HIGH RESOLUTION CLIMATIC ZONING OF THE PORTUGUESE VITICULTURAL REGIONS

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Abstract
Viticulture and winemaking represent a key sector for the Portuguese economy. As grapevines are strongly governed by atmospheric factors, climate change may impose a major threat to this crop. In this study, the current-past (1950-2000) and future (2041-2070) climatic conditions in Portugal are analyzed using a number of bioclimatic indices, including a new categorized index (CatI). A two-step method of spatial downscaling is applied in order to attain a very high spatial resolution (near 1 km) over Portuguese mainland. Future projections are established using an ensemble of 13 regional climate models, under the IPCC A1B-SRES emission scenario. Results show that CatI integrates the most important bioclimatic characteristics of a given region, and allows the direct comparison between them. Outcomes for the recent-past are in clear agreement with the current geographical distribution of this crop and of the established winemaking regions. Conversely, under future scenarios, projections point to a lower bioclimatic diversity, due to the expected warming and drying throughout the country. This will likely lead to changes in grapevine suitability and wine characteristics of each viticultural region, which may result in additional challenges for the winemaking sector. As such, suitable adaptation measures need to be developed in order to mitigate climate change impacts on the Portuguese viticulture.

Keywords: Viticultural zoning; Bioclimatic downscaling; Climate models; Climate change; Portugal

1 INTRODUCTION

The study of the climate influence in environmental, agricultural, biological and energy sciences is of major importance today. Viticulture plays a key role in the development of the Portuguese economy, representing approximately 2% of national exportation revenue (IVV 2011), corresponding to an annual revenue slightly higher than 700 M€. Portuguese vineyards are effectively grown over most of the country, accounting for nearly 238.000 ha and generating approximately 6 million hl of wine annually (IVV 2011). Some of the most renowned winemaking regions (Fig. 1) are contained within twelve designated wine regions (e.g. Douro, Dão and Alentejo). These regions are quite diverse showing unique viticultural characteristics, as well as geomorphological aspects, climates and varieties grown (Magalhães 2008), resulting in distinctive wine types. Example of the landscape diversity in Portugal includes Alentejo, a mostly flatland large region in southern Portugal, which has a homogenous warm and dry climate, contrasted with the Douro Demarcated Region (DDR; northeastern Portugal) which is a mountainous region, characterized by steep slopes. This historic winemaking region, known worldwide for its Port Wine and, more recently, for the production of other high-quality wines, was designated a World Heritage site by UNESCO in 2001, largely due to the vineyard landscape in the region. Taking into consideration the significant revenues the winemaking sector brings to the Portuguese economy, the climatic viticultural zoning in Portugal and the climate change implications on this sector are of utmost importance (Fraga et al. 2013).

Gridded climate datasets have been a valuable tool in assessing climate change impacts on viticulture. The heterogeneous climatic conditions in which vineyards are grown in Portugal must be taken into account in order to develop a useful viticultural zoning. The use of high resolution datasets is of great importance for this purpose, since relevant environmental variability can be partially/totally lost at low resolutions, particularly in areas with steep climate gradients. In effect, coarse resolution data cannot represent microclimates highly dependent on various topographic elements. Many previous studies have either used weather station data that are not representative of the regional climates, or use Global Climate Models (GCM) with very low spatial resolutions of about 100 km. Regional Climate Models (RCM) provide higher resolutions (10-20 km), but still provide insufficient spatial resolutions for more detailed local/regional assessments. The lack of high-resolution data over Portugal (< 10 km) has proven to be a large setback for a more direct application of the results by the stakeholders (Fraga et al. 2014a).

Given these issues the goals of the present study are to contribute to the improvement of the viticultural zoning in Portugal, at a higher spatial resolution that provides insights into better understanding climate change impacts. A set of bioclimatic indices were calculated using data from the WorldClim Project for the baseline period of 1950-2000 (www.worldclim.org). Future viticultural zoning was achieved by calculating the bioclimatic indices from 13 model experiments from the ENSEMBLES project (http://ensemblesrt3.dmi.dk/) and for the future period of 2041-2070. This data was subsequently downscaled to a near 1 km grid resolution using a method of spatial pattern downscaling. This new innovative downscaling approach allows both the characterization of the climate conditions within Portuguese viticulture regions and their likely future changes at a resolution useful for the industry.

2 MATERIALS AND METHODS

Three bioclimatic indices were selected in the current study. The Huglin Index (HI; Huglin 1978), a classic index that includes a radiation proxy (day length), is used to assess the heliothermic potential of a given region, thus linking the varietal thermal demands to phenological stages. This index is expressed by the following equation:

$$\sum_{April}^{Sept.} \frac{(T-10)+(T_{\max}-10)}{2} d \quad ,$$

where T is the mean air temperature (°C), T_{max} the maximum air temperature (°C) and d the day length coefficient. The Dryness index (DI; Tonietto and Carbonneau 2004) is based on the potential water balance of the Riou index (Riou et al. 1994), and evaluates the soil water availability to the vine. This index is expressed by the following equation:

$$\sum_{April}^{Sept.} \left(W_0 + P - T_v - E_s \right) \quad ,$$

where W_0 is the initial available soil water reserve (mm), P is the precipitation (mm), T_v the potential vineyard transpiration (mm) and E_s the direct evaporation from the soil (mm). Lastly, the Cool Night Index (CI; Tonietto 1999) accounts for minimum temperatures during maturation. High daily temperature ranges with relatively cool nights during ripening are beneficial for the production of high-quality wines, such as the synthesis of anthocyanins in grapes (Fregoni et al. 2003).

