ANALYSIS OF THE SPATIAL CLIMATE STRUCTURE IN VITICULTURE REGIONS WORLDWIDE

G. Jones[1], M. Moriondo[2], B. Bois[3], A. Hall[4] A. Duff[5]

[1]Southern Oregon University
Ashland, Oregon USA
gjones@sou.edu
[2]University of Florence
Florence, Italy
marco.moriondo@unifi.it
[3]University of Burgundy
Dijon, France
benjamin.bois@u-bourgogne.fr
[3] National Wine and Grape Industry Centre
Charles Sturt University
WaggaWagga, NSW 2678 Australia
ahall@csu.edu.au
[5] Washington Department of Fish and Wildlife
Olympia, Washington USA
duffaad@dfw.wa.gov

ABSTRACT

This research utilizes a gridded climate data set (WorldClim) at 1 km resolution to examine the spatial structure of six commonly used climate-viticulture suitability indices in winegrowing regions. This paper focuses on a subset of 16 European regions to determine the usefulness of the approach and compares the results to other western United States and Australian regions. Future work will further develop and summarize the climate grids for winegrowing regions worldwide making available globally comparable climate information.

RIASSUNTO

Questo lavoro utilizza un database meteorologico spaziale (WorldClim) con 1 km di risoluzione, per analizzare la struttura spaziale di sei indici comunemente utilizzati per valutare la vocazione di un territorio per la viticultura. In particolare, questo articolo ha come obbiettivo di valutare l´utilità dell´approccio proposto su un campione di 16 regioni viticole europee e di paragonare i risultati con quelli ottenuti per regioni viticole presenti negli Stati Uniti occidentali ed Australia. Il lavoro verrà sviluppato ed esteso per comprendere l’analisi della climatologia delle regioni viticole a scala globale, rendendo disponibili informazioni, a livello mondiale, paragonabili fra loro.

1 INTRODUCTION

Historically, climate-viticulture structure and suitability has been assessed via climate station analysis, which seldom depicts the spatial variation of climate found within winegrowing 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 or 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 to distance weighing schemes and arithmetic means, have been applied for climatology data interpolation. Is some cases, elements from these simple methods were integrated resulting in good performances to produce daily (Thornton et al. 1997; DAYMET package) or monthly surfaces (Willmott and Robeson, 1995; climatologically aided interpolation, CAI) of the most important meteorological variables.

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 world's wine regions has been done. 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 global climate assessments for six commonly used indices: the Huglin Index (HI) (Huglin, 1978), the cold night index (CI), and the dryness index (DI) as used in the Geoviticulture Multicriteria Climatic Classification System (MCC) (Tonietto and Carbonneau, 2004), along with the Winkler Index (WI)(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 winegrowing regions globally, making comparisons between these regions more appropriate than simple climate station comparisons. As such, global comparisons for the climate parameters are made and examples of the spatial climate structure in specific regions are detailed.

2 MATERIAL AND METHODS

To assess the spatial structure of climate in wine regions, this research utilizes the 1950-2000 WorldClim 1km climate grids (Hijmans et al. 2005). The WorldClim data were derived from numerous sources (e.g., GHCN, WMO, FAOCLIM, etc.) and stations were interpolated using the ANUSPLIN package using latitude, longitude, and elevation as independent variables. The gridded data set provides monthly maximum temperatures, minimum temperatures and precipitation, representing the highest resolution available at the global scale for spatial climate analyses. The monthly climate data was processed for each 1km grid point to produce the HI, CI, DI, WI, BEDD and GSTavg indices over the months specified for each index and for the entire globe. Also note that the HI and BEDD contain latitude adjustments for increasing day lengths at higher latitudes and this work is the first to apply the adjustment to gridded data to all potential areas outside of the 40-50° latitudes applied by Huglin (1978) for Europe.

To represent wine regions we collected a suite of boundaries in Europe, the western United States, and Australia from which the spatial pattern of climate can be assessed. Wine regions in the western United States and Australia come from governmentally defined boundaries for American Viticultural Areas (AVAs) and Geographical Indications (GIs), respectively. For Europe, wine regions were derived from the Corine Land Cover 2000 database (CLC), to identify only those regions under winegrape cultivation.

