

SPATIAL-TEMPORAL CLUSTER ANALYSIS TO IDENTIFY EMERGING  
AGGLOMERATION OF TEXAS WINERIES, 1973-2014

by

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## **DEDICATION**

“Sometimes our light goes out but is blown into flame by another human being. Each of us owes deepest thanks to those who have rekindled this light.” Albert Schweitzer

Without the love and support to the two most important people in my life, Marilyn and Jacob Shelton, this would not have been possible. I owe both of you the deepest thanks for rekindling my light.

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## **ABSTRACT**

Wine is of interest to geographers for a variety of reasons. To fully understand the geography of wine, one must consider many factors. For example, the geology, biology, climate, culture, economics, and politics of a particular region influence the wine produced there. In Texas, wine production dates back more than 350 years. However, only within the past few decades has the wine industry in Texas grown significantly. This paper has two goals: 1) an examination of the history of the Texas wine industry, and 2) a spatial-temporal cluster analysis to determine emerging patterns of agglomeration of wine production in Texas. Understanding the Texas wine history and identifying these patterns establishes a baseline that will be useful for future study which examines the factors driving growth and development patterns of the Texas wine industry from a geographical perspective.

To conduct the spatial-temporal analysis, I used ArcGIS 10.2.1. I created histograms and decadal snapshots to show change over time. I then created standard deviational ellipses using the decadal snapshots to examine emerging trends. Prior to processing the data with the mapping clusters tools, I used the Incremental Spatial Autocorrelation to determine that there is one statistically significant peak distance, at 198550 meters. I also created a spatial weights matrix to be able to include temporal factors.

I used all three of the mapping cluster tools (Grouping Analysis, Cluster and Outlier Analysis, and Hot Spot Analysis) to examine spatial clustering and, using the spatial weights matrix, spatial-temporal clustering. The Grouping Analysis divided along spatial lines and when time was added as a factor, separated out the early wineries and then along the spatial lines. The Cluster and Outlier Analysis also divided out similarly without time as a factor. When time was added the clustering and outliers were no longer in distinct spatial divisions. The Hot Spot Analysis gave similar results to the Cluster and Outlier Analysis tool, with and without the temporal weighting.

I created another spatial weights file, only using the wineries established after 2003. The spatial results appeared similar, with the exception that almost all of the clusters identified are now shown to have a 99% confidence level.

This study identified provides a solid baseline for further research into the Texas wine industry. It establishes the historical context of the industry and identifies statistically significant emerging agglomeration of wineries in Texas. This information can be used as the basis to study why this agglomeration is occurring.

## I. INTRODUCTION

Wine is of interest to geographers for a variety of reasons. To fully understand the geography of wine, one must consider many factors. For example, the geology, biology, climate, culture, economics, and politics of a particular region influence the wine produced there (Sommers 2008). Texas wine production dates back more than 350 years. However, only within the past few decades has the wine industry in Texas grown significantly. Indeed, this paper will show that the Texas wine industry continued to grow even during the recent 2008 economic recession that slowed growth in many other industries. The purpose of this paper is to establish the historical background and to use spatial-temporal cluster analysis to determine whether there are emerging patterns of agglomeration of wine production in Texas. Identifying these patterns will establish a baseline that will be useful in future studies which seek to examine the factors driving growth and development patterns of Texas wineries from a geographical perspective.

### History of Wine Growing in Texas

At least 15 of the 36 species of the grape (genus *Vitis*) are native to Texas, more than in any other region on Earth (Johnson 1994). Though grapes have grown in Texas throughout human history, there is no evidence that indigenous peoples ever fermented them to create wine. Not until Spanish missionaries arrived in Texas in the late 16<sup>th</sup> and early 17<sup>th</sup> centuries did viniculture become established the region (Crain 2013).

During the early 1600s, the Catholic Church established short-lived missions to minister to the Jumanos tribe of western parts of Texas. There is no evidence to indicate that any grapes were grown at these locations, however. Missions were also established in New Mexico and expansion of these Franciscan missions enhanced the demand for wine for religious ceremonies, particularly the Eucharist. The first record of viniculture

(growing grapes specifically to make wine) was associated with the establishment of the Mission de Nuestra Señora de Guadalupe (Our Lady of Guadalupe) by Fray Garcia de San Francisco in 1659. The grape variety that he planted is unknown, though most historical records refer to it as Spanish Black or the Lenoir grape (it is also often referred to as the Mission grape). The mission vineyard was established along the banks of the Rio Grande del Norte near what is now Ciudad Juarez, Mexico. The first harvest likely occurred in 1661 or 1662 and wine grapes flourished in the region until 1897 when a devastating flood destroyed most of the vines and removed the vineyard's top soil. In 1916, the construction of the Elephant Butte Dam brought demise to what remained of vineyards in the vicinity of the original site (Crain 2013).

Other than the missions near El Paso, the Spanish did not pursue a permanent presence in Texas until the late 1680s when they began to determine their New World border in relation to French land claims. The Mission San Francisco de la Espada was established on the Trinity River in 1690. The site was abandoned within two years because of recurrent flood events and the fear of the local native tribe, the Hasinai, who blamed the Spanish for introducing devastating diseases. The mission was later re-established in the area of present-day San Antonio in 1732 (Crain 2013). Between 1716 and 1718 missions were erected in the area known as "East New Spain"; four were built in eastern Texas, one in Louisiana, and one in the San Antonio area. Hostilities between France and Spain led to the outright closing and the relocation of the five missions to San Antonio. The last of the missions to be established was the Mission San Antonio de Valero, known more commonly as the Alamo. In all, during the Spanish colonial period, 29 missions were established in Texas. In retrospect, some have speculatively concluded

that wine grapes were a part of the agriculture at these sites, but the historical record does not provide support for this notion. The inhospitality of the Texas climate for European grape varieties and the absence of a wine culture in Texas were primary factors that explain the lack of viniculture outside of El Paso Del Norte (Crain 2013).

Very few Europeans lived in Texas prior to Mexican secession in 1821. The Mexican government authorized a number of *empresarios* to promote American and European settlement in Texas. The most successful of these were the father and son team of Moses and Stephen F. Austin. By 1830, the population had increased to more than 4000 settlers in Texas, most of which came from the American South. The relationship between the new settlers and Mexico's government was troubled. In 1836, the mostly Anglo population of Texas successfully gained their independence from Mexico. The new Republic of Texas encouraged immigration with its own *empresario* system that successfully motivated the Anglo population, primarily relocating from Tennessee and Alabama, to swell to more than 100,000 by the time Texas joined the United States in 1845. Not until after the Treaty of Guadalupe Hidalgo in 1847, did Texas become an attractive migration destination for continental Europeans. The European immigrants, many from the post-revolutionary Germanic states, brought their wine cultures with them; however they did not have much luck growing European grape varieties in Texas. There were attempts to cultivate native grapes (the Mustang grape in particular) for wine, but without much success (Kane 2012).

The Mustang grape is naturally low in sugar content, limiting its value for winemaking. However, by 1860, Texas was home to more than 600,000 people primarily

due to immigration. Increasingly, immigrants from Germany, France and Italy were having greater influence on viticulture in Texas. I will describe each in turn.

The native Mustang grape is naturally low in sugar content, limiting its value for winemaking. The Herbemont grape had made its way to Texas from Georgia by the mid-1800s and was being grown alongside Lenoir and Mustang grapes. The 1860 and 1870 censuses reveal that about two percent of German farmers produced wine during these years (Crain 2013).

Texas' French settlers emigrated primarily from the Alsace and Lorraine areas of France, and both of these areas were important wine producing regions. Records show that a large number of vines were imported and planted in Texas, but no records indicate that wine was produced from these plantings. Unlike the Germans, there is no record of the French attempting to use the Mustang grape (Legarde 2003).

The last of the major wine-culture groups to emigrate from Europe were the Italians. During the years between the Civil War and World War I thousands of Italians immigrated to Texas, settling in a number of colonies. A small group of Italian immigrants settled in south Texas along the banks of the Rio Grande. Their participation in wine production in Texas was virtually non-existent, with one very notable exception.

Frank Qualia, originally from Milan, found suitable land, with water and a favorable climate, near San Felipe del Rio (a community known today as Del Rio, Texas). He planted Lenoir vines and founded the Val Verde Winery in 1883. Other neighbors in the Del Rio area followed suit (Crain 2013). Overall, the influx of European wine culture resulted in more than 50 operating wineries in Texas before the ratification of the Eighteenth Amendment (i.e. Prohibition) brought an end to nearly all of these

operations. The only exception is the Val Verde Winery, which survived Prohibition by selling grapes to home winemakers and by producing medicinal and sacramental wines (Kamas et al. 2008).

Texas made its greatest impact on world wine culture during the years between the Civil War and Prohibition. In the 1840s, *oidium*, also known as powdery mildew, devastated the European wine crop. France lost nearly 80 percent of its vines. To save the industry, growers imported Labrusca root stock from North American vineyards. These hybridized vines seemed to effectively rescue the French wine industry. But in the early 1860s, plants seemed again to be dying off at an alarming rate, this time with no identifiable cause. The source of the devastation was not identified until 1868. The culprit was phylloxera, a plant louse native to North America. It is to grape vines as bubonic plague is to humans. By the time its presence was discovered, it was nearly too late. Phylloxera's devastating effect on the economies of Europe was dramatic, and motivated much European emigration. French botanists tried, with very limited success, to graft French vines to American stock. The grafting was seldom successful and when it was the American root stock performed poorly in the alkaline soils. Eventually, it was clear that this approach would not save Europe's wine industry. Another decade lapsed before grafting of the vines was tried again, this time with the help of American viticulturists (Crain 2013).

Thomas Volney (T.V.) Munson discovered his interest in viticulture on the farm of a professor while attending Kentucky A&M in the 1860s. After graduating, he followed his brother to the Denison, Texas area where he found many native grape species. Heavily influenced by Darwin, he set out to scientifically categorize native North



American vines, organizing them by the types of soil in which they were found. He gained notoriety as a North American grapevines expert. By 1880, phylloxera had been in France for 20 years and had spread to Portugal, Spain, Germany and Italy. Desperate for a solution, the French Minister of Agriculture sent Pierre Vialla to the United States to search for a solution. After meeting with officials from the United States Department of Agriculture, he traveled to Denison to meet with Munson. Munson's understanding of the relationships of native vines to soils was invaluable. He sent Vialla home with root stock from vines that grew in chalky limestone soils similar to those of the wine-producing regions of France. The American rootstock led to the resurrection of European wine production. Munson and two of his colleagues were honored in 1883 when the French Minister of Agriculture conferred the *Chevalier du Mèrite du Agricole* (the French Legion of Honor) for their role in saving the French wine industry, making Munson, his colleagues and Thomas Edison, the only Americans of the time to be so honored (Crain 2013).

T.V. Munson passed away in the early 1900s and after the collapse of America's wine industry following the passage of the Eighteenth Amendment, little research into viniculture was being practiced in Texas, except for the continued operation of the Val Verde Winery in Del Rio. Tommy Qualia had this to say on why their winery survived Prohibition and the following years: "To put it simply, Frank and his son Louis, my father, loved this vineyard and winery as only an Italian would" (Kane 2012). Wine was a part of the family's Old World traditions and they were not going to stop drinking wine just because somebody in Washington said it was illegal. As the Qualias were astute businessmen, they continued to make sacramental and medicinal wines and continued to

ship grapes to the Italian community in Houston. In fact, they benefited from the elimination of the other wineries in Texas. When Louis took over, he continued to find success at the Val Verde Winery. He began experimentation with Herbemont grapes. A few vines of this variety still remain in his honor, but the vineyard today is nearly exclusively planted with Lenoir grapes.

In the 1970s, interest rose in the prospect of growing vines and producing wines elsewhere in Texas. Robert Mondavi's work in California was paying off and America was experiencing a resurgent consumer interest in wine. The rebirth of Texas wine culture can be traced to a few pioneers. Clinton "Doc" McPherson, Robert Reed, and Roy Mitchell were professors at Texas Tech University and they shared a love for wine. McPherson and Reed began an experimental farm to study the viability of wine grapes in Texas. Mitchell, a chemistry professor, started making wine in his laboratory at Texas Tech. From their collaboration emerged the Llano Estacado Winery. It was established near Lubbock, Texas in 1976. About this time, scholars at Texas A&M University and the University of Texas were undertaking research into commercial harvesting of grapes. At Texas A&M, horticulturist George Ray McEachern provided support for vineyard development and graduate work by Ron Perry focused on the economic viability of wine production in Texas. Charles McKinney began growing grapes on University of Texas properties near Fort Stockton, Texas, and today, the largest winery in the state, Ste. Geneviève Winery and its Mesa Vineyards, are the fruit of his labor (Kane 2012, Crain 2013).

Other enterprising Texans also conceived of Texas wineries. Dr. Bobby Smith started the La Buena Vida Vineyard west of Fort Worth, in Springtown. Ed Auler planted

the Fall Creek Vineyards on the western bank of Lake Buchanan in the Texas Hill Country, and Gretchen Glascock began the Davis Mountain Vineyard near Fort Davis in west Texas. These early pioneers faced two main obstacles: Texas' environmental conditions and the state's antiquated alcohol laws, which may have been the strictest in the nation during the 1970s (Kane 2012).

Many of the early wineries were located in "dry" counties of the state, wherein the production and sale of alcohol is illegal. It was illegal to even grow grapes for the production of alcohol in many parts of the state. In 1977, these pioneers, led by Smith, managed to secure passage of the Texas Farm Winery Act, which legalized the development of vineyards in dry counties. Though on-site sale of wine and public tasting remained in prohibition, growers were able to produce wine grapes and produce wine (Kane 2012).

All wines produced at these wineries had to be sold to distributors to get them to consumers, but distributors were usually not eager to commit to producers of small quantities of wine, which meant business was still difficult. In 1979, passage of another bill allowed wine tasting and limited sales of wines at wineries. By 1981, seven bonded wineries operated in the state. This number is about a third of the nineteen that had been operating at the beginning of Prohibition (Crain 2013). Obstacles were cleared one at a time, and eventually a 2003 constitutional amendment that developed a new framework for wine production in Texas was passed. This new framework transferred the power to control wineries to the state, mostly bypassing control by local "wet"/"dry" regulations. The law allowed wineries to make and sell wine in dry regions as long as at least 75

percent of the wine was made with the fermented juice of Texas-grown grapes (Kane 2012).

Aside from the complications of Texas' laws, the biggest challenge was to achieve financial stability. Early wineries were located significant distances from consumers because they were often far from large metropolitan areas. In addition, wine enthusiasts who did visit their wineries often found the wines offered were not wines to which they were accustomed (Crain 2013). For example, the Federal Bureau of Alcohol, Tobacco and Firearms' (ATF) rules require that to be labeled with a varietal name (such as Merlot, Cabernet Sauvignon, or Chardonnay) a wine must be at least 75 percent *vinifera* grape juice. So consumers typically found wines with generic (red or white) or blended wine labels indicating vintner's names for their concoctions. The wines that the early customers were finding were made with Lenoir, Herbemont, and other hybrid varietals. To address this issue, when Kim McPherson, Doc McPherson's son, took over as the wine maker for Llano Estacado Winery in 1981, he began to encourage farmers to start producing more familiar European grape varieties (Crain 2013).

Despite these challenges, over the next twenty years the number of wineries grew slowly. Some were successful and others were spectacular failures. Pierce's disease wiped out more than one vineyard. In terms of weather, growers found that the biggest enemy to the success of their vineyards was not the Texas heat, but late spring freezes (Kane 2012).

The pioneering wineries of these decades were able to make decent wines during some vintages using the "big three" wine grapes Merlot, Cabernet Sauvignon, and Chardonnay; some of their wines even won awards. For a small winery, being able to

produce and sell these wines was critical to their success. However, these varieties are hard to grow consistently in Texas. While some were successful, the leading premium wineries knew that these grapes were not to be the future of Texas' *terroirs*. What "works" in California does not necessarily work well in Texas. In terms of land area, Texas is a little larger than France. And, like France, there is wide variation in geology and climate throughout the state. Geophysically, Texas is, in many ways, similar to southern France, the central plain of Spain, and parts of Italy. Based on studies of viticulture and growers' experiences ( de Blij 1983), it follows that the future of Texas wines ought to be based on warm-climate grapes. With this rationale, Tempranillo, Sangiovese, Spanish Black, other Mediterranean varieties, and hybrids like Blanc du Bois that thrive in Texas should emerge as defining varieties of Texas wine (Kane 2012, Crain 2013).

Since the change in the state constitution, the number of wineries in the state has been growing at a steady rate. The economic downturn in 2008 did little to slow growth of the number of new wineries being established in Texas (TABC 2014). Texas is fifth in wine production in the United States, behind California, Washington, Oregon, and New York. The state ranks fourth in volume of wine consumed and therefore little Texas wine makes it out of the state (TWGGA 2014). The wine industry in Texas is estimated to generate more than \$2 billion annually in economic activity (Kane 2012).

### *Terroir and Wine in Texas*

*Terroir* is a French word that is difficult to translate clearly in English. The closest direct translation might be "terrain" or "soil" (Johnson 1994). However, neither of

these encompasses the less specific emotive subtleties of the concept. *Terroir* has become a concept that means so much more than simply “soil,” especially when discussing viticulture and wine. *Terroir* can refer to the geographic, agricultural, environmental, and cultural aspects that affect the taste of a wine (Bohmrich 1996; Vaudor 2002; Van Leeuwen and Seguin 2006; Townsend 2012). The embodiment of certain characteristics such as climate, soil, drainage, geology, topography, elevation, slope, aspect, water availability, and the way that a wine is influenced by local cultural traditions of the grower and winemaker contribute to the “sense-of-place” resident in the wine. As such it can be said that the study of *terroir* is the study of the geography of a wine. This is probably why *terroir* is the single most studied subject matter in wine geography (Townsend 2012).

*Terroir*, as a concept, is often used to describe the uniqueness, personality and origin of wines. There are a variety of terms used to describe *terroir*. However, they can be roughly categorized into two groups, those that refer to the physical nature of the wine production landscape and those that refer to the human elements of the landscape (Valdour 2002). Aspects of the physical interpretation of *terroir* focus on a grape plant’s unique relationship with vineyard soil; sun angle, intensity, and duration; atmospheric and meteorological conditions and the timing of events; and how these unique characteristics are revealed in the finished product. The subtle differences in soils (and mineral composition) or aspect may be slight, but can determine if a vineyard is a Grand Cru or Premier Cru, such as found in the Burgundy region of France (Atkinson 2011).

A broader physical interpretation of *terroir* is needed to explain how the term is applied to wine-producing regions. Successful socio-economic history in a region cannot

be explained by the environmental properties alone. The establishment of an *Appellation d'Origine Controlée* (AOC) or an American Viticulture Area (AVA) is used to define a *terroir* that asserts a unique region of origin. These designations are legal constructs that use the physical place and conditions of origin to define and protect the economic and social interests of a community of growers (de Blij 1983).

The human elements of *terroir* revolve around collective and personal perceptions. The intellectual formation and recognition of a *terroir* relies on the identities and memories of, emotions toward, and perception of a space (Moran 1993). These correspond to the cultural, ethnological, and sociological meanings of a place of origin. This sense of identity is reinforced by the nominal *terroir* used to advertise and market a wine. It is in this way that *terroir* relates a product to the region in which it is produced (Carbonneau 1995; Bonnamour 1999). The term is used to recall the ecological and communal values of a region and, thanks to the French and their appellation system, the term is used to imply quality and typicality of the region (Vaudour 2002).

*Terroir* in the United States and other “New World” wine production regions do not have the history of the “Old World” wine regions. As the wine industry matures in new regions, local *terroir* is becoming more important. To become economically successful and to justify premium pricing of products, it is imperative to create regional identity through the formation of a regional *terroir*. This can be seen in the history of the Sonoma County and Napa Valley wines that have become internationally recognized wine regions with well-known and expected tastes and qualities. The success of the California wine revolution, and the concurrent development of a wine culture in

Australia, has inspired winemakers in other disparate and nascent wine production regions of the world.

In the United States, the wine industry has exploded over the last couple of decades. Wine is being produced every state (appellationamerica 2014). American wines are most often referred to by the variety of grape used. The *terroir* of a particular location is always reflected in its grapes and may be found in the wines made from those grapes - so long as the characteristics of the regional place have not been destroyed by the vintner or hidden by the blending of grapes from different areas or of different types.

Despite its long history, the wine industry in Texas is still relatively young. In a broad sense, the creation of American Viticultural Areas (AVAs, as described above) in Texas can be said to be a step toward the definition of regional identity. However, this is usually only a creation of an identity that defines and isolates a socio-economic region. As such determinate identity, or “styles” are not well defined in Texas Time is needed to match chosen varieties to specific places that can reveal unique local environmental characteristics. Advertising and marketing can aid the public’s emotional relationships to regional identity, something that is necessary elevate wines to premium status.

By persuading the consumer that the character and quality of wine depends upon the vine, historical background is not needed. When it can be shown that wine made from the same type of grape grown in different places around the world has a similar flavor, it is easy to argue that they are equivalent wines (Johnson 1994).

During the process of establishment, a winery’s reliance on making wines from the big three varieties (Chardonnay, Merlot and Cabernet Sauvignon) is critical for its survival, even if the grapes are grown elsewhere, perhaps even beyond Texas’



boundaries. The majority of Texas wineries are relatively small operations that rely on point-of-purchase sales to remain in business. They know that putting “Made in Texas” on the label will increase sales in Texas. As Texas wine culture matures, other varietals that are better suited for the soils and climates found in Texas will emerge.

## II. LITERATURE REVIEW

Viniculture (growing grapes for wine production) has been a part of human culture for thousands of years (de Blij 1983, Sauer 1994, McGovern 2003, Sommers 2008). Geographers have been researching this topic since the ancient Greek and Roman times and have a history of publishing books and articles on wine regions (Dougherty 2012). When published, de Blij's *Wine Regions of the Southern Hemisphere* analyzed the then little known wine growing regions of Australia, New Zealand, South African and South America (de Blij 1985). In *Landscapes of Bacchus*, Stanislawski (1970) examined wine in Portugal, noting the importance of the cultural geography in creating a distinctive landscape (Dougherty 2012). Others have focused on the wine regions of France and America (Baxevanis 1987a, Baxevanis 1987b, Baxevanis 1992, Peters 1997). Many articles pertain to a single region (Dougherty 2012). These articles are numerous for French, Australian, and the more famous California regions. Papers have also been published on lesser known regions, such as the Finger Lakes (Newman 1992), Walla Walla (Velluzzi 2007), and Rogue River Valley (Jones 2001, Jones 2006).

Despite the breadth of literature on viticulture and wine geography, there is little published scholarship that addresses regional development and differentiation of Texas wineries and wine regions. While there is some scholarship on Texas wine and wine production, the majority of that scholarship involves the scientific study of vineyards and grapevines. The earliest of these works is Munson's *Foundation of American Grape Culture* (1909). This work includes chapters on botany, breeding, descriptions of varieties, planting, protection from insects and fungi and others related to the grapevine (Munson 1909). *A Feasibility Study for Grape Production in Texas*, by Perry and Bowen

in 1974, has been cited as an influential paper in the growth of wineries in the 1970s and 1980s (Kane 2012, Crain 2013), but it also focuses on the grapevine and the economic feasibility of production (Perry 1974). Research on grape cultivar performance, irrigation strategies and plant manipulation has also been published (Lipe 1987, Basinger 2004, Basinger 2006, Hellman 2006). Yet, while these and other papers refer to issues related to growing wine in Texas, they do not address the development of regional identities and distinctions among wineries.

Another set of studies focuses on disease and fungi infestation and other hazards associated with grapevines in Texas; Texas root rot, Pierce's disease, phoney peach disease (Perry 1980, Kamas 2000, Vest 2004, Krawitsky 2009). Townsend's (2012) dissertation examines the perception of natural hazards among Texas viticulturists. Besides these and other works concentrating on vineyards and their physical environment, Dodd and his colleagues from Texas Tech's Texas Wine Marketing Research Institute have evaluated many aspects of marketing wine in Texas. However, none of these articles considers the clustering of Texas wineries (Dodd 1995, Dodd 1997, Orth 2005).

Some research concerned with emerging wine regions focuses on understanding wine tourism (Hashimoto 2003, Williams 2003, Getz 2006). More generally, the study of agricultural regions has concentrated on either the development of regions specializing in organic agriculture or on regional economic trends, on the implications of climate change, or on sustainability (Yussefi 2008, Sawant 1995, Anderson 2004, Tilman 2002). To date, none of these existing studies focus on the identification of emerging regions or

on ways to understand patterns of winery establishment. This research endeavors to fill that gap.

Although developing wine regions have not been their foci, extant and relevant research on emerging regions is available for reference in building a methodological design to study emerging wine regions in Texas. Such research involves studies of space-time cluster analysis, mainly as applied to disease-outbreak detection (Kulldorff 1998, Bernardinelli 1995, Kulldorff 2005). The ability to detect disease outbreaks early in space and time is important in epidemiology to minimize impact. These studies demonstrate that the application of space-time statistical analysis techniques to identify emerging regions can have tangible impacts in the real world. Although useful in framing my research methodology, the methods used in these studies focus more on evaluating already identified clusters for statistical relevance (to guide resource allocation, for example) and not on the identification of clusters themselves. In this way, the application of this method in my study is unique in the study of Texas wineries.

Space-time statistical analysis can be accomplished through the use of Graphic Information Systems (GIS) software, software which can uncover relationships, patterns, and trends by organizing, manipulating, analyzing, and visualizing spatial data (Scott 2010). ArcGIS is a tool that researchers use for a variety of types of analyses from comparing the spatial pattern of a disease outbreak or to examining unexpectedly high rates of crime in a particular area (Grubesic 2001, Kulldorff 2005). ArcGIS's Analyzing Patterns toolset are global statistic tools that answer the question: Is there statistically significant spatial clustering or dispersion? The tools in the Mapping Clusters toolset

identify where spatial clustering occurs, and where spatial outliers are located (Fischer 2009).

The Mapping Clusters toolset includes the Cluster and Outlier Analysis (Anselin's local Moran's I) tool that identifies clusters of high or low values as well as spatial outliers, given a set of weighted features. Fischer (2009) provides an example of how this tool can be used. He used the approach to identify the (often sharp) boundaries between affluence and poverty in Ecuador. Using this tool to analyze poverty in Ecuador, Fischer (2009) showed a string of outliers that separate clusters of high poverty from clusters of low poverty, indicating a sharp divide in economic status.

The Hot Spot Analysis (Getis-Ord  $G_i^*$ ) tool is another utility for mapping clusters. This tool identifies clusters of features with high values (hot spots) and low values (cold spots), given a set of weighted features. An example of how this tool is used was provided by Fischer (2009) when he applied it to the study of vandalism data for Lincoln, Nebraska. Running the Hot Spot Analysis tool on raw vandalism counts for each census block revealed a picture that would not surprise local police officers. Most vandalism is found where most overall crime, and most people, are found while fewer cases are associated with the lower density suburbs. However, normalizing the data to overall crime incidents prior to running the analysis showed that vandalism represents a larger proportion of total crime in the suburbs (Fischer 2009).

Using the Mapping Clusters and Hot Spot Analysis utilities in ArcGIS, I will identify emerging agglomerations of Texas wineries to provide a deeper understanding into their spatial distribution. The statistical analysis tools will be useful in identifying if statistically significant spatial clustering is occurring. Specifically, the mapping cluster

tools will further refine our understanding of wine agglomeration in Texas by showing if and where that clustering is occurring. As in the Hot Spot Analysis example of Lincoln, Nebraska (above), normalizing techniques can be used to uncover patterns that might not otherwise be clear. As such, my methods include normalizing location data over time to analyze the spatial distribution of Texas wineries over a certain timeframe. This analysis will provide insights into the spatial distribution of Texas wineries that might not otherwise be discernable. Moreover, establishing these patterns will provide baseline data that will be useful for future studies examining the factors driving growth and development patterns of Texas wineries.

