UPDATED ANALYSIS OF CLIMATE-VITICULTURE STRUCTURE AND SUITABILITY IN THE WESTERN UNITED STATES

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ABSTRACT

While tremendous advances have occurred in spatial climate data products, no large-scale update to our understanding of climate-viticulture structure and suitability for the western US has be done in the last three decades. The goals of this research are to better document the climate structure in wine producing regions throughout California, Oregon, Washington, and Idaho making comparisons between regions in the US and elsewhere in the world more realistic. The research utilizes the 1971-2000 PRISM 400m climate grids to assess four climate parameters commonly used to characterize climate suitability for viticulture and wine production: the Winkler Index (degree-days), the Huglin Index, the biologically effective degree-day index, and average growing season temperatures. The data are assessed and depicted as spatial averages of the climate parameters over 132 American Viticultural Areas in the western US. The method takes into account the entire region (not individual stations) and the relative relief of the growing regions to provide a much better representation of the spatial climate suitability in each region. The research also provides the first comprehensive comparison of the Huglin Index in the US and develops a greater latitudinal adjustment factor for calculating the index that can be applied elsewhere. The methods developed in this work are also being applied to other wine regions throughout the world (Europe, Australia, New Zealand, South Africa, and South America) with the goal of producing a world-wide set of similar data from which appropriate climate comparisons can be made.

INTRODUCTION

Historically climate-viticulture structure and suitability has been assessed via climate station analysis, which seldom depicts the spatial variation of climate found within wine producing regions. Data interpolation of existing data sources has been generally used to overcome this problem and different techniques have been proposed to obtain surfaces of valuable meteorological inputs at different spatial and temporal scales. Some examples are represented by statistical methods such as Kriging and its variants and smoothing splines (e.g. in ANUSPLIN package, Hutchinson, 2004), which, given certain assumptions, generate explicit optimal criteria and guarantees of unbiased predictions. Other simpler approaches, which lack such optimization criteria and validation, including nearest neighbour, inverse distance weighting schemes and arithmetic means, have been applied for climatology data interpolation. Is some cases, elements from these simple methods have been integrated resulting in daily (Thornton et al. 1997; DAYMET package) or monthly surfaces (Willmott and Robeson, 1995) of the main meteorological variables that have been spatially validated.

However, while tremendous advances have occurred in spatial climate data products, no large-scale update to our understanding of climate-viticulture structure and suitability for the western United States wine regions has been done over the last 30 years. While numerous climate parameters have been used for assessing viticultural region climate structure and suitability (see Gladstones, 1992; Fregoni, 2003; Tonietto and Carbonneau, 2004; Jones, 2006; and Ward et al, 2007 for good reviews), this research focuses on developing regional climate assessments for four commonly used indices: the Huglin Index (HI) (Huglin, 1978), the Winkler Index (WI)(Amerine and Winkler, 1944; Winkler, et al. 1974), the biologically effective degree-day index (BEDD) (Gladstones, 1992), and average growing season temperatures (GSTavg) (Jones, 2006). Overall, the goals of this research are to better document the spatial climate structure in wine producing regions in the western United States, making comparisons between these regions and others more appropriate than simple and often problematic climate station comparisons.

MATERIALS AND METHODS

To depict wine region climate characteristics, this research utilizes a climate data set called PRISM (Parameter-elevation Relationships on Independent Slopes Model) that is the official spatial climate data set of the US Department of Agriculture (Daly et al. 2008). The 1971-2000 mean monthly minimum and maximum temperature data are created as 15 arc-second (~400 m) grids through an interpolation method that reflects the current state of knowledge of spatial climate patterns in the United States. In general, PRISM calculates a climate-elevation regression for each digital elevation model (DEM) grid cell, and stations entering the regression are assigned weights based primarily on the physiographic similarity of the station to the grid cell. PRISM takes into account the location, elevation, coastal proximity, topographic facet orientation, vertical atmospheric layer, topographic position, and orographic effectiveness of the terrain. Furthermore, PRISM has been validated using remote vineyard locations (Jones, unpublished data) and used successfully in applied viticulture studies (Jones et al. 2004) and other spatial assessment applications (Nolin and Daly, 2006).

