet conditions (Table 5.1). Growers specify this month as a crucial time for excess rainfall to affect resulting wine quality, disease potential and harvesting practices. Survey and interview respondents in the Elkin and Yadkinville region agree that excessive rainfall is a risk to their enterprise. All but one survey respondent believe rainfall is a strong or very strong risk. Few winegrowers in the case study area have experienced changes in rainfall patterns, but those that do perceive changes believe rainfall is becoming more frequent and more intense.

Winegrape growers in the case study region discussed many memorable excessive precipitation conditions. One grower remembers, “[In] 2003, it rained all year. If you have excess there is nothing you can do about that. Nobody in the state made any good wines in ‘03.” Another said, “The worst was 2004, remnants of Hurricane Ivan. We had 30, 40 inches after normal.” Other severe storms that affected the Elkin or Yadkinville growers include outer rain bands from Tropical Storm Lee in 2011 and Hurricane Irene in 2012. One grower also mentioned 2012 was their second or third wettest year on record. In Yadkinville, 2005 was perceived as a good season, meaning there was very little rain and it was hot and dry the whole summer. Many

believe 2007, 2010 and 2011 were years of, “serious drought. But that’s what makes the good wines.”

Time series were created based on daily precipitation records for every August over the 54 year period and fitted with linear trends. The maximum (Fig. 6.3), total (Fig. 6.4), and frequency (Fig. 6.5) of August rainfall were calculated. The Elkin station does show 2007 having one of the lowest maximum rainfall measurements on record (Fig. 6.3), which agrees with the growers’ statements. Graphs show that around the 1960’s produced many years of increased precipitation (Fig. 6.4.1 and 6.4.2). The 1980’s were the last time for increased precipitation over multiple years, which may influence growers’ perceptions of recent increased rainfall years. The rainfall amount for each month of August over the past 54 years shows 2003 as one of the highest spikes for both the Elkin and Yadkinville stations in total number of rain days (Fig. 6.5), which agrees with the growers. The highest outlier for each station’s maximum rainfall in August was in 1970 and has the highest number of rain days in August for Yadkinville was in 2012 (Fig. 6.5.2). A period of very low rainfall throughout August was in 1997.

The Elkin station’s trend lines for maximum precipitation, total precipitation, and number of rain days have slightly negative slopes. Maximum precipitation change has a $R^2 = 0.0248$, total August precipitation has a $R^2 = 0.0588$ and number of August rain days shows a $R^2 = 0.0712$. The Yadkinville maximum precipitation indicates a trend line with a slightly positive slope and an r-square value of 0.0054. Yadkinville total precipitation change over the past 54 August records show a slightly negative slope with an r-square value of 0.0086.