### **III. STUDY SITE DESCRIPTION**

The area of study is the state of Texas. Texas is the largest and one of the southernmost states of the contiguous United States and shares a border with states of Louisiana on the east, Arkansas and Oklahoma on the north, New Mexico on the west. The southern border is the Gulf of Mexico and the Rio Grande bordering Mexico. Elevation ranges from sea level along the Gulf of Mexico steadily increasing to the higher elevations found in the northern and western parts of the state. Located east of the continental divide, rivers in Texas flow gradually eastward and southeastward towards the Gulf of Mexico (Prout 2012). Due to its size and location, Texas is home to a large variety of landscapes, terrains, geologies, soil-types and climates. The western part of the state falls within the arid Köppen B climate classification and the eastern part of the state falls within the humid Köppen C classification.

#### **IV. DATA**

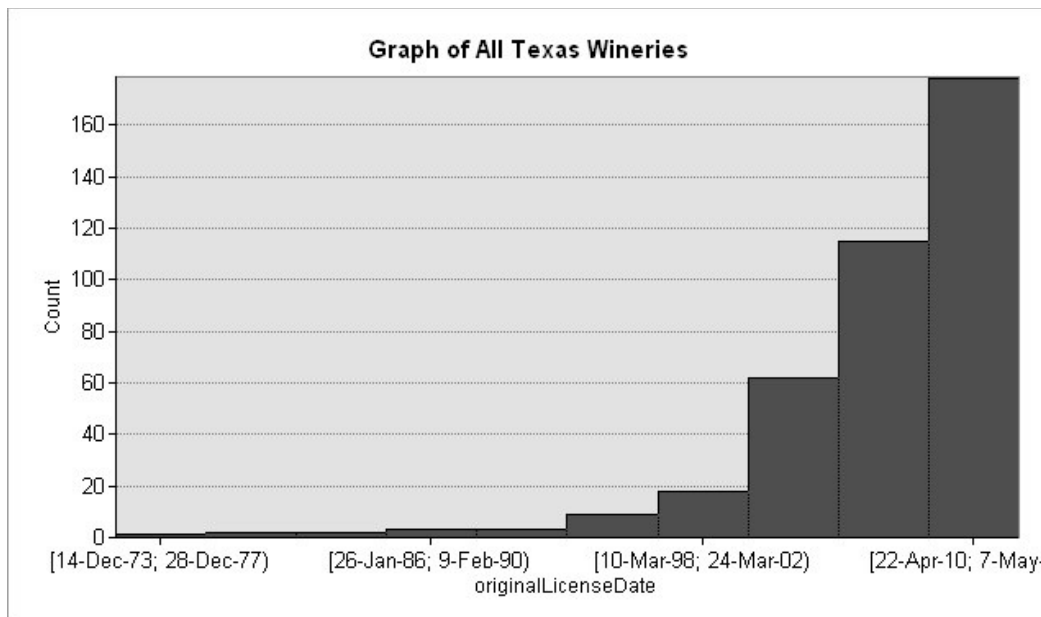
Several types of data are needed to establish a baseline of winery locations in Texas and to enable the temporal analysis. I identified three necessary elements to conduct this analysis: a list of all licensed Texas wineries, the location of each, and the date each winery was established. I used data obtained from the Texas Alcoholic Beverage Control Board (TABC) website (<https://www.tabc.state.tx.us>, accessed May 15<sup>th</sup>, 2014) to identify all wineries licensed for operation in the state. This list established the population to be studied. The TABC database includes spatial and temporal information on licensees. The spatial data include the addresses of the all wineries and the temporal data include the dates on which a license was first issued for all wineries. I geocoded this list of wineries using ArcGIS and then analyzed the data using spatial analysis tools found in ArcGIS.

The TABC data indicate that there are 399 wineries in Texas. Six of these wineries still had license applications pending on May 15, 2014, and were removed from the analysis. The addresses of the 393 remaining licensed wineries were standardized and imported into ArcGIS. Each winery was given a unique ID to associate with geolocated street addresses for mapping and analysis.

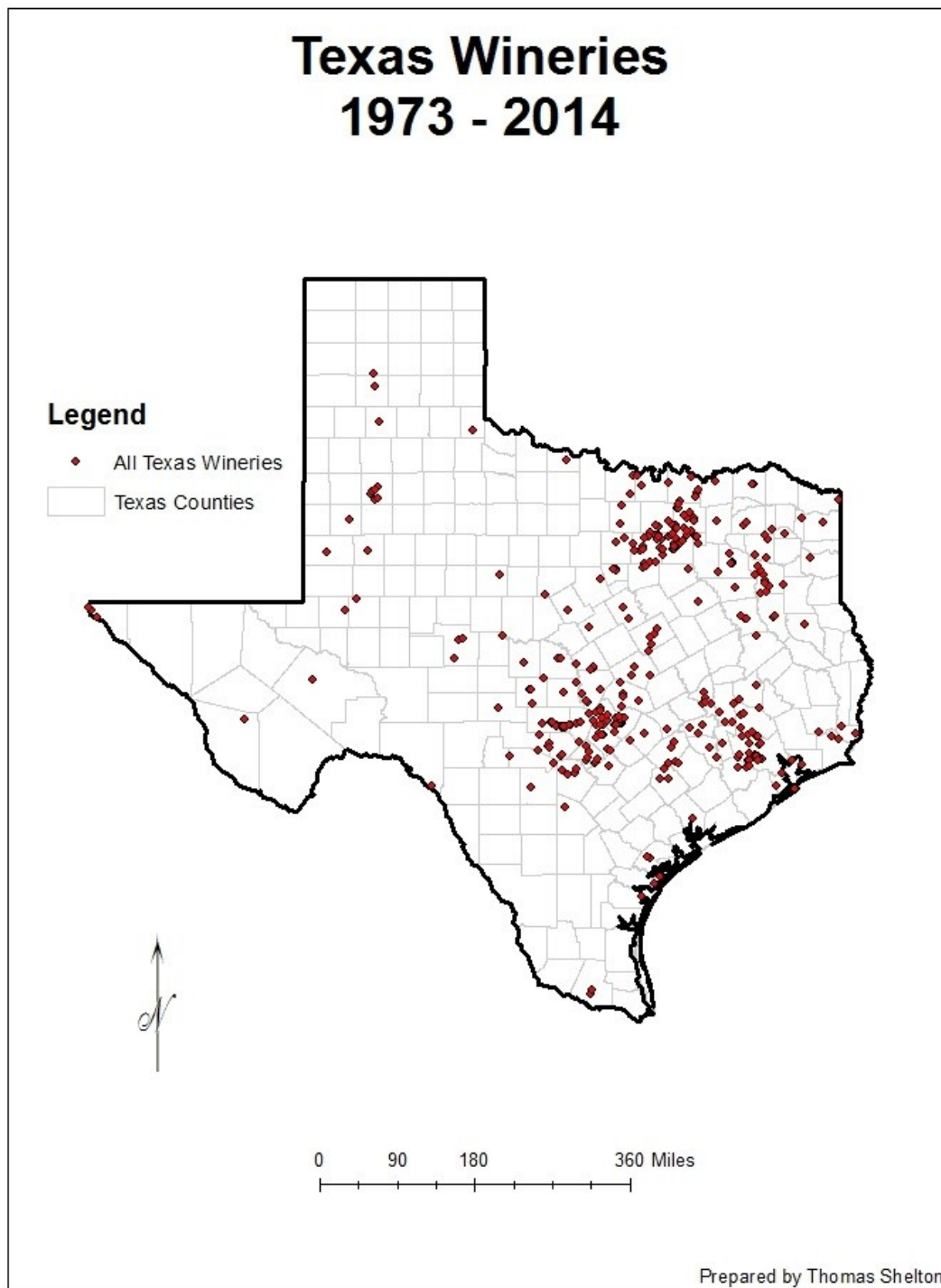


## V. METHODOLOGY

Everything happens in space and time and spatial data analyzed without regard for space-time context only reveals part of the story. In 1973, there was only one licensed winery (Val Verde Winery) in Texas. The number grew slowly (to 44) by the time of passage of the state constitutional amendment in 2003, which eased the legal restrictions applicable to wineries. The number of wineries has grown steadily in the ten years since the law's passage (Figure 1) and, as of May 2014, 393 wineries have been licensed in Texas (Figure 2). The goal of this research is to determine if and where emerging patterns of agglomeration of wine production in Texas are occurring.



**Figure 1. 4-Year Histogram.** This histogram shows the number of original licenses issued, grouped into 4 year intervals.

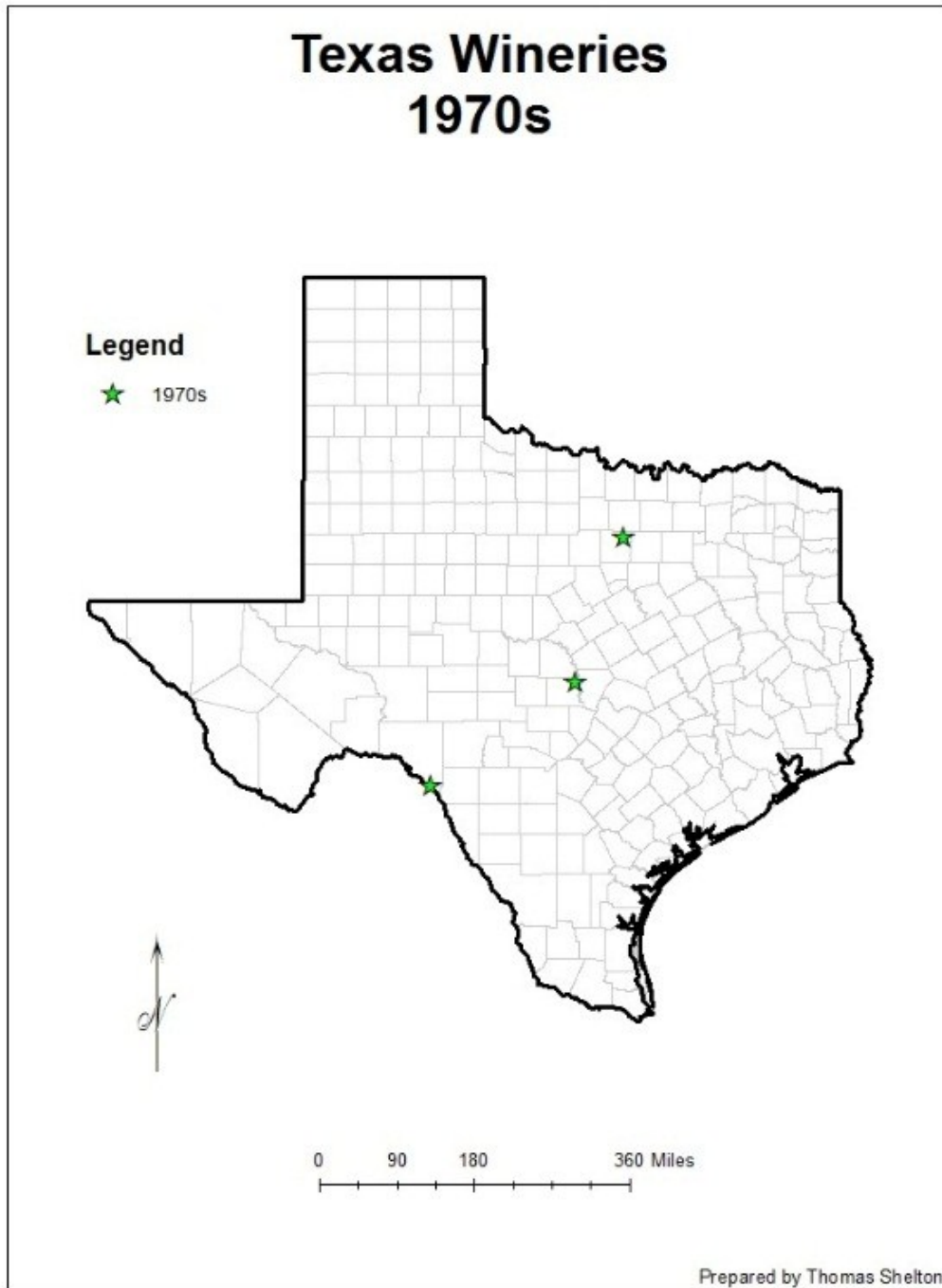


**Figure 2. The Locations of Texas's 393 Wineries.** This map shows the location of all wineries issued a license in Texas.

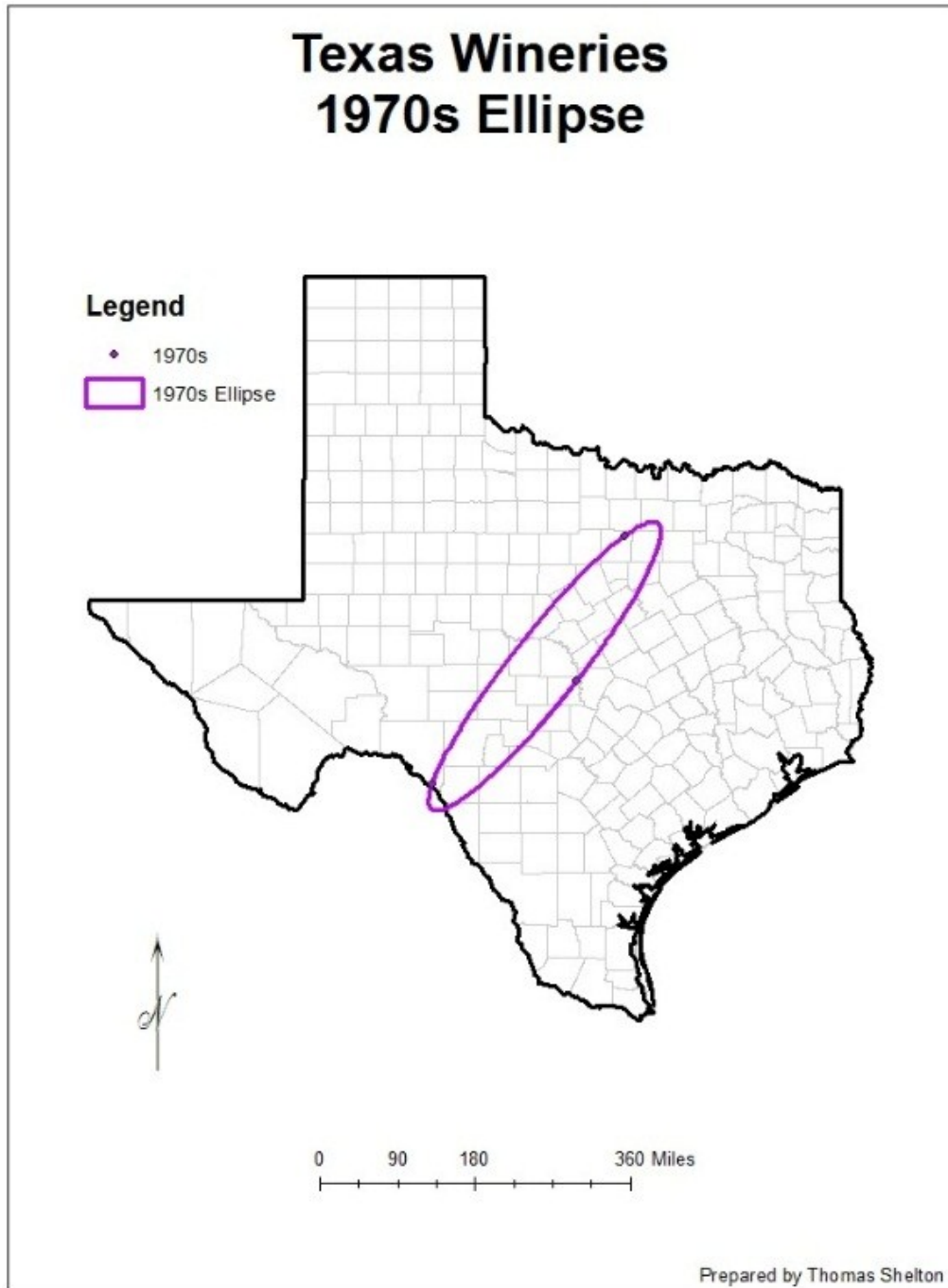
To determine whether agglomeration of wine production is occurring in Texas, several techniques are used. There are a few common strategies used to integrate time into spatial analysis. GIS is very a useful and effective tool for spatial analysis. Spatial-temporal analysis, however, is more difficult in a GIS. ArcGIS 10.2.1 has tools useful for graph and map making, for spatial statistics and analysis, and for temporal analysis.

A common strategy to combine spatial and temporal data is the creation of “snapshots.” The data may be segmented into decades and “snapshots” are created to examine the patterns at a particular moment in time to investigate changes from one moment to the next. For instance the snapshot in Figure 3 shows the distribution of wineries during the decade of the 1970s. A comparison of these maps begins to reveal the changes that occur over time. Further analysis of the decadal snapshots can be used to summarize the spatial characteristics of central tendency, dispersion, and directional trends.

The Directional Distribution (Standard Deviational Ellipse) tool is included in ArcGIS’s Spatial Statistics tools. This tool creates elliptical polygons with attribute values for the mean center, two standard distances (long and short axes), and the orientation of the ellipse (Figure 4). The polygons can be created with one, two, or three standard deviations and using Euclidean or Manhattan distances. One standard deviation will cover approximately 68 percent of the data points, two standard deviations will cover approximately 95 percent, and three standard deviations will cover approximately 99 percent of the data points. The ellipse maps use Euclidean distances and one standard deviation. Like the snapshots, these maps serve to reveal the spatial-temporal changes occurring in the distribution of wineries in Texas.



**Figure 3. Wineries in Texas during the 1970s.** These are the three original “modern” wineries in Texas; Val Verde Winery, La Buena Vida Vineyards Smith Estate Wines, and Fall Creek Vineyards.



**Figure 4. 1970s Ellipse.** This ellipse was created with the attribute values for the mean center, the long and short axes standard distances and orientation using the three 1970s points.

Considering the distribution of all Texas wineries present today (Figure 2), it is easy to conclude that clustering (or agglomeration) is occurring. Additional maps created for this study highlight different aspects of the changes that have occurred. ArcGIS 10.2.1 is equipped with multiple tools that can be used for space-time cluster analysis to verify if the changes have significance. Space-time cluster analysis tools can be used to identify space-time hotspots, to detect spatial-temporal outliers, and to group features using space-time constraints. Six pattern-analysis tools will be used in this analysis:

Incremental Spatial Autocorrelation, Generate Spatial Weights Matrix, Cluster and Outlier Analysis (Anselin Local Morans I), Grouping Analysis, and Hot Spot Analysis (Getis-Ord  $G_i^*$ ).

Interpretation on how each of these ArcGIS 10.2.1 spatial- statistic tools function is derived from each tool's corresponding descriptive file. The ArcGIS pattern-analysis tools begin their statistical tests by identifying a null hypothesis of Complete Spatial Randomness (CSR) of the features themselves or of the values associated with them. Z-scores and p-values returned by the pattern analysis tools are used to determine whether you can reject the null hypothesis. Rejecting the null hypothesis indicates that the features exhibit statistically significant clustering or dispersion. Both p-values and z-scores are associated with standard normal distribution. The p-value is a probability. For the pattern analysis tools, the p-value is the probability that the observed spatial pattern was created by a randomly operating process. The null hypothesis can be rejected when the p-value is very small, indicating that there is a small probability (very unlikely) that the observed spatial pattern is random.

Z-scores are standard deviations. Very high or very low (negative) z-scores, associated with very small p-values, are found in the tails of the normal distribution. This indicates that it is unlikely that the spatial pattern reflects the random pattern represented by the null hypothesis (CSR). A confidence level is the level indicating the risk for falsely rejecting the null hypothesis. A conservative confidence level (99 percent) indicates that one has a 1 percent probability that rejection of the null hypothesis is in fact an error; that is, the null hypothesis is actually true. Typical confidence levels are 90, 95, or 99 percent. A confidence level of 90 percent uses a critical z-score of  $\pm 1.65$  standard deviations and a p-value of 0.10. A confidence level of 95 percent uses a critical z-score of  $\pm 1.96$  standard deviations and a p-value of 0.05. A confidence level of 99 percent uses a critical z-score of  $\pm 2.58$  standard deviations and a p-value of 0.01.

Incremental Spatial Autocorrelation measures spatial autocorrelation for a series of distances and creates a line graph of those distances and their corresponding z-scores. The z-scores reflect the intensity of spatial clustering. Statistically significant peak z-scores indicate distances where spatial processes promoting clustering are most pronounced. This tool also creates a table showing the Global Moran's I by distance. A statistically significant peak value can be used as an appropriate Distance Threshold for use in tools, such as the Hot Spot Analysis tool, and it is used in this study.

One other tool that must be run before the analysis utilities are used is the Generate Spatial Weights Matrix tool. The Generate Spatial Weights Matrix tool, as the name indicates, constructs a spatial weights matrix (SWM) file to represent the spatial relationships among features in a dataset. The SWM file was designed to generate, store, reuse, and share conceptualization of relationships among a set of features. The SWM file

is necessary for space-time analyses. To specify how spatial relationships, including time, among features are conceptualized the SPACE\_TIME\_WINDOW choice is selected in the Conceptualization of Spatial Relationships drop-down menu. This tool identifies features that occur within a specified critical distance and specified time interval as neighbors. Space is defined by specifying a threshold distance value and time is defined by specifying a date/time field, a date/time type (such as days, weeks or months) and an interval value.

The Grouping Analysis tool groups features together based on attributes and spatial/temporal constraints. The output assigns each feature to a cluster. This tool is used to generate maps that show how a grouping is influenced by time by displaying the grouping with and without a time parameter. Maps were created using this tool to show: grouping based on time; grouping based on spatial constraints; and grouping based on spatial/temporal constraints using the SWM file. These maps (Figures 17-21) provide a useful background picture by showing the spatial distribution of the groupings.

The Cluster and Outlier Analysis (Anselin Local Moran's I) tool, given a set of weighted features, identifies statistically significant hot spots, cold spots, and spatial outliers using the Anselin Local Moran's I statistic. This tool creates the following attributes for each of the input features: Local Moran's I index, z-score, p-value and cluster/outlier type (COType). The z-scores and p-values are measures of statistical significance. They, in effect, indicate whether the apparent similarity or dissimilarity is more pronounced than one would expect in a random distribution. Similarity is the state of spatial clustering of either high or low values and dissimilarity is the presence of a spatial outlier.



A high positive z-score for a feature indicates that the surrounding features have either similar high or low values. The COType will indicate either “HH” for a statistically significant cluster of high values or “LL” for a statistically significant cluster of low values. A low negative z-score indicates that a feature is a statistically significant spatial outlier. The COType will indicate either “HL” for a feature with a high value that is surrounded by features with low values or “LH” for a feature with a low value that is surrounded by features with high values. The COType will always identify statistically significant clusters and outliers at the 95-percent confidence level.

For this study, this tool was run twice. The first time used the distance value identified by running the Incremental Spatial Autocorrelation tool, and the second time it used the aforementioned SWM file. The purpose of running this tool with both values was to discern the influence of time on the clustering. The first generated a map showing the spatial relationships and the second produced a map showing space-time relationships. The two methods were also used with the Hot Spot Analysis tool.

The Hot Spot Analysis (Getis-Ord  $G_i^*$ ) tool identifies statistically significant hot spots (high values) and cold spots (low values) using the Getis-Ord  $G_i^*$  statistic. It creates a z-score, p-value, and confidence level bin ( $G_i\_Bin$ ) value for each input feature. The z-scores and p-values indicate whether the observed spatial clustering of high or low values is more pronounced than one would expect in a random distribution of those same values. A feature that has no apparent spatial clustering is indicated by a z-score nearer to zero. The higher (or lower) the z-score is, the more intense is the clustering. A high z-score and small p-value for a feature indicates a spatial clustering of high values. A low negative z-score and small p-value indicates a spatial clustering of low values.

The Gi\_Bin field assigns features identified as statistically significant hot and cold spots. Features that reflect a statistical significance at a 99-percent confidence level are assigned +/-3 bins; features that reflect a 95-percent confidence level are in the +/-2 bins; features in the +/-1 bins reflect a 90-percent level; and bin 0 is for features that do not reflect statistically significant clustering. A hot spot is a feature that is identified as having a statistically significant positive z-score. The larger the z-score is, the more intense is the clustering of high values. A cold spot is a feature that is identified as having a statistically significant negative z-score. The smaller the z-score is, the more intense is the clustering of low values.

In 2003, the change to the Texas state constitution related to alcohol production and sales led to a profound change in the number of established wineries in the state. The original SWM file, which included all licensed wineries in the state, specified a minimal distance of 500,000 meters and time period of 72 months for the time parameter to ensure statistical significance. However, to determine whether seventy-two months (six years) is a reasonable period of time, in context of the growth of the last decade, I created a second SWM file for the purpose of comparison with the first.

Creating the new SWM file involved revising the data set to include only a subset of the data, in this case, Texas wineries licensed after 2002. I then ran the Generate Spatial Weights Matrix tool again. The analysis procedure is the same as for the original SWM, but this time, for the smaller data set (349 wineries), the time period was reduced to 18 months. The new data set and SWM file were then used in the Hot Spot Analysis tool. This new time period was the minimum that still encompasses all features. Reducing the time period resulted in a higher degree of confidence of the clustering results.

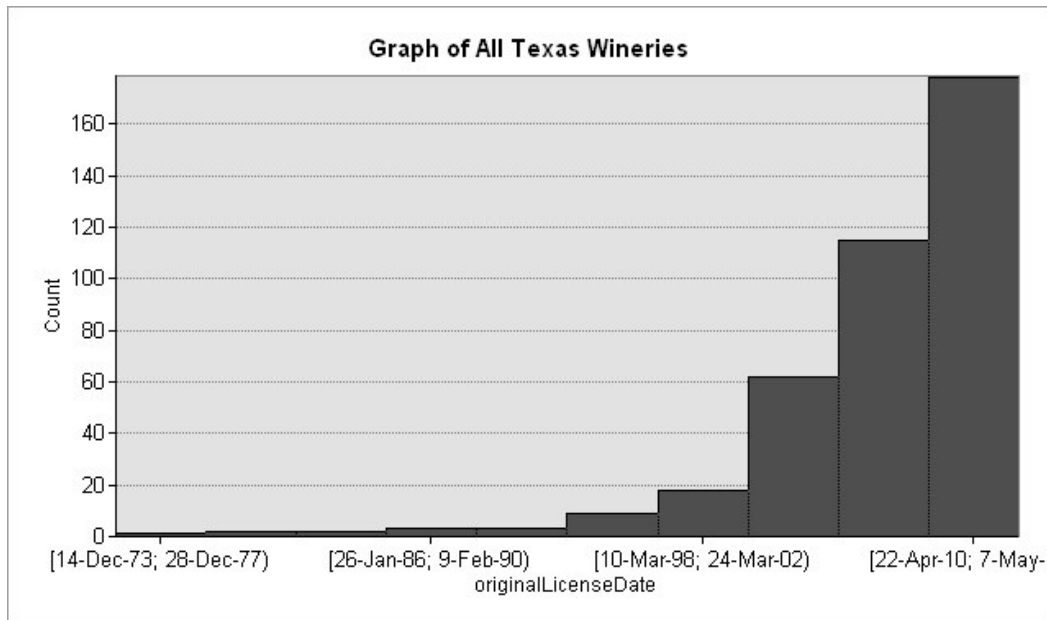
## VI. RESULTS

The locations of all wineries that have been issued a license by the Texas Alcohol Control Board (presented in Figure 2 on page 23) would seem to show that the distribution of wineries in Texas is not random. The majority of wineries are in the eastern “half” of the state. Clustering (or agglomeration) appears to be occurring near the Dallas/Fort Worth area in the north, the Hill Country in the center of the state north and west of the Austin/San Antonio corridor, and perhaps outside of Houston. While this map (Figure 2) shows the spatial distribution of Texas wineries, it does not reflect temporal trends.