While the overall aim of this work is to categorize wine region climates at the global scale, this paper focuses on a spatial analysis five major European grape growing countries (Germany, France, Italy, Spain and Portugal), makes a comparison to a few locations in the western United States and Australia, and discusses the global scale results and future work. From the five European countries a total of 16 wine regions were chosen for the focused analysis so as to represent a range of latitudes, climates, and wine production styles. For each grid point included in a wine region, the spatial structure and variability of the HI, CI, DI, WI, BEDD and GSTavg indices were assessed using a probabilistic approach. Due to the large amount of data to consider, data distributions from each area were conveniently examined graphically by means of box plots. These devices graphically depict groups of numerical data through their quantile summaries; minimum, lower quartile, median, upper quartile, and maximum and are combined to depict the general index structure and possible outliers.

3 RESULTS AND DISCUSSION

The processing of the WorldClim 1km climate monthly temperature grids produced six climate indices mapped for the entire globe (see Figure 1 for an example, others not shown due to space limitations). Overall the production of the climate indices at the global scale provides a sensible spatial depiction of climates suitable for viticulture. Preliminary examinations at the global scale show that the HI, BEDD, and GSTavg tend to better represent known wine regions, while the WI leaves out many existing higher latitude locations. This is due to the WI not including an adjustment for increasing day lengths at higher latitudes. Also note that the CI classification as suggested by Tonietto and Carbonneau (2004) produces extremely broad regions with similar class values, which do not help differentiate regions in terms of ripening, and needs to be re-examined.

3.1 Terrain and climate characteristics of European winegrowing regions

A focused spatial analysis was performed for five major European countries (Germany, France, Italy, Spain and Portugal), for which terrain and climate grids were restricted to areas actually planted in grapevines as defined by the CORINE Land Cover database 2000. This considerably reduced the extent of winegrowing regions, as the winegrowing appellations, either provided by wine atlas demarcation or administrative structure of countries, cover areas substantially larger than the actual planted vineyard areas (Figure 2). Spatial characteristics of the winegrowing region areas, topography, and climate indices are shown in Tables 1 and 2.

Table 1: Average values of elevation and slope of the vineyards of 16 European winegrowing regions. For the aspect, the more frequent class of the distribution is indicated.

Country	Region	Area (km²)	Elevation (m)	Aspect (°)	Slope (%)
Germany	**Baden**	189	245	270	6.2
	Mosel	198	179	200	9.5
	Rheinhessen	327	170	270	4.5
France	**Bordeaux**	1471	50	270	1.5
	Bourgogne	260	264	140	5.4
	Champagne	381	170	200	5.9
	Côtes du Rhône Méridionales	1440	174	180	3.6
Italy	**Barolo**	56	314	270	6.2
	Chianti Classico	101	321	250	5.9
	Valtellina Superiore	5	476	180	36.7
	Vino Nobile di Montepulciano	28	307	300	2.6
Spain	**Jerez-Xéres-Sherry**	126	57	300	2.3
	La Mancha	2864	689	200	0.7
	Rioja	605	506	200	3.7
Portugal	**Porto**	807	437	150	9.8
	Vinho Verde	61	190	250	6.5
	Minimum	5	50	140	0.7
	Maximum	2864	689	300	36.7
	Range	2858	639	160	36.0

The subset of analyzed winegrowing regions exhibits a large diversity of terrain and climate characteristics. For the 16 regions, La Mancha is the largest with 2864 km^2 while Valtellina Superiore is the smallest at 5 km^2 (Table 1). Elevations are variable amongst the different wine regions, ranging from 50 m asl (Bordeaux) to 689 m asl (La Mancha), whereas the variability for both slope and aspect are much less evident.

On average, the most frequent aspects in the wine regions range from SSE in Bourgogne (140°) to WNW in Montepulciano and Jerez-Xéres (300°). There is a slight negative relationship between the wine region average elevation and the relevant aspect, where growing regions at lower elevations are mainly exposed to SW aspects while those at higher elevations are more dominantly oriented to the South.