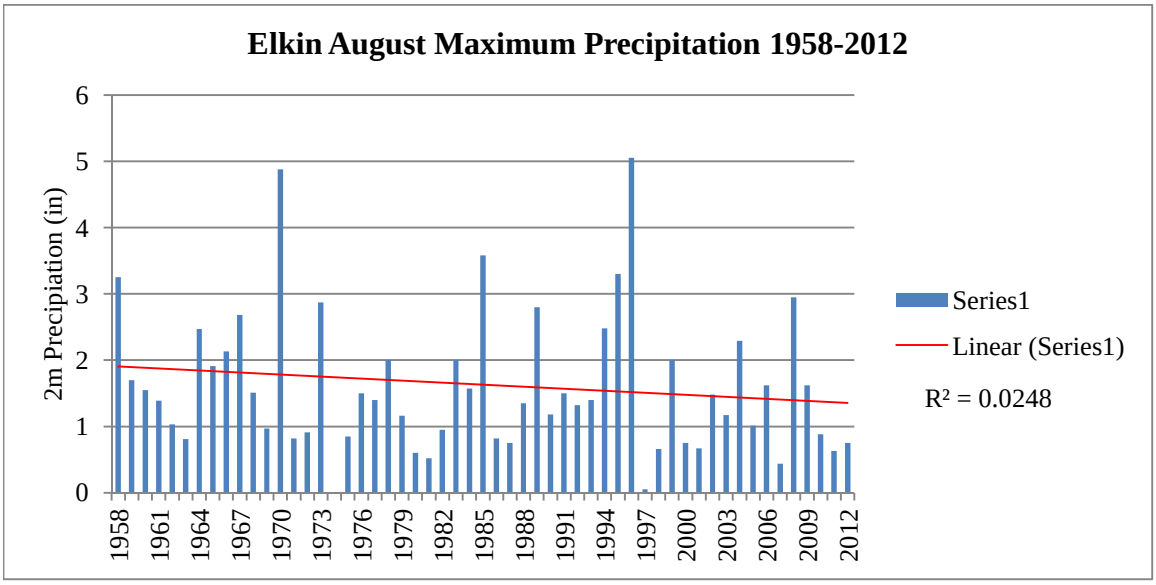

Figure 6.3.1

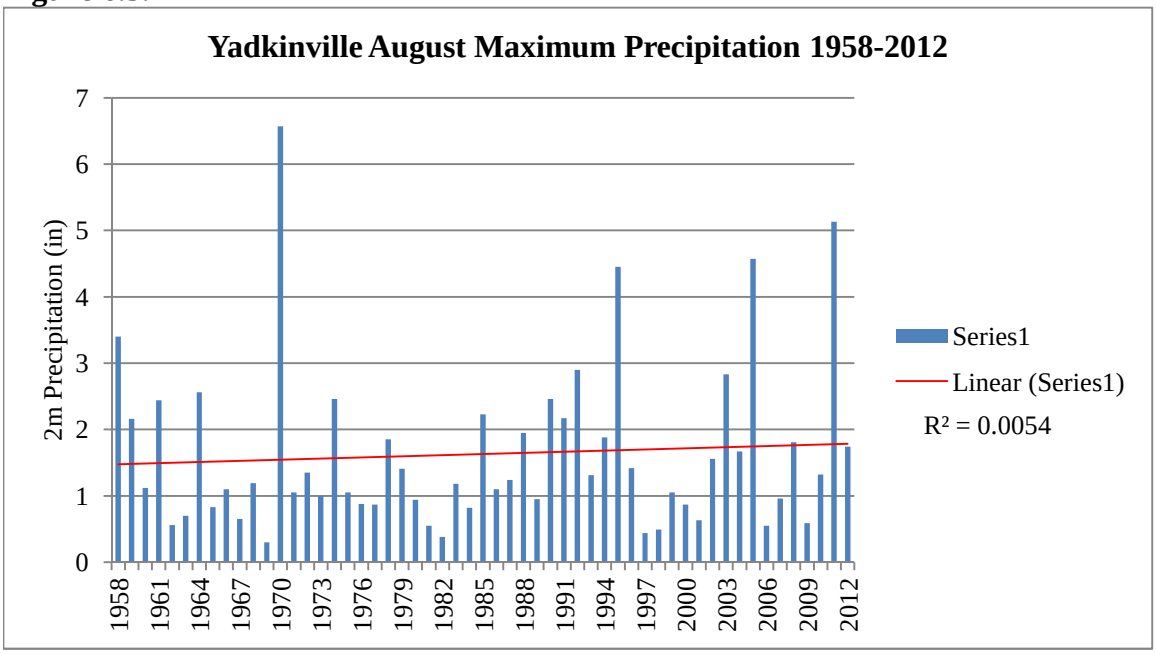

Figure 6.3.2

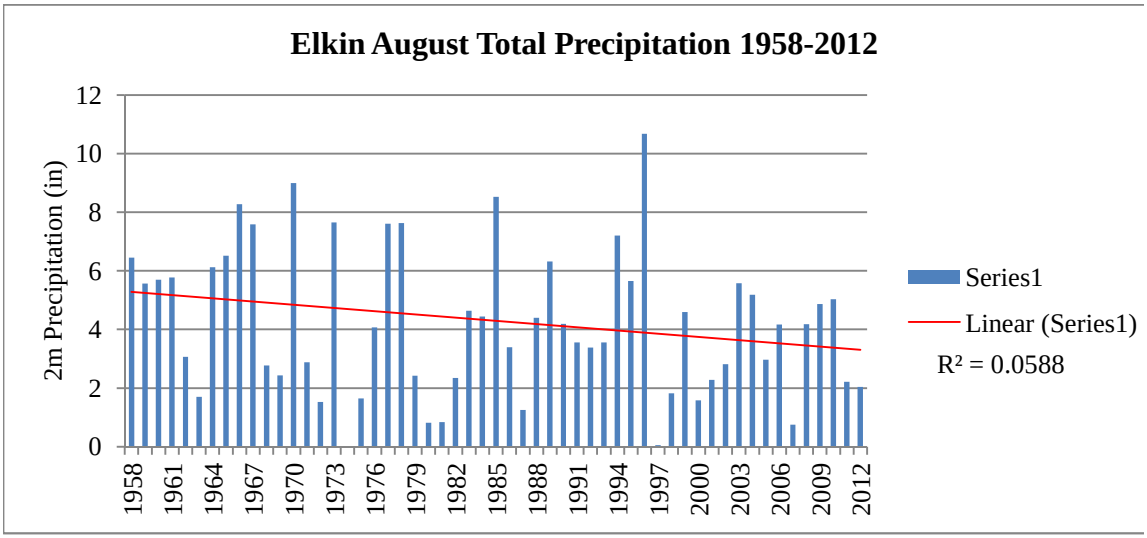

Figure 6.4.1

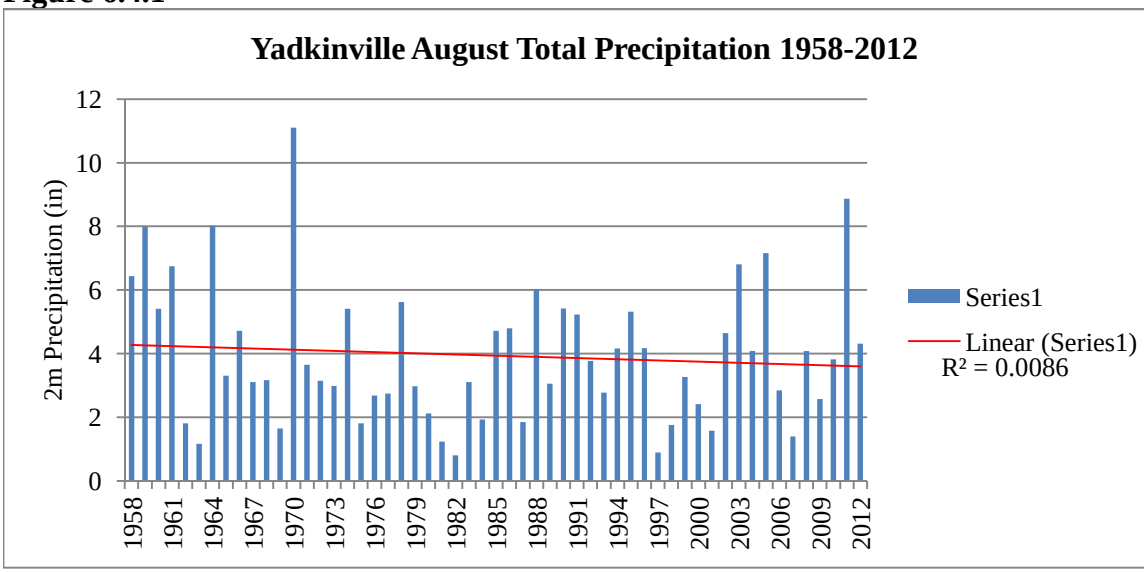

Figure 6.4.2

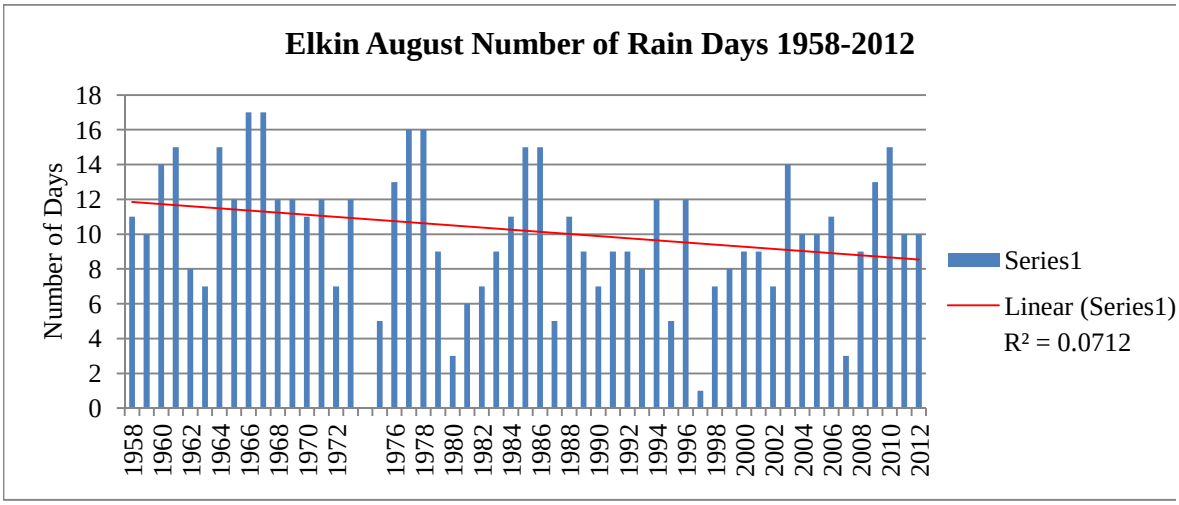

Figure 6.5.1

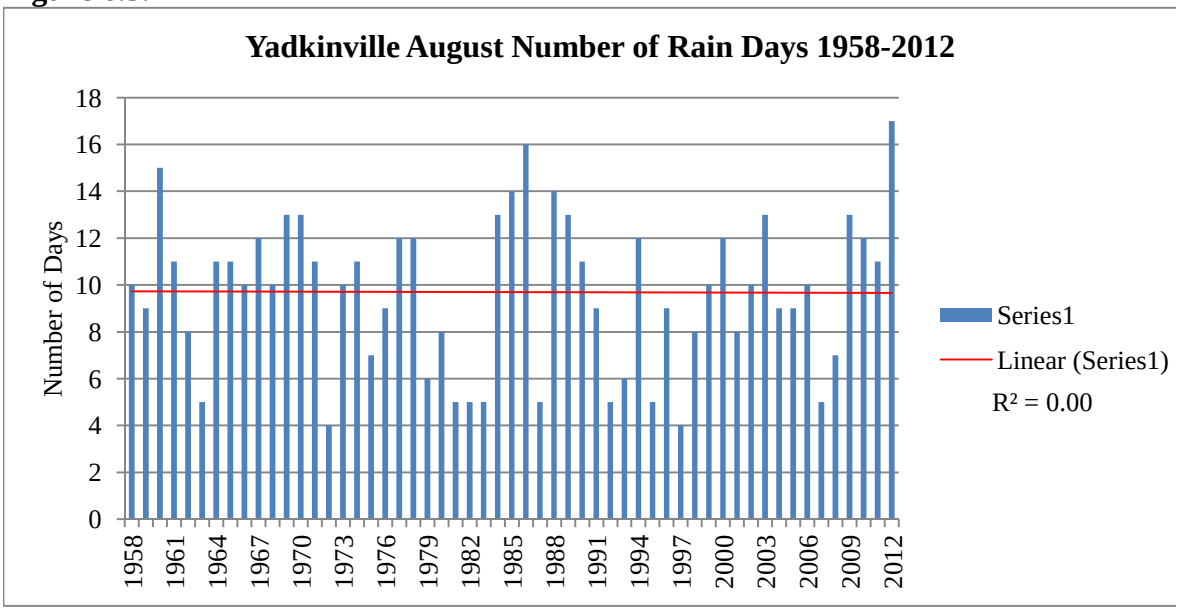

Figure 6.5.2

The correlation coefficient was used to determine the relationship between the Yadkinville and Elkin station time series. The coefficient will vary from -1, perfect negative correlation to +1, perfect positive correlation. The maximum rainfall time series correlation coefficient is 0.374953 and the total precipitation time series coefficient is 0.446878. The number of rainfall days time series produced a 0.621755 coefficient closest to positive 1, indicating a slightly positive relationship between the Yadkinville and Elkin number of rainfall days during the 54 year period.

Rainfall is an erratic variable to study over time as shown by the stations in this case study with conflicting trends and fairly low correlations. The change in slope is not significant over the 54 year time scale. Conditions may become increasingly erratic as some growers have experienced changes in rainfall frequency and intensity. The Elkin station data indicates increasingly drier conditions overall. The Yadkinville station shows less overall change in rainfall for this time period. The overall consensus is that maximum rainfall is not as important as the number of days with high precipitation and cloud cover in North Carolina.

6.2 High Temperature Case Study

Survey respondents from the Yadkinville and Elkin buffer area perceive high summer temperatures as a strong or very strong risk. Growers emphasize the importance of maintaining high temperatures throughout the summer and especially August to ensure optimum sugar content and acidity. However, there are concerns about extreme high temperature conditions influencing these factors. A more in-depth investigation of maximum temperatures during July and August reflects on a time period when grapes are sensitive to very hot conditions according to piedmont growers (Table 5.1).

A small, piedmont grower said, “This is the hottest year that I’ve ever seen.” Another said, “Last year [2011] we had a very mild summer. This year [2012] we’re having a brutal summer. 2007 was a brutal summer, but ‘08, ‘09, ‘10 and ‘11 weren’t that bad.” Figure 6.6 shows observed daily maximum temperatures throughout the summer of 2007. Summer 2007 temperatures remained above or slightly below 80°F throughout June and July, while high temperatures in August never fell below 80°F.

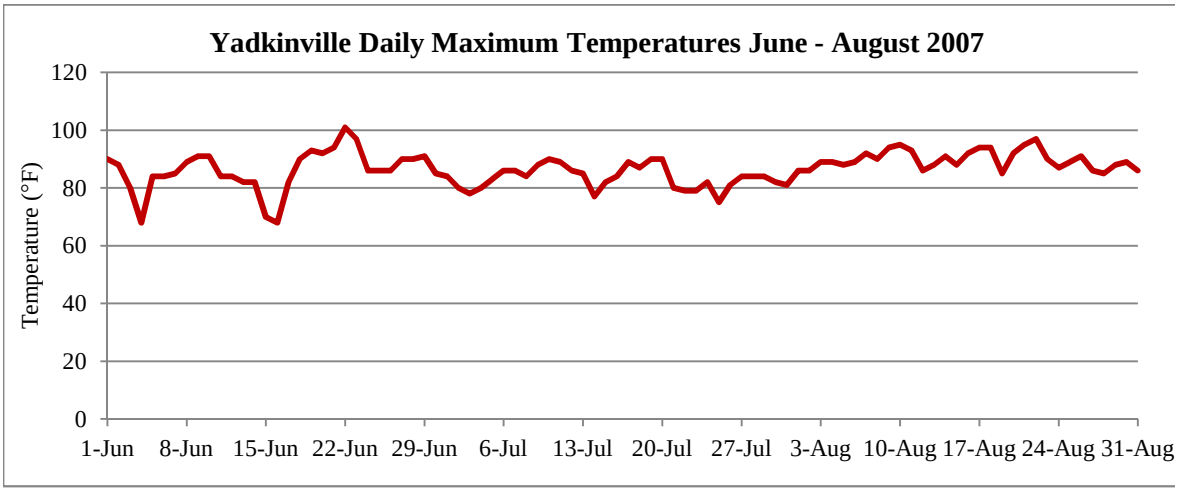

Figure 6.6

From an experienced grower's perspective: "This year [2012] has been very hot. Now we're getting warmer in the summers. This year we were up to 97°F." He continues, "I was born and raised here, I remember in the 60's, 70's, and 80's, we never got [temperatures] above mid 80's. It's increased at least 10 degrees [since then]." Figure 6.7 shows observed daily maximum temperatures throughout the summer of 2012. High temperatures stay above 80 degrees for the majority of the summer. Between June 29th and July 10th high temperatures never drop below 91 degrees.

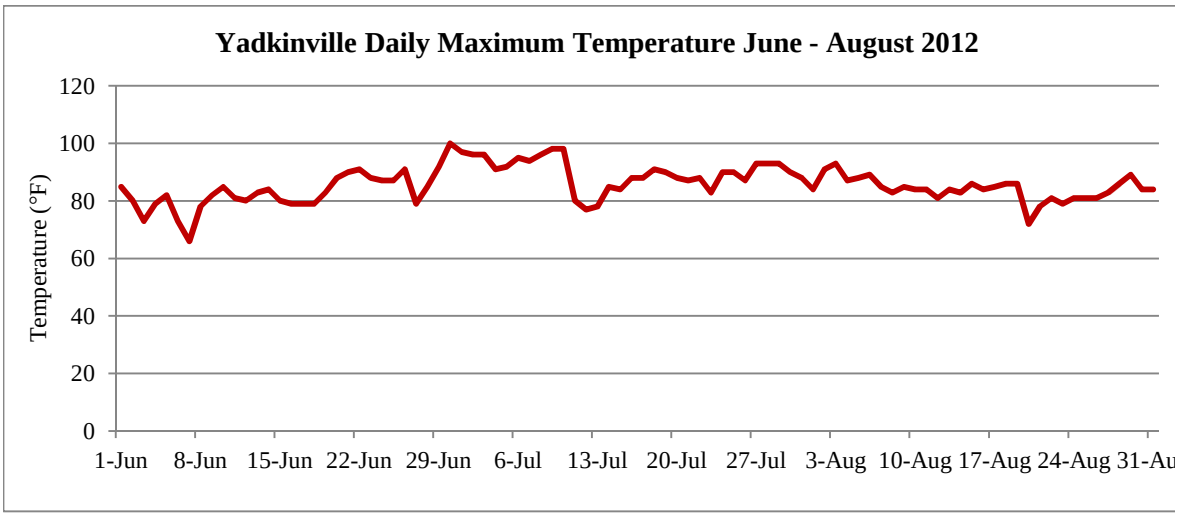

Figure 6.7

The daily maximum temperatures for the month of July and August over the past 54 years are used to study observed trends at the Yadkinville station. The annual July trend line has an r-square value of 0.0091 indicating almost no change in maximum temperatures during this time of the year (Fig. 6.8). July's graph shows relatively steady temperatures between 1958 and 1970, random occurrences of temperatures near 70°F between 1970 and 2003, and high variability in maximum temperatures after 1970.

The annual August maximum temperature trend line has an r-square value of 0.0251 (Fig. 6.9). The red box, in Figure 6.9, once again shows maximum temperatures in 2007 remained above 80°F for the entire month, as growers have expressed. Many other periods in the 80's and 90's have steady temperatures above 80°F in August. The August graph shows highly variable maximum temperatures between 1963 and 1970 with large increases near 100°F and decreases near 70°F. The period between 2002 and 2012 has considerable dips in maximum August temperatures and less spikes in higher temperatures above 90°F as compared to the previous period.

Maximum temperature trend lines for July and August in Yadkinville do not show significant slopes, indicating no significant changes over this 54 year period. The graphs do reflect what growers are experiencing in specific years, but there is no evidence of overall warming taking place at this station with maximum temperatures.

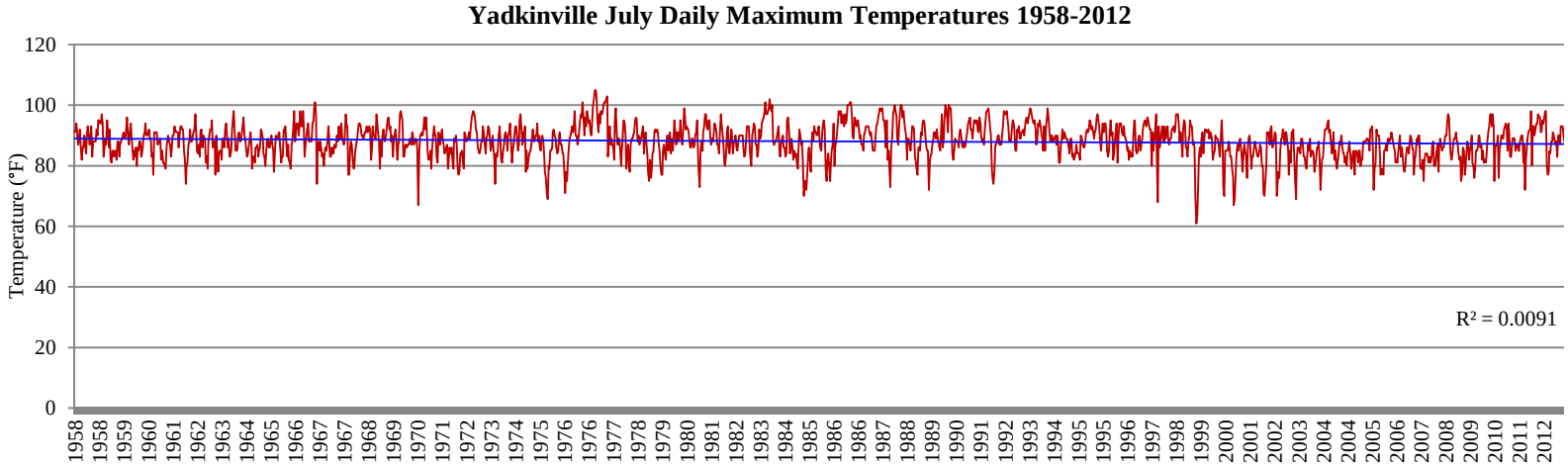

Figure 6.8

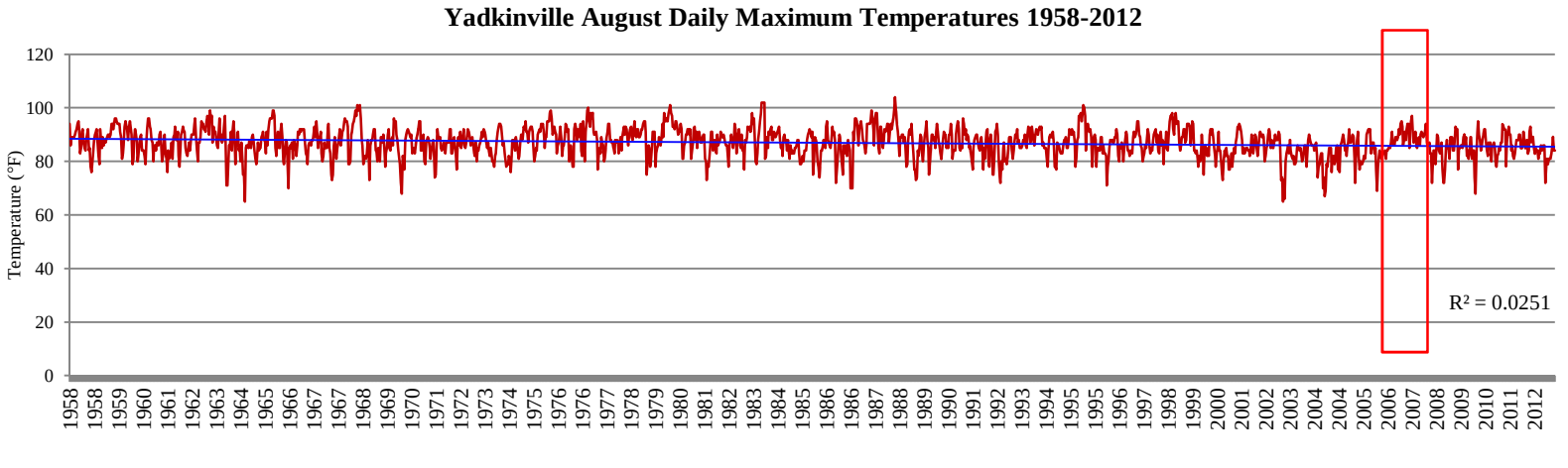

Figure 6.9

6.3 Low Temperature Case Study

Survey respondents from the Yadkinville area perceive low temperatures as a very strong risk or moderate risk. A more in-depth investigation of minimum temperatures during April will reflect on a time period that piedmont growers in this study have expressed as sensitive to cold conditions (Table 5.1). One grower said, "I lost almost all the grapes out there in 2007, 2008. We had a late freeze April 2007. On April 7th and 9th it got down to 20 degrees." Another grower reiterated these dates: "In 2007, I think the freeze was around the 7th or 8th, I think it was two, three days in a row of lows in the teens." Other survey and interview respondents from this area repeatedly mentioned, "The Easter freeze of April 2007." A western piedmont grower said that if late frost occurs, there's nothing you can do about it and it doesn't become an issue unless it continues. If you have a very warm February into March, like what happened in 2007, when it was extremely warm and everything had a really early bud break. And then at Easter, when it's traditionally warmer, we had three nights of 20 degree temperature. That was very hard and really reduced the [amount of] fruit for everybody."