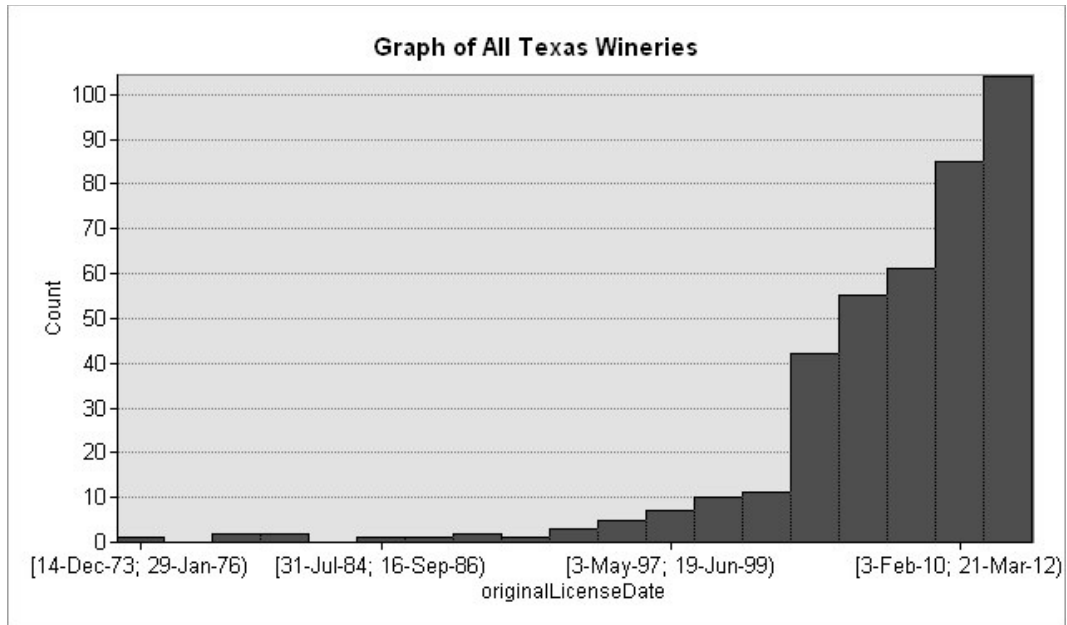
### Histograms

Figure 5 shows the slow beginnings and explosive growth of wineries in Texas, dividing the roughly forty-year period into ten segments. The graph in Figure 5 shows the slow acceleration of growth in the first seven segments (28 years) as well as the rapid increase in the last three segments (12 years). More than seventy-five percent of the wineries began operating since the change to the Texas Constitution in 2003, which made the state a friendlier business environment for vintners.

Reexamining the histogram using smaller time units, two years instead of four, reveals the impact of the economic downturn that began in 2008 (Figure 6). While the graph shows that growth continued, the winery population was not growing as fast as it had been during the previous four years (years 2004 through 2007). These two graphs, taken together, help to visualize the temporal aspects of the Texas winery establishment, but do they do not provide any spatial information.



**Figure 5. 4-Year Histogram.** This histogram shows the number of original licenses issued, grouped into 4 year intervals.



**Figure 6. 2-Year Histogram.** This histogram shows the number of original licenses issued, grouped into two-year intervals.

### Snapshots

For this analysis, the data were segmented by decade and snapshots were created to represent each decade to visually examine the spatial distribution. In the map showing the locations of wineries during the decade of the 1970s (Figure 7), the original three wineries in Texas are represented, and their distribution seems random.

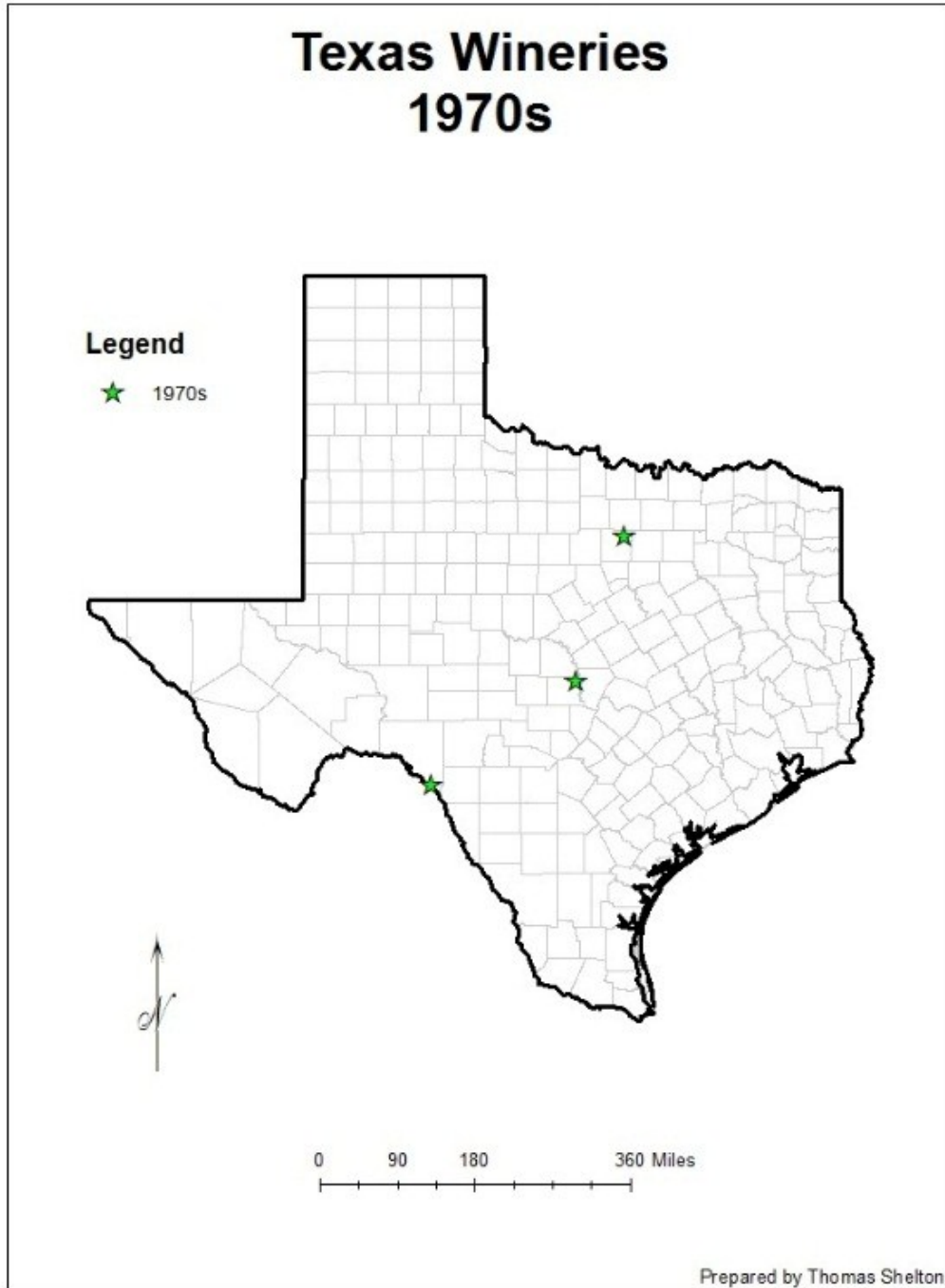
Moving forward in time, five wineries were added to the original three during the 1980s (Figure 8). In this map, the Llano Estacado Winery/Staked Plains Winery, located in the panhandle, and Piney Woods Country Wines, located in the east on the Louisiana border, seem to be randomly placed. The other three new wineries (Bell Mountain Vineyards, Sister Creek Vineyards, and Wimberley Valley Winery) are located in the center of the state, which, particularly with hindsight, appear to show the beginnings of a cluster.

As seen in Figure 9, twenty-three new wineries were established in the state during the 1990s. Influential wineries started in this time period include Messina Hof, Comal Creek, Pleasant Hill and Becker. This map shows a stronger agglomeration in the Texas Hill Country.

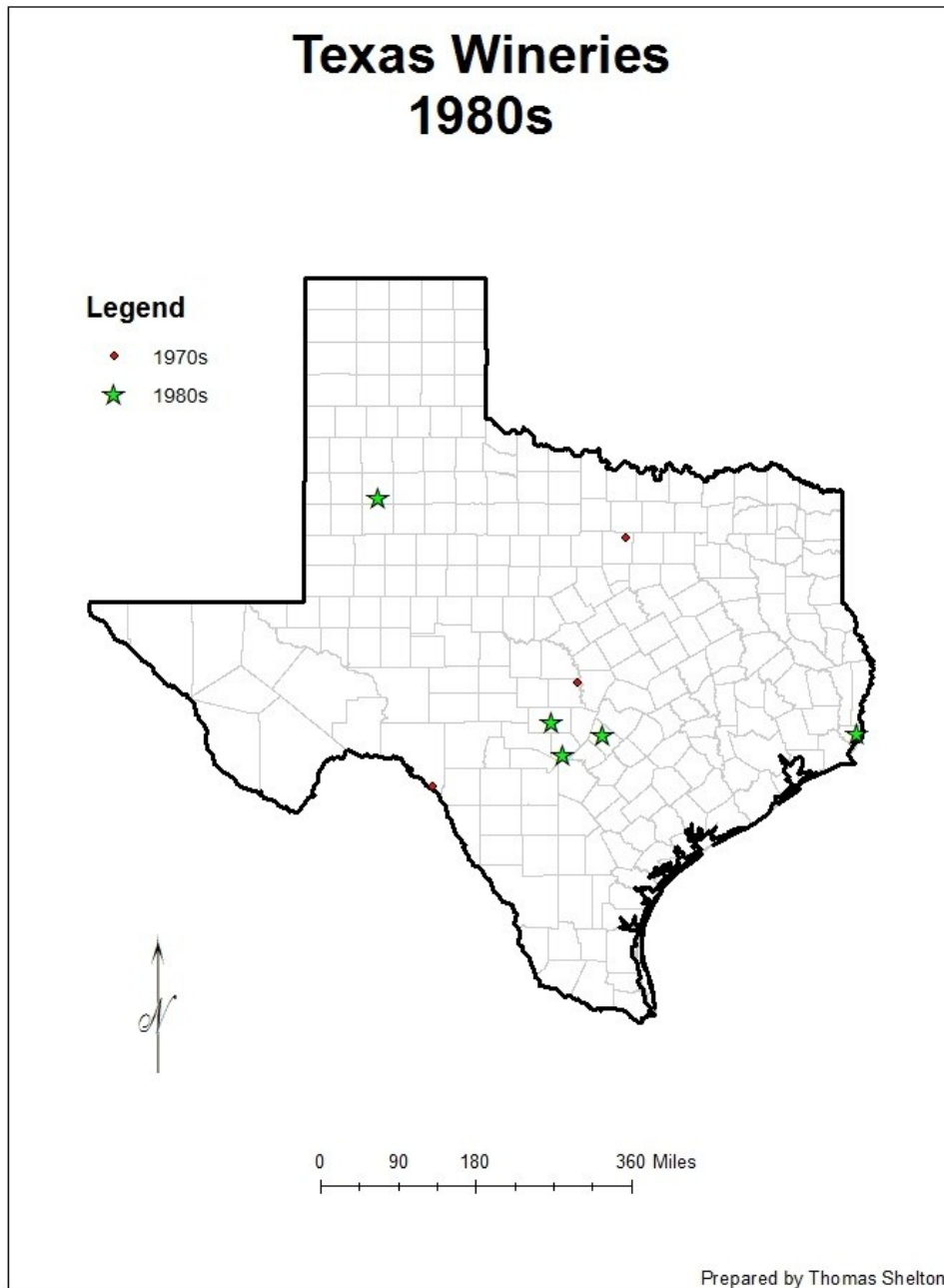
The distribution of wineries established during the first decade of the twenty-first century (years 2000-2009) demonstrates the accelerated growth that followed the 2003 constitutional amendment (Figure 10). Three things are apparent in the patterns on this map. The first is the proliferation of wineries: The total of 171 wineries present is almost six times the number established during the previous three decades. The second is that wineries are shown to be spreading throughout the state. The third is the apparent

clustering that appears to be happening in the Hill Country, in the Dallas/Fort Worth area in the north, and, to a lesser degree, in East Texas and near Houston.

Exponential growth of winery establishment continues into the present decade (Figure 11). An extraordinary number of new wineries, 191 in all, in just four years (less than one-half of a decade). Spatially, the Dallas/Fort Worth region and the Hill Country region continue to show growth, as does East Texas and the area around Lubbock in the Texas Panhandle (Figure 11)

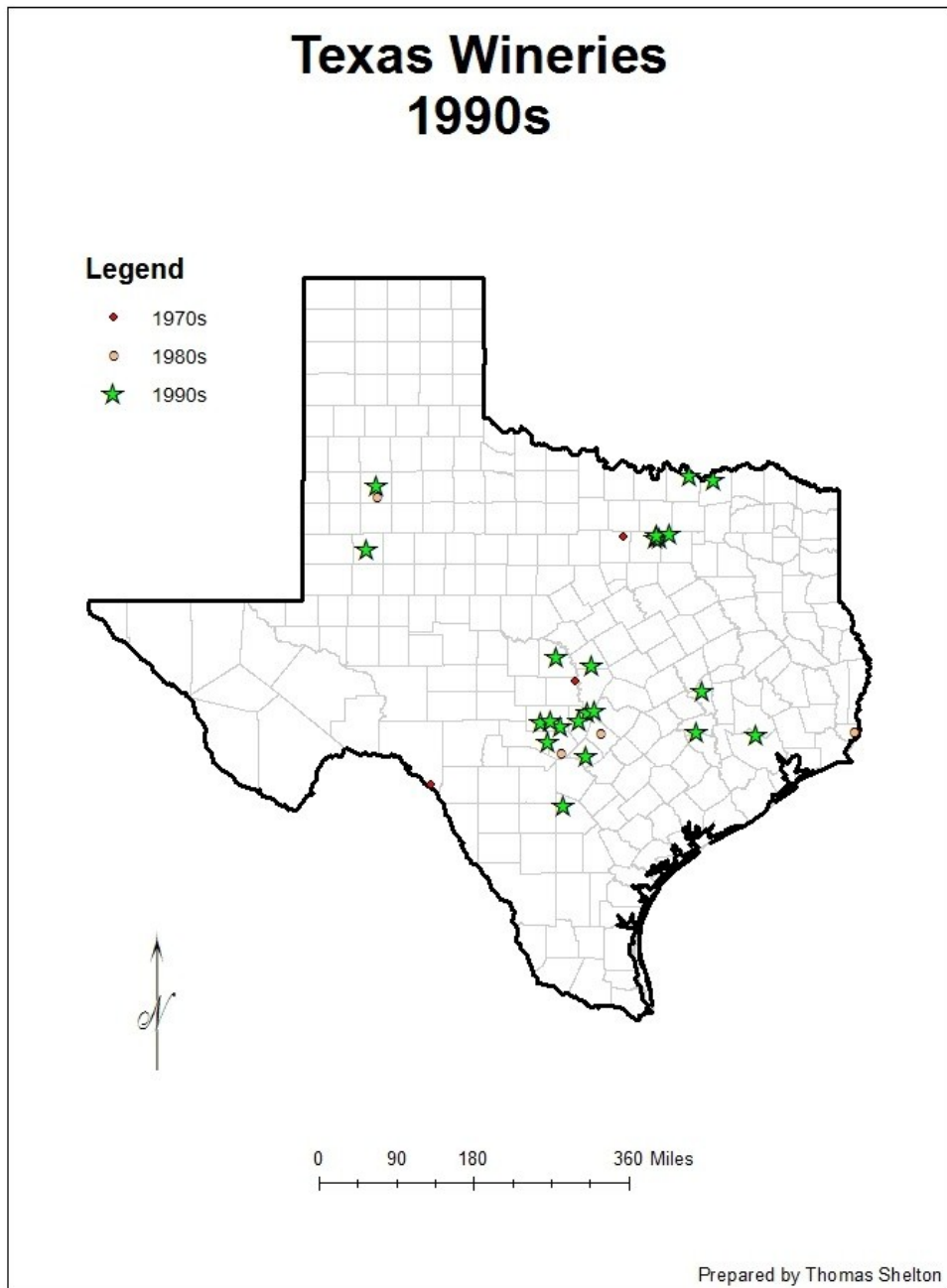


**Figure 7. Wineries in Texas during the 1970s.** These are the three original “modern” wineries in Texas; Val Verde Winery, La Buena Vida Vineyards Smith Estate Wines, and Fall Creek Vineyards.

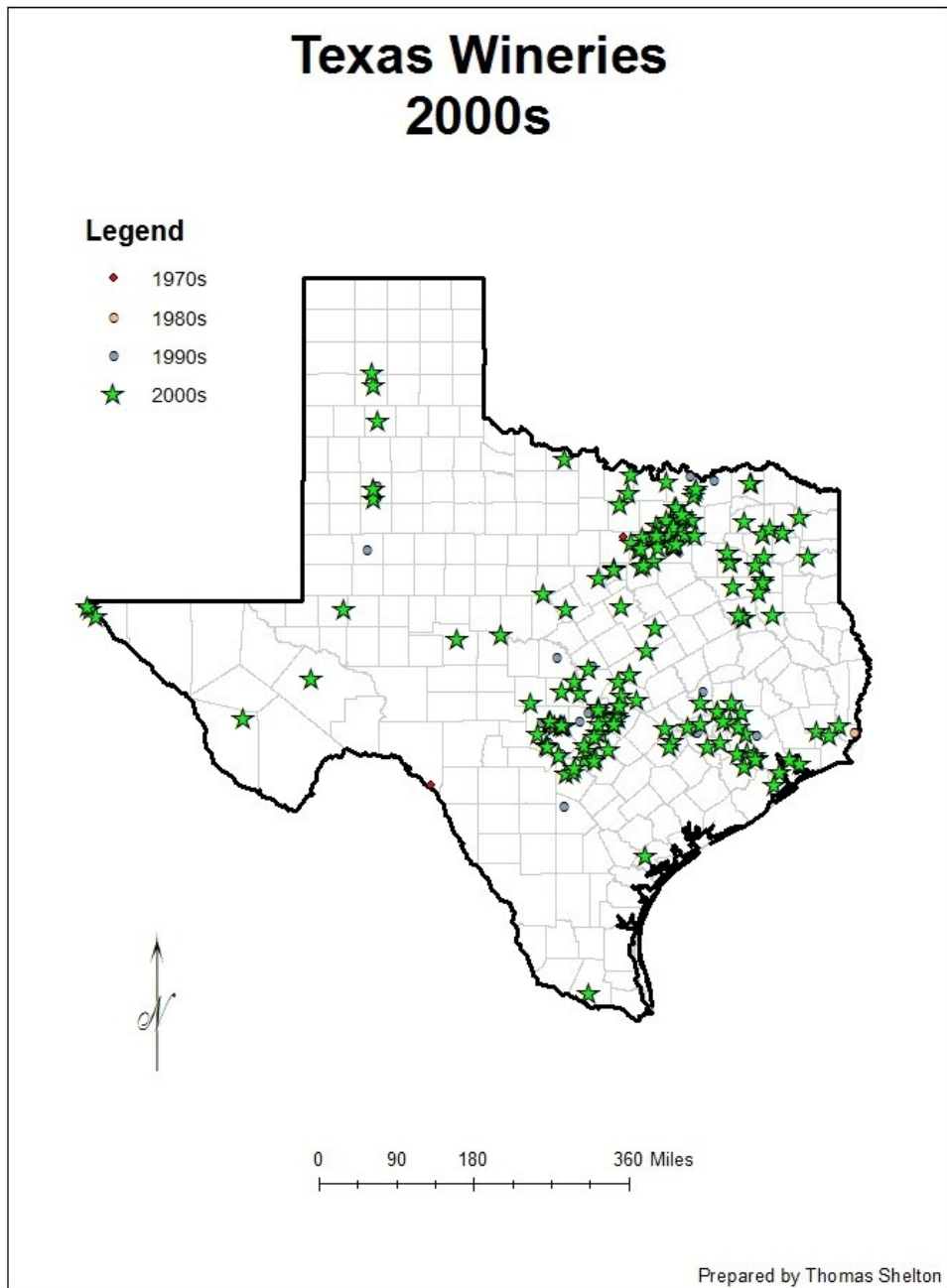


**Figure 8. New Wineries Established during the 1980s.** This map shows the addition of five wineries licensed 1980s to the three previously licensed wineries.

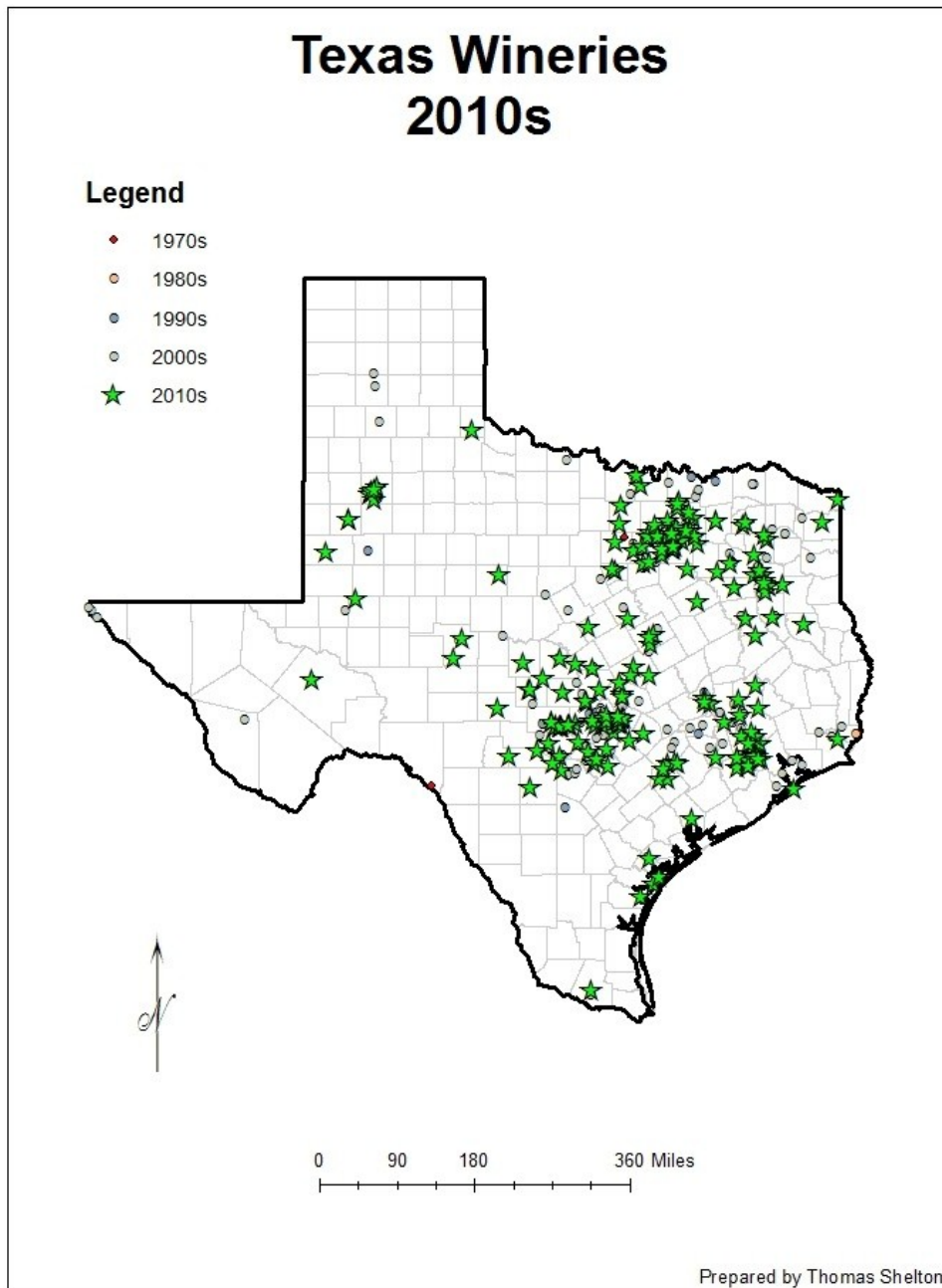




**Figure 9. New Wineries Established during the 1990s.** This map shows that the number of new wineries was increasing in the 1990s and that they are showing grouping.



**Figure 10. New Wineries Established during the 2000s.** The number of new wineries has greatly increased and spatial patterns are becoming clearer.

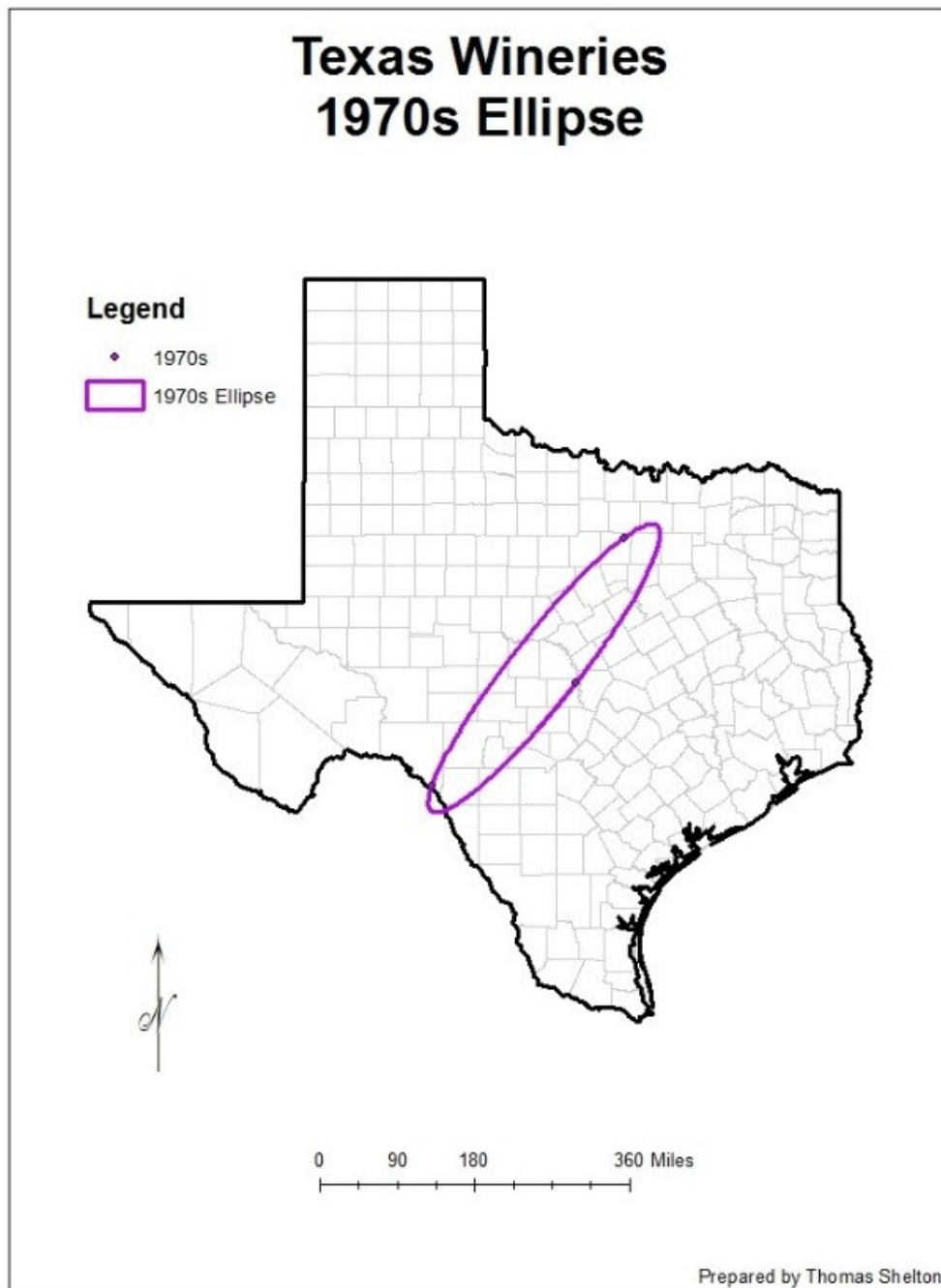


**Figure 11. New Wineries Established since 2010.** The number of wineries in the first part of the decade is comparable to the previous decade and continues to show similar spatial distribution.