Slopes ranged from 0.7% to 36.7% but the latter should be considered an outlier since the rest of the data is included between 0.7% and 9.8%. In general, not considering the outlier, there is a positive relationship between elevation and slope up to ~450 m asl whereas, after this break point, the relationship between elevation and slope is negative, implying that above this threshold, in the examined areas, the grapevine growing regions are found on broad plains or plateaus were mechanic management practices are possible.

The subset of European winegrowing regions exhibits a large range of thermal and hydric climate conditions. The GSTavg ranges from 14.0 to 20.9°C, which corresponds to cool to hot conditions, as defined by Jones (2006). The degree-day indices indicate similar information with the WI ranging below Region I in the Mosel, Rheinhessen, and Champagne to Region V in Jerez-Xéres. The fact that the WI does not adequately depict suitability in the more northern, cooler regions is likely due to the fact that the WI does not account for day lengths as in the HI. BEDD values range from the coolest maturity group (e.g., Mosel, etc.) to the warmest maturity group (Jerez-Xéres). Average HI values observed in this region subset correspond to very cool to warm climates in the multicriteria climatic classification (MCC) of winegrowing regions worldwide (Tonietto and Carbonneau, 2004). In terms of cool night index (CI) classification system, this subset of regions are mostly very cool (CI < 12°C) to cool nights (12°C < CI < 14°C) with only Barolo classified as warm nights (14°C < CI < 18°C) and Jerez-Xéres as hot nights (CI > 18°C). The third index of the MCC, the dryness index, shows a wide range over this subset of wine regions, varying from very dry in La Mancha (DI < -100 mm) to humid climates in Valtellina Superiore (DI > 150 mm).

Table 2: Mean values of climate indices of the vineyards of 16 European winegrowing regions. GSTavg: average growing season temperature; BEDD: biologically efficient degree days; WI: Winkler index; HI: Huglin index; CI: cool night index; DI: dryness index. The unit DD stands for degree-days.

Country	Region	GSTAvg (°C)	BEDD (DD)	WI (DD)	HI (DD)	CI (°C)	DI (mm)
Germany	**Baden**	14.9	1117	1056	1602	10.4	149
	Mosel	14.0	966	891	1411	9.7	131
	Rheinhessen	14.1	989	922	1473	9.5	109
France	**Bordeaux**	16.5	1382	1387	1890	12.1	85
	Bourgogne	15.2	1171	1118	1648	11.0	125
	Champagne	14.2	981	923	1492	9.9	106
	Côtes du Rhône Méridionales	17.3	1447	1570	2067	12.9	39
Italy	**Barolo**	17.5	1559	1600	1960	14.6	90
	Chianti Classico	17.9	1507	1685	2112	13.8	32
	Valtellina Superiore	16.2	1304	1335	1880	11.7	175
	Vino Nobile di Montepulciano	17.5	1473	1613	2057	13.2	18
Spain	**Jerez-Xéres-Sherry**	20.9	1921	2343	2441	18.8	-57
	La Mancha	18.9	1445	1912	2417	13.5	-122
	Rioja	16.6	1343	1410	1886	12.3	14
Portugal	**Porto**	17.9	1489	1684	2155	13.1	-45
	Vinho Verde	17.6	1576	1635	1987	13.7	19
	Minimum	14.0	966	891	1411	9.5	-122
	Maximum	20.9	1921	2343	2441	18.8	175
	Range	6.7	955	1420	949	9.0	297

Analyzing the MCC with the average values of the 1950-2000 WorldClim grids over the CLC winegrowing regions might lead to small differences in the classification compared to single station values using 1961-1990 monthly averages (Tonietto and Carbonneau, 2004). For example, Porto is classified as warm climate (HI > 2400 DD) by Tonietto and Carbonneau, when using climate data from the weather station of Peso da Régua, whereas it is considered as temperate warm (2100 DD < HI < 2400 DD) with the average values of climate data of CLC winegrowing regions. Beside the fact that the two datasets were not established for the same periods, the vineyards of Porto, covering 807 km² (i.e. 80700 ha) are subject to considerable spatial variability of climate (Figure 3), especially concerning degree-days indices and GSTavg. This shows the usefulness of the winegrowing region-climate analysis approach in that it captures the spatial structure of climate within regions, instead of single station representation which often has problems associated with the potential temporal and spatial appropriateness of data from individual stations.