Figure 6.10 does reflect minimum temperatures dropping into the low 20's at the Yadkinville station on the specific dates mentioned, shown inside the boxed area. Isolated areas further from the weather station could certainly experience lower temperatures during a frost event like the 'Easter freeze'.

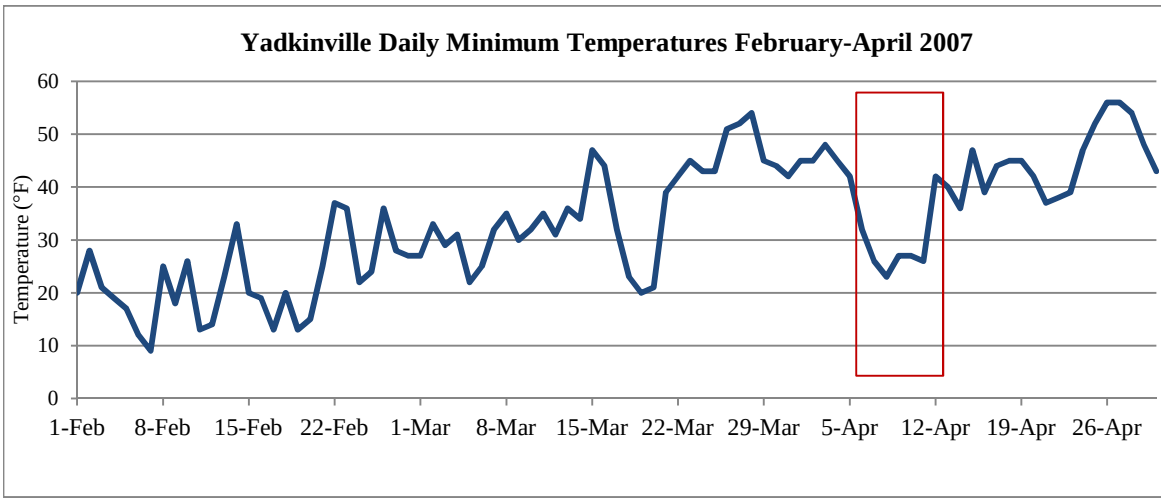

Figure 6.10

An experienced grower learned from past frost damages, “last year we’ve probably had the best crops we’ve ever had. We had no frost damage because [the vigneron] is a really good farmer. [Other] people lost 60% of their vineyard to frost so we had a lot of people standing in line in Yadkin Valley.” Other growers also mentioned spring, 2012 was a difficult time for late frost following a mild winter. Daily April minimum temperature calculations for the entire time scale at the Yadkinville station (Fig. 6.11) have an r-square value of 0.0046, meaning minimum temperatures are very slightly increasing.

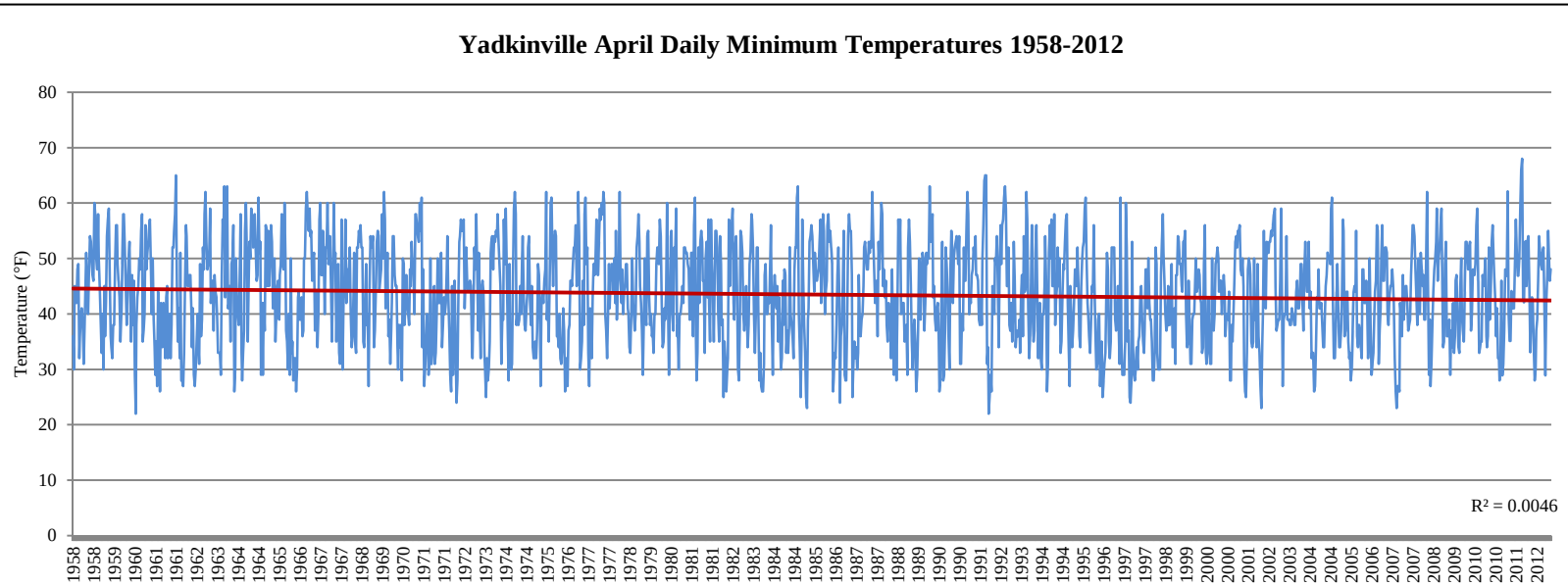
Yadkinville April Daily Minimum Temperatures 1958-2012
Temperature (°F)
80
70
60
50
40
30
20
10
0
R² = 0.0046
1958 1958 1959 1960 1961 1961 1962 1963 1964 1964 1965 1966 1967 1967 1968 1969 1970 1971 1971 1972 1973 1974 1974 1975 1976 1977 1977 1978 1979 1980 1981 1981 1982 1983 1984 1984 1985 1986 1987 1988 1989 1990 1990 1991 1992 1993 1994 1994 1995 1996 1997 1997 1998 1999 2000 2000 2001 2002 2003 2004 2004 2005 2006 2007 2007 2008 2009 2010 2010 2011 2012

Figure 6.11

A piedmont farmer said, “This winter was a mild winter, the previous one, two different occasions I had a foot of snow up here. I really want it to get cold, like this past winter it was very, very warm so I delayed pruning as long as I could because I was hoping for maybe a week or two of cold snap and we never got it.” A more experienced grower remembered, “cold weather back in the 80’s, about the mid 80’s, got down to 11 below [zero]. We haven’t seen anything that cold [since then].” These comments justify the reasoning for looking at the history of January minimum temperatures as well.

Daily January minimum temperatures follow a reoccurring pattern between 1958 and 2012 (Fig. 6.12), producing a trend line r-square value of 0.0008, also indicating a very slight minimum temperature increase. The period between 1970 and 1990 do show very cold minimum temperatures overall with the exception of one spike above 50°F. During 1985, the January graph shows a significant drop near -10°F as expressed by one grower. After 1994, minimum temperatures at this station do not fall below 0°F. Between 1994 and 2012 the graph shows a higher frequency of spikes in high minimum temperatures compared to the previous period.

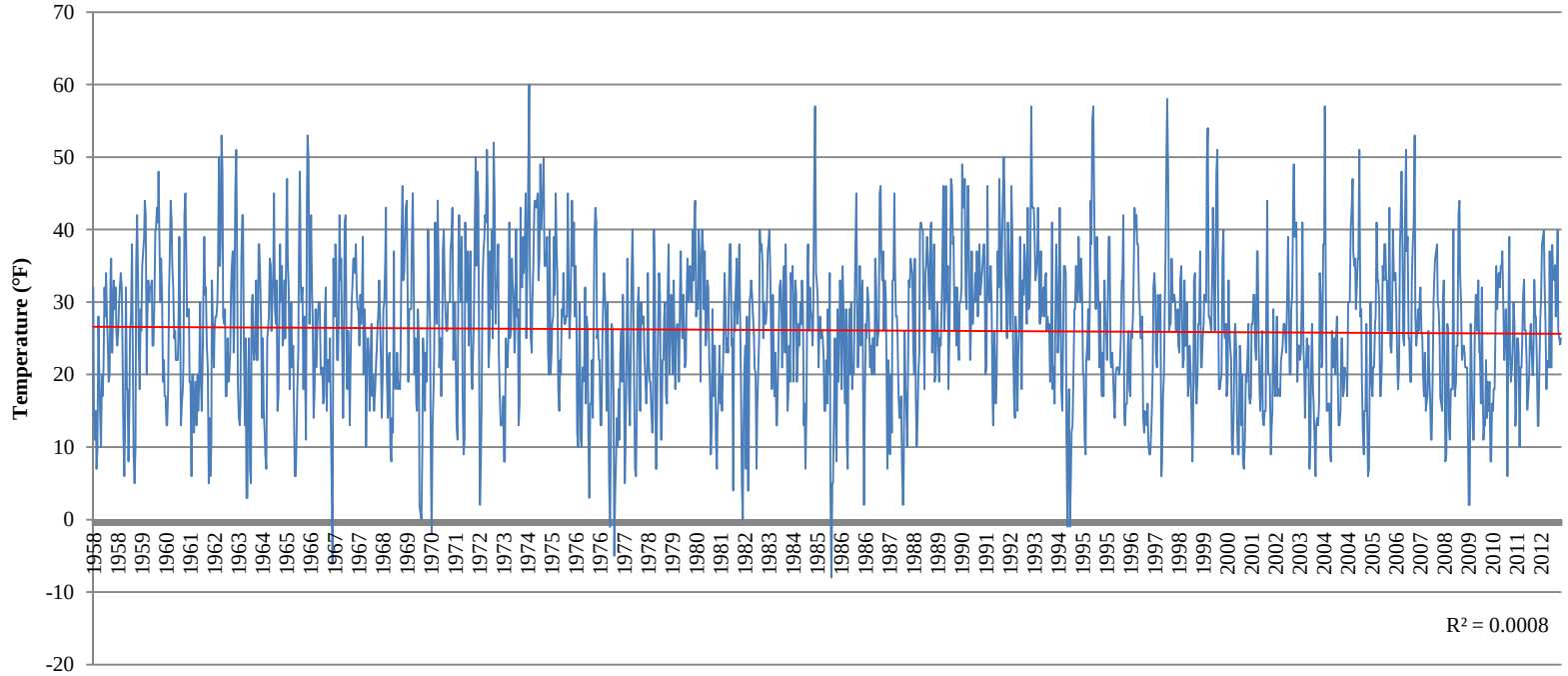
Yadkinville January Daily Minimum Temperatures 1958-2012
Temperature (°F)
70
60
50
40
30
20
10
0
-10
-20
R² = 0.0008

Figure 6.12

6.4 Spatial Analysis of Viticulture Site Suitability

COOP stations were selected with the most complete maximum temperature and minimum temperature daily observations over a 30 year time scale, January 1982 to December 2012. Stations with incomplete data for the time scale had to be eliminated from the interpolation study, leaving 72 stations (Fig. 6.13).

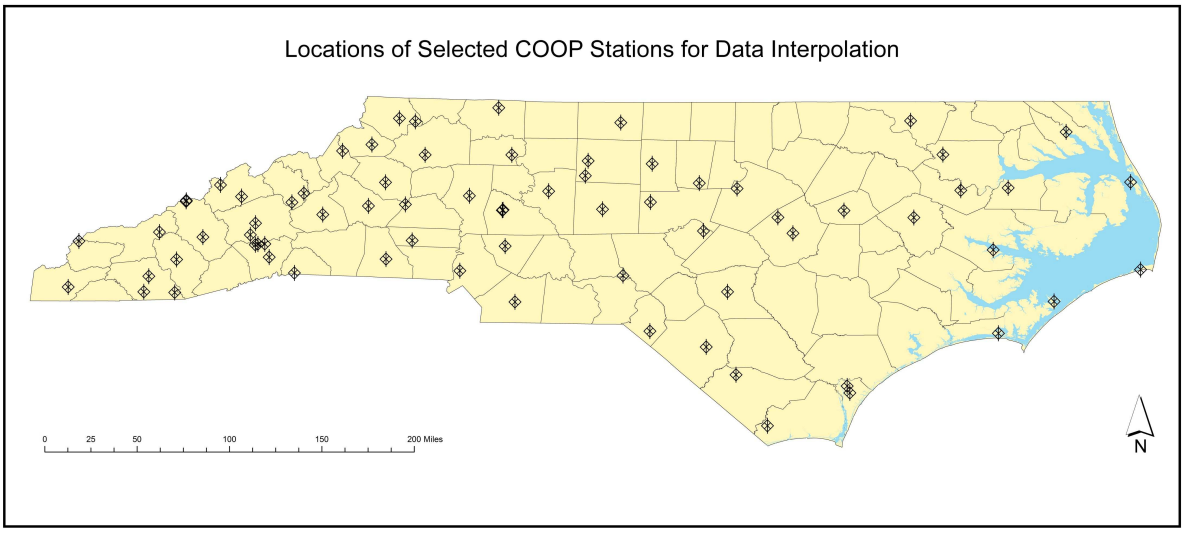

Figure 6.13: COOP stations (72) used in interpolation of 30 year daily observations data calculations

To investigate climate changes a series of spatial interpolation maps were created similar to those shown in Chapter 3, created by John Boyer for the period between 1970 and 2000. Minimum temperatures were examined at 72 stations for the period between 1982 and 2012. The average occurrence of temperatures below -8°F per decade is shown in Figure 6.14 and the average occurrence of temperatures below 0°F per decade is shown in Figure 6.15. Temperatures below 0°F are focused in the mountain region and the occurrence of extremely low temperatures is higher in the northern mountain region. The eastern piedmont and coastal regions rarely experienced extremely low temperatures between 1982 and 2012.