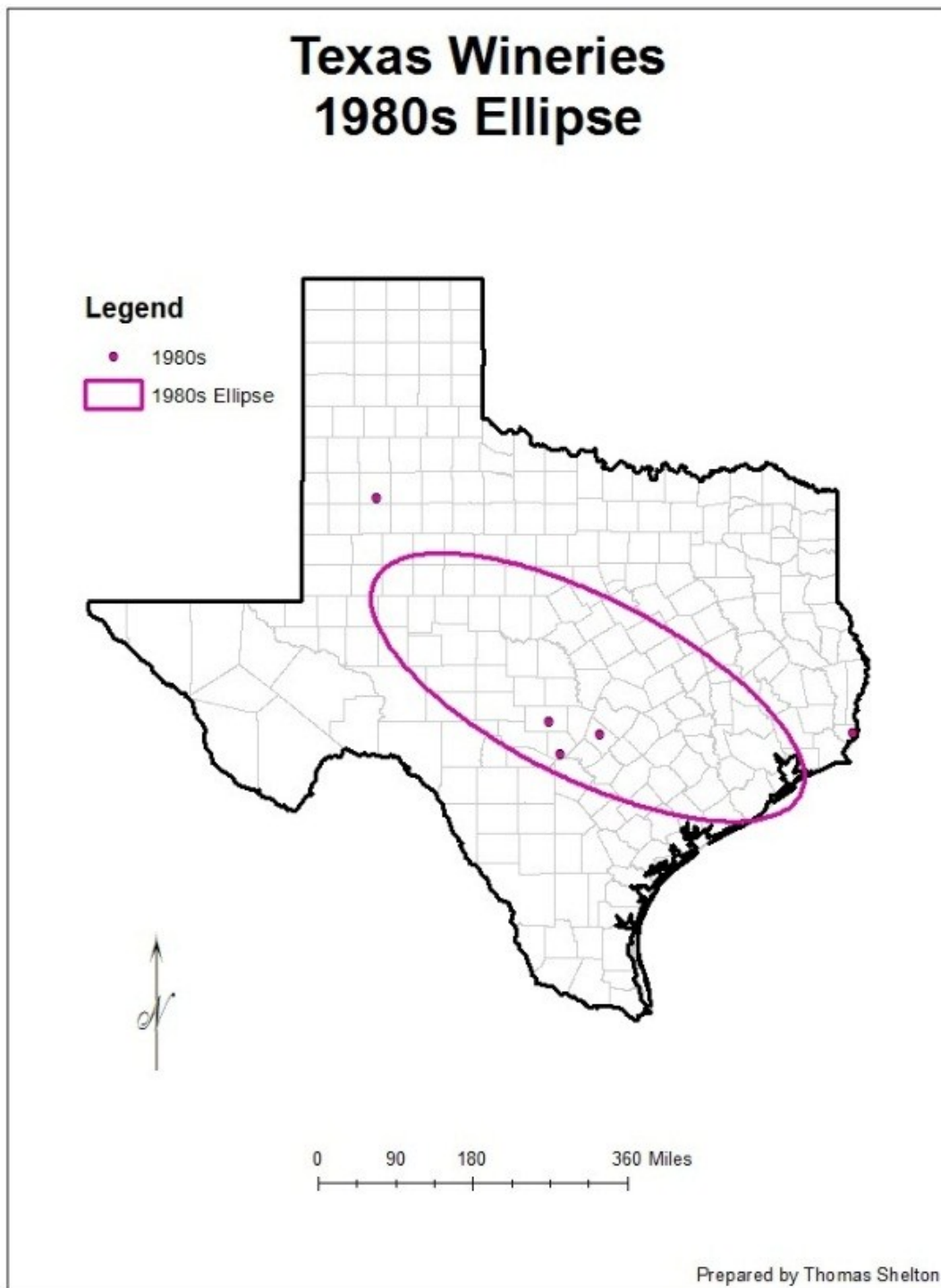
### Directional Distribution (Standard Deviation Ellipse)

The Directional Distribution (Standard Deviation Ellipse) tool in ArcGIS was used to analyze the spatial characteristics of central tendency, dispersion and directional trends of the decadal snapshots. Using this tool, I created elliptical polygons with attribute values for the mean center, two standard distances (long and short axes), and the orientation of the ellipse. The polygons can be created with one, two or three standard deviations and using Euclidean or Manhattan distances. The ellipses used in this analysis were created using Euclidean distances and one standard deviation, which covered approximately 68 percent of the wineries.

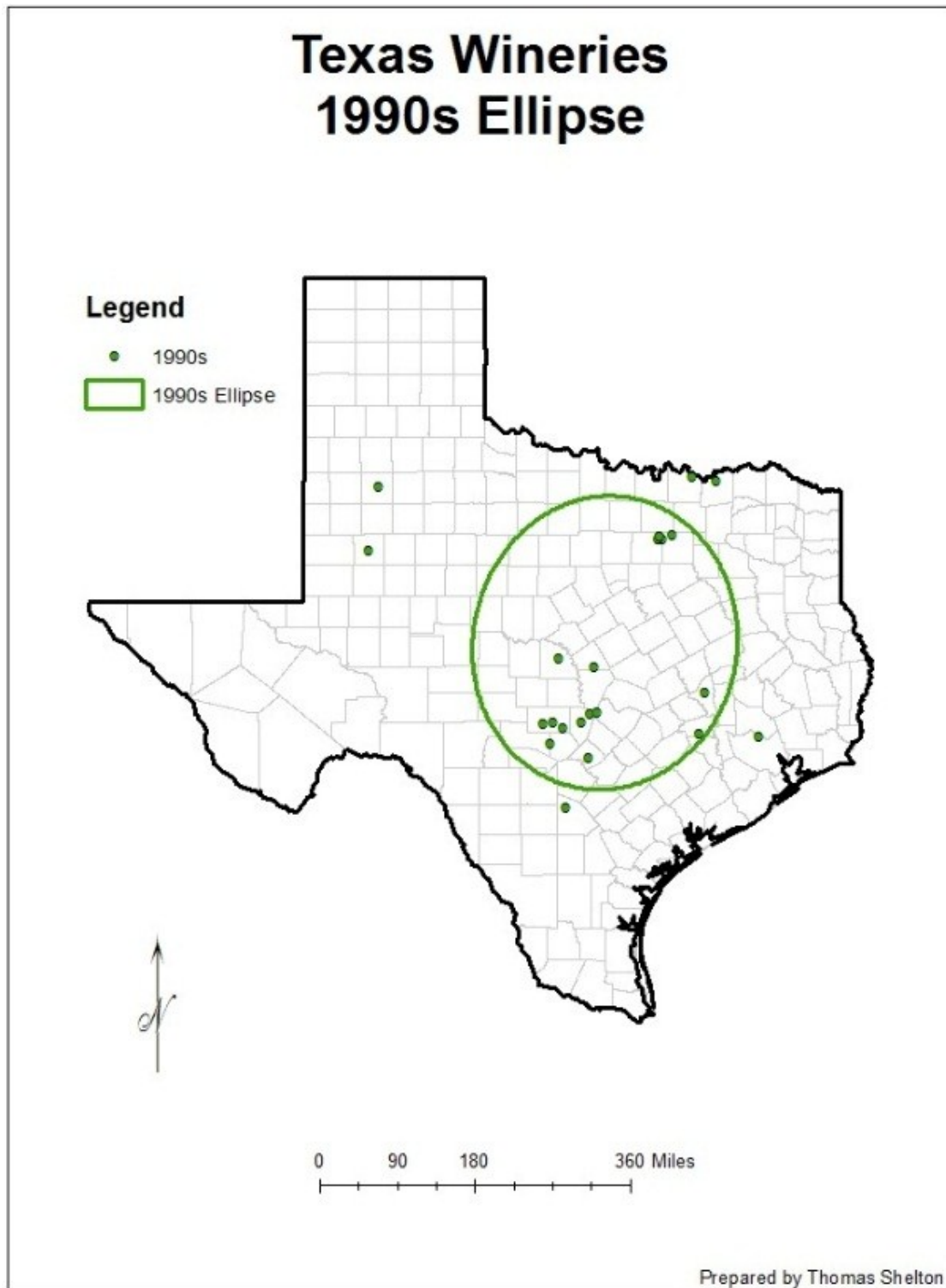
Comparing the ellipses generated for each decade reveals that the directions of growth of wineries in the early decades of the 1970s (Figure 12) and the 1980s (Figure 13) changed quite dramatically. Growth during the 1990s (Figure 14), 2000s (Figure 15), and during present decade (Figure 16) also revealed significant shifts. This is primarily due to the fact that the first two decades had fewer data points (i.e. few wineries were established). By the 1990s, however, the trends of the ellipses become more established and the differences between decades began to diminish. The mean center and shapes of the later ellipses show as similar, a trend that becomes more obvious when all five ellipses are layered onto one map (Figure 17). The spatial characteristics of central tendency, dispersion and directional trends over the last three decades have changed little.



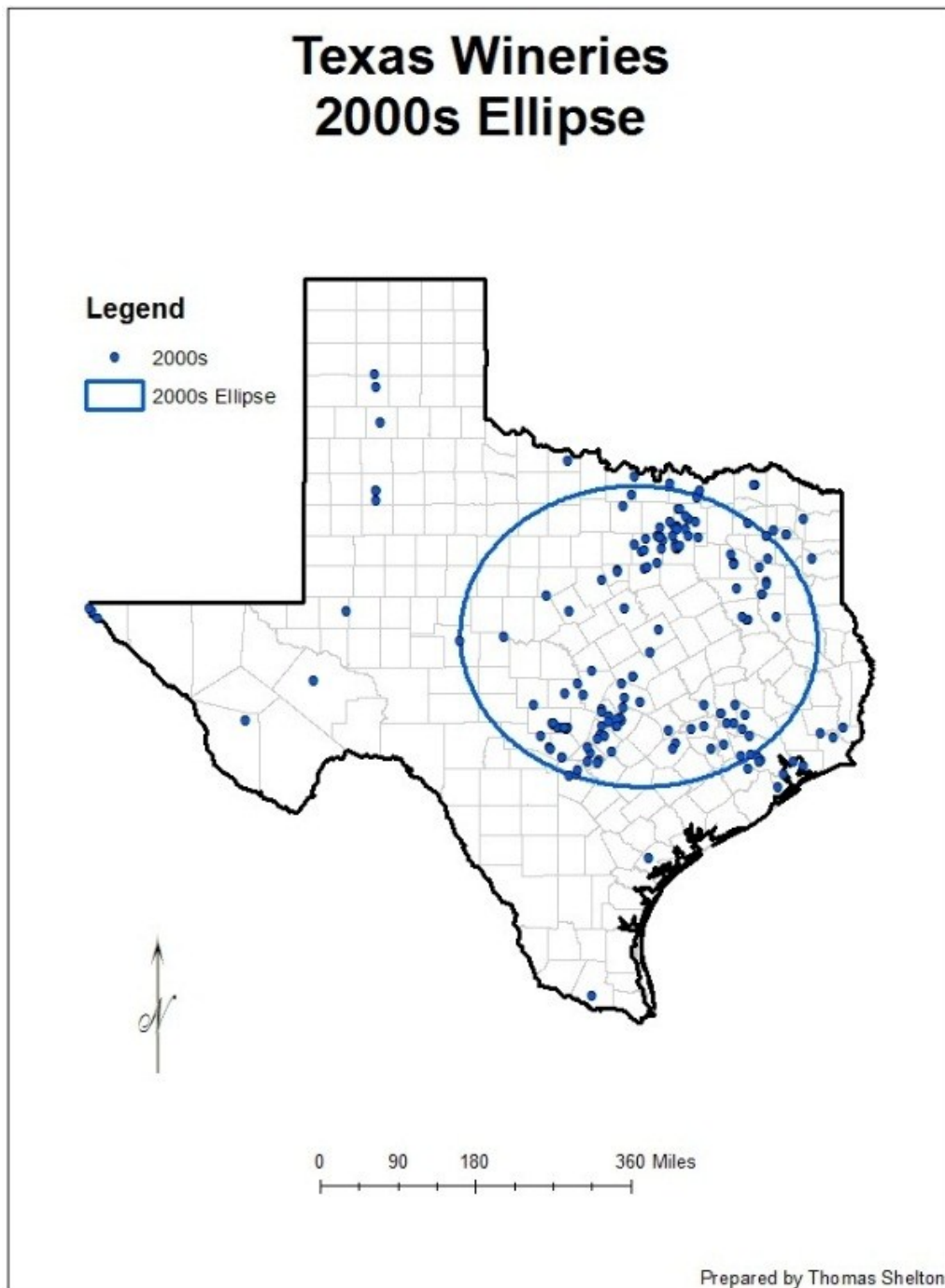
**Figure 12. 1970s Ellipse.** This ellipse was created with the attribute values for the mean center, the long and short axes standard distances and orientation using the three 1970s points.



**Figure 13. 1980s Ellipse.** The orientation of this ellipse is very different from Figure 10, reflecting the small number of data points for each map.

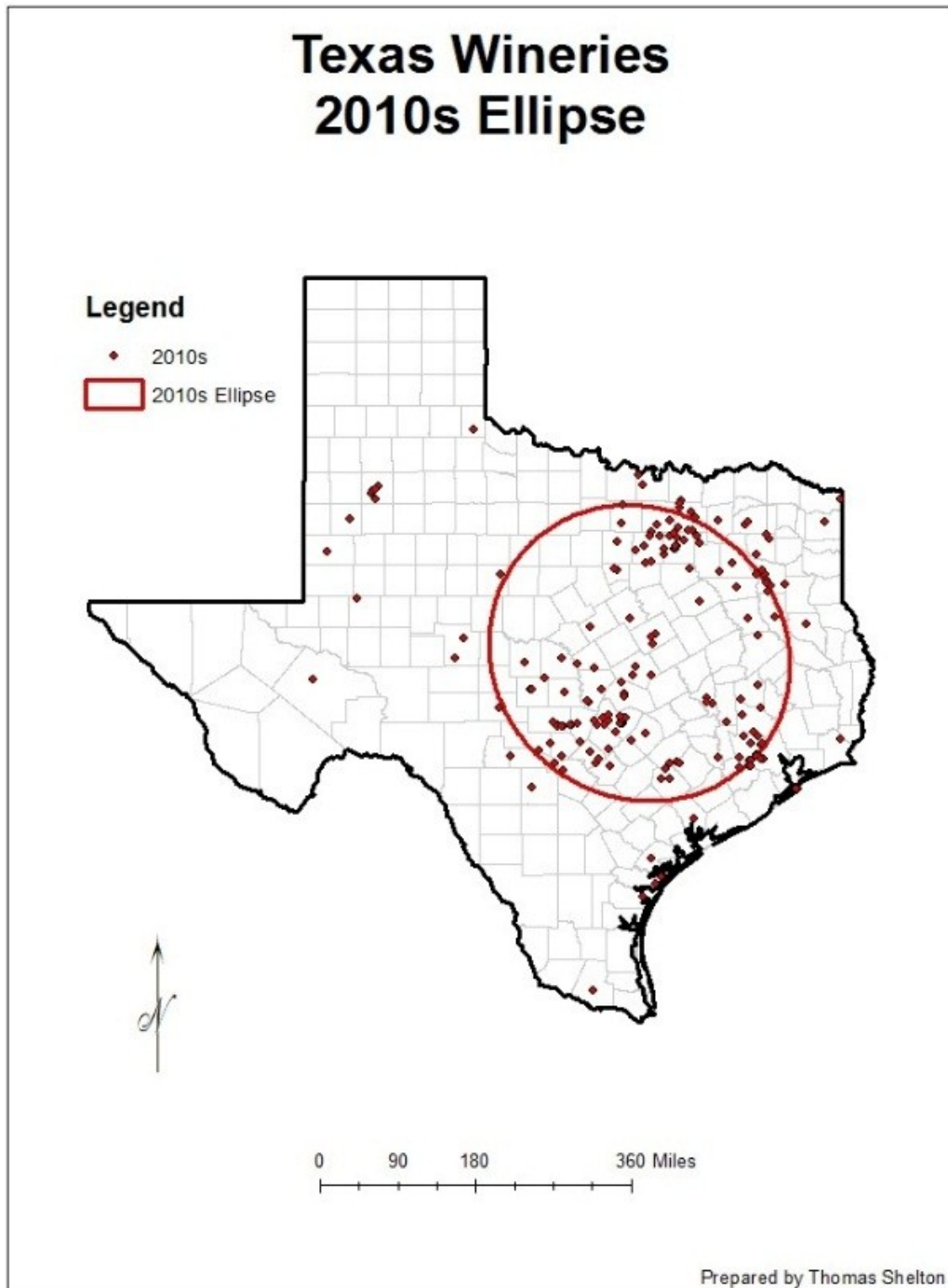


**Figure 14. 1990s Ellipse.** The increase in the number of data points decreases the difference between the long and short axes, producing a much rounder ellipse.

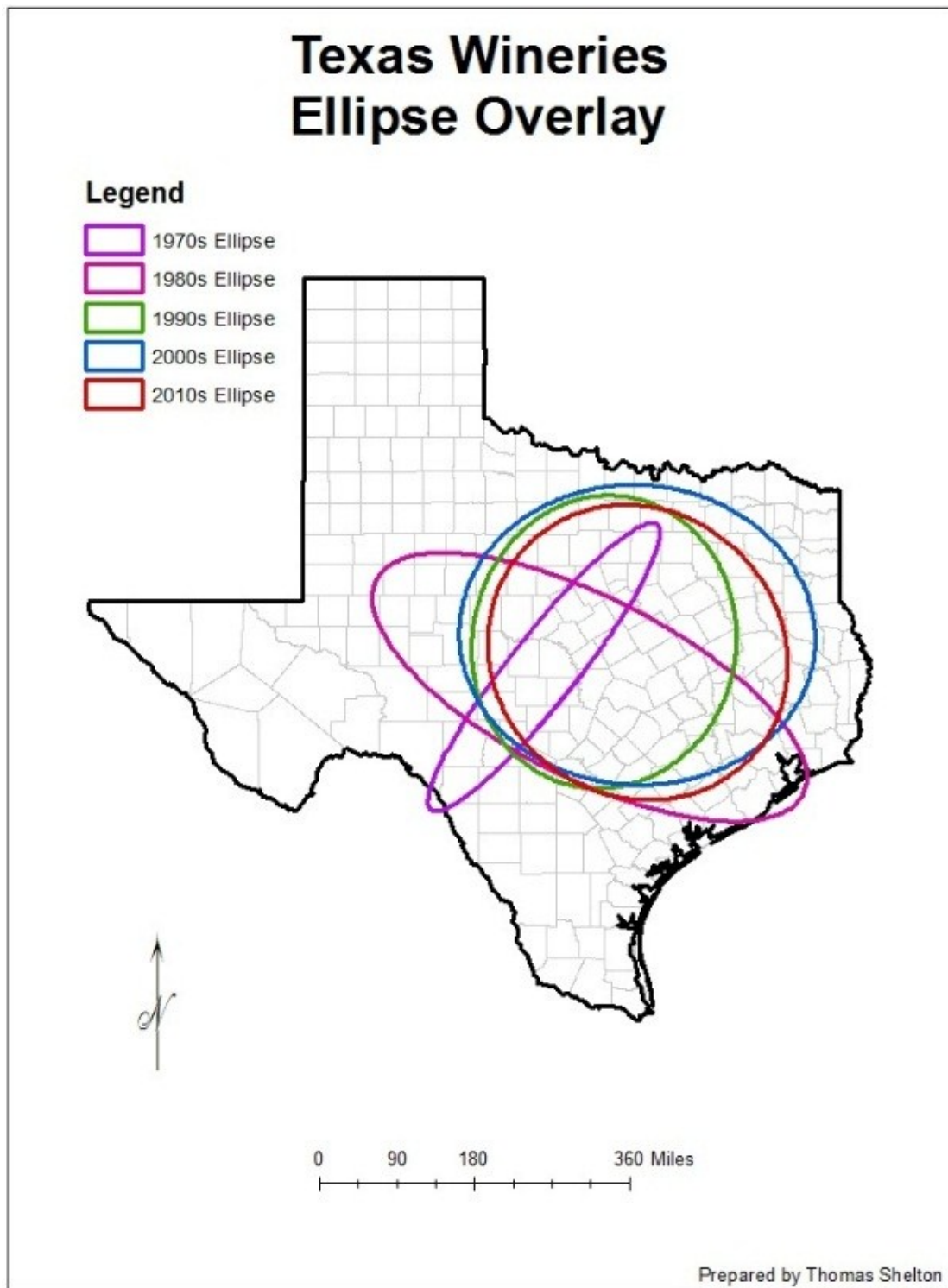


**Figure 15. 2000s Ellipse.** This ellipse, created with many more data points, is centered in the same area of the state as Figure 12.





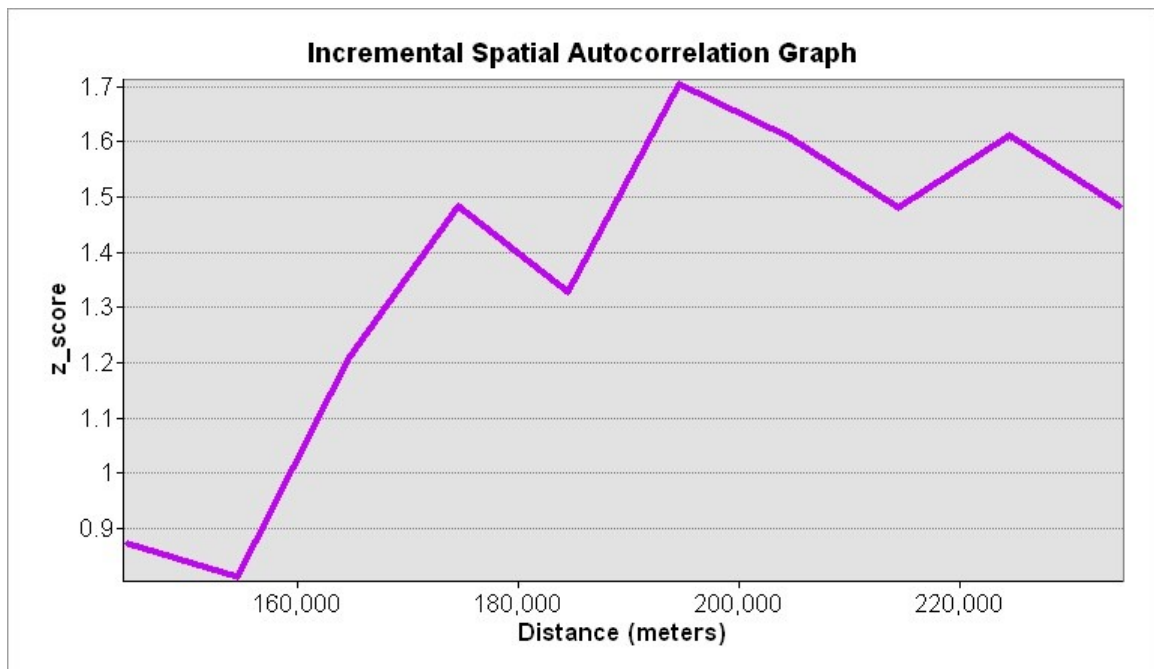
**Figure 16. 2010s Ellipse.** Also created with a larger number of data points, this ellipse shows comparable size and mean center as the previous two maps.



**Figure 17. Ellipse Overlay.** Overlaying the decadal ellipses shows the similarity of the ellipses created with the data of the latest three decades.

### Incremental Spatial Autocorrelation

Running the Incremental Spatial Autocorrelation tool identified one statistically significant peak value (Figure 18). At the distance of 194550.15, the z-score is 1.704584. This is the only z-score in this table that is greater than the threshold value of 1.65. The corresponding p-value of 0.088272 is the only value smaller than the threshold value of 0.10. These two values indicate that the distance value of 194550.15 is significant. As such, I used this in the Cluster and Outlier Analysis and Hot Spot Analysis.



**Figure 18. Incremental Spatial Autocorrelation Graph.** This graph plots identified peak values and shows that there is only one peak value that is statistically significant, having a z-score value greater than 1.65.

### Generate Spatial Weights Matrix

A spatial weights matrix (SWM) file was created prior to running the cluster analysis tools by using the Generate Spatial Weights Matrix utility. This file was necessary to ensure inclusion of time in the space-time analysis. For space-time analysis, the SPACE\_TIME\_WINDOW option was selected to conceptualize the spatial temporal relationships. This parameter requires the selection of a threshold distance and time. The matrix must include all of the features to calculate statistical significance. Through a process of trial and error, I found that 500,000 meters and 72 months were the minimum values necessary to include all of the data points. These values were used to create the SWM file that was used when running the clustering tools.

### Grouping Analysis

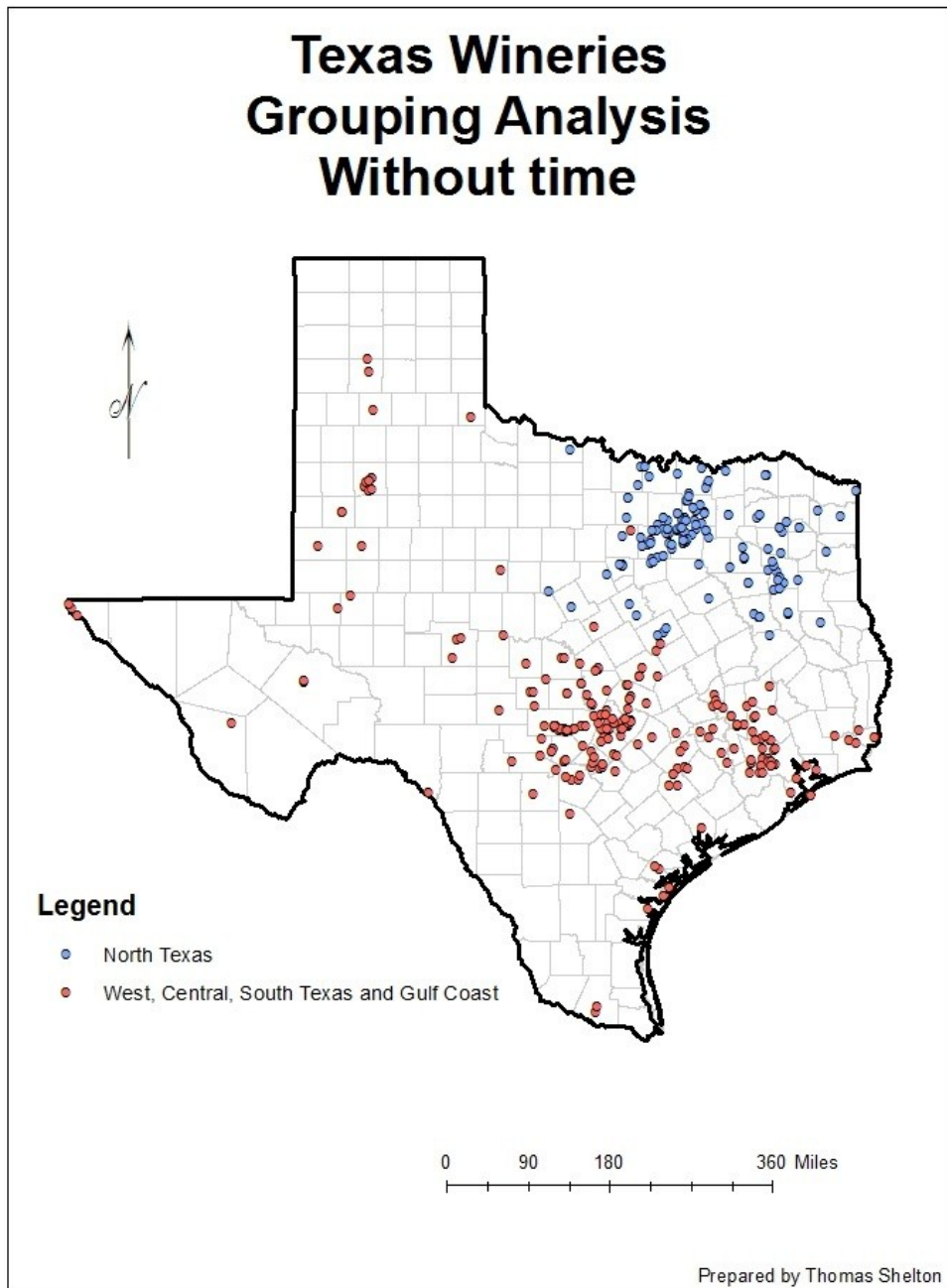
Running the Grouping Analysis tool, without time as a factor, divides the wineries into two groups (Figure 19). The division resulted in one group comprised of the wineries in north Texas, shown in blue, and another group comprised wineries the in west, south-central, and gulf-coast areas of the state.