The spatial variability of these indices is more homogeneous however in some large regions with relatively low topographic relief, such as Bordeaux and La Mancha, whereas substantial variations are found in smaller regions such as Valtellina Superiore. The latter, located in a mountainous region with high topographic relief, results in greater variation of temperatures over the winegrowing area, whereas the relatively flat terrain in Bordeaux and La Mancha, contributes to low temperature variations. However, even though the WorldClim grid was established by interpolations of weather station measurements guided by elevation, they might not, for all regions, capture the temperature and rainfall variations induced by other topographic factors, such as inversions, water bodies, and urban effects, as observed, for example in the Bordeaux winegrowing region (Bois, 2007).

The distributions of climate indices reveal some similarities between different winegrowing regions. For example, Champagne and Rheinhessen have similar heliothermic and hydric characteristics. Both regions have very cool to cool and sub-humid climate conditions during the grape growing season with very cool temperatures during the maturation period. The winegrowing regions of Chianti Classico and the Southern Côtes du Rhône (Côtes du Rhône méridionnales) also exhibit numerous climatic similarities. Both regions, within which a large spatial variability is observed, have warm and moderately dry climate conditions, although September minimum temperature (i.e., cool night index) is slightly higher in Chianti. This is consistent with the recent and successful development of cv. Syrah within Toscany.

3.2 Comparison between European and other winegrowing regions

To assess the broader applicability of the spatial climate data, five regions in the western United States and four in Australia are used for comparison to the European regions. The only difference here is that the winegrowing regions are more general (American Viticultural Areas and Geographic Indicators) than the CLC-derived winegrowing regions in Europe. To account for the skewing of the median in these regions, Table 3 also includes the maximum values, which when combined with the median, give the range of likely planted areas in each region. The results show that there are some similarities and differences between commonly compared regions. For example, Bourgogne and the Willamette Valley both grow similar varieties and structurally have similar climates. However, Bourgogne's climate indices reveal a warmer region on average, but very similar if the range between the median and maximum is used in the Willamette Valley. Another region that grows similar varieties to Bourgogne and the Willamette Valley is the Yarra Valley in Australia, with these results showing that the Yarra Valley is significantly warmer that both regions. Similarly, Bordeaux and the Napa Valley are often compared and the results here reveal that the Napa Valley is overall substantially warmer on all indices compared to Bordeaux, except the CI where Bordeaux has warmer nights (Table 3). From this analysis Coonawarra is more climatically comparable to Bordeaux than the Napa Valley. In addition, the CI tends to range much lower over the entire western US where median values between 7 to 14°C are common, while in Australia the values range from 10 to 17°C over most regions. The DI was not calculated at the global scale at this time.

Table 3: Median and maximum values of the climate indices for five regions in the western United States and four regions in Australia. All variables and units as described in Table 2.

Country or State	Region	GSTavg (°C)		BEDD (DD)		WI (DD)		HI (DD)		CI (°C)	
		Med	Max	Med	Max	Med	Max	Med	Max	Med	Max
California	**Napa Valley**	18.3	19.7	1766	1952	1684	2020	2294	2637	10.8	20.4
California	**Paso Robles**	18.4	20.3	1892	2069	1685	2113	2399	2800	9.2	22.0
California	**Lodi**	20.2	20.8	1906	1966	2082	2234	2637	2787	13.0	18.2
Oregon	**Willamette Valley***	14.3	15.1	992	1173	881	1042	1504	1683	7.8	16.9
Washington	**Walla Walla**	16.8	17.6	1350	1491	1380	1501	2120	2263	9.0	17.7
Australia	**Barossa Valley**	18.1	19.1	1570	1661	1661	1842	2063	2215	12.2	13.2
Australia	**Coonawarra**	16.7	17.0	1373	1418	1328	1387	1833	1923	10.9	11.1
Australia	**Margaret River**	18.4	19.1	1523	1665	1662	1843	1850	2090	14.6	16.1
Australia	**Yarra Valley**	16.2	17.6	1251	1500	1236	1540	1652	1929	11.1	12.8

*Note that the Willamette Valley values come from the statistics of the six most prominent appellations within the broader region.