The PRISM maximum and minimum temperature grids were processed into the four climate parameters shown in Table 1. The four climate measures used in this analysis were chosen based on their applicability in understanding general wine region structure and suitability, their widespread use in different regions, and their lack of in depth comparison in the western US. Of note in the formulation of the variables is that the HI and the BEDD utilize adjustments to the base values. Both the HI and the BEDD use a latitude adjustment to account for increasing day lengths at higher latitudes. Huglin (1978) originally proposed this adjustment for latitudes from 40 to 50°N as these zones applied well to existing wine regions in Europe. However, many other wine regions in the western US, Australia, etc have existing regions outside these latitudes. To account for the complete range of day length effects over the western US this research applies a latitude adjustment for the months of the growing season (April-September) that starts at 34°, where the day length effect ceases to exist and increases to 1.08 at the northern border of Washington. This development is the same as Huglin (1978) first applied over a more limited range of latitudes and more exact than originally applied by Gladstones (1992). Also note that the BEDD index has a further adjustment to account for differences in the diurnal temperature range of each grid (see Gladstones, 1992 for further details).

In order to summarize the climate structure for wine regions in the western US this research uses American Viticultural Area (AVA) boundaries created from the federally approved descriptions (Code of Federal Regulations, 2008). The AVA boundaries were digitized from these descriptions and resulted in a total of 132 individual AVAs in California (109), Oregon (16, three shared with Washington and one with Idaho), Washington (9, three shared with Oregon), and Idaho (1, shared with Oregon) (Figure 1). Of the 132 boundaries, 130 were approved as of the beginning of 2008 and two were under review, but were included in the analysis (Calistoga and Tulocay AVAs in California).

The four climate grids were then processed for their spatial structure within each AVA producing quantile statistics for each AVA (minimum, 25%, median, 75%, and maximum values). These limits are important because many of the AVAs encompass elevations that are too high and cold for viticulture and are likely never to be planted (e.g., the Columbia Valley AVA and many others). For some regions the median may well represent the average value of each climate parameter for each AVA, however for many regions the range from the median to the maximum, or 75% to the maximum may well be more indicative of the actual suitable areas. The overall structure and comparison of this process will be shown at the whole region level, but due to space limitations will only be detailed for a few regions in this paper. See Jones et al (2009) for more detail and results.

RESULTS AND DISCUSSION

The spatial depiction of the four climate parameters over the western US are shown in Figure 2A-D. Each parameter describes the generally intuitive spatial structure with warm to hot conditions for viticulture in south-central and southeastern California to cool and cold conditions north into Washington and cooler conditions with increasing elevation throughout the region. The spatial structure of GSTavg (Figure 2A) reveals the prominent cool to intermediate climate types throughout much of the intermountain valleys from the Puget Sound south through Oregon, in the Snake River Valley of Idaho and Oregon, and along the narrow coastal zones of California. Warmer climate types are seen throughout a broad area of the Columbia Valley of Washington and Oregon, throughout the inter-coastal valleys and Sierra Nevada foothills of California and into the middle portion of the central valley of California. The hottest climate types suitable for viticulture are found in the northern and southern sections of the central valley of California.

Similar patterns are seen for growing degree-days or Winkler regions (Figure 2B) where Region I is mostly confined to western Oregon, the coastal zone of California, higher up in the Sierra Nevada foothills, and along valley extensions in parts of Washington and Oregon. Region II is found broadly throughout the Columbia Valley of Washington and Oregon, in the Rogue Valley of Oregon, in the Snake River Valley of Idaho, and along a band of the inter-coastal valleys and foothills of California. Region III is limited to a small area outside California, with only a few areas of the Columbia Valley of Washington falling into this class (Figure 2B). In California, Region III locations are found slightly more inland than those of Region II and in regions of lower elevation along the Sierra Nevada foothills. Region IV is limited to California only, with prominent areas on the eastern fringes of the coastal mountains, the western fringes of the central valley, and through the central valley east of San Francisco up into the Sierra Nevada foothills. Region V encompasses broad areas of the north valley and central valley of California.