A second Grouping Analysis, this time using time as factor for consideration, grouped wineries in a completely different manner (Figure 20). The new groups are based on their temporal characteristics : one group, comprised of wineries licensed prior to 2003 (the green stars) and another category including wineries licensed after 2003 (the red dots).

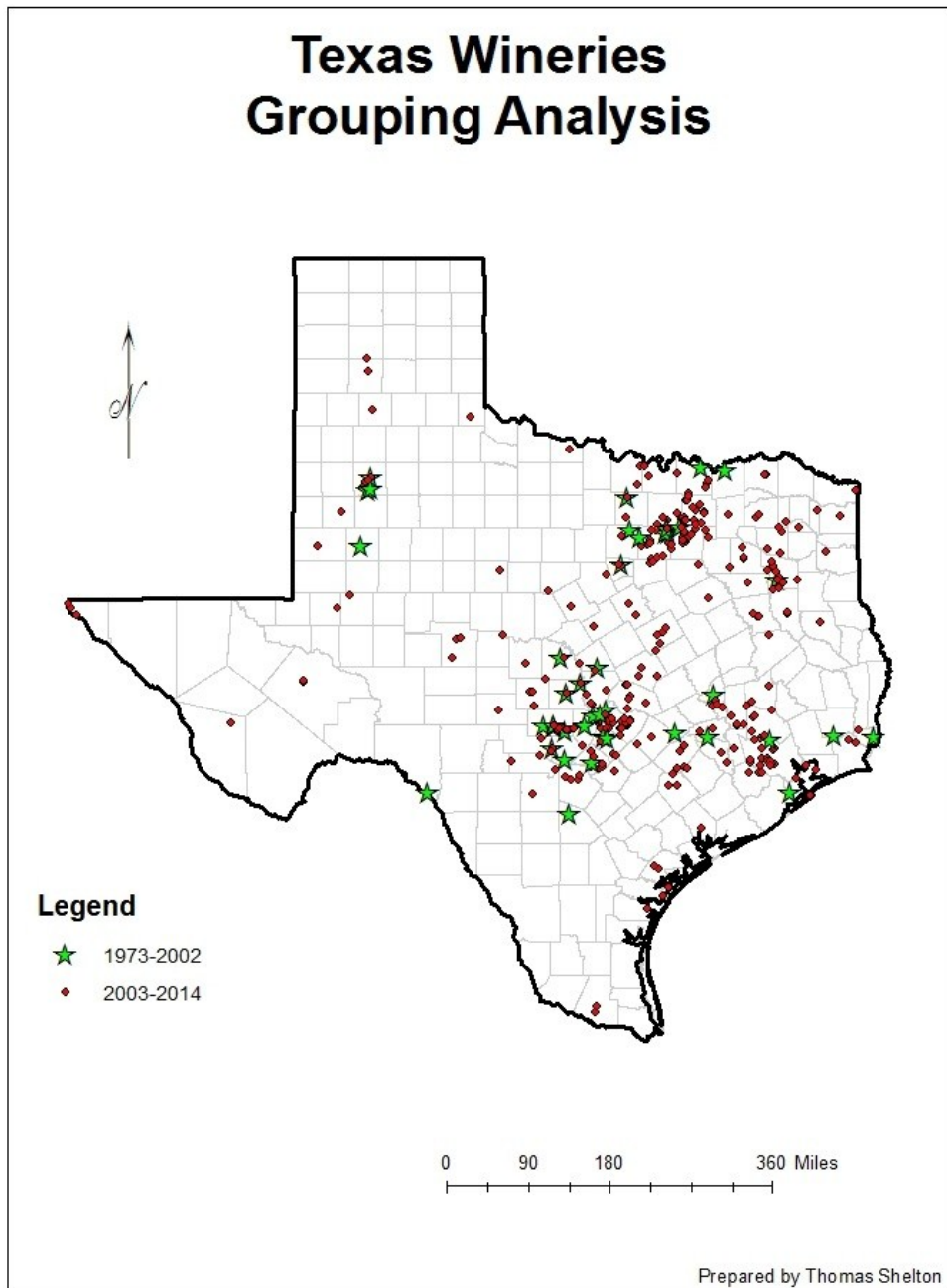
By increasing the number of groupings, I was able to continue to produce temporally defined groups (Figure 21). With this method, the first group is still composed

of those wineries licensed before 2003. However, I was able to further distinguish the more-recently licensed wineries spatially. Selecting four groupings separates not only the North Texas wineries from the rest of Texas, but the West Texas wineries as well (Figure 22). Finally, by creating five groupings, the results distinguish the remaining, previously ungrouped wineries, grouping the gulf coast and central Texas wineries separately (Figure 23).

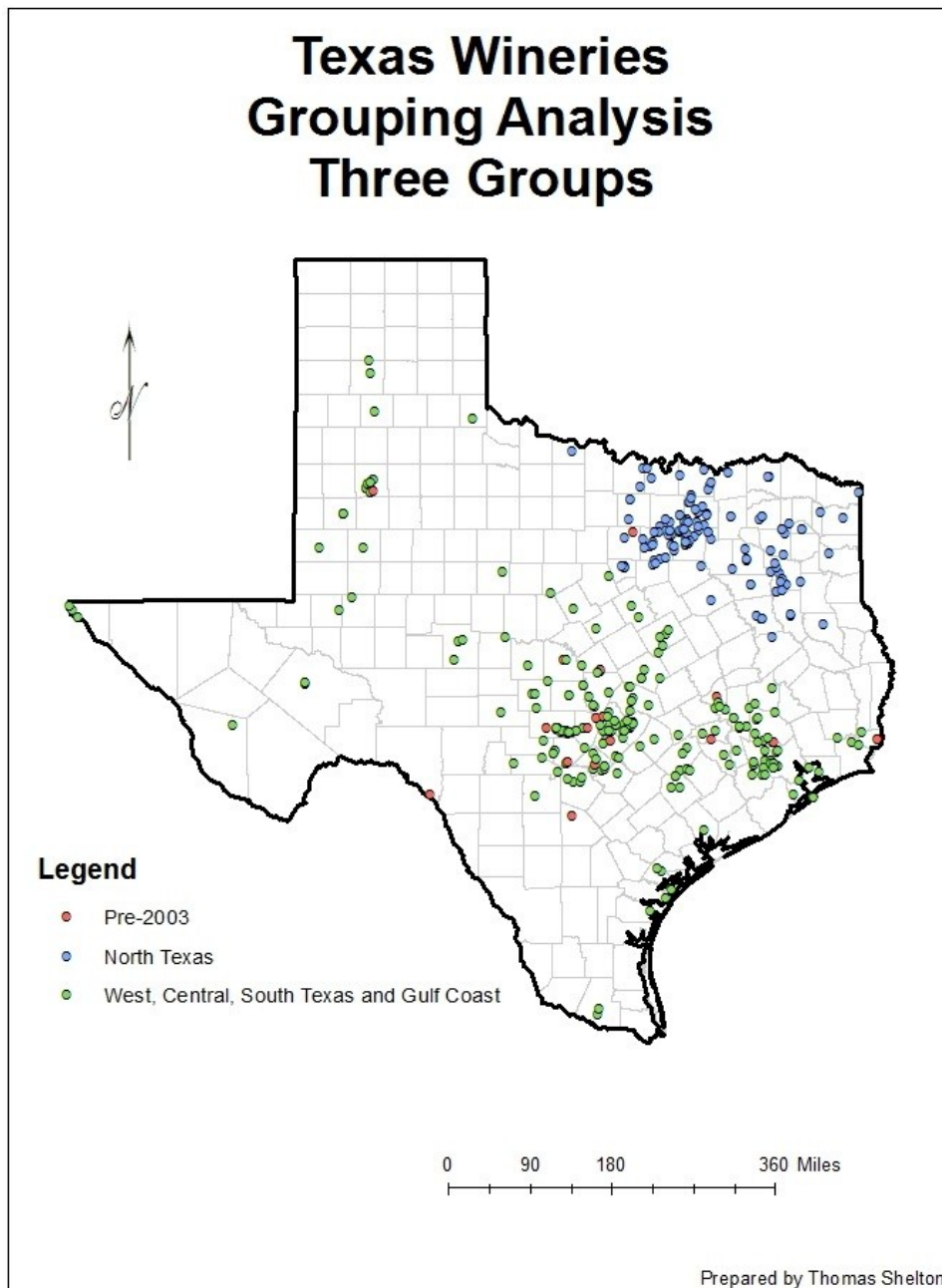
My hypothesis was that this study would reveal an emerging agglomeration of Texas wineries. The data, as analyzed here, reveal that the earliest wineries were dispersed randomly throughout the state, often being established where the early pioneers of the wine industry owned land. However, the emerging patterns shown in this paper reveal that agglomeration is now occurring, and is primarily occurring in areas in close proximity to major population areas. In particular, two regions separate themselves as the areas of greatest significance: the Texas Hill Country, centered on Fredericksburg, and the region north of Dallas-Fort Worth.



**Figure 19. Grouping Analysis without Time.** This map shows groupings based solely on spatial factors and divides the state into two distinct groups based on geographical location.

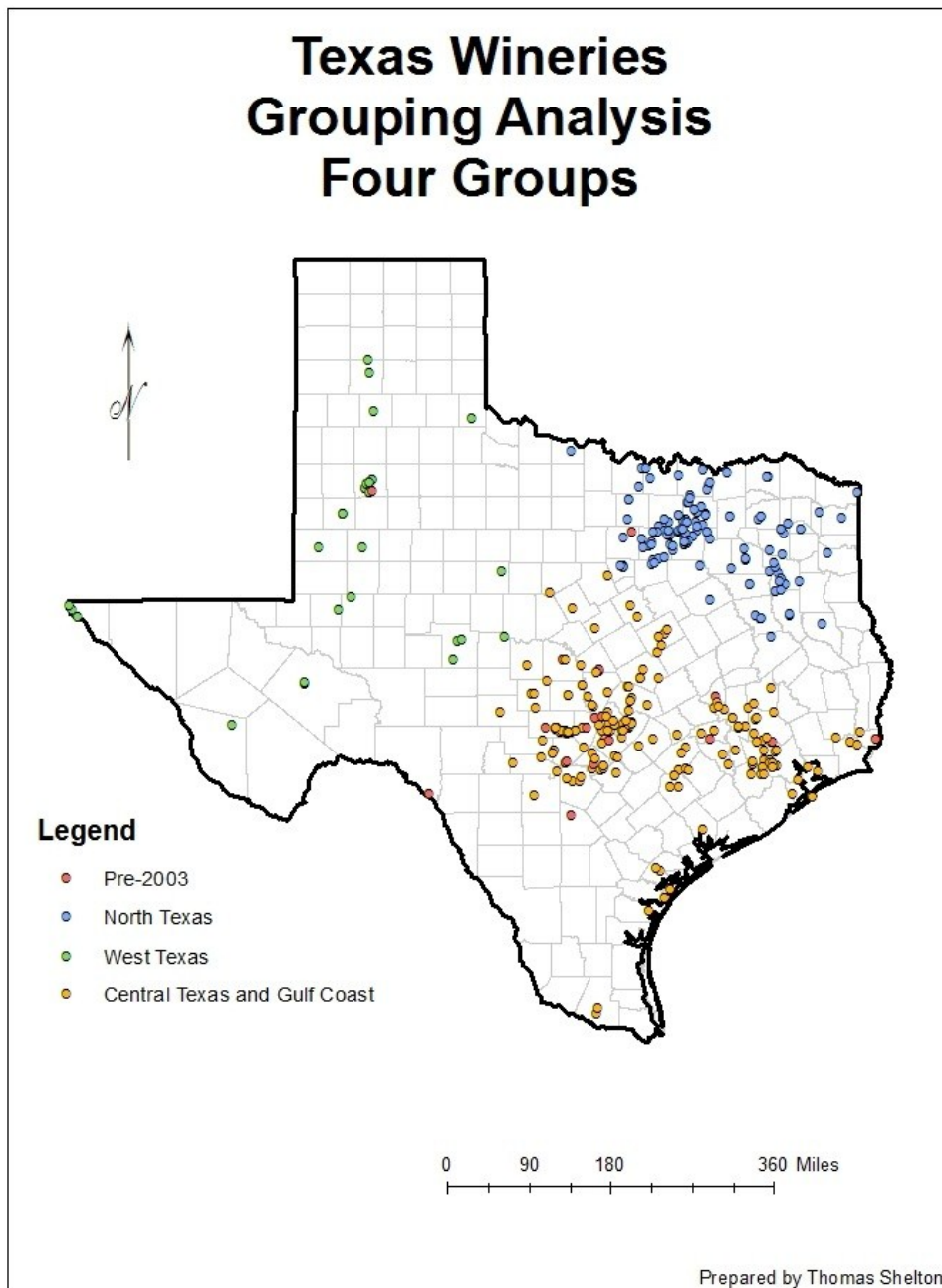


**Figure 20. Grouping Analysis using Time as a Factor.** When time is added as a variable the grouping of wineries changes from a geographical division to one based on temporal values.

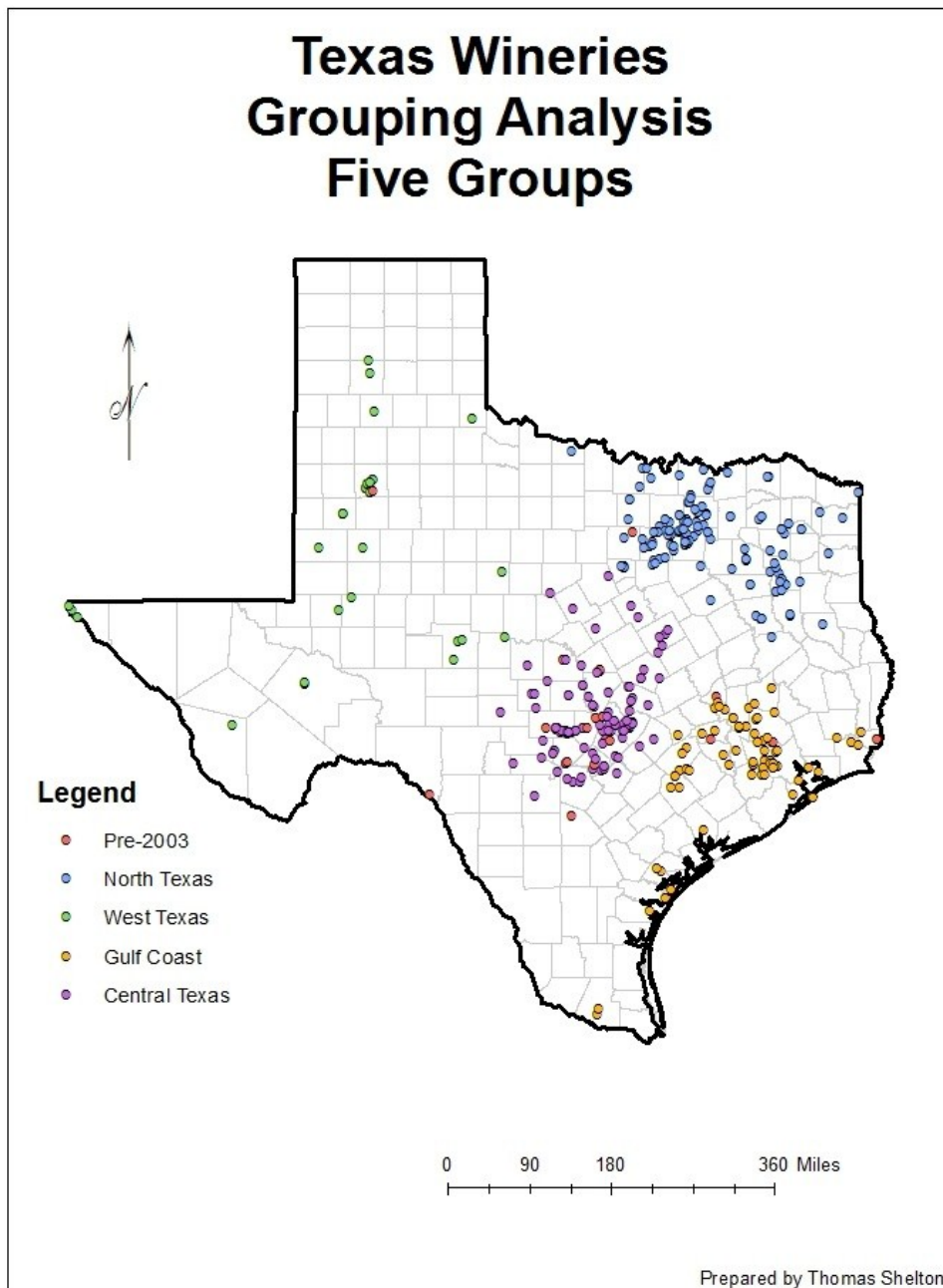


**Figure 21. Grouping Analysis Three Groups.** Increasing the number of groups combines spatial and temporal divisions. The first group is separated by temporal factors (pre-2003) and the other two groups are divided along spatial aspects.





**Figure 22. Grouping Analysis Four Groups.** Adding a fourth group separates out the wineries in western Texas.



**Figure 23. Grouping Analysis Five Groups.** Adding another group makes another spatial grouping by separating the Gulf Coast area and central Texas.

### Cluster and Outlier Analysis

Two output data sets were created using the Cluster and Outlier Analysis tool. The first set of data points were created by selecting the FIXED\_DISTANCE\_BAND option to specify how spatial relationships were conceptualized by the utility. The threshold distance specified for these data was 194550 meters, the distance figure generated using the Incremental Spatial Autocorrelation tool (see page 48). The second set of data points was generated using the SWM file created using the Generate Spatial Weights Matrix tool (see page 49).

Figures 24 and 25 were generated using the output features based on a threshold distance of 194550 meters; Figure 24 is a map of all results while Figure 25 is a map of only the 147 features (in this case, wineries) that were in statistically significant clusters. Figure 25 helps to clarify the pattern(s) of winery establishment and clustering in Texas. Through this analysis, and the resultant maps, two groupings become apparent. One group of wineries is in north Texas and contains the Low-Low (LL) cluster and High-Low (HL) outliers. The second group, located in a region stretching across central and southeast Texas, contains the High-High (HH) cluster and the Low-High (LH) outliers.

A high positive z-score, greater than the 95-percent confidence level value of 1.96, indicates a similarity in spatial clustering of either high or low values. A total of 87 features (wineries) were identified as being a part of statistically significant clustering, 40 in the HH group and 47 in the LL group (Figure 26). These results reveal the similarity of low values surrounded by low values, LL, in northern Texas, primarily in the Dallas/Fort Worth area. There are also two wineries included in this group that are in the Lubbock

area. The clustering of high values surrounded by high values, HH, is shown to be in central Texas and towards the gulf coast.

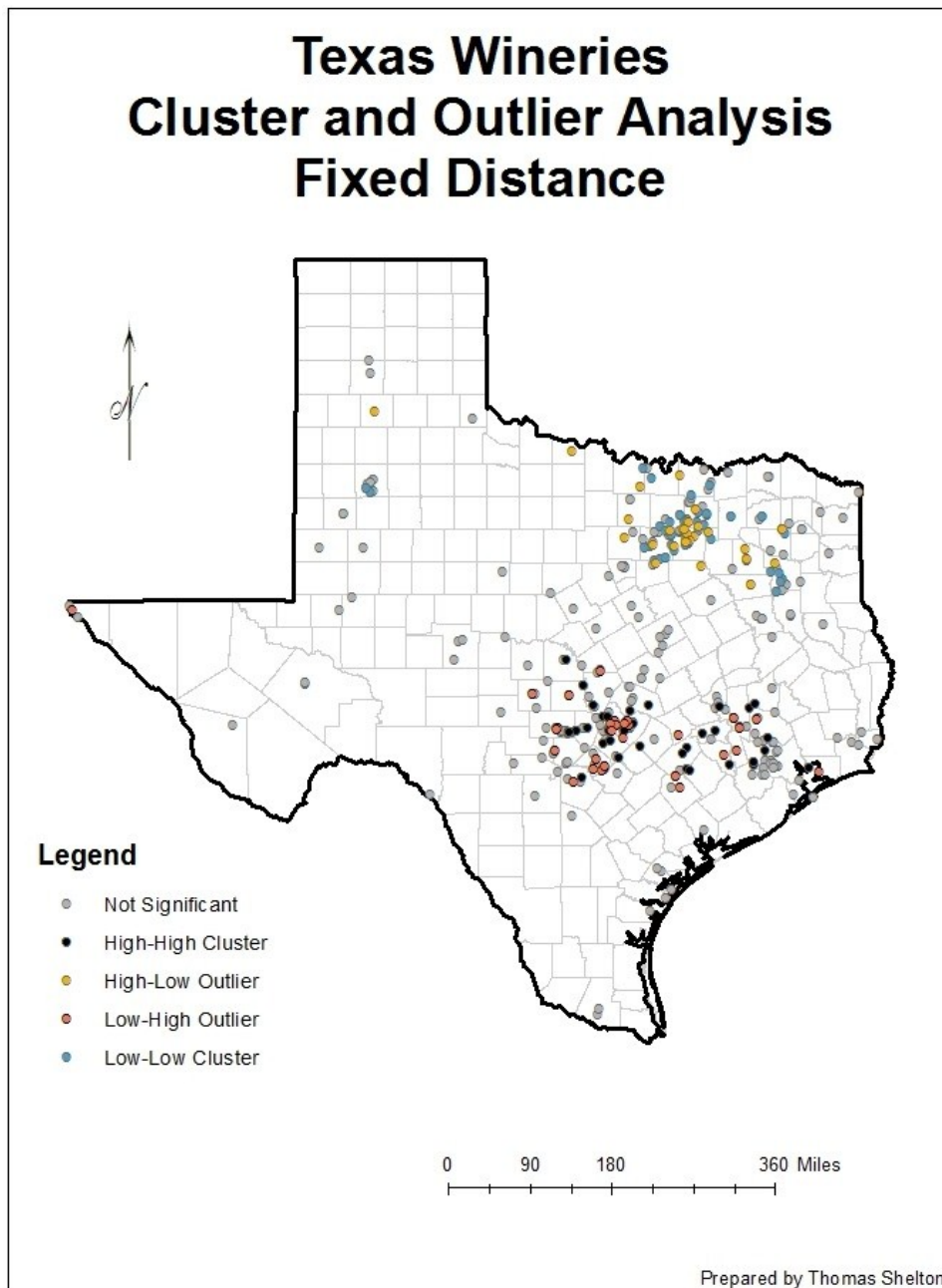
Low negative z-scores, less than the 95-percent confidence level value of -1.96, indicate dissimilarities and identify features to be spatial outliers. A total of 60 features (wineries) were identified as statistically significant outliers, 30 in the HL group and 30 in the LH group. The map in Figure 27 shows the similarity of high values surrounded by low values, HL, in northern Texas, similar to previously described LL clustering. The clustering of low values surrounded by high values, LH, is found in central Texas and towards the gulf coast, similar to the previously described HH clustering.

To add temporal aspects to this conceptualization of the spatial relationships among wineries in Texas, I ran the Cluster and Outlier Analysis tool a second time using the SWM file. With this process, I created a map of all results (Figure 28) and a map of only the 120 statistically significant features (wineries) in the clusters (Figure 29). Groupings were not as readily recognizable on these maps. In other words, the regionality and agglomeration apparent in the previous analyses are less apparent in these maps featuring the 120 statistically significant wineries created when time is added as a contributing factor.

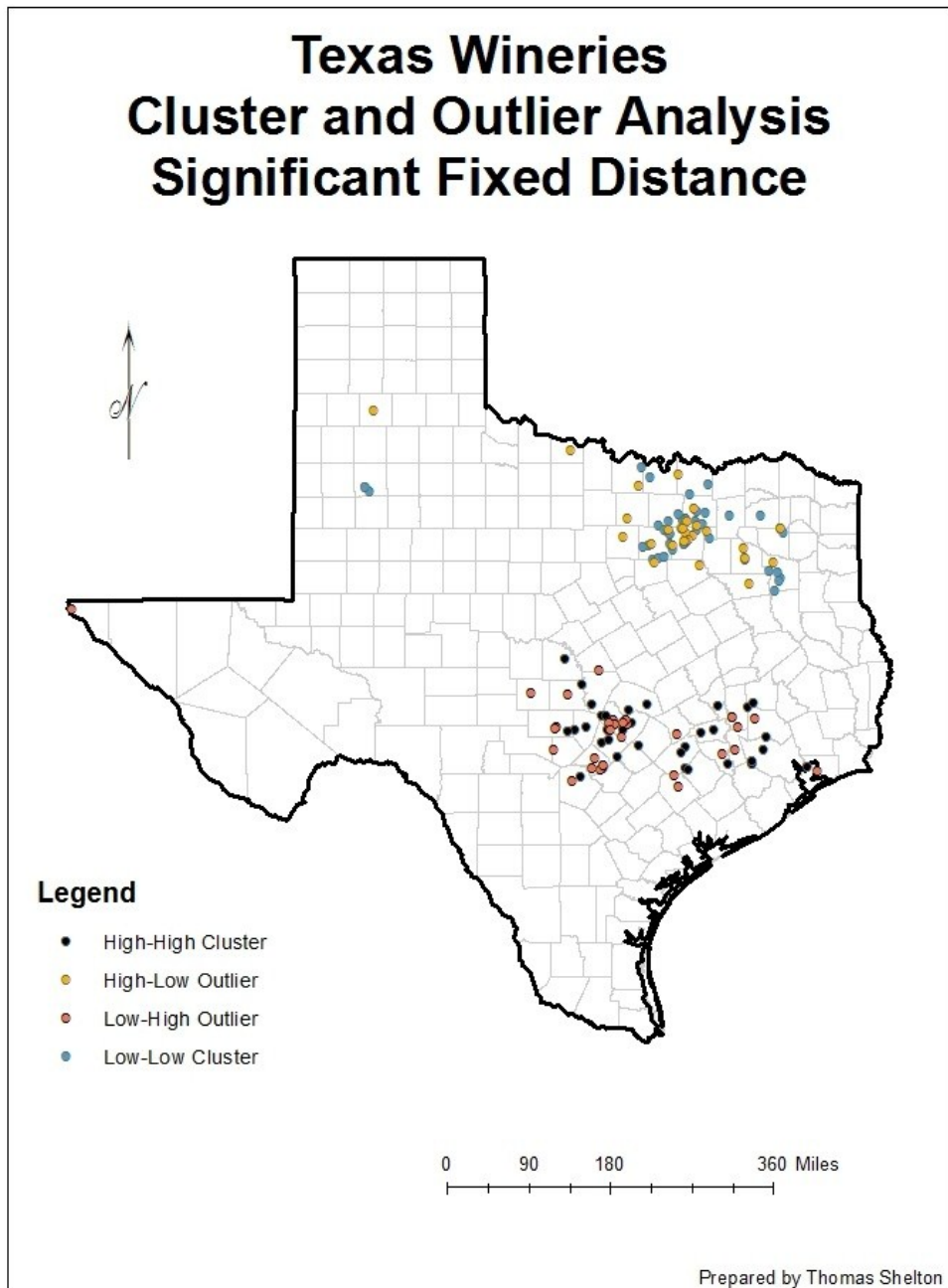
The cluster analysis reveals a subset of 69 wineries, 30 in the HH group and 39 in the LL group, to have a statistically significantly fit into clusters. Figure 30 shows the similarity of low values surrounded by low values (LL) in northern Texas as well as in central Texas and towards the gulf coast. The spatial dispersion of the HH group is also greater in this data set such that wineries further north and south than in the other data set are also included.

A total of 51 features (wineries) were statistically significant outliers, 31 in the HL group and 20 in the LH group (Figure 31). Figure 31 shows a wider-spread spatial distribution, in comparison to the cluster analysis. In this analysis, the outliers even intermingle with the regional clusters. The outliers were spatially distant, extending into the distant edges of the state, near El Paso and McAllen.