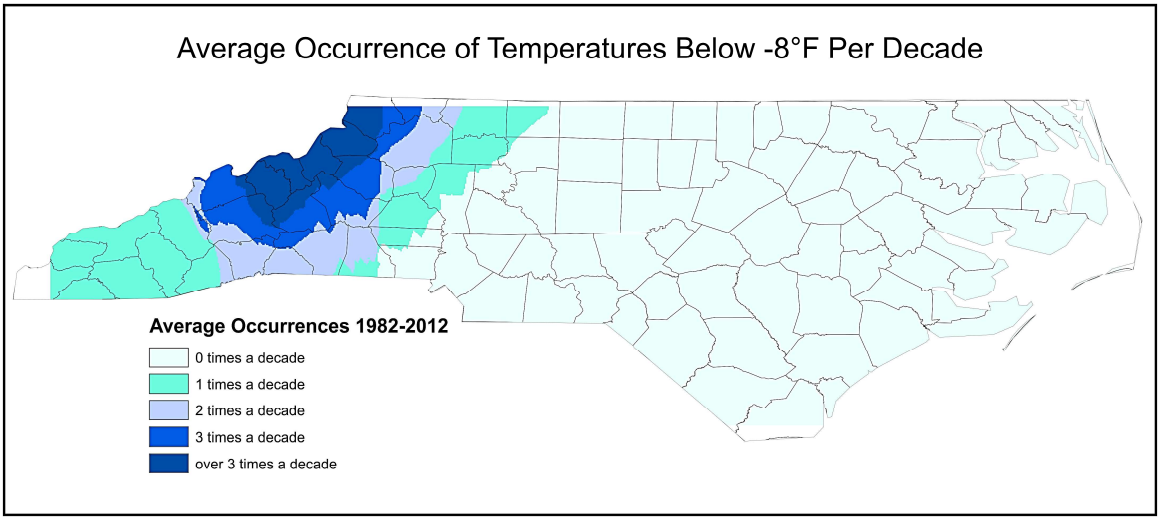

Figure 6.14

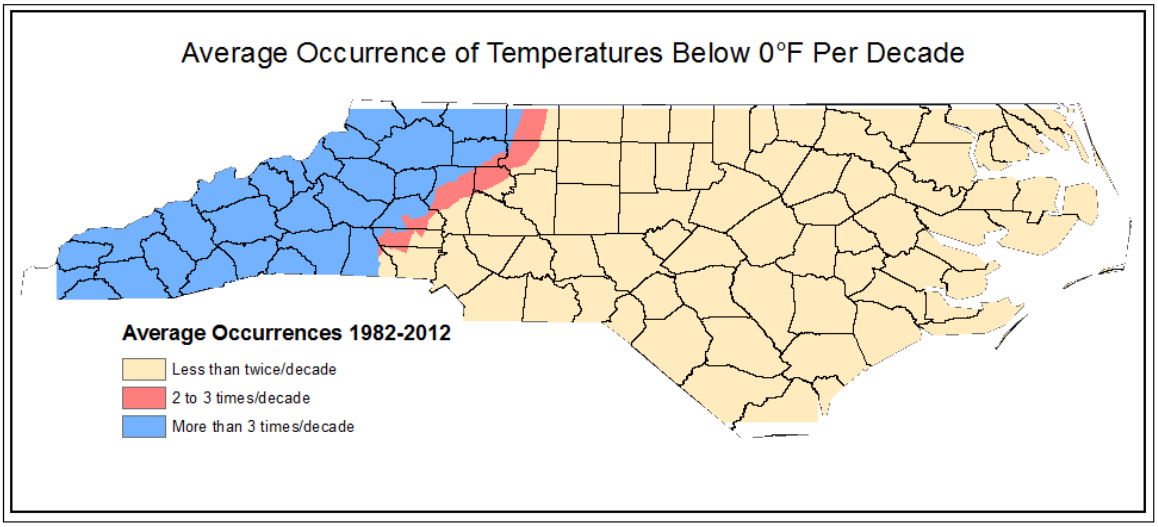

Figure 6.15

Lower January mean minimum temperatures are important in preventing Pierce's disease (PD). Figure 6.16 shows the potential extent of Pierce's disease is high in the red and dark red areas where average minimum January temperatures remain above 30°F. Lower chances of PD throughout the piedmont and southern mountain region are denoted by minimum temperatures between 25 and 30°F on average. The northern mountain region and a portion of the southern

mountains do not experience PD risks because average winter temperatures fall below 25°F, killing any carriers of the disease before the growing season.

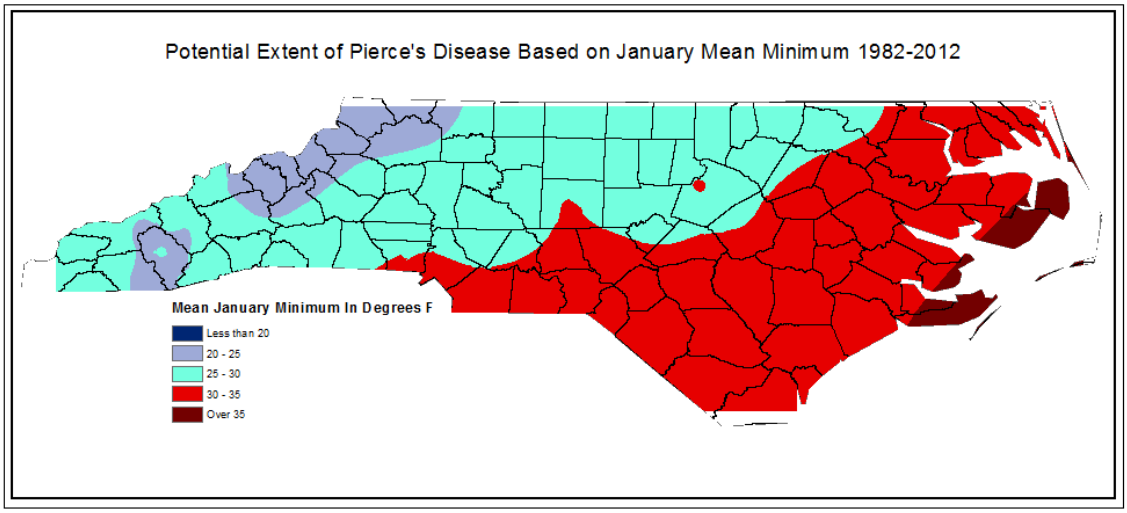

Figure 6.16

Site suitability has not drastically changed between the 1970 to 2000 period and the 1982 to 2012 period (6.17.1). The Zone boundaries are based on the overlap of January mean minimum temperatures, occurrence of 0°F, and high elevations. Figure 6.17.2 shows Zone 1 continues to be the best region for growing Muscadine varieties because so many disease pressures exist in this region. Zone 2 can be successful for growing all varieties, but some areas may experience issues with cold temperatures. Zone 3 experiences the lowest temperatures providing less disease pressures and late blooming vinifera varieties can prosper. Zone 4 will remain a challenging grape growing site based on the extremely high elevations.

Three counties that did show a change from 1970-2000 to 1982-2012 were Wake, Stanly, and Hertford counties. Wake and Stanly shifted from being primarily suited for Muscadine (Zone 1) to being adaptable to vinifera and hybrids (Zone 2), while the reverse happened for Hertford County.

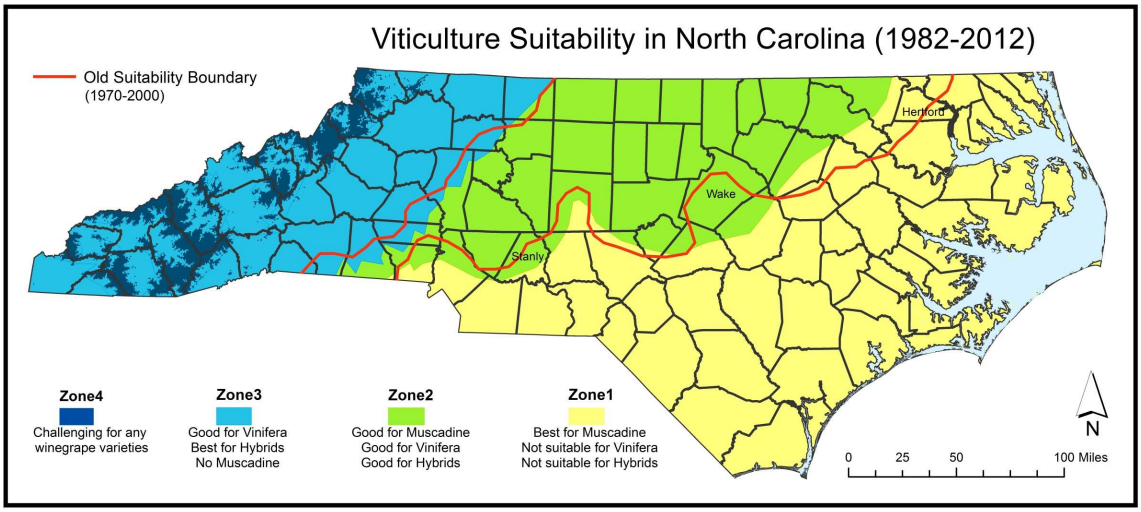

Figure 6.17.1: Viticulture Suitability boundary changes

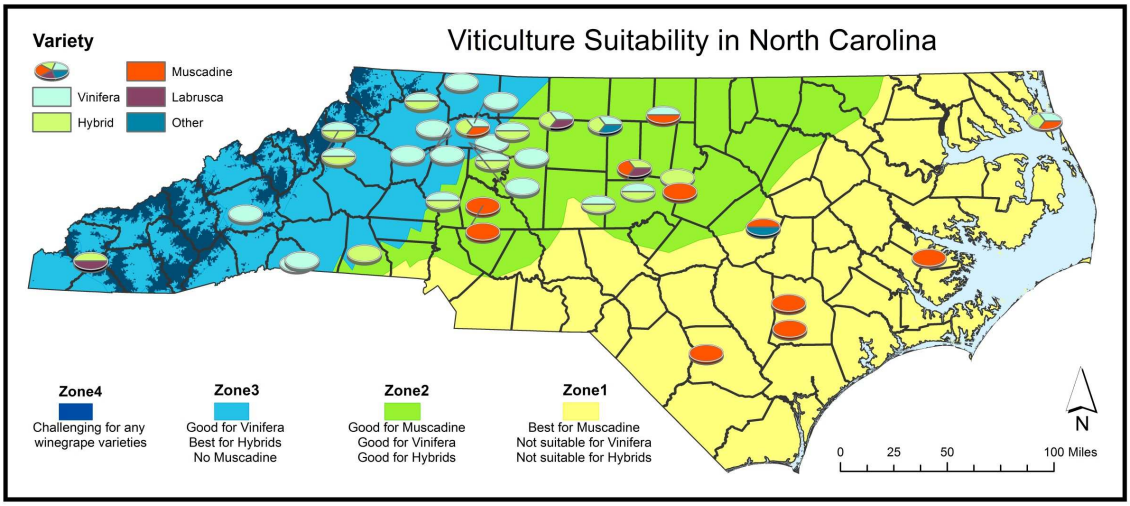

Figure 6.17.2: Site suitability in North Carolina between 1982 and 2012 in comparison to varieties the survey and interview respondents are currently producing

The pie graphs in Figure 6.17.2 show that the majority of winegrowers in this study have chosen varieties suitable for their growing region. A few vineyards produce the labrusca variety, which is native to eastern North America and is suitable for production in Zone 1-3. One vineyard on the NC coast currently produced a portion of each variety, which may provide many market opportunities but also increased weather and climate risks. The winery producing exclusively muscadine winegrapes in Wake County (Fig. 6.17.1) could diversify as the recent climate data places it in Zone 2, which is suitable for vinifera and hybrids.

6.5 Spatial Interpolation of Climate Trends

To investigate linear trends in temperature conditions across the entire state, annual averages in minimum January temperatures and maximum August temperatures were calculated for each station between 1982 and 2012. A linear trend line was fit to each series of averages and the slopes calculated at each station were interpolated to spatially analyze regional changes. Positive slope values represent a linear increase in maximum or minimum temperatures over the 30 year period, while negative slopes represent a linear decrease in maximum or minimum temperatures.

An earlier spatial interpolation analysis of North Carolina's climate trends is shown in Figure 6.18 and 6.19 for the time period between 1949 and 1998. Researchers concluded that there are statewide patterns in maximum and minimum temperatures (Boyles and Raman 2003). Maximum summer temperature observations from this time period show decreasing trends in the piedmont and mountain regions, while the coast shows increasing trends and the remaining regions of the state show no changes (Fig. 6.18).