While Winkler et al (1974) did not put an upper limit on simple degree-days; this research applies a Region VI upper limit that includes a small portion of the north valley and broad areas of the south-central valley of California.

The other two indices (HI and BEDD) produce broadly similar patterns of suitability across the western US (Figures 2C and 2D). However, due to the application of a latitude adjustment for day length influences, both the HI and BEDD suggest zones of greater viticultural suitability over much of Oregon, Washington and Idaho. For the Huglin Index much of the Pacific Northwest falls into 'Very Cool' and 'Cool,' classes that match the more northern areas of Europe where the index was first applied (e.g., parts of Germany, Champagne, Chablis, Burgundy, etc.) than does the WI. Furthermore, much of the central valley of California is depicted in the HI as being 'Too Hot' whereas the WI shows it being at the upper limit of suitability. The BEDD depicts a spatial pattern intermediate to the WI and HI, whereby more of the known cool to warm climate regions in the Pacific Northwest standout but where suitable zones at the warmer limits are still maintained in California. In addition, the HI and BEDD tend to more strongly differentiate the within region variation in climate suitability than does the GSTavg or WI. Overall the four indices are highly spatially correlated over the region ($0.70 < r < 0.99$), however correlations can be low for small regions dispersed over large areas.

Comparing the climate parameters over a few regions yields insights into the spatial structure of climate suitability within those regions. Table 2 shows the spatial statistics for the four climate parameters for seven geographically dispersed regions. Note that the range between the minimum and maximum values represents the entire climate structure within each region, not necessarily those areas that might be planted. However, it is highly likely that the 75% quantile represents a regions' suitable mean and that the range between the median and maximum values the range of suitable climates. The results show, for example, that the Napa Valley AVA is largely a warm to hot climate type in terms of GSTavg, a Region III to just over the Region V limit for WI, a warm to very warm climate type on the HI, and in the highest maturity climate zone on the BEDD (Table 2). At the other end of the spectrum, the Dundee Hills AVA, a sub-AVA of the Willamette Valley, is GSTavg cool climate, a low to slightly below WI Region I, a cool to slightly temperate HI, and in the first and second maturity climate zone of the BEDD. As an example of the elevation range and climate index limitation, for the Rogue Valley AVA, where the elevation range is 1750 m, much of the higher elevations are indicated by the minimum to 25% quantile where those zones would be unsuitable on all indices. However, examining the 75% quantile and maximum value finds the Rogue Valley AVA an intermediate to low warm climate type on the GSTavg, a Region II to low Region III on the WI, warm-temperature on the HI, and in the third and fourth maturity classes on the BEDD (Table 2). For a region such as the Lodi AVA where the elevation range is 150 m, the entire quantile structure from the minimum to the maximum values better represent the region's climate structure. See Jones et al (2009) for more details and results.

CONCLUSIONS

Since Amerine and Winkler (1944) and Winkler et al (1974) formulated suitable climates zones for viticulture in California over 30 years ago, little has been done to update this information. This research is the first to update and depict the climate structure for viticulture over the western US using recently available higher resolution and spatially validated climate grids. In addition, the research provides for the first time a comparison of four commonly used climate parameters that have historically been used in various regions around the world (Winkler et al, 1974; Huglin, 1978; Gladstones, 1992; and Jones, 2006). Furthermore, the research describes the spatial framework of the climate parameters over the AVAs instead of the common method of station to station comparison that is wrought with problems associated with the potential temporal and spatial appropriateness of the data that comes from individual stations. The results show that each of the climate parameters depicts the broad structure across a range of cool to hot climates suitable for viticulture across the western US. Overall, the HI and BEDD provide a more region-wide depiction of known climate suitability owing to the use of a latitude adjustment for increasing day lengths poleward. Furthermore, the HI and BEDD appear to better differentiate the within region climate structure, with the BEDD showing the greatest promise due its tie to variety maturity groupings (Gladstones, 1992).