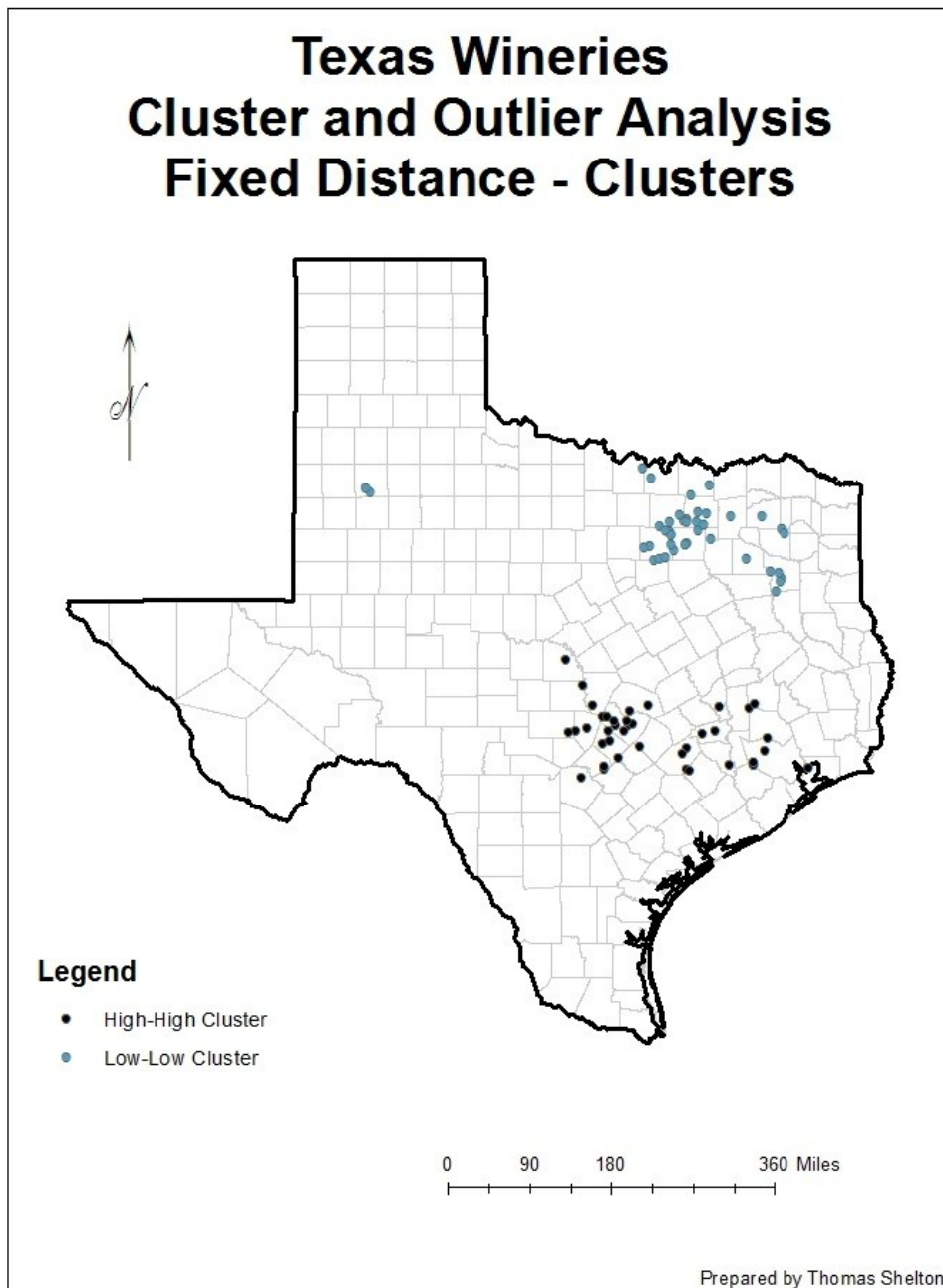
The maps generated from the Cluster and Outlier Analysis tool (as displayed in Figures 24-31) show that there is statistically significant clustering occurring among wineries in Texas. A comparison of the two analyses shows that spatial clustering is readily apparent in two distinct regions. The additional element of time (as represented in Figure X) breaks down the spatial segregation of the two groups. This same phenomenon is also apparent when comparing the outliers.



**Figure 24. Cluster and Outlier Analysis Fixed Distance.** This map shows the complete results of using the Cluster and Outlier Analysis tool using the fixed distance value of 194550 meters that was identified using the Incremental Spatial Autocorrelation tool.

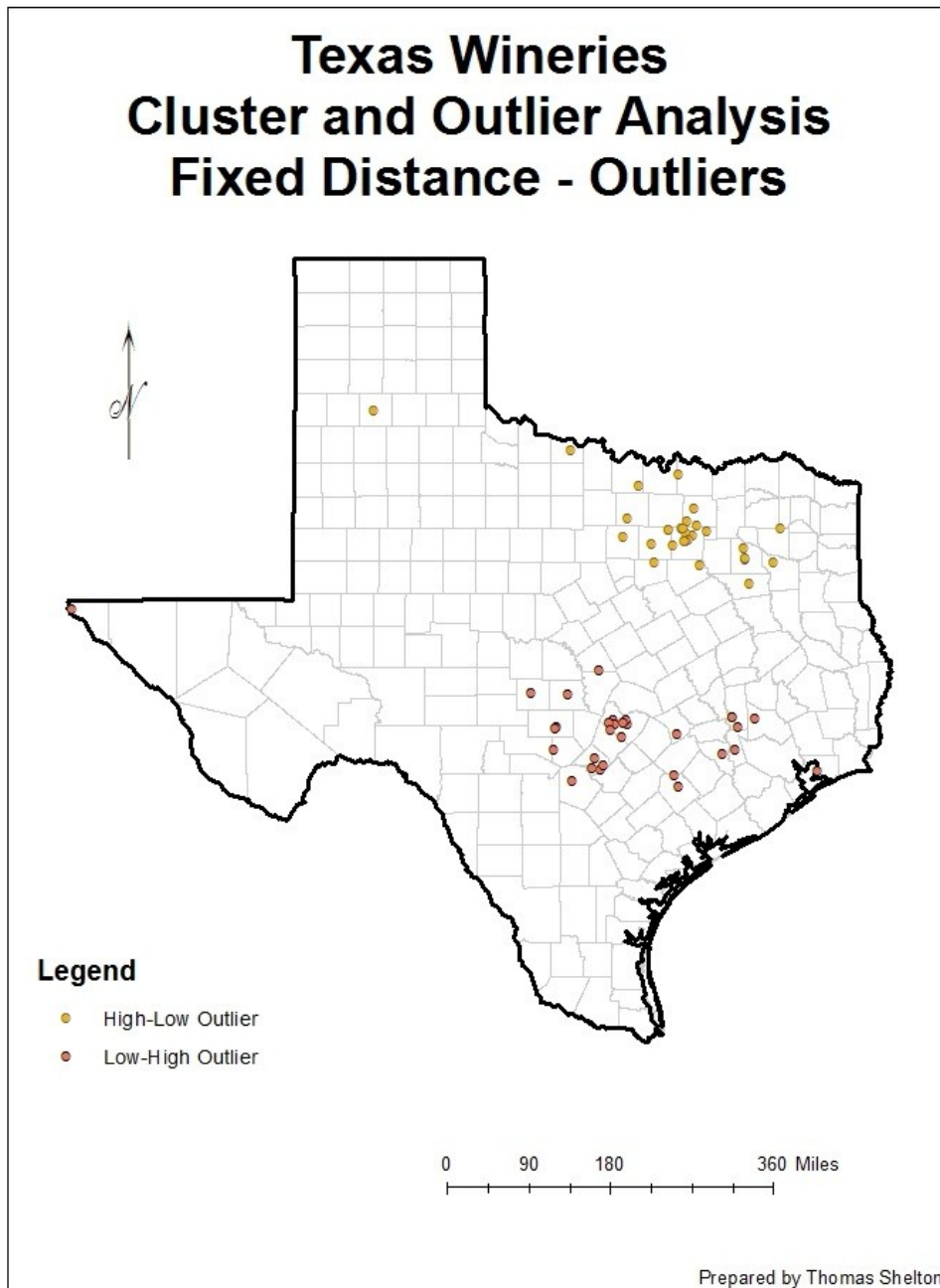


**Figure 25. Cluster and Outlier Analysis Significant Fixed Distance.** Removing the points that were identified as not significant reduces clutter and makes it easier to view the groupings of clusters and outliers.

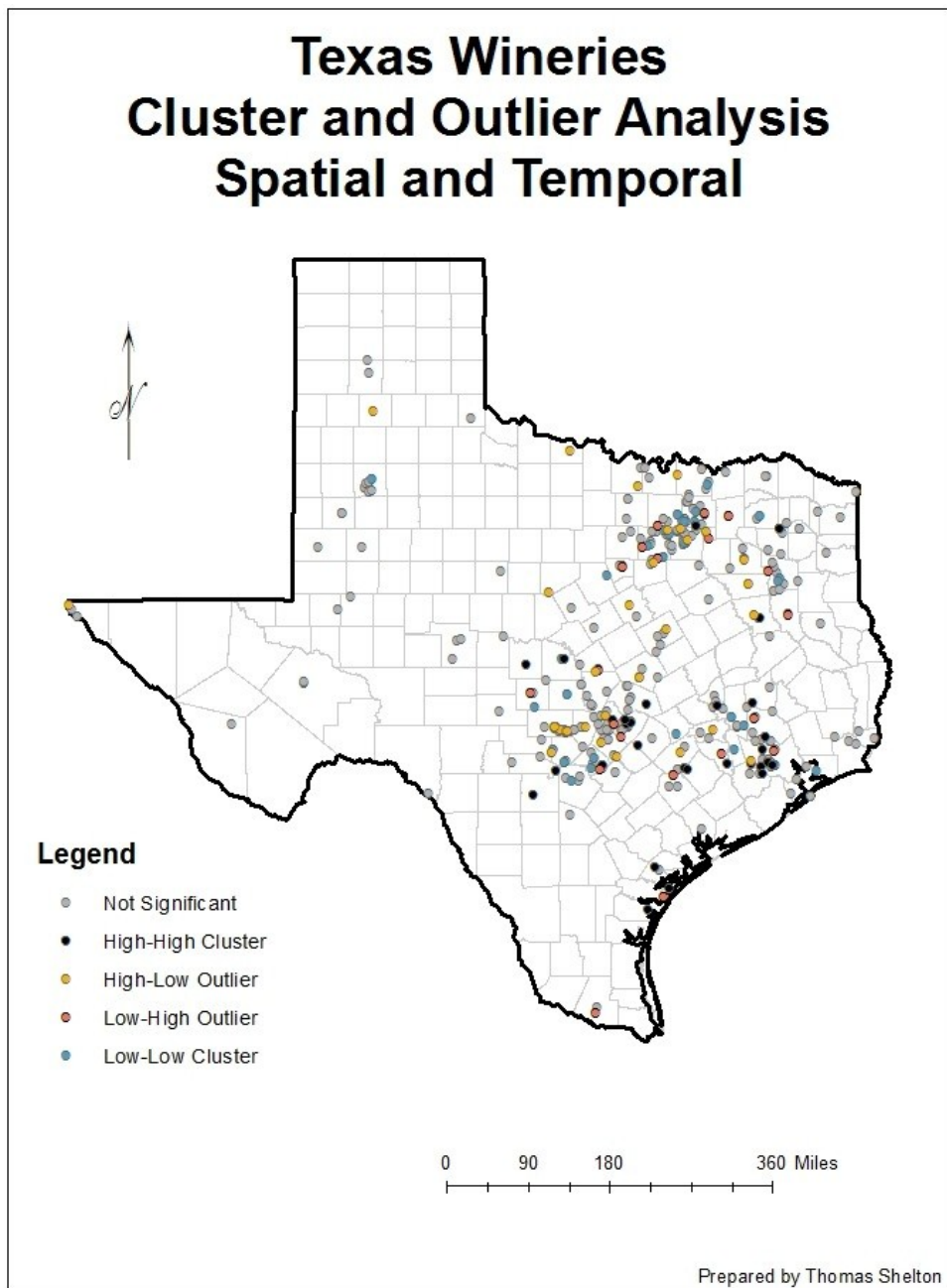


**Figure 26. Cluster and Outlier Analysis Fixed Distance Clusters.** The statistically significant clusters show spatial clustering on this map.

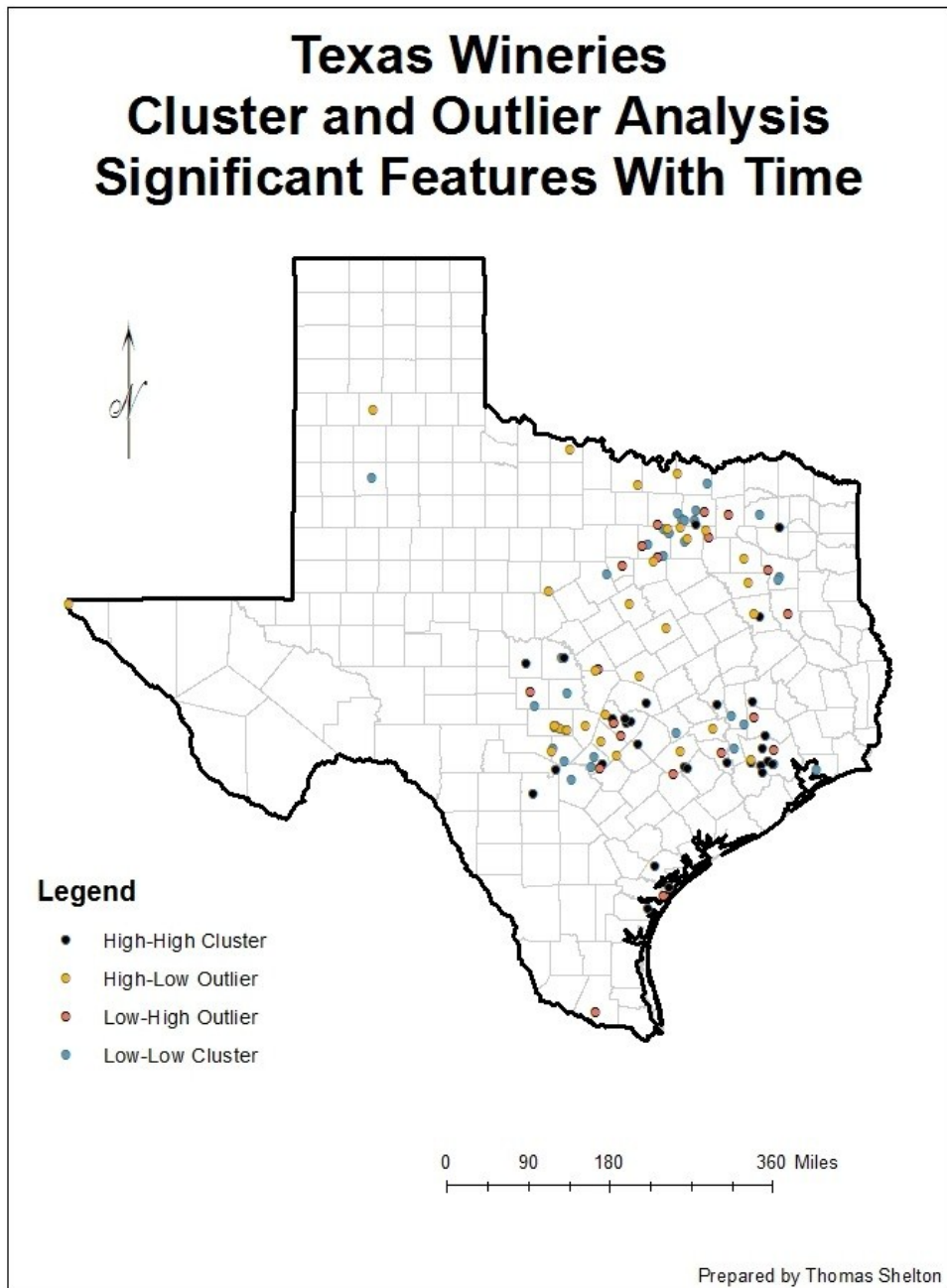




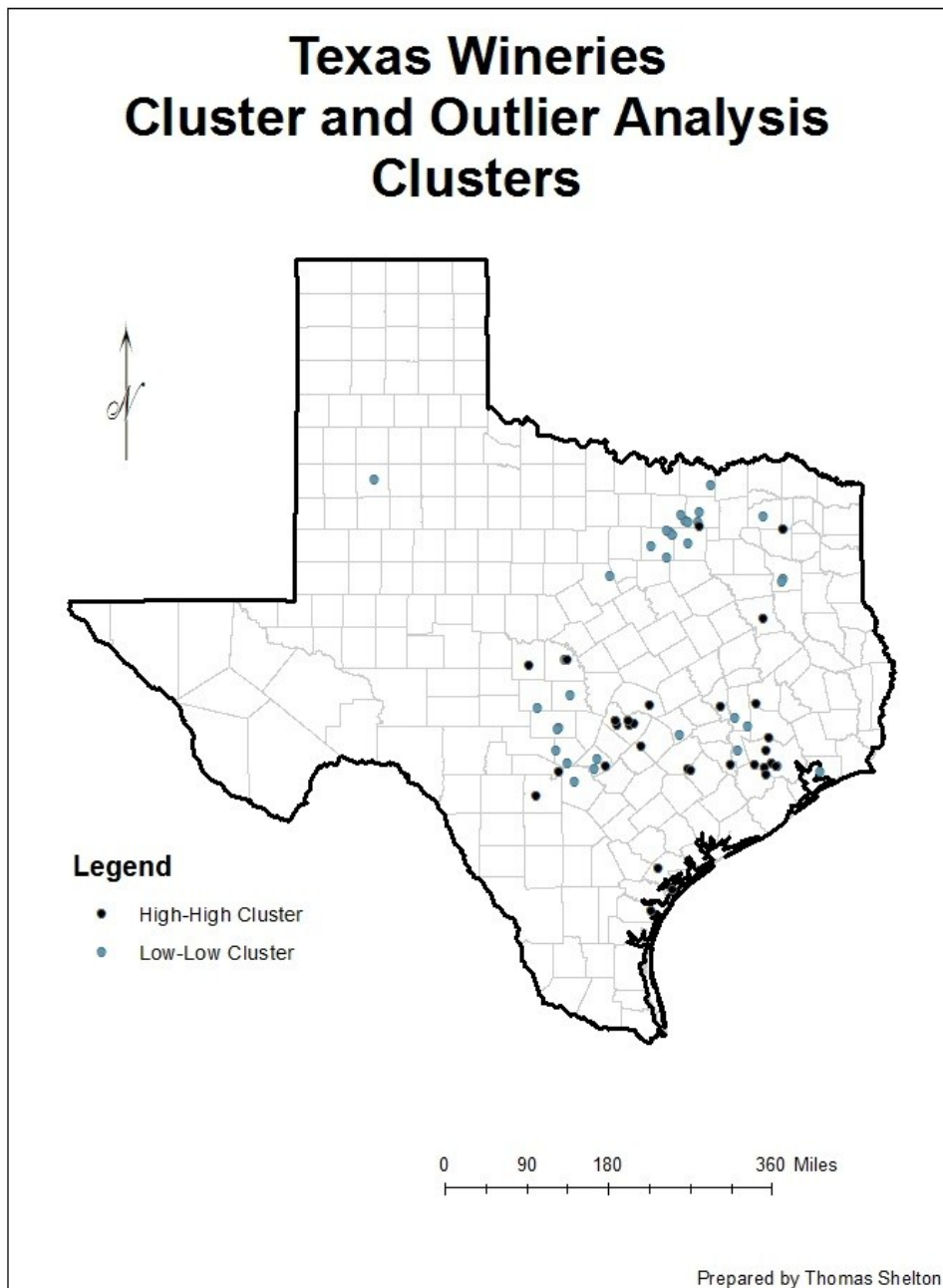
**Figure 27.** Cluster and Outlier Analysis Fixed Distance Outliers. The statistically significant outliers show similar spatial grouping to the clusters on this map.



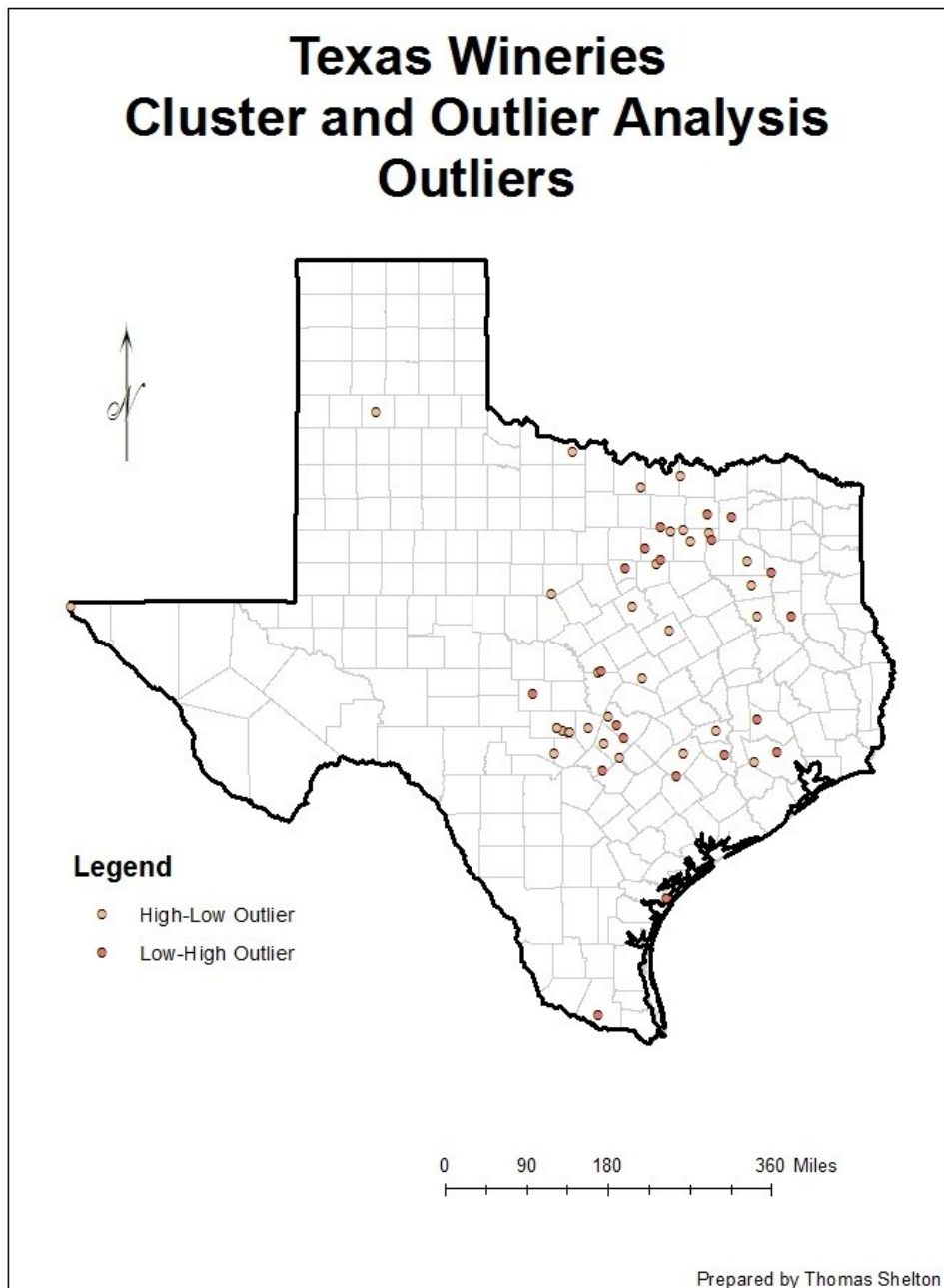
**Figure 28. Cluster and Outlier Analysis Spatial and Temporal.** This map shows the complete results of using the Cluster and Outlier Analysis tool, this time using the SWM file generated using the Generate Spatial Weights Matrix toll to include temporal features.



**Figure 29. Cluster and Outlier Analysis Significant Features with Time.** Removal of the points that were identified as not significant reduces some of the clutter, but this map is not as clear as before the temporal features were included.



**Figure 30. Cluster and Outlier Analysis Clusters.** The statistically significant clusters shown on this map have a greater spatial dispersion when time was added as a weighted factor.



**Figure 31. Cluster and Outlier Analysis Outliers.** Similar to the map of statistically significant clusters, the outliers also show greater spatial dispersion.

### Hot Spot Analysis

As described in the Cluster and Outlier Analysis Section (above), two output data sets were created using the Hot Spot Analysis tool. The first set was created by selecting the FIXED\_DISTANCE\_BAND option to specify how ArcGIS conceptualized spatial relationships. The threshold distance specified for these data was 194550 meters, the significant distance generated using the Incremental Spatial Autocorrelation tool. The second data set was generated using the same SWM file created by the Generate Spatial Weights Matrix tool.

Hot and cold spots identified using the fixed distance show the intensity of development of the wineries. These results are presented in a map of all results (Figure 32) and a map of only the 266 statistically significant features (wineries) (Figure 33). The hot and cold spots are spatially divided along the same lines as generated with the Cluster and Outlier Analysis tool. The cold spots are in northern Texas and the hot spots are located in the central part of the state.

Examination of only the wineries identified as hot spots reveals the most intensely developing areas within the central and southeastern parts of Texas (Figure 34). All of these wineries are grouped together, but the hot spots are divided into three groupings based on confidence levels. There are 52 wineries that have a 90 percent confidence-level fit; this grouping includes the Val Verde Winery (the first time that it has been clustered). Fifty-three wineries, in a much tighter spatial grouping, are more strongly associated (at the 95-percent confidence level). And 21 wineries are very strongly associated, at the 99-percent confidence level. Their grouping is within the area encompassed by the second group.

Conversely, the cold spots can also be analyzed. The wineries identified as cold spots are not grouped as tightly clustered as are the “hot spot” wineries (Figure 35). Most of these wineries are in northern Texas, but more than a dozen cold spot wineries are found in the Panhandle. The group of 17 wineries related at a 90-percent confidence level includes all but two of the Panhandle wineries. However, the group also includes the two wineries most southeastward of the cold spots. There are 32 wineries with a 95- percent confidence level association with the cold spots. This group includes the two northernmost statistically significant wineries in the Panhandle a tightly grouped set in northern Texas. Ninety-one wineries are grouped together in northern Texas and reflect a confidence level of 99 percent association with the cold-spot characteristic.

Time was incorporated in the analysis using the SWM file. These analyses are again presented in a map of all results (Figure 36) and a map of only the statistically significant features (216 wineries, in this case) (Figure 37). As with previous analyses using the SWM file the spatial grouping is not as well defined ; the groupings overlap with each other.