A new innovative categorization was then developed, integrating the classes from the HI, DI and CI, similarly to the work done in the multi-criteria climatic classification by Tonietto and Carbonneau (2004). However, this new Categorized Index (CatI) includes 16 different categories (Table 1), allowing a better mapping of different regions in Portugal based on their climatic characteristics (also described in Table 1). These computations were performed for the baseline period (1950-2000) using a high resolution climate dataset of the WorldClim project (Hijmans et al. 2005). This gridded dataset provides monthly normals (precipitation, minimum, maximum and mean temperatures) at 0.008º × 0.008º spatial resolution (< 1 km), developed from compiled monthly means recorded by weather stations from a large number of sources. The above mentioned variables were extracted over the Portuguese mainland using GIS software for 649 × 865 grid cells. Monthly normals were then compared against the widely used E-OBS observational data for validation purposes. For assessing climate change impacts, the period of 2041-2070 was used.

For the assessment of climate change impacts in Portuguese viticulture in the future, a downscaling method based on the spatial pattern interpolation of the climate change signal of 13 RCM runs was developed. The signal of each RCM (2041-2070 minus 1951-2000) was subjected to a smoothing technique, based on bi-cubic interpolation (16-cell interpolation). The 13-member ensemble climate change signal mean was then applied to the baseline high resolution dataset. This approach is based on the assumption that the climate change signal has a high spatial correlation within each RCM grid. Similar methodologies were already used in previous studies (Ramirez-Villegas and Jarvis 2010), but using lower resolution GCM data (much stronger assumption then when using RCM data). This downscaling procedure has the benefit of not needing any statistical error correction of the model outputs, since the signal itself is independent of these calibrations (e.g. bias in the means).

3 RESULTS AND DISCUSSION

The CatI index patterns hint at the Atlantic/Mediterranean contrast over Portugal (Fig. 2a), highlighting not only significant spatial variability throughout the country, but also in each viticultural region. In the more Mediterranean-like regions (Alentejo, Algarve, Península-de-Setúbal, Tejo, southern half of Terras-da-Beira and innermost part of Douro/Porto), where CatI 10 currently prevails, the projected warming may promote the abandonment of some less adapted grapevine varieties, leading to a loss of biodiversity. Furthermore, in these regions, severe dryness in the future may lead to lower yields, where irrigation is not available (Fig. 2b). The combined effect of warming and drying may cause detrimental effects at biochemical and physiological levels.

Night-time warming and lower thermal amplitude in the last stages of crop development can also result in lower wine quality (Tonietto and Carbonneau 2004).

For the northern and coastal regions of Portugal (Minho, Trás-os-Montes, Lisboa, Terras-do-Dão, Terras-de-Cister and Beira-Atlântico), which are more exposed to Atlantic influences, lower CatI categories are found (Fig. 2a). These results suggest some beneficial impacts of climate change, although projections also give evidence for strong warming trends in the growing season. In these regions, future conditions may be beneficial for late maturing varieties. However, increased dryness in these regions, although still not limiting for grapevine suitability, may have impacts on yield maintenance. Nevertheless, these conditions may indeed be considered advantageous, as lower humidity levels should result in lower risks of pests and diseases (e.g. downy mildew) and may enable a reduction of phytosanitary measures. Nevertheless, these projections may also urge changes in viticultural practices such as the traditional training systems in Minho, where vineyards are grown in environments of moderate to excessive hydric regimes (Fraga et al. 2014b).

4 CONCLUSIONS

The CatI provides reliable information for comparing the climatic characteristics of each Portuguese viticultural region. Previous studies have established the significant role played by climate in viticultural zoning (e.g. Jones et al. 2010; Santos et al. 2012; Webb et al. 2011) and also emphasized the relevance of various bioclimatic factors in the geographical distribution of winegrapes, phenology and crop development. The current vineyard cover in Portugal takes advantage of the prevailing climatic diversity, explaining the relatively high number of wine regions, specialized in the production of very specific wines, and the large number of grapevine varieties grown all across the country. Despite the important empirical knowledge acquired along the centuries, the very high resolution maps of the bioclimatic indices provided by the present study can still represent an important tool for near-future viticultural zoning in Portugal.