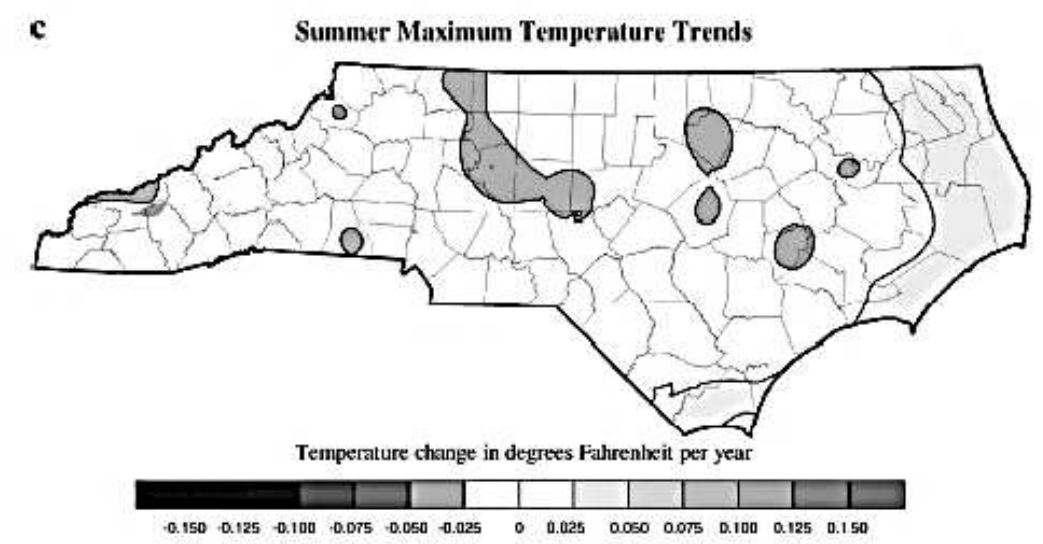

Figure 6.18: Interpolation of summer maximum temperature trends, linear slopes for summer months between 1949 and 1998 (Boyles and Raman 2003)

Researchers concluded that winter minimum temperature trends show negative slopes for the southern coast and northern piedmont, where minimum temperatures appear to have decreased between 1949 and 1998 (Fig. 6.19). The southern mountain region shows positive trends for the winter months over the same period (Boyles and Raman 2003).

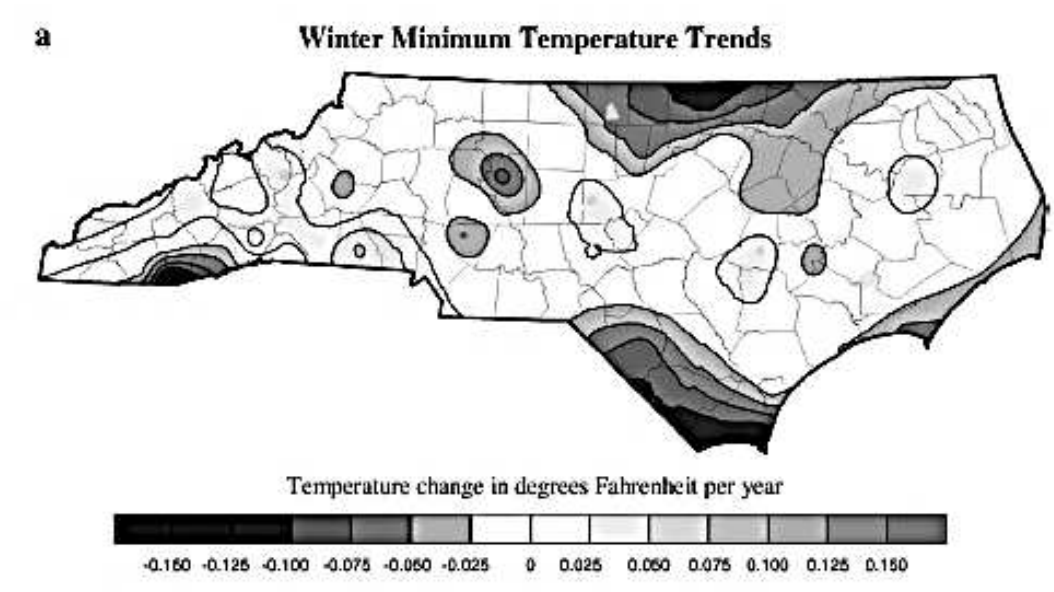

Figure 6.19: Interpolation of winter minimum temperature trends between 1949 and 1998 (Boyles and Raman 2003)

Figure 6.20 shows my interpolated trend surface for August mean maximum temperatures. Higher positive trends are located in the southern mountain region, shown in dark red, and maximum temperature trends are weakly positive around the western piedmont, shown in light tan. The southern mountain stations produced the highest positive slope values, which indicate temperature increases around 0.05°F per year. August mean maximum temperature trends are not increasing substantially outside of the southern mountain region, but overall, this map shows that the state is warming. This is one change that NC winegrowers are experiencing.

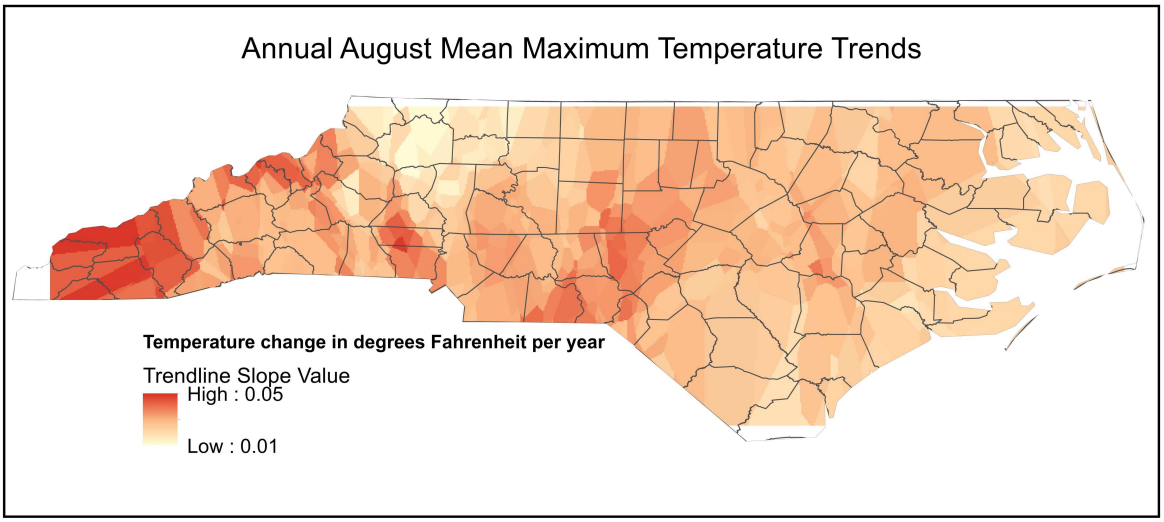

Figure 6.20: Interpolation of average August maximum temperature trends between 1982 and 2012

Figure 6.21 shows my interpolated trend for January minimum temperatures. Positive trends are located in the central piedmont, shown in dark red, and lower slope values are located in the northern mountain region and western piedmont, shown in tan and light blue. The remaining part of the state shows very little increase or decrease in minimum temperatures. The central piedmont stations produced the highest positive slope values, over 0.1°F per year, located in the darkest red area. Generally, January mean minimum temperatures are slightly increasing per year across the state with the exception of a small region in the northern mountains that is slightly decreasing per year over the 30 year period.

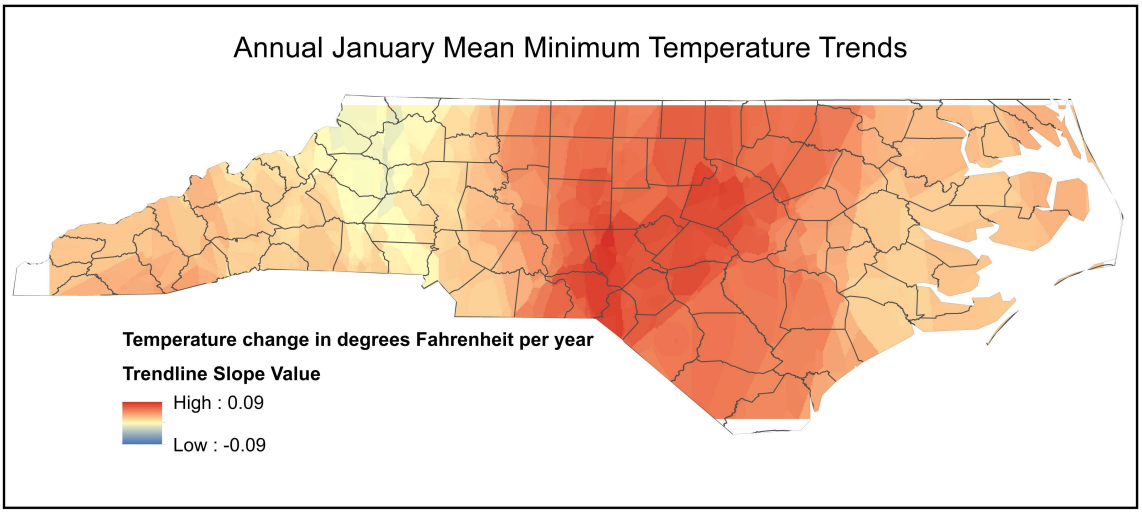

Figure 6.21: Interpolation of average January minimum temperature trends between 1982 and 2012

CHAPTER 7: MANAGING RISKS AND ADAPTIVE CAPACITY

7.1 Managing Changes in Risks and Sensitivities

One of the objectives of this research is to better understand how producers respond to the challenges of climate change and the ways that they prepare for present or future risks. Risk management can be reactive, that is responding to harmful situations when they happen, or proactive, by preparing for or attempting to control a potential negative occurrence or situation. One large, coastal grower anticipates the former, stating, "[There is] nothing we can really do to prevent [negative impacts], without spending a great deal of money." Other winegrape producers, however, indicated that specific actions are possible. Respondents have the capacity to adapt, and many are being proactive, as one stated, "We had a lot of issues that we were trying to prevent in the winery more so than trying to fix. Our philosophy here is always to prevent things happening rather than try to fix them afterwards." A number of farmers agreed, believing that it is never going to be a perfect world and some form of adaptation in the field or in the winery is required every year. This chapter examines some of the strategies used by growers or winemakers to manage possible risks associated with climate change.

7.1.1 Crop Insurance

One obvious way to prepare for unforeseen circumstances is to carry crop insurance. A cost study by Cal Davis discusses the following:

> Growers may purchase Federal crop insurance to reduce the production risk associated with specific natural hazards. Insurance policies vary and range from a basic catastrophic loss policy to one that insures losses for up to 75% of a crop. Insurance costs will depend on the type and level of coverage (Weber et al. 2003).

All but one interviewee in this study does not currently have crop insurance. The large, western piedmont producer that does have insurance maintains many different crops on their farm. She told me farmers have to carry crop insurance. Other crops grown on this farm, such as corn, wheat, and soybeans are basic rotation crops. If a hurricane or frost comes through then [maintenance costs] do not come from a farmer's pocket, but there is no profit. Because grape vines are not annual crops, grape insurance requires growers to create a crop report by tonnage for each variety, each year. This grower explained:

> [If] this year [provides] 6 tons instead of 10, because of weather related [issues] that can be investigated or proven, then you're going to get a percentage of the difference between that 6 tons and 10 tons. [That] covers your spray program, harvesting and your premium, the maintenance and all the out of pocket expenses it took for you to have gotten that crop.

The same farmer admits that insurance is very expensive and even mentioned, "I don't know that it is a good asset. To my knowledge I don't think we've collected on it [for our grapes]." Another large, mountain grower agrees, "[Crop Insurance is] too expensive. They were going to give us a value of concord [table grapes], where they were going to give us $200 a ton. There's no use. We'll take our chances. Now we're high risk and your rates would be so high. Insurance lasts 10 years but we've lost three crops. It's like somebody having three wrecks."

Many have experienced problems with other agricultural loans. A large, coastal grower said, "I qualified for an emergency loan last September [2011] when [Hurricane] Irene hit. You know how much the agriculture allowed me to borrow? Barley a dime." He also points out that, "There is no insurance for grapes [particularly in NC]. In Napa Valley they're all insured. But [here] you have to have 100% percent loss before you can get any insurance money. There is never 100% loss. It's not like wheat, cotton, tobacco, potatoes [where] you can lose the crop and replant next year and get 100% gain." For these reasons, growers in NC have used other kinds of

strategies to mitigate the potential negative consequences of weather events and climate change; focusing in particular on growing and winemaking approaches.

7.1.2 Site Selection

Proper site selection is a crucial element in natural protection against potential climate variability. A medium, coastal grower dealing with limited slopes, chose vineyard locations, "from knowing where our highest elevations are, which around here isn't much. If it's sandy and 18 feet above sea level, that's much preferred to like a black loam at 10 feet above sea level." Throughout a rainy season, "the highest most well drained sites are the ones that are still shedding water and the ones that are below them are holding the water that they're shedding."

The piedmont and mountain regions have more slope options than the coast, but still need to consider proper varietal placement along the hillsides. A small, eastern piedmont grower describes how he prevents frost damage by selecting the suitable site:

> What creates the micro environment here is sitting on top of this hill so we can get more air stirring in the vineyard when a lot of other places can't. The way we have oriented our rows, picks up [and] allows the air to flow down the row rather than try to flow across the rows, which helps a lot to keep air moving. And you got your [cold] air drainage that's working for us too on top of this hill that creates the no frost area.

Another farmer with limited space for planting stated, "[We] picked higher [areas] where there was less opportunity for frost. And beyond that it was what was open so we took what would be available on the farm and then chose the best sites with that in mind." She continued to add, "North to South orientation with open sun coming in is important." Row spacing and orientation of rows were discussed as planting strategies to allow for optimal sunlight and air flow. During periods of excessive rainfall, sunlight and airflow will provide drying and during periods of frost airflow will prevent cold air from settling.

7.1.3 Variety Selection

Many survey respondents and interview participants noted that preparing for anticipated warmer temperatures may require different variety selection. A large, coastal grower plans to, "continue to diversify [by growing] more grapes in different locations, as much as we possibly can. There is a cost with that but it's well worth it." Costs may mean waiting several years for a newly planted vine to reach maturation and produce optimum yield as well as the labor and care involved in tending to younger vines. A survey respondent making preparations says, "I am planting French-American hybrids which, I hope, will fare better in our increasingly hot summers." Other respondents experiencing warmer temperatures throughout the growing season mentioned strategies such as, "Replanting with hot varietals, planting more southern European varieties and moving toward more hybrids and Muscadines." Multiple varieties may reduce overall vulnerability because a grower can expect certain varieties to withstand a weather event or climate condition when others cannot. Managing multiple varieties on one vineyard may also be costly to maintain the different needs of each variety.