Similar work to this analysis is being conducted by this research team and others with the hope that a better spatial understanding and comparison of viticultural climates worldwide can be realized. However, it is important that as greater spatial resolution of the climate grids and new time periods (i.e., 1981-2010 climate normals) of data become available that this work be updated so that climate suitability, variability and change can be monitored in a more appropriate and timely manner.

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Table 1: Climate variables derived for the western United States using the PRISM data.

Variable/Source	Equation	Months	Class Limits
Average Growing Season Temperature (GSTavg) Jones (2006)	Σ ((Tmax+Tmin)/2)	April - October	Too cool = < 13°C Cool = 13-15°C Intermediate = 15-17°C Warm = 17-19°C Hot = 19-21°C Very Hot = 21-24°C Too Hot= >24°C
Growing Degree-Days (GDD)* Winkler et al (1974)	Σ ((Tmax+Tmin)/2)-10°C)	April - October	Too Cool = <1111 (Region I) 1111-1389 (Region II) 1389-1667 (Region III) 1667-1944 (Region IV) 1944-2222 (Region V) 2222-2500 (Region VI) 2500-2778 Too Hot >2778
Biologically Effective Degree-Days (BEDD) Gladstones (1992)	Σ ((Tmax+Tmin)/2)-10°C)*k*DTR where (Tmax+Tmin)/2 has a 19°C upper limit and is adjusted for both latitude/day length and diurnal temperature range (DTR)	April - October	Too Cool = <1000 1000-1200 1200-1400 1400-1600 1600-1800 1800-2000 2000-2200 Too Hot = >2200
Huglin Index (HI) Huglin (1978)	Σ ((Tavg-10°C)+(Tmax-10°C)/2)*k adjusted for both latitude/daylength	April - September	Too Cold = <1200 Very Cool = 1200-1500 Cool = 1500-1800 Temperate = 1800-2100 Warm Temperate = 2100-2400 Warm = 2400-2700 Very Warm = 2700-3000 Too Hot = >3000

Note that the GDD classes are based upon rounded °F limits for Winkler Regions (in parentheses), which produce non-rounded classes (for the °F table see the supplementary material)
**k = is a latitude coefficient that takes into account increasing day lengths from 34° to 65°, starting with 1.0 at 34° and is based upon day lengths using Julian day and latitude as inputs.

Table 2: Spatial statistics for the four climate parameters for a subset of the western United States American Viticultural Areas (AVAs).

AVA Name	GSTavg (°C)					GDD				
	Min	25%	Median	75%	Max	Min	25%	Median	75%	Max
Dundee Hills	14.3	14.7	15.0	15.2	15.4	940	1022	1081	1115	1154
Lodi	20.0	20.2	20.3	20.4	20.7	2133	2175	2211	2225	2290
Napa Valley	15.1	18.2	18.8	19.2	20.4	1131	1753	1883	1970	2235
Paso Robles	16.4	18.3	18.9	19.2	20.2	1361	1779	1903	1978	2177
Rogue Valley	10.5	14.9	15.7	16.2	17.0	486	1101	1225	1326	1509
Russian River Valley	16.3	17.0	17.1	17.2	18.4	1347	1492	1520	1539	1796
Walla Walla Valley WA	13.7	16.7	17.1	17.3	17.5	894	1444	1528	1564	1617

AVA Name	HI					BEDD				
	Min	25%	Median	75%	Max	Min	25%	Median	75%	Max
Dundee Hills	1532	1640	1725	1764	1822	1009	1115	1176	1213	1255
Lodi	2743	2781	2797	2828	2906	1904	1958	1980	2001	2022
Napa Valley	1668	2317	2504	2601	2884	1210	1743	1850	1923	2060
Paso Robles	2048	2585	2681	2736	2900	1619	1982	2032	2059	2158
Rogue Valley	853	1794	2011	2168	2391	440	1231	1386	1522	1715
Russian River Valley	1901	2107	2152	2167	2473	1505	1703	1747	1756	1951
Walla Walla Valley WA	1640	2202	2296	2331	2393	1063	1408	1480	1510	1556