Under human-induced climate change, however, the current viticultural zoning will likely experience some remarkable changes that can represent important threats or challenges to the Portuguese winemaking sector. The CatI summarizes the most important outcomes regarding the bioclimatic characteristics of each region. Future shifts in the index to higher classes are largely expected, and are in close agreement with the human-driven warming already reported in several European countries (Duchene and Schneider 2005; Fraga et al. 2012; Malheiro et al. 2012; Neumann and Matzarakis 2011; Orlandini et al. 2009). This may also yield earlier phenological events throughout the country. Similar results linking phenological events to future warming have been found across many locations worldwide (Jones et al. 2005; Tomasi et al. 2011; Webb et al. 2012). Future climates may imply lower diversity of bioclimatic categories, resulting in a more homogeneous warm and dry climate throughout the country (mostly CatI categories 10 and 14), with the exception of Trás-os-Montes, where this warming will result in more heterogeneity. Therefore, suitable adaptation measures can play a key role in preserving the wine typicity of each region. In fact, these measures can be an opportunity to develop more environmentally sustainable and eco-innovative practices in the viticultural sector, also promoting the economic sustainability of this sector.

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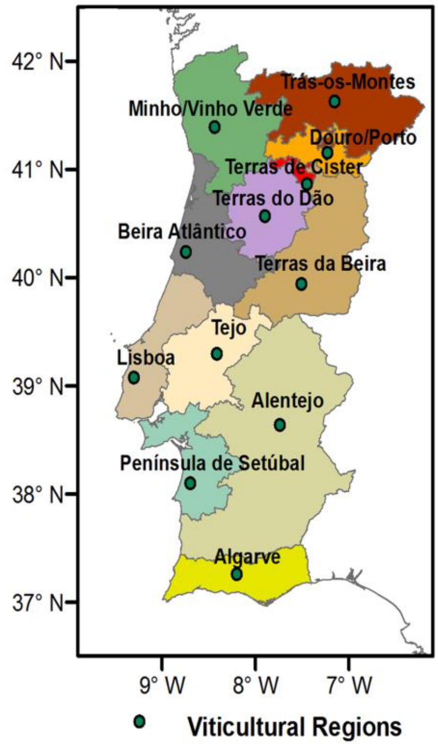

Figure 1: Winemaking regions in Portugal (IVV 2011).

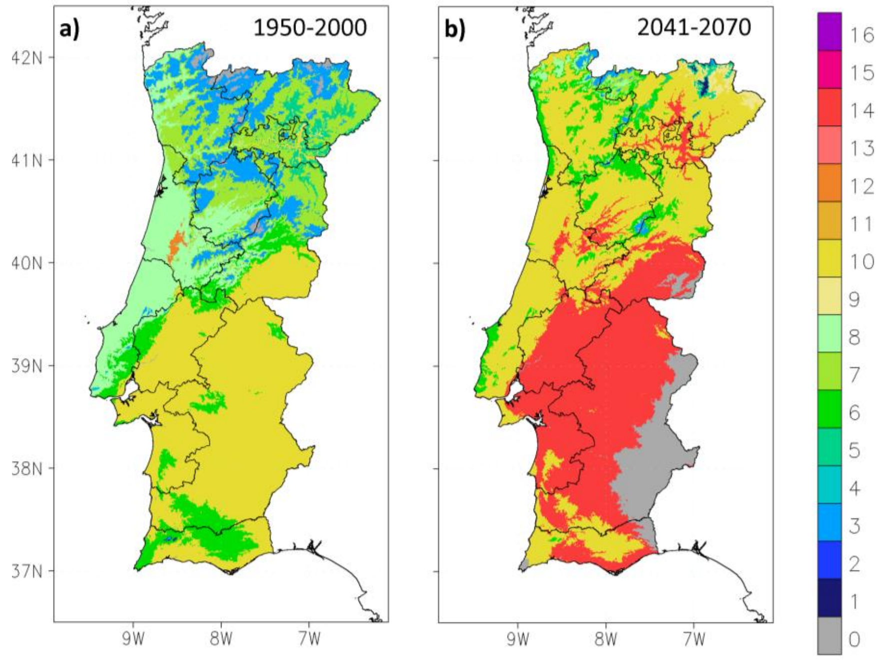

Figure 2: Categorized Index for (a) 1950-2000 and (b) 2041-2070 under the A1B IPCC-SRES for mainland Portugal

Table 1: Categorized Index and the combined indices classes

Categorie	Huglin Index (C° units)	Dryness Index (mm)	Cool Night Index (°C units)	Description
0	<900	<-100		Unsuitably cold or excessively dry
1	900 – 1500	-100 – 50	< 14	Cool, dry with cool nights
2			> 14	Cool, dry with warm nights
3		> 50	< 14	Cool, humid with cool nights
4			> 14	Cool, humid with warm nights
5	1500 – 2100	-100 – 50	< 14	Temperate, dry with cool nights
6			> 14	Temperate, dry with warm nights
7		> 50	< 14	Temperate, humid with cool nights
8			> 14	Temperate, humid with warm nights
9	2100 – 2700	-100 – 50	< 14	Warm, dry with cool nights
10			> 14	Warm, dry with warm nights
11		> 50	< 14	Warm, humid with cool nights
12			> 14	Warm, humid with warm nights
13	> 2700	-100 – 50	< 14	Very warm, dry with cool nights
14			> 14	Very warm, dry with warm nights
15		> 50	< 14	Very warm, humid with cool nights
16			> 14	Very warm, humid with warm nights