4 CONCLUSIONS

While much research has been conducted examining the climate structure of winegrowing regions in different areas of the world using different approaches (Winkler et al, 1974; Huglin, 1978; Gladstones, 1992; Tonietto and Carbonneau, 2004; and Jones, 2006), these analyses have often focused on climate station summaries which are not often fully representative of the true climate structure in these regions. This research attempts to capture the spatial structure of climates in winegrowing regions globally by using a moderately high resolution (1 km) gridded climate product (WorldClim). In addition, the research provides for the first time a comparison of six commonly used climate parameters that have historically been applied in various regions around the world. As an example this paper details the initial results of our work whereby a subset of 16 European regions are examined for their spatial climate structures and compared to other characteristic regions in the western United States and Australia. Further work will detail these climate parameters for other wine regions throughout the world (Canada, New Zealand, South Africa, South America, and the eastern United States) with the goal of producing a worldwide set of similar data from which to make more appropriate climate comparisons and facilitate future research. However, it is important that as greater spatial resolution of climate grids and new time periods of data become available that this work be updated so that climate structure, suitability, variability and change can be monitored in a more appropriate and timely manner.

ACKNOWLEDGEMENTS

We would like to thank Dr. Camilla Dibari for GIS elaboration on the European data. Andrew Hall's contribution to this work is supported by the Wine Growing Futures Program through the Grape and Wine Research and Development Corporation of the Australian Federal Government, the NWGIC and by a CSU competitive grant.

BIBLIOGRAPHY

Blanco-Ward, D., Garcia-Queijeiro, J.M., and G.V. Jones (2007). Spatial climate variability and viticulture in the Miño River Valley of Spain. Vitis 46(2):63-70.

Bois, B. (2007). Cartographie agroclimatique à méso-échelle : méthodologie et application à la variabilité spatiale du climat en Gironde viticole. Conséquences pour le développement de la vigne et la maturation du raisin. PhD Thesis, Bordeaux, Université de Bordeaux 2. 211p.

Fregoni, M.; (2003): L'indice bioclimatico di qualitá Fregoni. In: M. Fregoni; D. Schuster; A. Paoletti (Eds): Terroir, Zonazione Viticoltura, 115-127. Piacenza, Italy (Phytoline: Piacenza).

Gladstones, J. (1992). Viticulture and Environment. Winetitles, Adelaide. 310 pp.

Hijmans, R.J.; Cameron, S.E.; Parra, J.L.; Jones, P.G.; Jarvis, A. (2005). Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology, 25(15) :1965-1978.

Huglin, P.; 1978: Nouveau Mode d'Évaluation des Possibilités Héliothermiques d'un Milieu Viticole. C. R. Acad. Agr. France, 1117-1126.

Jones, G.V. (2006). Climate and Terroir: Impacts of Climate Variability and Change on Wine. In Fine Wine and Terroir - The Geoscience Perspective. Macqueen, R.W., and Meinert, L.D., (eds.), Geoscience Canada Reprint Series Number 9, Geological Association of Canada, St. John's, Newfoundland, 247 pages.

Seguin, B. (1982). Synthese des travaux de recherche sur l'influence du climat, du microclimat et du sol sur la physiologie de la vigne, avec quelques elements sur arbres fruitiers. Vignes & Vins-Special number Agrometeorologie et Vigne (Sept. 1982), 13-21.

Tonietto, J., Carbonneau, A., 2004: A multicriteria climatic classification system for grape-growing regions worldwide. Agricultural and Forest Meteorology, 124, 81-97.

Winkler, A. J., Cook, J. A., Kliewere, W. M. and Lider, L. A., 1974, General Viticulture, (4th ed.): University of California Press, Berkeley, 740 p.

Hutchinson MF. 2004. Anusplin Version 4.3. Centre for Resource and Environmental Studies. The Australian National University. Canberra, Australia.

Thornton PE, Running SW, White MA. 1997. Generating surfaces of daily meteorology variables over large regions of complex terrain. Journal of Hydrology 190: 214–251

Willmott, C.J., Robeson, S.M., 1995. Climatologically Aided Interpolation (CAI) of terrestrial air temperature. Int. J. Climatol. 15, 221–229.