Since the beginning of production, one piedmont grower said, "We've been through 27 different varieties. [If] we weren't happy with the production, we pulled them out. I think we've done enough exploration to figure out what is and isn't going to work for us." The overall idea is to plant more of what works and eliminate what does not.

7.1.4 Altering Practices

Altering vineyard practices is another common response by growers experiencing climate changes. A small, eastern piedmont grower said, "We do whatever the weather is offering us, you know? What steps we're going through in the vineyard, that sort of thing, it's all one big

[cycle]. Every year we have to do the same things, but if the weather stays constant, then you are doing things about the same time every year." Much like all farmers, winegrape producers have to consider the whole operation by looking at what needs to be done for the entire year.

Survey respondents concerned with increasing temperatures have closely monitored the thickness of the leaf canopy to allow more air flow between the vines and allow more sunlight wherever necessary. Irrigation is another element, with most growers introducing large irrigation systems for the first time when facing periods of little rain. In preparation for increased periods of rainfall, many plant grasses under the vines to absorb some of the water in the soil. A few growers mention reinforced line posts and trellis design to withstand strong winds in severe storms.

One grower concerned with late frost notes, "we are changing the training system in the lowest or coldest portion of the vineyard to elevate and protect the plant or crop." Others battling frost have introduced wind mills to mix the cold air or delayed winter pruning to prevent damage to shoots and early buds. A piedmont producer said, "Before frost we sprayed solidly twice a day for three days and coated the leaves with a liquid fertilizer and that's why we didn't have frost damage." The liquid forms a barrier between the grapes and any frost. Others may be wary of this technique because of concerns that the fruit will become too heavy and fall off.

The timing of viticulture practices is extremely important in wine production. As previously discussed, growers anticipating periods of excessive rainfall are forced to make quick decisions to pick before rainfall or wait for a drying period. Many interviewees mentioned experiences with an extended growing season, which is a positive for tourism, but may change the timing of all practices. One grower recalled a positive experience in 2005, when the season of

warm, dry conditions was extended so much that he harvested grapes with the most complexity he had ever seen.

Some growers have learned to utilize a successful growing year to offset an unsuccessful year. After a very successful season, a large, coastal grower said, “it is good to have extra grapes because you know you are going to have years where you have hurricanes and you’ll have years with a late freeze.” Another proactive strategy many use is keeping a back-up inventory of wine in the barrel or bottles. A small, eastern piedmont grower says, “Some of your risks you know you’re going to have [are] those rainy years, and if you keep enough wine made up - cash and wine made up - for a period [of rain] then that will save you if you have bad crops and things like that.” A western piedmont grower told me, “you really have to utilize the good years.” Bad years are expected and other times there may be twice as many grapes to keep as a backup supply. The same grower said, “As it stands now we can never say never but we know what our trends are but you know we could not have a single grape for one year and still have enough because in your tanks now.”

Another common practice during unsuccessful seasons is purchasing grapes from other growers within the state or even outside of the state. A large, coastal grower explains:

> With hurricanes and late frost, you know, different things happen. We decided we need to diversify if we can. We have a contract grower in Mississippi, Florida and South Carolina. But hopefully if we get hit here with a hurricane we can make up for it by going down to Florida and Mississippi and buy more.

When altering vineyard practices do not suffice and the business cannot afford additional winegrape purchases, growers may alter winemaking techniques. Some growers that experienced a rainy season picked grapes that were too wet or watered down, but discovered they could produce a better Rosé wine than a red wine. Rosé wines are commonly produced with less

tannins than a red wine. A very large mountain grower noted, however, that this is not an optimal solution:

> You get no color [and] the flavor is not real good. [The main] problem is Rosé is only about $7 a bottle whereas the Cabernet is $15 or $20. You have to either blend it with some other grapes or something. If we get at least a ton from two acres, here that's still $7,500 coming in that we wouldn't have if we didn't pick

Many winemakers also have the ability to blend juices, enhance flavors, and adjust time in tanks or barrels to make up for growing issues. A piedmont grower said, "You never manipulate wine, but it's all controlled with how you move it around, how quickly you ferment it, tank temperature." One vineyard in the northern mountains of NC has even learned to take advantage of their cold temperatures by producing an ice wine from thick skinned grapes left on the vine until December. Overall, interviewees emphasized that some years the winemaker has to do very little and other years require "you to go deeper into your bag of tricks to turn out quality wine."

7.1.5 Viticulture Experience: Personal and Outside Resources

Some interview participants felt very strongly that the number one factor in the success of a vineyard is field experience. A lifelong farmer operating a large vineyard in the western piedmont passionately said, "A farmer is a farmer. For people who are non-farmers, it's like learning a foreign language. If you're coming out of corporate it's like learning a foreign language." She continues, "It's purely a matter of perspective and from what background you're coming. For growing grapes, it's just one more crop and one more form of farming, which [we have] done for 50 or 60 years, so it's no big deal."

Research by Howden et al. (2007) shows that social and institutional structures can influence the capacity for adaptation. Building relationships with other growers, for example, can

introduce growers to new ideas and experiences. In NC, the wine industry is made up of a unique series of connections involving wine trails, where the cooperation between wineries in each winegrowing region is essential. Interview participants also utilize trusted contacts, university sources, and private sources including grower associations. Producers with less experience reach out to other sources more often than those who believe they have enough experience or rely on their own knowledge to guide management decisions.

North Carolina State University's Department of Horticultural Science provides many research opportunities within the wine industry. A number of winegrowers mentioned Sara Spayd, from this department, who doubles as an extension agent and bunch grape researcher. A large, western piedmont grower suggests that, "other extension agents, they're great help but they're learning too. Our biggest resource for all the questions we had for the first years is Virginia Tech. And they've been doing it in the microclimates of VA, which are similar enough to here." She continues, "Tony Wolf is the one who's been saying to people [that] you all can do in North Carolina what we've done in VA." Another small, eastern piedmont producer added:

> Over the past 10 years we've seen a lot more education and understanding from the government side of it. When I first had an extension agent come out, [they knew of] muscadine. They didn't know anything about hybrids [and] they didn't know anything about viniferas. And grapes weren't a huge part of the extension anyway.

Today, the NC wine industry is improving research and viticulture resources. "Approximately eighteen people were employed on a full time basis in North Carolina in wine-related education, consulting and research, with a payroll of approximately $1 million. State and regional organization support is critical to the success of the renewed industry" (Rimerman & Co. 2011). These organizations include the North Carolina Wine & Grape Council, (which is part of the North Carolina Department of Commerce), North Carolina Winegrower's Association, Yadkin Valley Winegrowers Association and the North Carolina Muscadine Grape

Association. Viticulture organizations focus on business and marketing support, while people like Sara Spayd and Tony Wolf focus on grape quality and sharing information with the growers. One grower emphasized, “We’re really not doing anything that a dozen people before us have done. It’s just a lot of time we’re stubborn. We want to learn it ourselves and do it ourselves. I think overall we’ve got some pretty good support.” Many interviewees have voluntarily served on the Grape Council or in roles with the North Carolina Winegrowers Association since its establishment in 1973.

7.2 Future in North Carolina Wine Industry

North Carolina winegrowers certainly face many challenges, but the future of the industry holds many opportunities to improve adaptive capacity. An eastern piedmont grower describes his experience, “You know, they can grow grapes everywhere in the world. I mean, you’d be surprised where they grow grapes. You can’t grow every grape everywhere in the world though.” He continues, “when I talk to people about coming to the winery I talk about three distinct growing regions. I don’t know of any other state that has that and ours is so unique.”

Because the North Carolina Wine Industry is generally considered young and inexperienced, the most common opportunity identified was marketing. A western piedmont grower said, “I can’t wait for people to taste some of the wines we have because they’re going to say there’s no way this is from North Carolina.” Many growers feel strongly that they already have the proper knowledge and experience to produce high quality wine in the NC climate, although one grower disagreed: “Just because you know how to make wine doesn’t mean you know what good wine is. I think there are a lot of people in North Carolina that make wine and they don’t have any clue what the wine is.” She is referring to owners and operators that did not

come from a farming or viticulture background. This emphasizes the value of pooled information regarding everything that can affect NC viticulture.

Unfortunately, the Wine & Grape Council's budget was recently cut in half, resulting in fewer funds for marketing programs on behalf of the wine industry (Rimerman & Co. 2011). This may not impact vineyard growth or tourism, but will reduce opportunities to expand the consumer market. This is another reason to increase localized support and cooperation as well as University research.

Producers are constantly making critical decisions that sustain their crop and overall business. Again, grape vines are perennial crops that cannot be quickly replaced if damaged and expected to produce optimal yield the following year. One grower emphasizes, "Sustainable means that you're here to stay. We are caretakers of the land, so we do what we need to keep the land workable and usable." For farmers to sustain a vineyard and a winemaking operation they have to constantly create a plan for the next five years and into the future. Sustainable practices provide defense against potential climate changes and can lead to a more successful business in the wine industry.

CHAPTER 8: CONCLUSIONS

This study incorporates mixed methodology in a way that has not been previously applied to North Carolina viticulture. The goal was to use the experiences and explanations of producers to better understand the impacts of weather, climate, and climate change on the NC wine industry. North Carolina is a specialized growing region where risks and seasonality of risks are unique to each vineyard. The wine industry is a significant element of the NC economy, culture and heritage. Improving our understanding of climate sensitivity can help to identify both its potential and greatest risks.

The first research question was addressed by identifying the most important variables perceived by winegrowers in the context of creating a successful enterprise and then identifying how winegrowers perceive weather and climate risks specifically. Variation in survey and interview responses to weather and climate risks were analyzed based on suitability zone, experience, vineyard acreage, and winegrape varietal grown to address the second research question. Based on winegrowers' experiences, specific weather and climate variables were analyzed on a 30 year time scale to better understand current climate trends at critical times in the growing cycle. Focusing on an area with the greatest concentration of survey and interview respondents made it possible to link actual weather station measurements with specific changes that growers are experiencing as stated in the third research question. Visualizing trends in important variable and viticulture suitability across the entire state addresses the fourth research question. This identifies what could potentially affect the wine industry and varietal suitability in the future. The survey and interview questions measured the level of concern for such potential changes and preparations in place in order to answer the final research question.

8.1 Research Results

The results of the survey and interviews show that growers balance many variables in the vineyard and the business at different times of the year. According to NC winegrowers, weather and climate are the most important variables to consider in a wine enterprise but there are other very important variables that determine a successful year. Pest and disease risks are almost as important when heightened by humidity and excessive rainfall. The physical growing environment is the center of any agricultural industry and growers in this study rank it as somewhat or very important. The government is less important to overall respondents, but a few had strong comments against the government's involvement in their business. Winemaking is closely monitored in NC and the permitting process has been a frustrating experience for many in this study. Producers utilize irrigation in an effort to reduce production risks from the rapid onset of high temperatures and little rainfall. However, water availability is not a crucial issue for most growers because sufficient rainfall is usually received naturally. Technology is often used to reduce overall labor costs, but many vineyards continue to do everything by hand. Other costs discussed include advertising, purchasing winegrapes, and operating facilities. Growers believe these costs are important to the winery business but they are not ranked as very important aspects of a successful year. As the industry progresses, the market expands, or environmental conditions change, growers may rate the variables of a successful year differently.

Growers in this study indicate that there is a relationship between weather risks and other variables that are a part of a successful enterprise. For example, negative weather impacts in the vineyard could lead to increased pests and lower quality, forcing a producer to increase costs. Increased costs may indirectly affect bottle prices and tourism.

The majority of producers expressed high concerns for excessive rainfall and subsequent diseases or quality reduction. Rainfall combined with constant cloud cover can severely affect ripening winegrapes, particularly in August, and growers can do little to manage these conditions. Severe weather and hail are a large risk to many growers in this study. Interviewees recall major storm events that watered down grapes, produced heavy erosion, and interrupted harvest. In addition, high winds are perceived by most as a moderate risk because it can blow down rows of vines. If they can be set upright quickly then the impact is minimal. Most respondents perceive high and low temperatures as a moderate to strong risk. Late frost is a higher risk to early blooming varieties, especially in regions of the state that do not regularly receive frost throughout April and May. January minimum temperatures are crucial to preventing disease and early shoot growth. Many growers indicate that the rapid onset of high temperatures paired with insufficient rainfall can create moderate to strong risks throughout the summer months. Most growers in this study perceive drought as a slight to moderate risk because it provides the best grape quality and can be managed with a properly working drip irrigation system.

While many individuals continue to debate the details and the magnitude of climate change, fewer are denying it outright. Some wine producers, particularly those with a long experience history, strongly believe that the idea of climate change is a hoax amplified by the media and politics. The reason most growers are not very concerned is because most did not express having experienced any changes in weather variables except for high temperatures. Most producers believe high temperatures are becoming more frequent. A high percentage of respondents indicated August as a particularly sensitive month to changes in excessive rainfall.

NC growers in this study are aware of what potential fluctuations in climate can do to their vines but not all have recognized ideal management and responses to climate change.

Producers who have recognized climate changes as a concern expressed many ways to respond to weather and climate risks. In some cases, producers implement strategies to prepare for climate variability from the beginning of the vineyard. These strategies may include specific site selections, variety selection, and crop insurance. Producers mentioned a variety of alterations to viticulture practices and timing as the growing conditions and environment change. Preventative practices include the delay of pruning, use of chemical sprays, reinforcement of trellises, and the introduction of new technology. Reactive practices may require producers to delay harvest, purchase grapes from an outside source, or utilize winemaking skills. Growers have expressed specific adaptations for the future, which include selecting hardier varietals able to handle warmer temperatures. Vineyards with multiple winegrape varieties, each with differing sensitivities, are subject to risks that require different management. A mix of varieties may also reduce overall vulnerability, if one variety does not have a successful season. Managing multiple weather risks in one year can be difficult, especially if growers have trouble identifying the cause of multiple impacts on the crop.