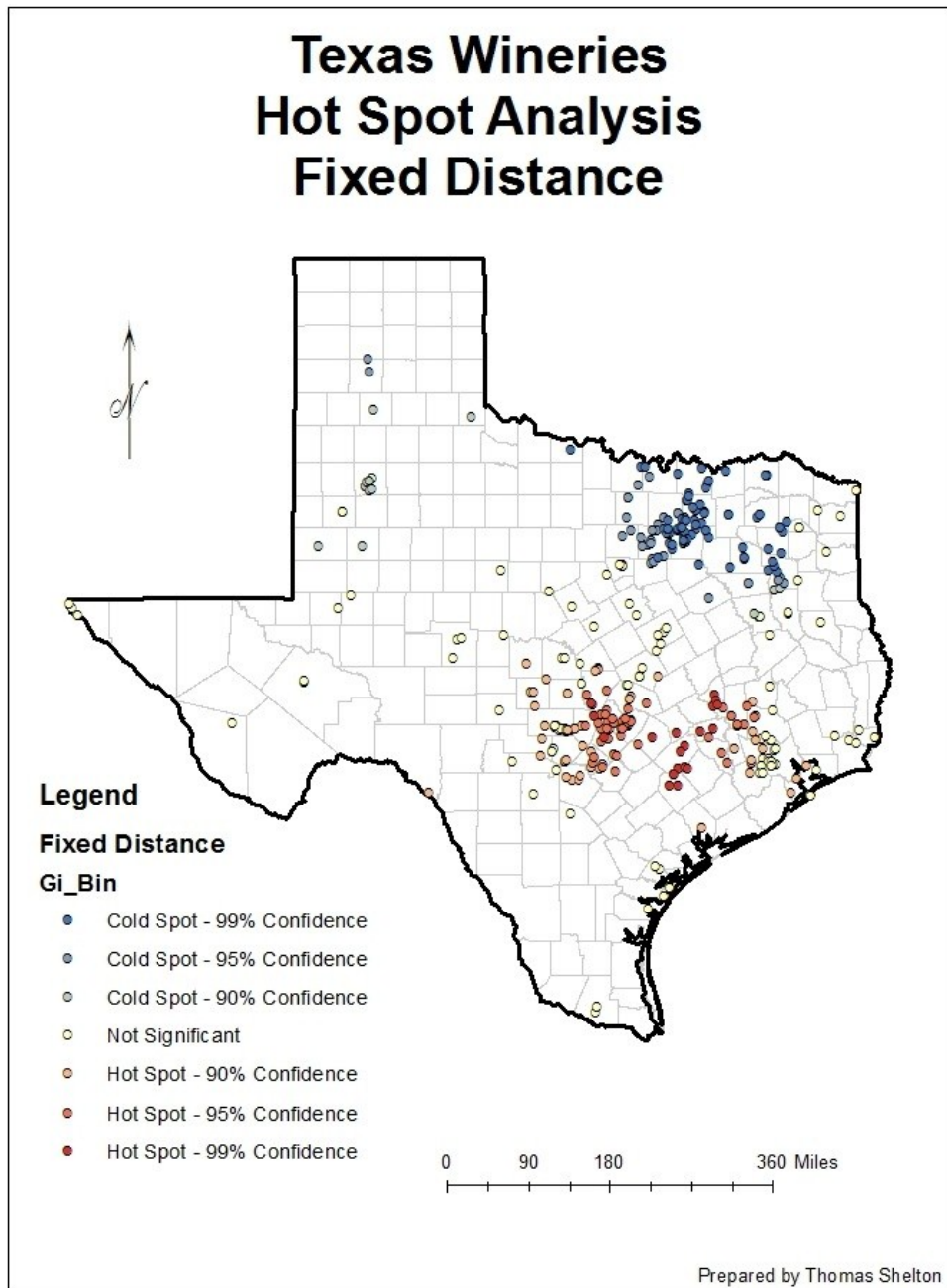
Based on this analysis, the 101 hot spots throughout the eastern half of the state appear to be randomly distributed (Figure 38). Forty-one wineries are associated with spatio-temporal hot spots at the 90-percent confidence level, 52 at the 95-percent confidence level and 8 at the 99-percent confidence level. The spatial distribution of the wineries in each of these categories are loosely coalesced, and their areas overlap.

The 115 cold spot wineries are also scattered across the eastern half of the state, albeit with a bit more densely grouped set in the north as compared to the hot spots (Figure 39). There are 13 wineries placed at the 90-percent confidence level, 31 at the 95-

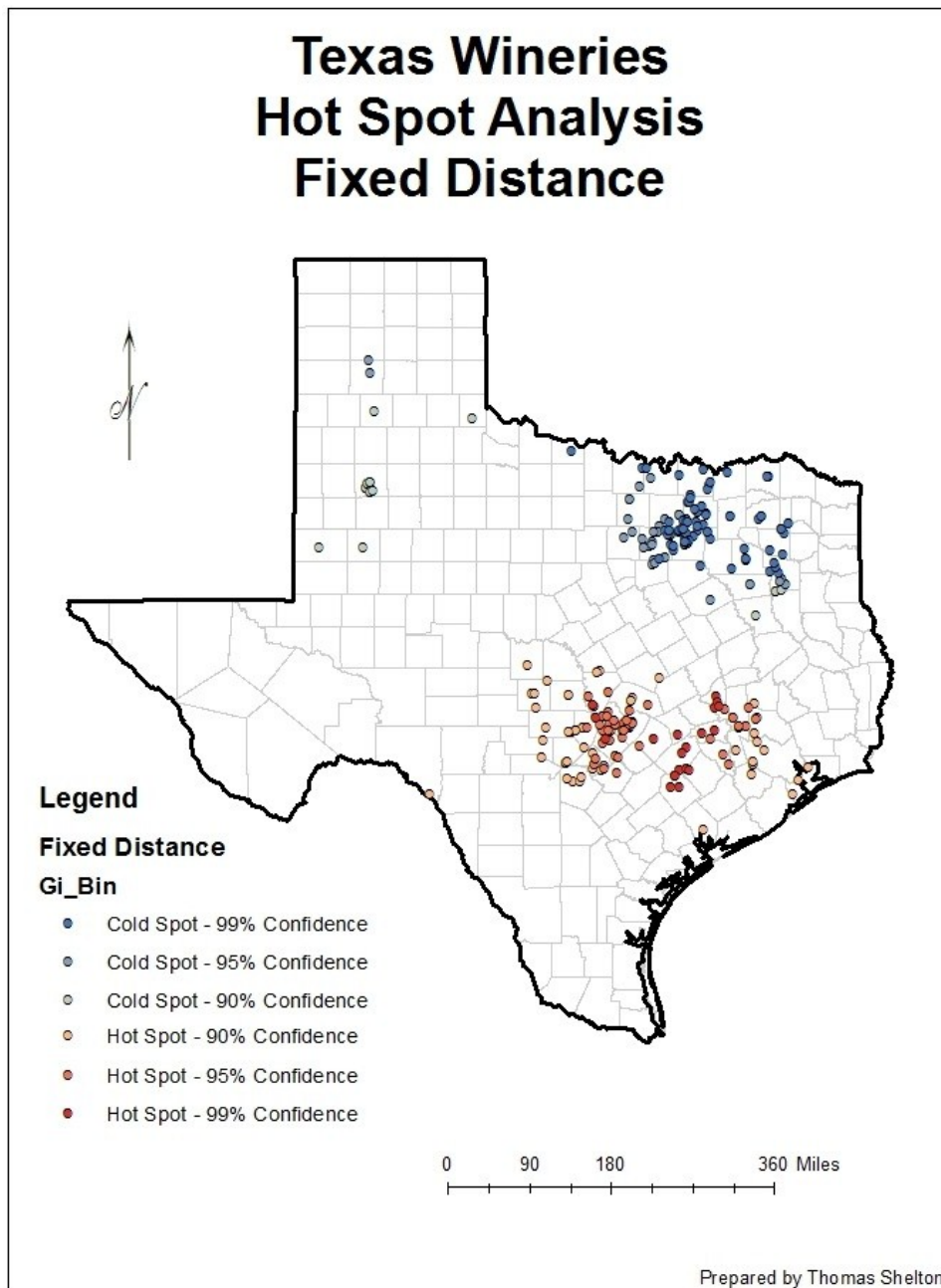
percent confidence level, and 71 at the 99-percent confidence level. Like the hot spots, all three groups overlap and intermix spatially with each other.

When the SWM file is incorporated, time becomes the primary factor in the analysis (Figure 40). The cold spot wineries (with one exception) were all established prior to the wineries identified as hot spots. Moreover, the statistically significant cold spots are spread out over a greater period of time. The graph presented in Figure 40 helps to show why the spatial distribution is so scattered. The graph shows that time (date established) has the greatest significance in separating the statistically significant identified hot and cold spot.

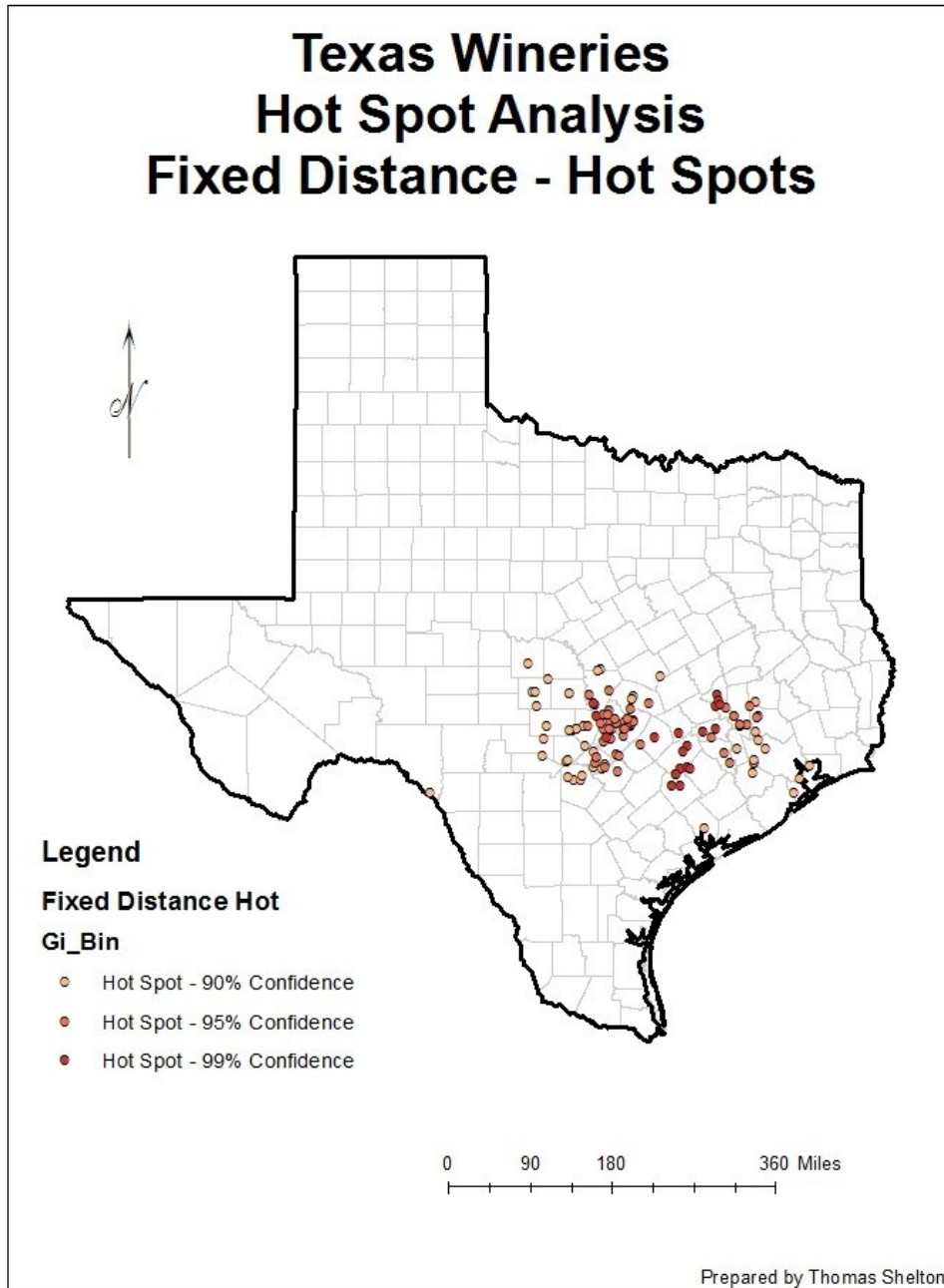




**Figure 32. Hot Spot Analysis Fixed Distance.** This map shows the complete results of using the Hot Spot Analysis tool using the fixed distance value of 194550 meters that was identified using the Incremental Spatial Autocorrelation tool.

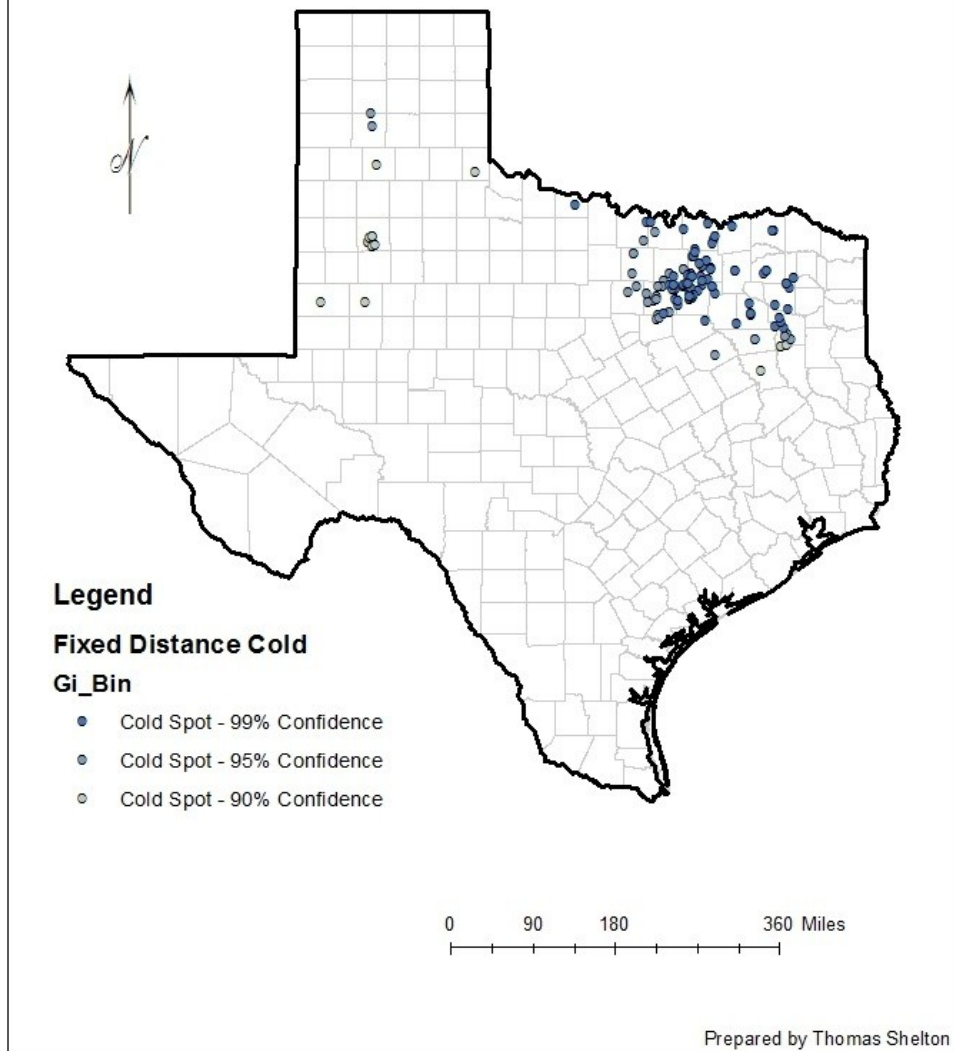


**Figure 33. Hot Spot Analysis Significant Fixed Distance.** Removal of the data points identified as not significant clarifies this map. The results show a similar distribution to the points identified in the Cluster and Outlier Analysis tool using the same fixed distance.

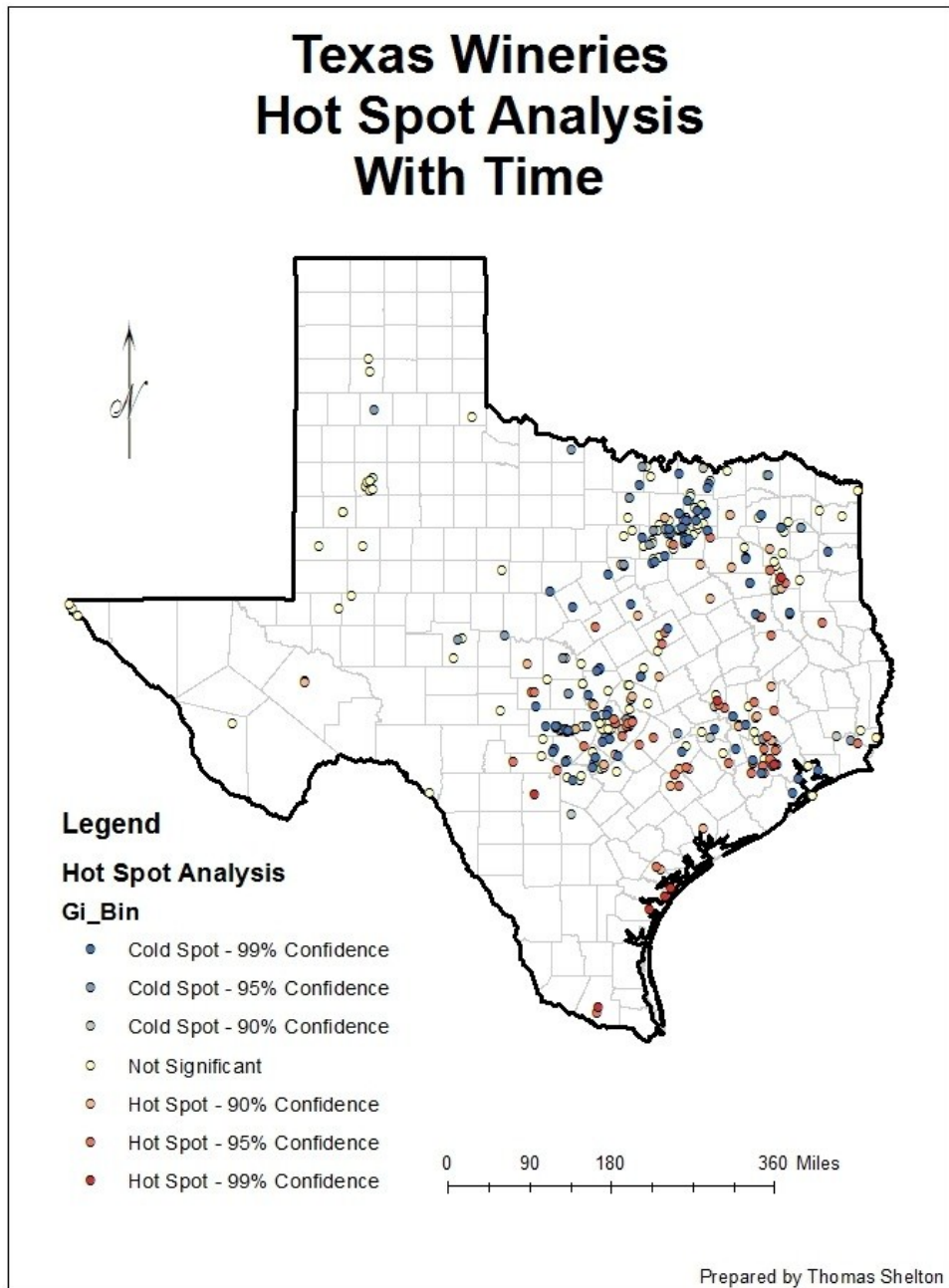


**Figure 34. Hot Spot Analysis Fixed Distance Hot Spots.** This map shows the features identified as being hot spots and their associated confidence level. These points are grouped in the central part of the state.

# Texas Wineries Hot Spot Analysis Fixed Distance - Cold Spots

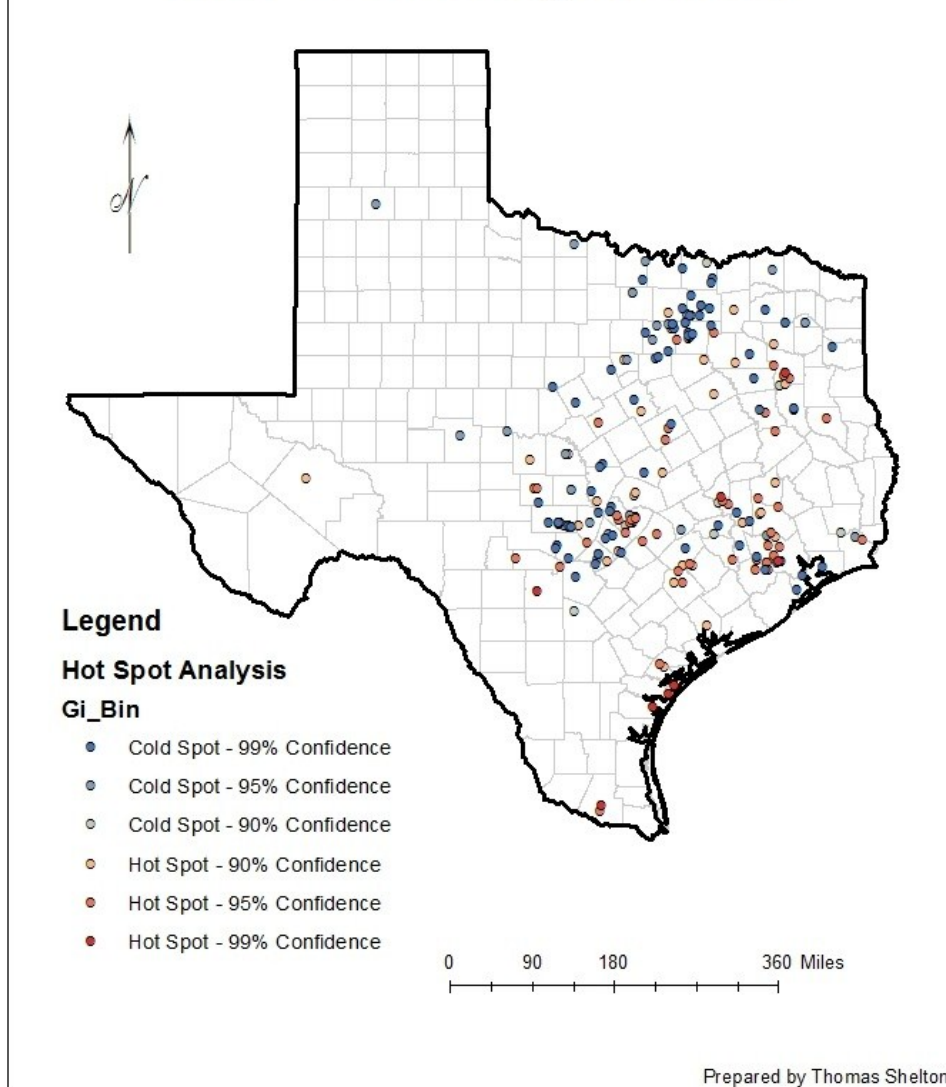


**Figure 35. Hot Spot Analysis Fixed Distance Cold Spot.** This map shows the features identified as being hot spots and their associated confidence level. This map also shows geographical grouping, this time in the panhandle and north Texas.



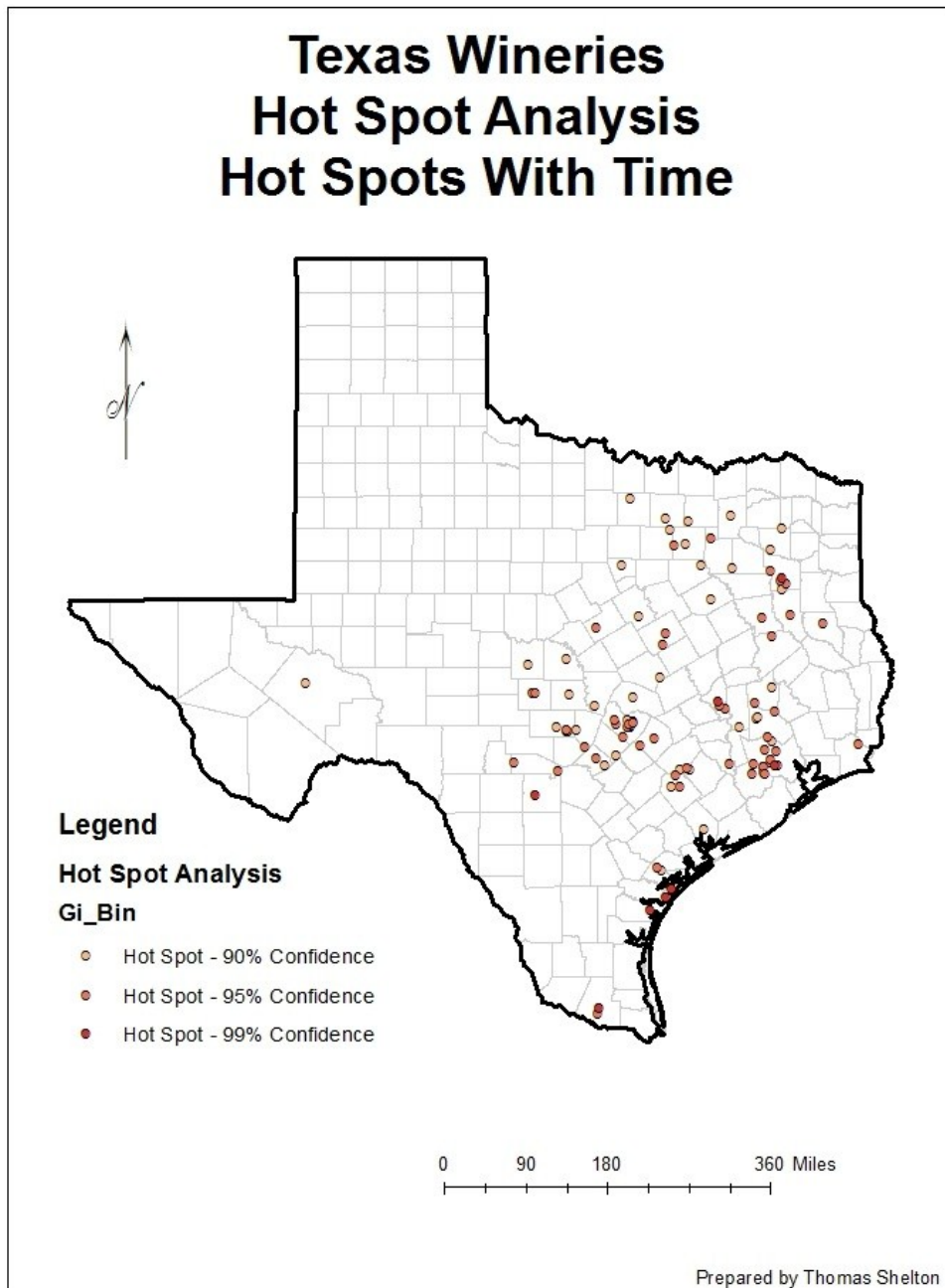
**Figure 36. Hot Spot Analysis with Time.** This map shows the complete results of using the Hot Spot Analysis tool using the SWM file generated using the Generate Spatial Weights Matrix toll to include temporal features.