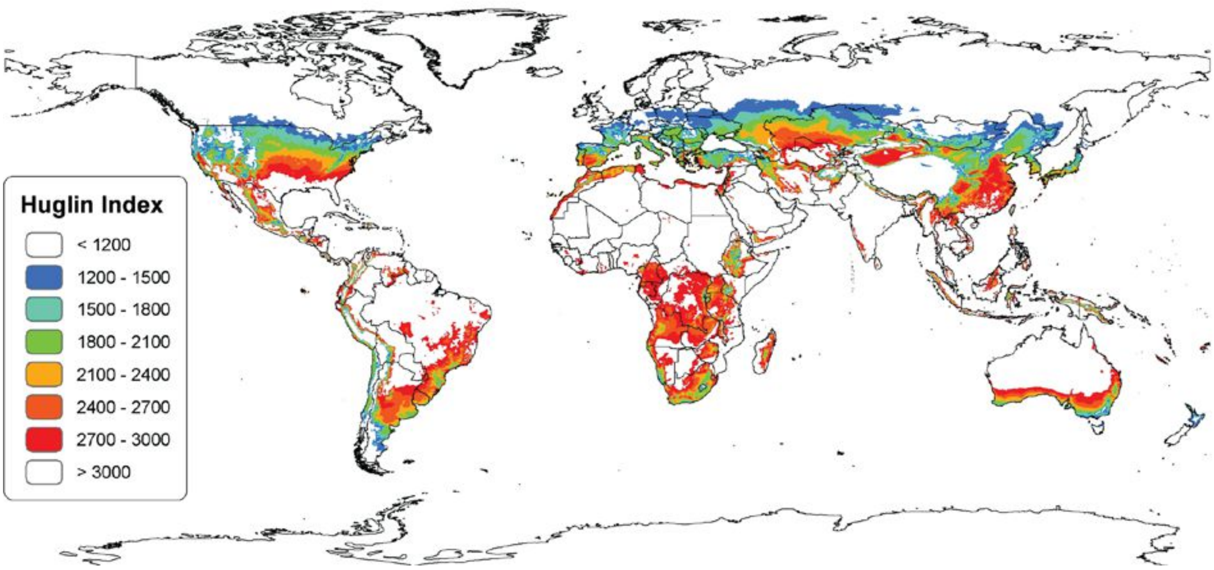

Figure 1: Huglin Index depicted as split map with the Northern Hemisphere being April through September and the Southern Hemisphere being October through March.

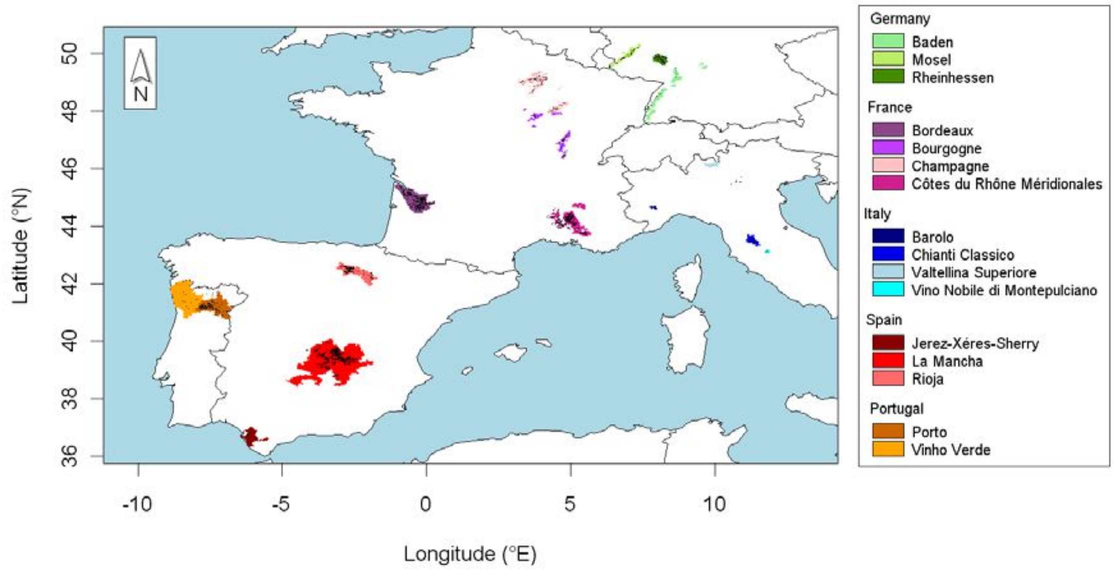

Figure 2: Limits and vineyards of the subset of 16 European winegrowing regions. The black spots indicate the vineyards identified by CORINE Land Cover 2000.