There are many different influences of perception of risk and risk management, including personal and social experiences, which can affect the capacity for adaptation (Julien 2007, Adger et al. 2007). The t-test did not identify growers' experience in the industry or the size of operation to have a significant influence on responses to questions of risk. Interviewees operating large vineyards did discuss more opportunities to prevent negative impacts to their enterprise than smaller vineyard operators. A higher yield is at risk on large vineyards but more resources may be available to take preventative measures. Smaller vineyards with fewer resources to

protect their crop discussed many reactive strategies. The ANOVA analysis did not show significant differences in survey responses between groups of winegrape varieties or between suitability zones with the exception of insufficient rainfall. Responses to insufficient rainfall risk show similarities within the suitability zone and varieties grown in each zone. Eastern growers perceive drought as a higher risk because rainfall is regularly received and there may not be an irrigation method in place. Several survey respondents from Zone 2 and 3 specify that irrigation is established and risk to drought is lower.

Balancing decisions to avoid damage and produce optimum quality can vary every year. Producers stress the importance of collaboration with each other and viticulture organizations to learn what others are doing to manage risks. The greatest opportunities in the NC wine industry involve education, experience, and proper marketing of North Carolina's wine quality and rich viticulture history.

Overall, the case studies from the Elkin and Yadkinville weather stations reflect similar conditions that winegrowers express as either good or bad years. The aim of each case study is not to be representative but to understand how experiences and responses reflect on historical climate data in a local context (Flowerdew 2005). The greatest $R^2 = 0.0712$, shown in the Elkin station's August total number of rain days trend line, suggests that the number of rain days may be decreasing. The Yadkinville area has experienced very little change in August maximum temperatures over the past 54 years. There have been periods of high variability and outliers but this case study does not show an increase in high temperatures that survey respondents are experiencing. Low temperatures in April and January have very flat trend lines as well and do not show change over the 54 year time scale. However, there are obvious changes in the variability of minimum temperatures during the period between 1994 and 2012.

Based on the statewide spatial analysis of minimum and maximum temperature trends over a 30 year period, general climate change conclusions can be made. Trend lines suggest that the southern mountain region is experiencing a positive increase in August mean maximum temperatures. January mean minimum temperature trend lines suggest that the central region of the state is experiencing warming and the western piedmont is slightly decreasing temperature each year. Overall, most of the state is slightly increasing in both August maximum temperatures and January minimum temperatures each year. Future changes may or may not follow the historical trend line. Natural climate fluctuations may contribute to the climate variability shown in historical records (Gladstones 2011, Hurrell 1996). Viticulture suitability has not drastically changed since 2000, with some exceptions. Wineries near the zone boundaries may need to be particularly watchful for climate conditions in determining varietal selection. If minimum winter temperatures follow an increasing trend line, pest and disease risks may become more prominent, especially in regions where growers are not concerned about climate changes.

8.2 Limitations

Using a web survey has many limitations. Winegrowers who do not have a personal email provided at NCwine.com or on their winery's webpage resulted in using a general information email for the winery. Many emails may have been mistaken for spam and deleted, despite multiple reminder emails. A questionnaire is subjective in the tone and questioning set by the surveyor. Ambiguous terms, such as the importance of a variable on the success of a winery, may have different meanings to each respondent. Some survey questions lack the explanation or reasoning behind a response (Flowerdew 2005). The limited response to the web survey does not equally represent each growing region, making it difficult to compare responses from each. This

is also due to the fact that NC wineries are not evenly distributed across the state. Because surveys collect data at a single point in time it is difficult to measure how responses change as growers experience variations in weather and climate.

Semi-structured interviews limit the number of participants due to time constraints. Having only one principal investigator with limited resources also reduced the number of interviews conducted in the time frame available. Cold calling may have caught people at an inopportune time and some then requested email contact, but unfortunately most email inquiries did not result in a response. A level of subjectivity is also present with qualitative research involving personal understanding and characteristics into questioning and interpretation (Hay 2010).

A potential limitation to a trend analysis with weather station data includes any change in physical location. If any sensors had been moved, data accuracy changes or if there are gaps in measurement (Boyles and Raman 2003). The scale that each station represents lacks accuracy when studying localized vineyard climates. Vineyards are positioned on various slopes and North Carolina's complex climate and diverse topography requires more weather station locations with complete continuous observations. A station cannot account for this amount of variability unless it is positioned directly onsite. A few stations had missing records that could have affected the mean or mode calculations and resulting trend lines.

As defined previously, interpolation is only an estimation of values between weather stations in this study. Obtaining data from more weather stations would improve interpolation accuracy, but this was not possible in NC because of an incomplete 30 year historical record at many stations. The kriging analysis used trend values, as opposed to actual observations, which increases uncertainty. The prediction standard error maps (Fig. 8.1) produce a value quantifying

the uncertainty of a prediction or the difference between the true and predicted value for kriging maps from Chapter 6 (Fig. 6.14-6.16).

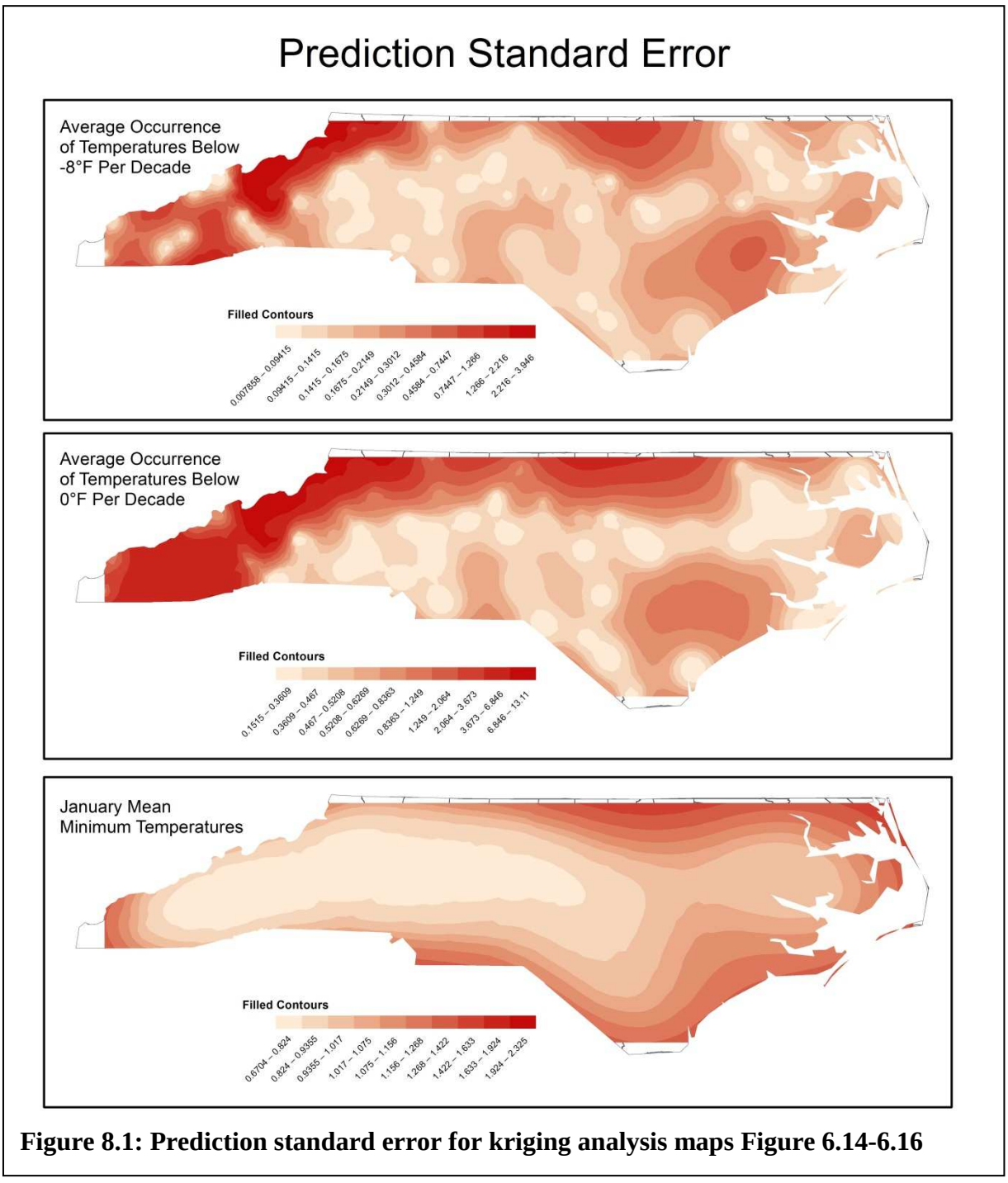

Figure 8.1: Prediction standard error for kriging analysis maps Figure 6.14-6.16

Figure 8.2 shows the prediction standard error for the kriging maps from annual August mean maximum temperature trends (Fig. 6.20) and annual January mean minimum temperature trends (Fig. 6.21).

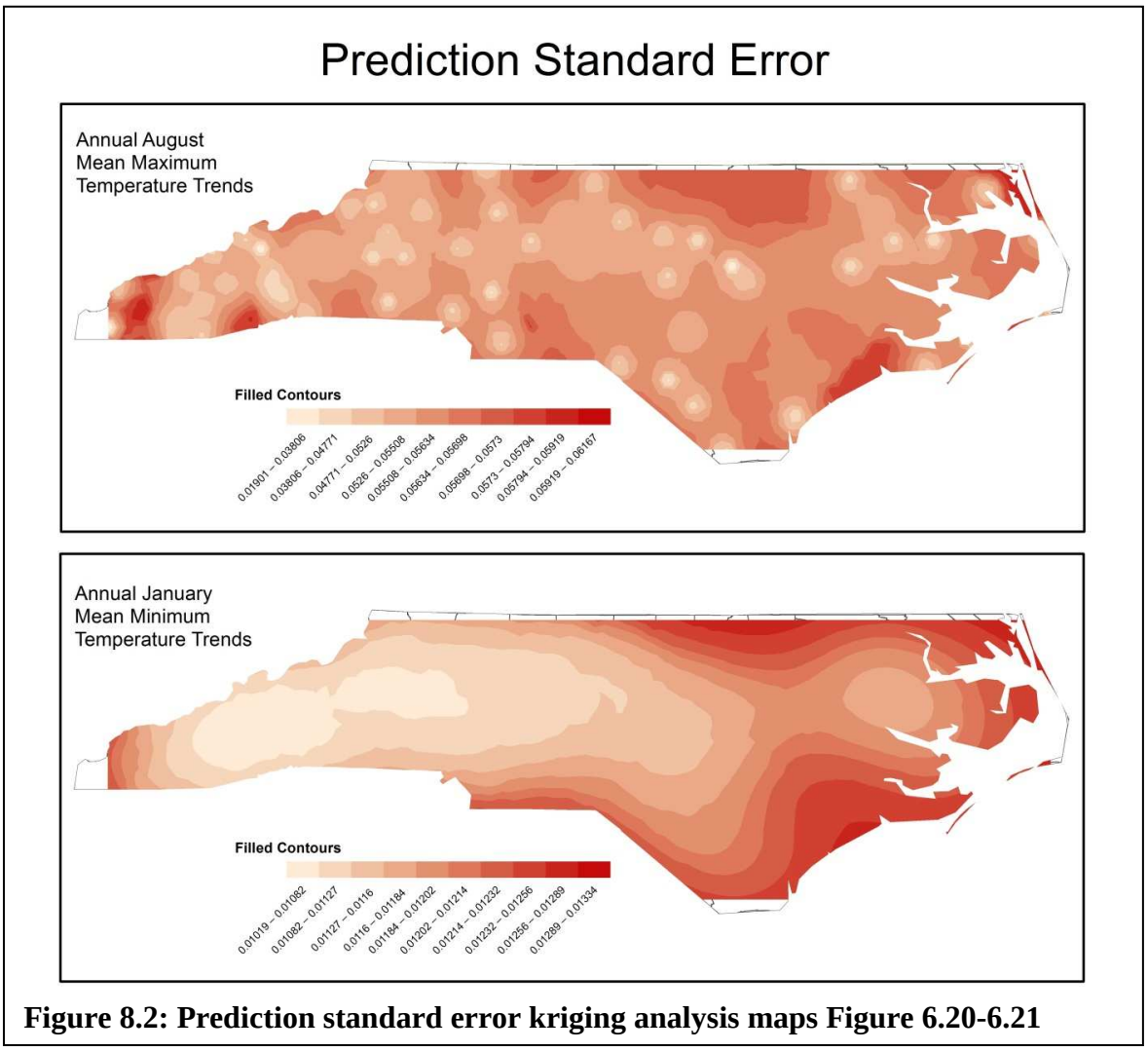

Figure 8.2: Prediction standard error kriging analysis maps Figure 6.20-6.21

Dark red areas have higher uncertainty and white areas have lower uncertainty. 95 percent of the time the true value will lie within the predicted value plus or minus two times the prediction standard error if data is normally distributed.

8.3 Future Research

This study, and others like it, serve as a model to be applied to other winegrowing regions of North America and other areas where limited understanding exists. The survey and interview questions can be extended to growers that did not participate in this study to develop a better representation of their localized perceptions of weather, climate, and climate change. A similar survey implemented at different points in time may be compared to the results of this thesis to identify changes in responses. Many different forms of content analysis could be applied to the qualitative data in this study to better understand meaning and reasoning behind responses. GIS provides powerful opportunities to visualize environmental data and can be better utilized in climatology research. Interpolating trend lines for other sensitive months that this study did not analyze could provide further insight to climate changes throughout the year.