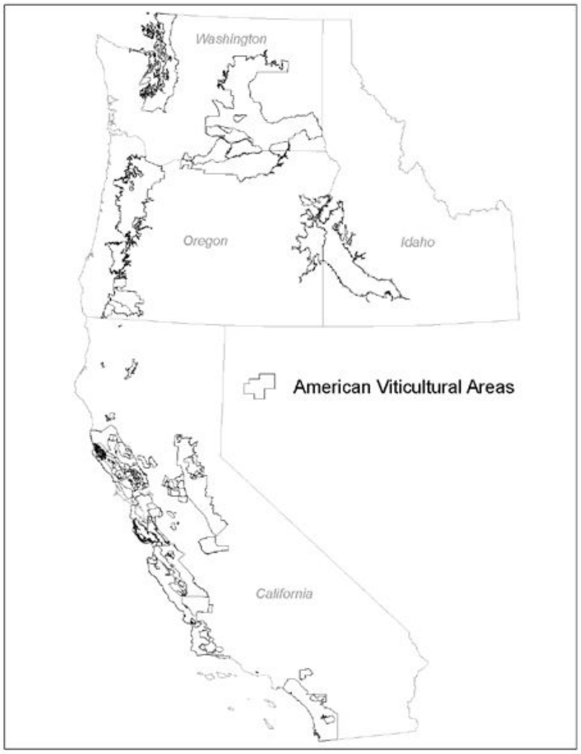

Figure 1: Map of the American Viticultural Area Boundaries used in the analysis.

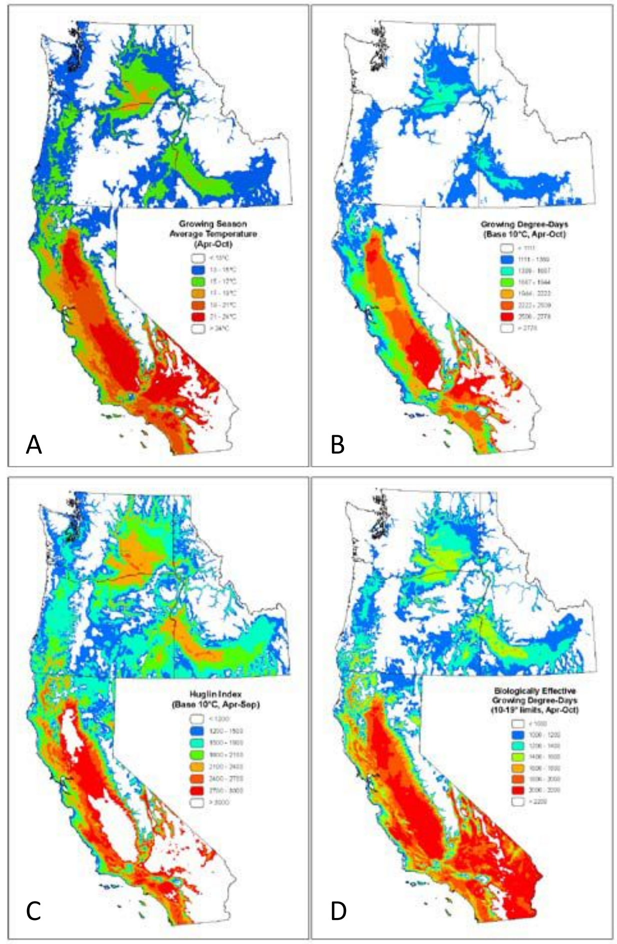

Figure 2: Maps of the four climate parameters over the western US; A) growing season average temperature (GSTavg), B) simple growing degree-days or Winkler Regions (WI), C) the Huglin Index (HI), and D) the biologically effective degree-day index.