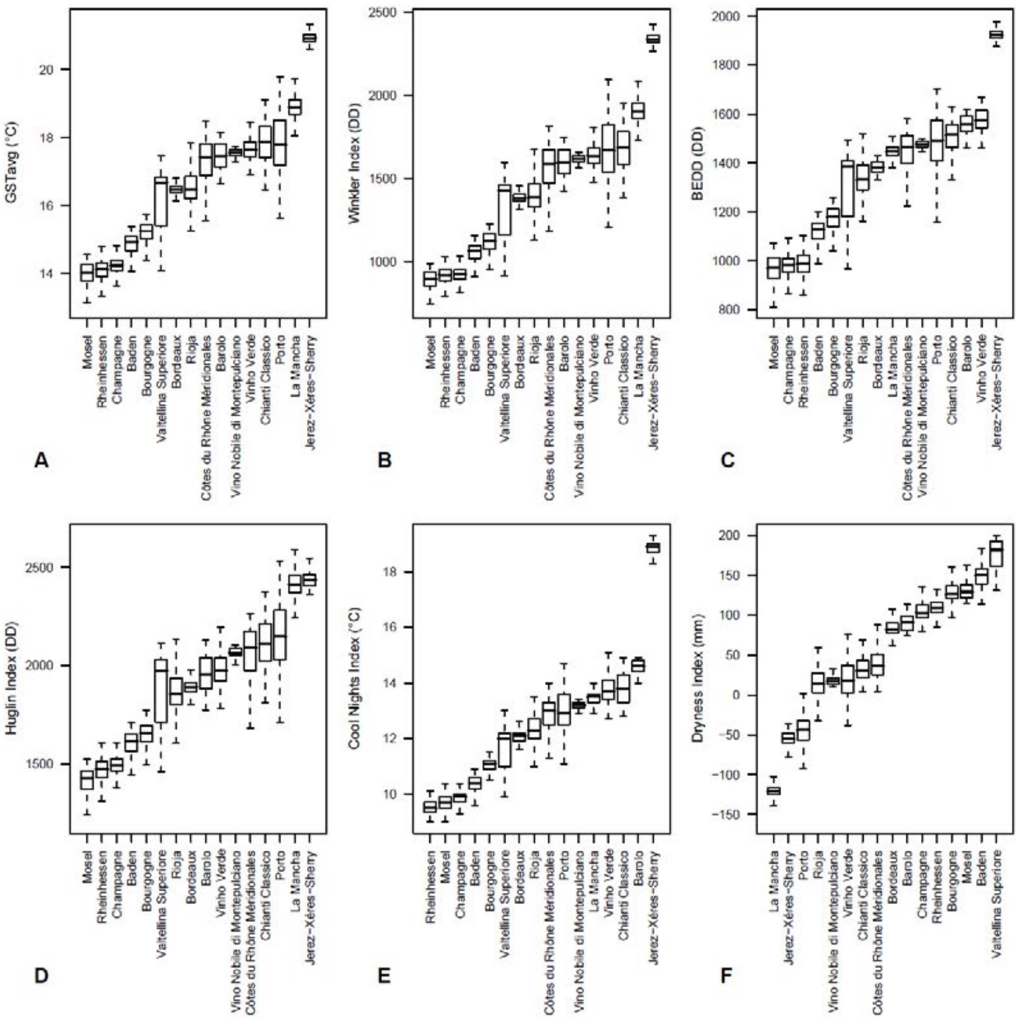

Figure 3: Boxplots of climate index values, for the vineyards of 16 European winegrowing regions. A: average growing season temperature (GSTavg), B: Winkler index (WI); C: Biologically efficient degree days (BEDD); D: Huglin index (HI); E: Cool Night Index (CI); F: Dryness Index (CI).