# Texas Wineries Hot Spot Analysis With Time & Significance

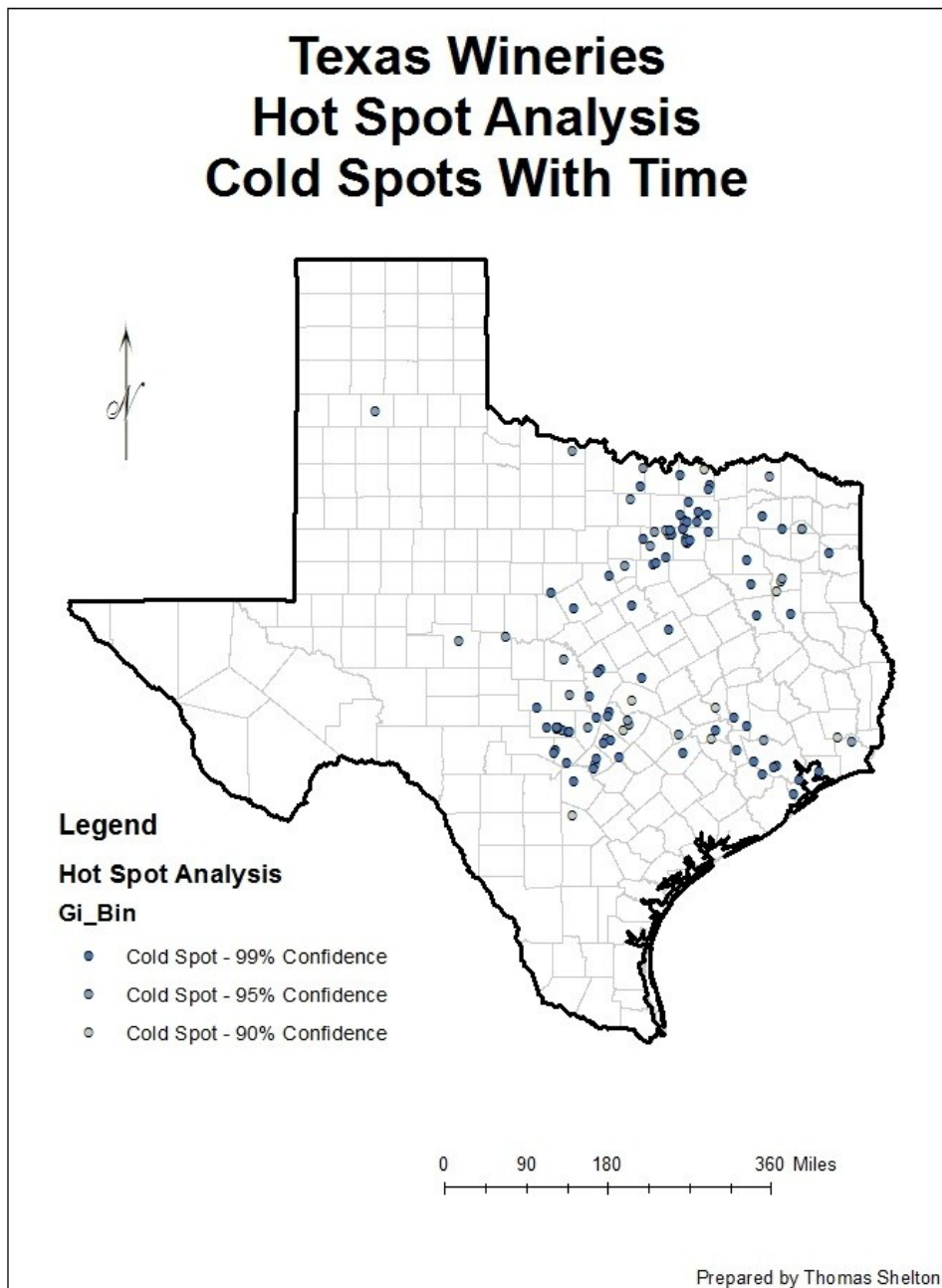


**Figure 37. Hot Spot Analysis with Time & Significance.** This is the same map with the features identified as not significant removed for clarity. The geographical grouping of similar points is not as apparent as when time was added as a factor.



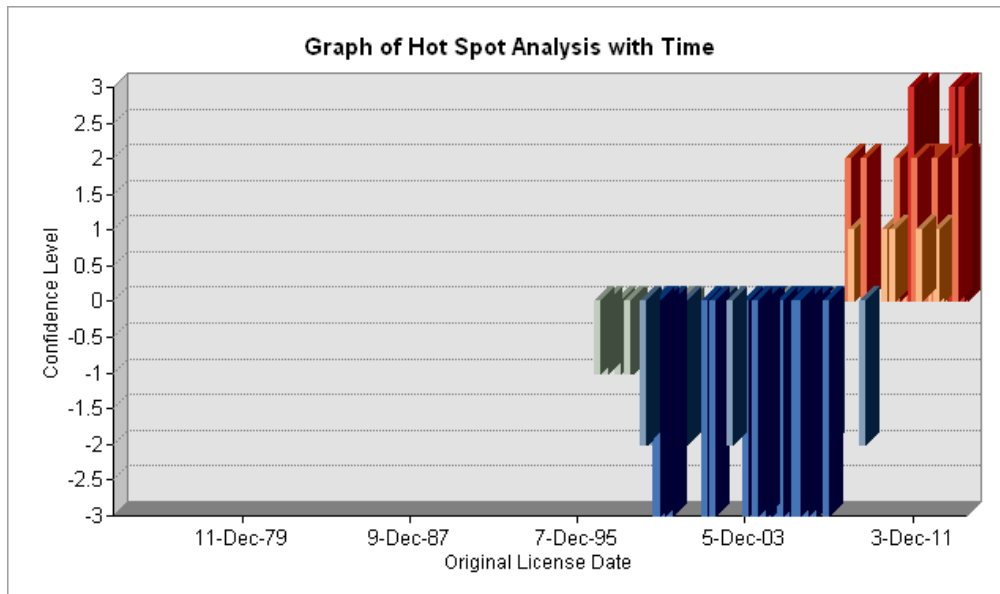


**Figure 38. Hot Spot Analysis Hot Spots with Time.** A look at just the features identified as hot spots indicates spatial randomness among points with similar confidence levels.



**Figure 39. Hot Spot Analysis Cold Spots with Time.** This map of the cold spots shows the same general dispersion as the hot spot map.





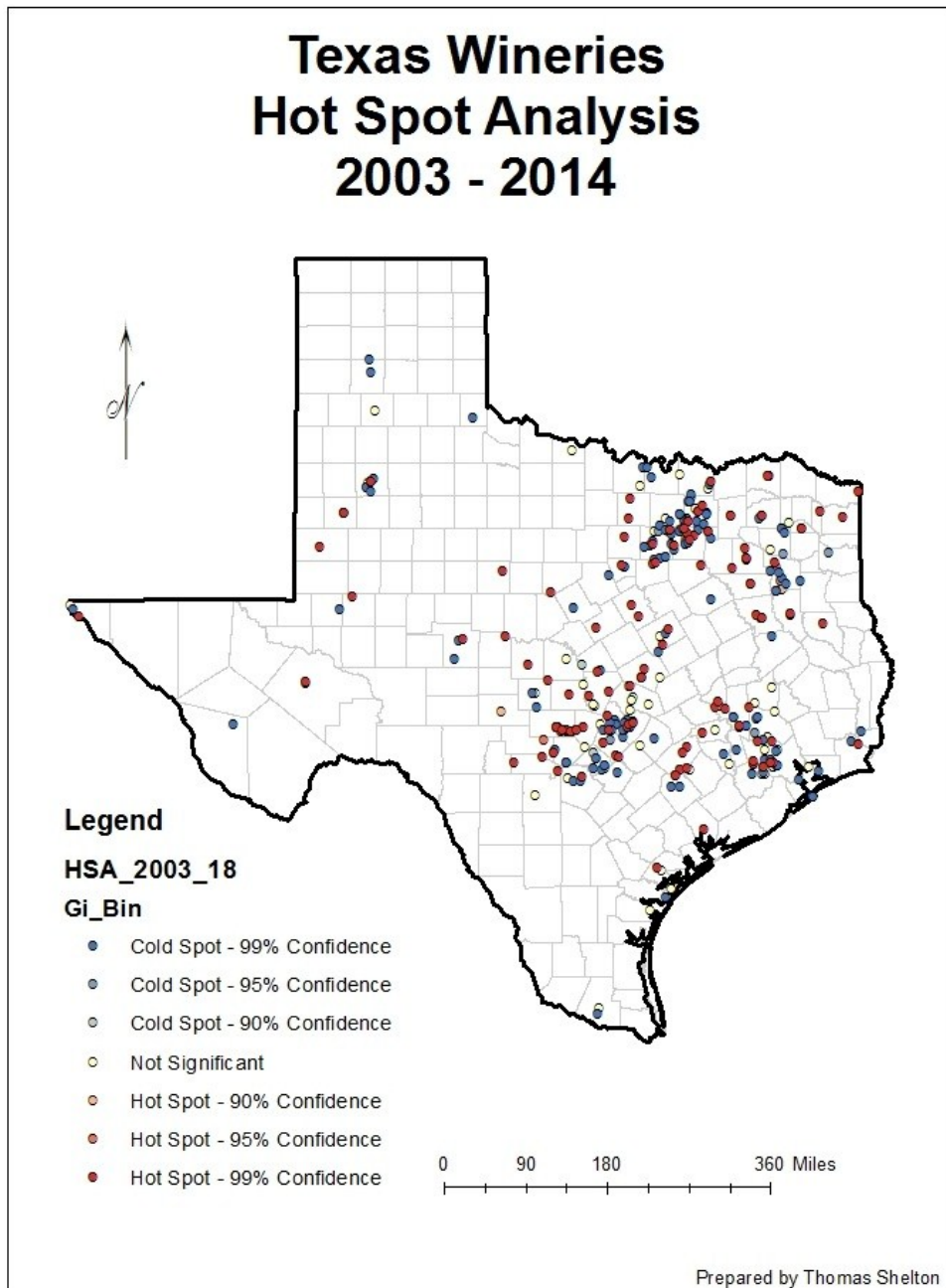
**Figure 40. Hot Spot Analysis Graph.** This graph shows that when time is included when running the Hot Spot Analysis that time becomes the decisive factor in separating hot and cold spots.

To better account for the recent growth that has taken place since the constitutional change in 2003 that spurred the rapid growth in winery establishment, I created a revised data set and a new SWM file. The data set is identical to the first set except that the 44 wineries that were licensed prior to 2003 were removed. The new SWM file uses the new data set and a time parameter of 18 months (much shorter than the previous 72 months). This shortened time period was the minimum needed to successfully cover the 349 wineries of the new data set.

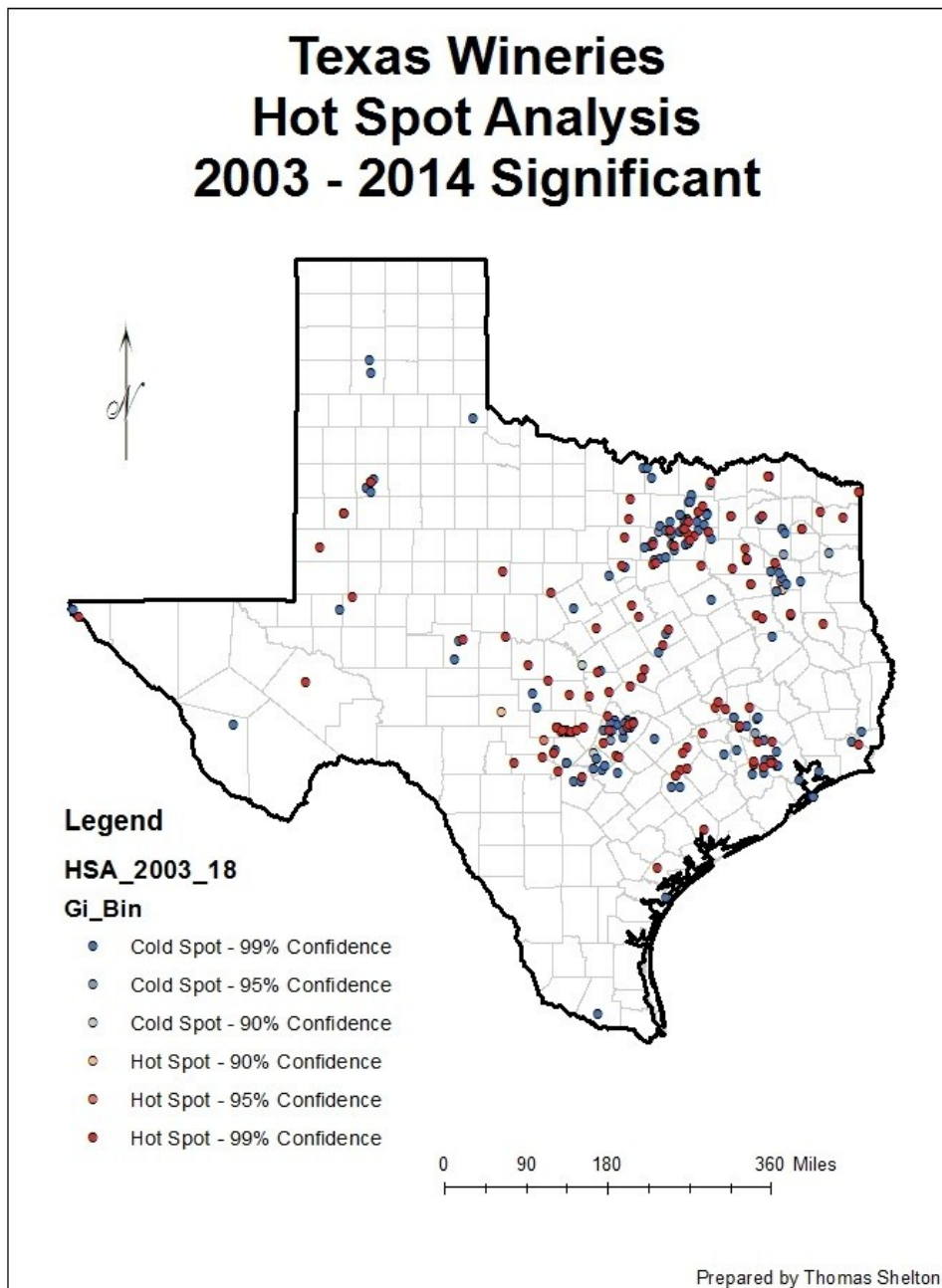
The distribution of all 349 wineries is shown in two ways: With hot and cold spots identified and with the 77 wineries identified as not having statistically significant relationship to the clusters (Figure 41) and then again showing only those associated with hot spots and cold spots (Figure 42). In the second (Figure 42), the wineries are much more tightly clustered spatially than in the original analysis. The grouping of 272 statistically significant features (wineries) is larger in number than the number of those identified as statistically significant in the larger original data set (only 216).

The hot spots identified in this analysis appear to have a random distribution when compared to the locations of all of the wineries in Texas (Figure 43). One hundred and twenty wineries (compared to 115) were identified as significantly related, statistically, to spatial and temporal hot spots. While the spatial distribution seems random on the map, closer inspection reveals that almost all (112) of the winery locations are related at the 99-percent confidence level. Five wineries are identified as related at the 95-percent confidence level, and the remaining three are statistically related at the 90 - percent confidence level.

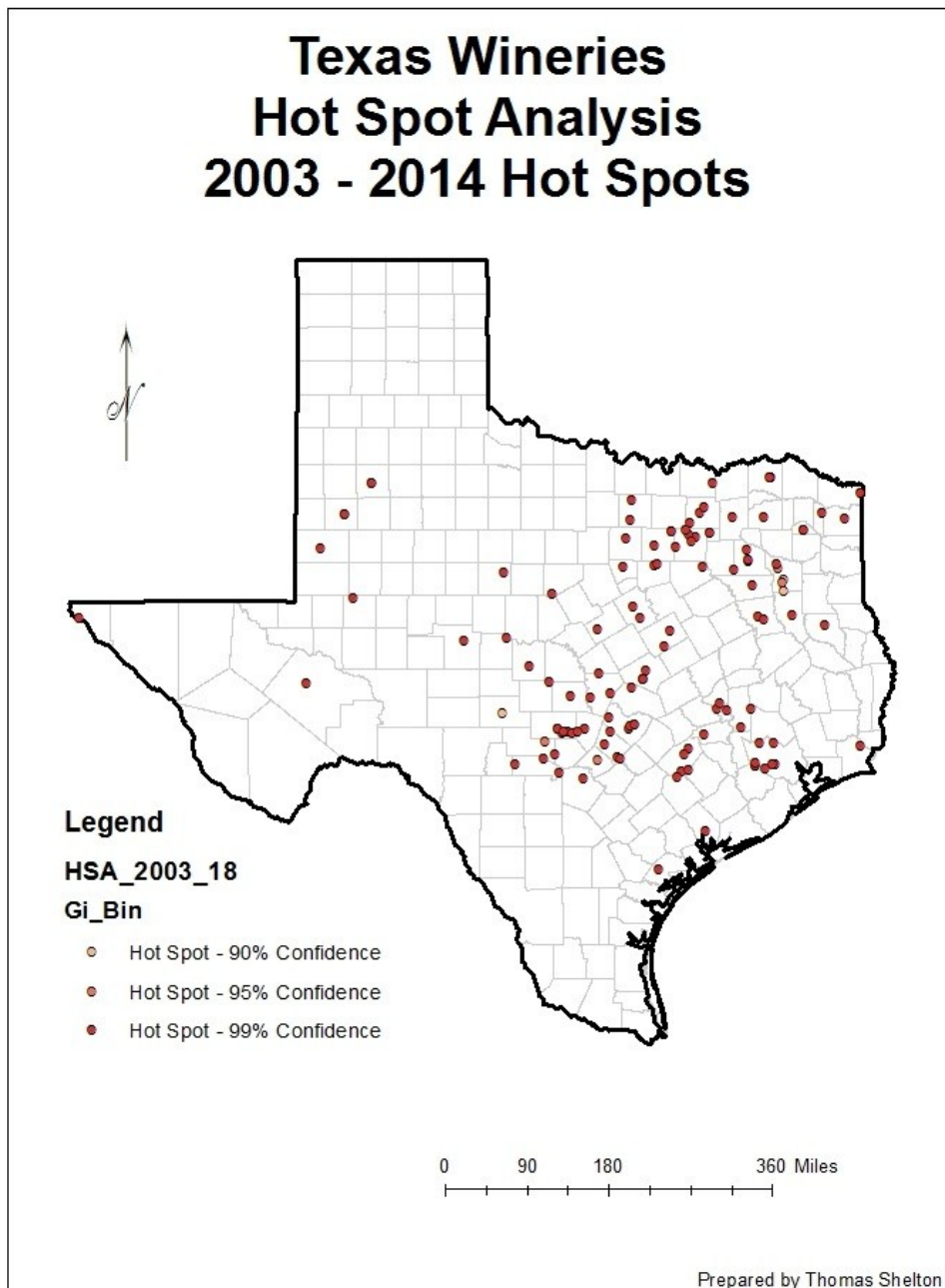
Similarly, cold spots are also analyzed (Figure 44). The cold spot wineries seem to be group together more tightly. This group of 152 wineries identified as cold spot wineries is larger than the 101 previously identified as cold spots using the entire data set. The confidence levels also reflect the increased strength shown with the second-round hot spot analysis: 137 features are related at the 99-percent confidence level, 11 at the 95-percent confidence level, and 4 at the 90-percent confidence level.



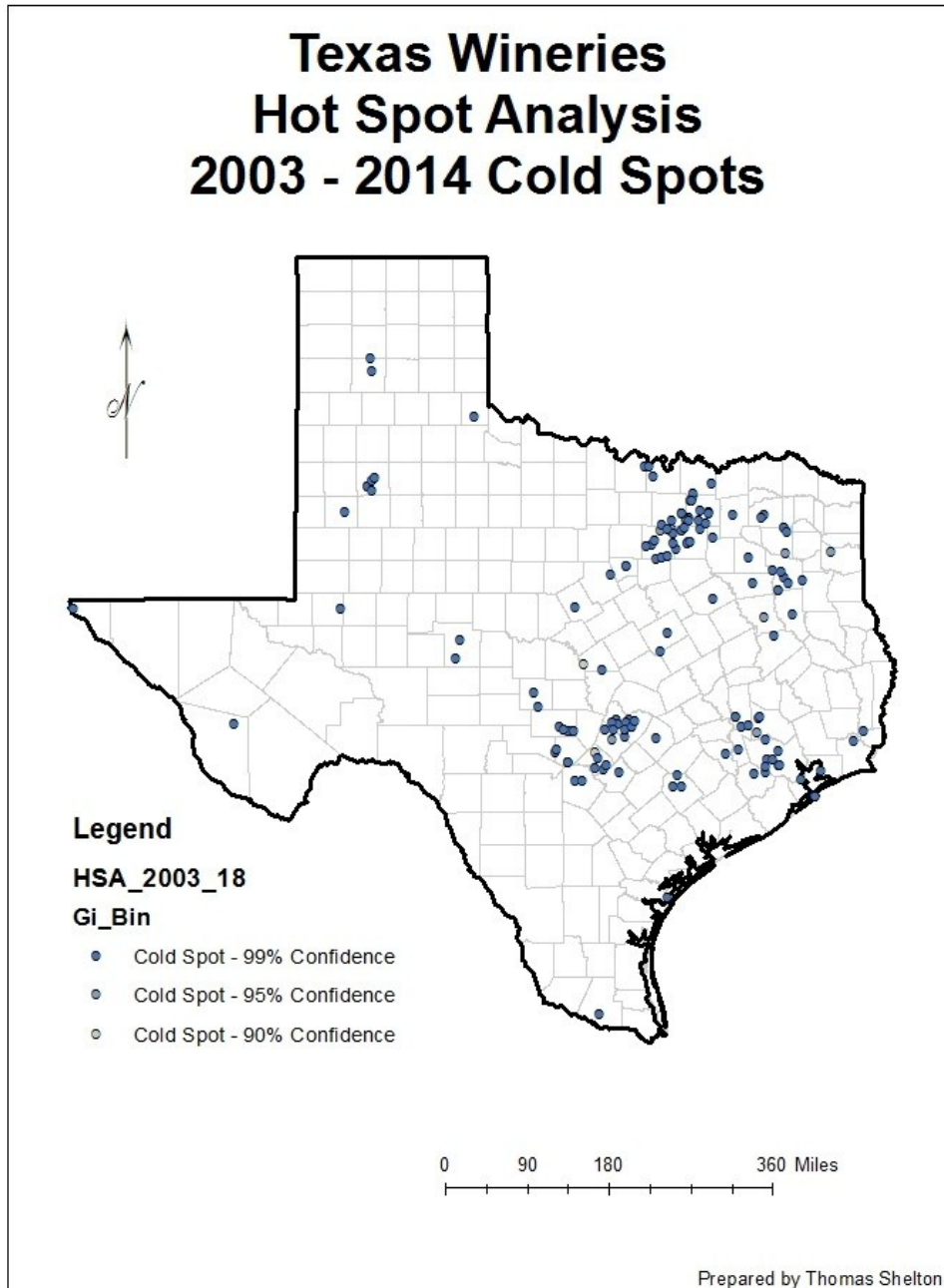
**Figure 41. Hot Spot Analysis 2003 – 2014.** This map shows the complete results of using the Hot Spot Analysis tool using the new SWM file generated using the tighter parameters possible with shorter time period.



**Figure 42. Hot Spot Analysis 2003 – 2014 Significant.** This is the same map showing only the features identified as being statistically significant.



**Figure 43. Hot Spot Analysis 2003 – 2014 Hot Spots.** The spatial distribution of the hot spots is still scattered throughout the state, however the overall majority of the points are identified as having a 99% confidence level.



**Figure 44. Hot Spot Analysis 2003 – 2014 Cold Spots.** The cold spots show a little more spatial clustering than the hot spots and also show an overwhelming majority identified as having a 99% confidence level.

## **VII. DISCUSSION**

The purpose of this thesis is to assess the growth and development patterns of Texas wineries from a historical and geographical perspective and to determine whether spatial-temporal cluster analysis can reveal emerging agglomerations of wine production in Texas. Applying ArcGIS's pattern-analysis techniques confirms the presence of statistically significant spatial patterns among Texas wineries.

The histograms shown in Figures 5 and 6 illustrate the explosive growth in the number of licensed wineries during the last decade. The snapshot maps (Figures 7-11) also convey that growth, but by adding the spatial dimension to a temporal analysis. The standard-deviation-based ellipse maps (Figures 12-17) show that growth in winery establishment over the last three decades has adhered to the geometrical shape (center point and ellipse shapes) of the growth of the previous decades. The Incremental Spatial Autocorrelation Graph (Figure 18) reveals that distance values are statistically significant, and enables spatial statistics to be calculated with strong confidence.

The Grouping Analysis maps (Figures 19-23) reveal several groupings of wineries in time and space. The map created without the time dimension divided the wineries in to two groups: one centered in northern Texas and the other including all of the remaining wineries to the west and south of the first group. Adding a temporal dimension to the analysis made a fundamental difference. The grouping of wineries relies more heavily on the temporal nature of establishment than in the spatial distribution of wineries: one group included those wineries licensed prior to 2003 and the other was comprised of those wineries licensed afterward. The grouping of pre-2003 wineries remained static, even when increasing the number of groups. Increasing the groupings (from 2 to 3 to 4 and 5), simply distinguished wineries by regions, dividing them into groups in northern



Texas, west Texas and the Texas Panhandle, the central Texas region, and the southeastern gulf coastal region.

The Cluster and Outlier Analysis maps and Hot Spot Analysis both identified numerous statistically significant features. Both tools showed similar spatial groupings when they were run without the temporal component. Concentrations of similar points were located in two distinct areas, central Texas and northern Texas. Factoring time into the calculations affected both tools similarly. Many statistically significant features were still identified; however, they were no longer concentrated spatially. The new groupings exhibited considerable overlap. The Hot Spot Analysis suggests that the addition of time to the calculations has the consequence of grouping statistically significant features along temporal, not spatial, aspects.

Finally, limiting the Hot Spot Analysis to the time period after the 2003 change in winery laws created even stronger results. The groupings still overlapped with each other, but the confidence level became stronger with more than 90 percent of the points possessing z-scores above  $\pm 2.58$ . The overwhelming majority of statistically significant features (and the majority of all features) reflects a 99-percent confidence level.

Analysis of the statistically significant clustering of the wineries in Texas does give insight into the growth that is occurring. Strict spatial analysis confirms that the Dallas/Fort Worth and central Texas' Hill Country areas are experiencing the most growth. Moreover, space/time analysis clearly demonstrates that the growth is not only centering in those two areas, but is spreading to all areas throughout the state.

The successful use of spatial-temporal cluster analysis techniques to identify emerging patterns of agglomeration of wine production as described in the results (pages

32-84, along with a detailed description of the historical background of the industry described in the introduction (pages 1-14), establish a baseline that will be useful to examine the factors driving growth and development patterns of Texas wineries from a geographical perspective. Having addressed the question of if and where agglomerations of wineries are emerging in Texas, the next would be: Why and how are agglomerations of wineries emerging in the state of Texas? Identifying clustering locations across time and space provides a foundation for researching why such clustering is occurring in particular places.

## **VIII. FUTURE RESEARCH**

While conducting this research I have identified additional questions to address and more issues to be considered. For example, Texas estate wineries (those which use grapes from one estate to produce certain vintages) and those that only use Texas grapes in their production warrant further study. The location of vineyards in relation to the locations of the wineries that use them is another aspect of the Texas wine industry that is ripe for study.

The purpose of this paper was to examine factors of growth and the development patterns of Texas wineries from a geographical perspective in order to determine if spatial-temporal cluster analysis could identify whether there are emerging agglomerations of wine production in Texas. The spatial-temporal analysis presented here did identify emerging agglomerations of wine production in Texas. This research is useful in establishing a baseline understanding of the rapidly growing wine industry in Texas, and there are many areas of research that can be expanded upon.

As with most research there are more questions to be asked and more aspects to be considered. The most obvious question for further research is why emerging agglomerations are developing in their locations. The answer to the questions presented in this section are vital to gaining an overall understanding of the Texas wine industry. Three areas of research that will build on this study need to be addressed. The first is further evaluating the current data set, the second is applying different techniques to process that information, and the third, and most crucial, is to integrate different aspects of the Texas wine industry (e.g., vineyard and wineries).

Other elements to consider include that this study treats all winery licenses as equal. Further analysis of this data set reveals that they are not all the same. This study is based on winery licenses issued and does not take into account whether wine was actually produced. Some of wineries have multiple licenses that they use for wine tasting rooms located away from their primary location. Sorting the list of wineries to remove these locations will further refine the analysis. Another factor in this data set that warrants investigation are the licenses that have expired, been canceled, or were voluntarily cancelled or suspended. These wineries need to be evaluated to identify patterns and commonalities.

ArcGIS's spatial-temporal analysis tools are well documented as being useful for investigating such things as malaria rates in Ghana, or the rates of petty theft on Gallifrey, and this paper shows that these techniques can be useful in identifying agglomeration of Texas wineries. Other ArcGIS techniques can be used with this data set to broaden the understanding of the Texas wine industry to be able to answer the question of why the agglomerations are where they are located. These tools can be used to incorporate additional data into the study.

Integrating population data would be advantageous in perceiving the effect that urban centers have on the growth of the number of wineries and their locations. Tourism, and the implications of the changing consumer and changing taste, undoubtedly influences winery locations and should also be integrated into the picture. Certainly the inclusion of vineyard data has to be included for a complete understanding of the Texas wine industry.

Integrating vineyard data would be useful in separating those wineries that are just processing plants from the wineries that are either estate wineries or are committed to only using Texas grapes in the production of their wines. Understanding this last point is essential to understanding the Texas wine industry and should be kept in mind for any future research.

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