8.4 Contribution

This research provides an opportunity for winegrowers to share opinions, experiences, strategies, and hopefully improve on future climate change defenses and overall production of their vineyards. This research has the potential to inform all sectors of the wine industry with similar climates and through many forms of agribusiness. The end results can be used to formulate action plans used by agricultural education professionals to help the producers adjust to potential climate changes. Several existing organizations could serve as a platform for sharing results, including the North Carolina Wine Growers Association, NC Wine & Grape Council, NC Muscadine Grape Association, and the Carolina Farm Stewardship Association. Working through such organizations, winegrowers can pull and share resources together, working to protect the NC wine industry, and keeping connected to further education and research in the

field. Climate change impacts on the wine industry could also indirectly affect other industries such as tourism; therefore any education and adaptation could potentially protect tourism across the Mid-Atlantic United States.

Winegrowers are familiar with their own microclimates and the environmental conditions that shape their vineyards, and their knowledge and insight can provide a different perspective on their industry. This record of survey respondents and interviewees are doing their best to cope with current changes and prepare for potential future changes in weather and climate. We can continue to learn from their local expertise, balanced with climate science, to reduce viticulture vulnerability. North Carolina growers told me the risks, challenges, and the uncertain future in this state make for a job that is far from boring.

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APPENDIX A

INSTITUTIONAL REVIEW BOARD LETTER OF APPROVAL

EAST CAROLINA UNIVERSITY
University & Medical Center Institutional Review Board Office
4N-70 Brody Medical Sciences Building· Mail Stop 682
600 Moye Boulevard · Greenville, NC 27834
Office **252-744-2914** · Fax **252-744-2284** · www.ecu.edu/irb

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From: Social/Behavioral IRB
To: Heather Blair
CC: Jeff Popke
Date: 5/17/2012
Re: UMCIRB 12-000978
North Carolina Winegrowers' Perceptions of Climate Change Impact

I am pleased to inform you that your Expedited Application was approved. Approval of the study and any consent form(s) is for the period of 5/17/2012 to 5/16/2013. The research study is eligible for review under expedited category #6, 7. The Chairperson (or designee) deemed this study no more than minimal risk.

Changes to this approved research may not be initiated without UMCIRB review except when necessary to eliminate an apparent immediate hazard to the participant. All unanticipated problems involving risks to participants and others must be promptly reported to the UMCIRB. The investigator must submit a continuing review/closure application to the UMCIRB prior to the date of study expiration. The Investigator must adhere to all reporting requirements for this study.

The approval includes the following items:

Name	Description
Initial Survey | History	Surveys and Questionnaires
Interview Guide | History	Interview/Focus Group Scripts/Questions
Participant Consent Form | History	Consent Forms
Survey Oral Consent Script | History	Consent Forms

The Chairperson (or designee) does not have a potential for conflict of interest on this study.

APPENDIX B

INFORMED CONSENT DOCUMENT

Title of Research Study: "North Carolina Winegrowers' Perceptions of Climate Change Impacts"

Principal Investigators: Heather Blair
Institution: East Carolina University
Address: Department of Geography, Greenville, NC 27858
Work Telephone #: (240) 674-9325

INTRODUCTION

This document may contain words that you do not understand. You should ask the study investigator to explain any words or information in this form that you do not understand.

You are being asked to participate in a study being carried out by Heather Blair (Department of Geography). The goal of the study is to better understand the impact climate change presently has on viticulture in North Carolina. For this reason, we are interested in the opinions and experiences of winery or vineyard owners and operators in the region. You are being asked to provide an interview that will last approximately 60 minutes. Your participation is voluntary, and you may choose not to answer any question you are asked. The information you provide will be strictly confidential and used only for research purposes. Your name, and the name of your winery or vineyard, will remain completely anonymous, and any information that you provide will only be presented using the size of your operation and general location. The interviewer will request your permission to record the interview to enable us to correctly document your responses. Interviews will be recorded and transcribed. Digital audio files will be accessible only to the study investigators; written transcripts will use code names. The digital audio files will be destroyed after one year. Any material (such as direct quotations) used from interviews will be presented without any identifiable information, beyond a generalized description of the respondent's position and grape varieties (e.g., Winery Owner, small winery with less than 10 acres located in Yadkin Valley" or "Vineyard Operator, large vineyard located in Piedmont region"). Access to data will be restricted to study investigators and kept in locked office spaces and/or password protected computers.

RISKS AND BENEFITS

Given the subject matter (Climate Change impacts) it is possible that certain questions may pose large disagreements or disbelief. This may lead to refusal to continue responding or overall disagreement with remainder of questions. The key benefit to participating is the opportunity for you to contribute to our understanding or misunderstanding of climate change conditions in the region and adaptation strategies.

INFORMED CONSENT

My participation in this study is voluntary and I may stop at any time I choose. I may also choose not to answer specific questions without entirely stopping my participation. Should I at any time have any questions about this research the investigator(s) will be available to answer them. Also, if I have any questions about my rights in this research, I may contact the Chair of the University and Medical Center Institutional Review Board at (252)-744-2914.

- ☐ I have read and/or understood all of the above information, asked questions and I willingly consent to participate in this voluntary research study.

- ☐ I do not wish to participate.

PERSON ADMINISTERING CONSENT: I have conducted the consent process and orally reviewed the contents of the consent document. I believe the participant understands the research.

Person Obtaining Consent **(PRINT)**	**Signature**	**Date**

Principal Investigator's **(PRINT)**	**Signature**	**Date**

APPENDIX C

WEB SURVEY

This survey is a part of a project that aims to better understand the current and potential impact of weather, climate, and climate change presently on viticulture in North Carolina. I am interested in your experiences and opinions as someone involved in the wine industry. The survey will only take approximately five minutes. It will be stored with complete confidentiality and be presented without any identifiable information. I sincerely appreciate your participation!

Q1 What is the name of your vineyard?

Q2 What is your role in this enterprise? Check all that apply.

- ❑ Owner, Co-Owner and/or President
- ❑ Vintner
- ❑ Vineyard Operator
- ❑ General Manager
- ❑ Other _____

Q3 How many years have you been involved in the wine industry?

Q4 What year was your vineyard established?

Q5 What winegrape varieties are grown, how much land is dedicated to each, and if known what is the estimated yield of each variety?

	Approximate Acreage							Please fill in:	Select units of yield:	
	None	< 1	1 - 5	5.5 - 10	10.5 - 15	15.5 - 20	20.5 <	Average Yield	Cases	Tons
European (vinifera)	❍	❍	❍	❍	❍	❍	❍		❍	❍
French-American Hybrids	❍	❍	❍	❍	❍	❍	❍		❍	❍
Muscadines (vitis rotundifolia)	❍	❍	❍	❍	❍	❍	❍		❍	❍
Labrusca-type	❍	❍	❍	❍	❍	❍	❍		❍	❍
Other	❍	❍	❍	❍	❍	❍	❍		❍	❍
Other	❍	❍	❍	❍	❍	❍	❍		❍	❍

Q6 How important are the following variables in determining whether or not your enterprise has a successful year?

	Importance:					(optional)
	Not at all Important	Somewhat Unimportant	Neither Important nor Unimportant	Somewhat Important	Very Important	Additional comments or explanation:
Weather & Climate	❍	❍	❍	❍	❍	
Cost of Inputs	❍	❍	❍	❍	❍	
Growing Environment	❍	❍	❍	❍	❍	
Market Conditions	❍	❍	❍	❍	❍	
Technology	❍	❍	❍	❍	❍	
Pest & Disease Control	❍	❍	❍	❍	❍	
Irrigation	❍	❍	❍	❍	❍	
Government	❍	❍	❍	❍	❍	
Other	❍	❍	❍	❍	❍	
Other	❍	❍	❍	❍	❍	

Q7 How big of a risk do the following weather and climate conditions or events pose to the success of your enterprise in any given year?

	Vineyard Risk:					Additional comments/explanation:
	No Risk	Slight Risk	Moderate Risk	Strong Risk	Very Strong Risk	(i.e. time of year, variety at risk, etc.)
Excessive Rainfall	❍	❍	❍	❍	❍	
Drought or Insufficient Rainfall	❍	❍	❍	❍	❍	
Extreme High Temperature	❍	❍	❍	❍	❍	
Extreme Low Temperatures	❍	❍	❍	❍	❍	
High Humidity	❍	❍	❍	❍	❍	
High Wind	❍	❍	❍	❍	❍	
Hail	❍	❍	❍	❍	❍	
Severe Weather	❍	❍	❍	❍	❍	
Other	❍	❍	❍	❍	❍	
Other	❍	❍	❍	❍	❍	

	Any particularly time(s) in the growth cycle more at risk?												
	All Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Excessive Rainfall	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
Drought or Insufficient Rainfall	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
Extreme High Temperature	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
Extreme Low Temperatures	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
High Humidity	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
High Wind	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
Hail	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
Severe Weather	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
Other	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
Other	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑

Q8 Have you experienced any changes in the following weather and climate conditions or events in the last 5-10 years? If yes, continue to fill in columns to the right:

	Experienced any changes?		Changes in Frequency of Occurrence?			Changes in Intensity of Condition or Event?			Additional comments/ explanation:
	Yes	No	Less Frequent	Same Frequency	More Frequent	Less Intense	Same Intensity	More Intense	(i.e. season, variety affected, reactions, etc.)
Excessive Rainfall	❍	❍	❍	❍	❍	❍	❍	❍	
Drought or Insufficient Rainfall	❍	❍	❍	❍	❍	❍	❍	❍	
Extreme High Temperatures	❍	❍	❍	❍	❍	❍	❍	❍	
Extreme Low Temperatures	❍	❍	❍	❍	❍	❍	❍	❍	
High Humidity	❍	❍	❍	❍	❍	❍	❍	❍	
High Wind	❍	❍	❍	❍	❍	❍	❍	❍	
Hail	❍	❍	❍	❍	❍	❍	❍	❍	
Severe Weather	❍	❍	❍	❍	❍	❍	❍	❍	
Other	❍	❍	❍	❍	❍	❍	❍	❍	
Other	❍	❍	❍	❍	❍	❍	❍	❍	

	Any particularly time(s) in the growth cycle more at risk to changes?												
	All Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Excessive Rainfall	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
Drought or Insufficient Rainfall	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
Extreme High Temperature	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
Extreme Low Temperatures	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
High Humidity	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
High Wind	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
Hail	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
Severe Weather	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
Other	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
Other	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑

Q9 How concerned are you that climate change will impact your vineyard in the future?

Not at all Concerned ❍
Slightly Concerned ❍
Somewhat Concerned ❍
Very Concerned ❍

Q10 How has your vineyard prepared for potential impacts of climate change?

Q11 Would you be willing to be contacted for clarification and/or follow-up questions?
Please provide your preferred means of contact (e-mail or phone):

Q12 Would you like to receive a summary of the results of this survey?
Please provide an e-mail or mailing address:

APPENDIX D

INTERVIEW GUIDE

Personal Background

- What is your role at the winery or vineyard? How long have you farmed here?
- How did you enter the wine industry?
- Have you always lived in North Carolina?

Winery and Vineyard Characteristics/History

- How was this land acquired? What were the main variables that made the site ideal for growing grapes?
- How many acres? How has the acreage increased/decreased since establishment?
- What types of grapes are grown, and how much land is dedicated to each? Do you outsource for any grapes?
- What has grown in the past? And why did it change?
- Do you sell your grapes? Where do you sell your wine products?

Growing Practices

- What the key challenges or variables that cause stress on your vineyard?
    - Has weather and climate had an influence on the vineyard's operation since establishment?
    - How do the costs of inputs influence the winery and/or vineyard?
    - How do the market conditions influence the winery and/or vineyard operation?
        - How does the governmental policy or regulation influence your enterprise? Has anything changed from the past?
        - How do surrounding states' governmental policies or regulation influence your enterprise?
    - Has the environment (including soil, drainage and pests) had any influence on the vineyard's operation?
    - Has technology had any influence on your vineyard? (Including biotechnology, genetics)
- Have you made any changes to your growing practices based on these stressors? Has the vineyard ever purchased crop insurance?

Weather and Climate

- Can you describe the weather and climate conditions crucial for the success of your vineyard throughout a typical year?
    - Has the vineyard experienced any significant weather and climate events since establishment? (Hurricanes, Drought, Severe Weather – including strong wind and hail events)

- How did your winery respond? Were there any factors that helped or hindered the response? How effective was your response? Would you respond differently if the same event happened again?
- How does your enterprise utilize weather and climate information? Is there a particular weather station used? Has your winery consulted University research?

Weather and Climate Changes Over Time

- Past: Have you experienced any changes in weather and climate conditions or events in the last 5-10 years?
  - Has the occurrence or intensity of drought conditions changed over time?
  - Has the occurrence or intensity of excessive precipitation changed since establishment? (Any changes in the pattern of rainfall) Severe thunderstorms, hail and/or strong winds?
  - Have winter temperatures changed? Changes in extreme cold? Frequency or intensity of late spring frost?
  - Have summer temperatures changed? Changes in extreme heat? Patterns of high humidity?
  - Has the length of growing season changed since establishment?
- What is your personal meaning of climate change?
- Future: Are you concerned about future changes in weather and climate?
- Have your farming practices changed as a result of changes in the climate or environment?
- Have you adopted any specific adaptation strategies due to changes in weather and climate?

Region

- What is your winery's relationship with others within your growing region? And outside of the region?
- Do you share any growing strategies or experiences with other wineries?
- Would you benefit/learn from other wineries and vineyards if you had the opportunity to easily share growing or adaptation strategies?

Tourism

- Do you have significant involvement in the tourism industry?
  - Has the timing or intensity of the tourism season changed?
  - Is there a sense of brand loyalty? More or less in-state visitors than out-of-state?
- Sustainable Tourism: Does the winery or vineyard incorporate sustainable or environmental practices in its operation?

Closing

- Do you expect to continue working in the wine industry?
- Is the vineyard to be eventually sold or passed down to future generations?

- What are the major risks that could potentially affect your business over the next 5-10 years of operation?
- What are the major opportunities that could potentially improve your business over the next 5-10 years of operation?
- In your opinion, what is the future of the wine industry in North Carolina?