GLOBAL WARMING EFFECTS ON GRAPEGROWING CLIMATE ZONES WITHIN THE RIOJA APPELLATION (DOC RIOJA) IN NORTH SPAIN

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Abstract

Aims: The aims of this work were (1) to assess the changes in some of the main bioclimatic indices used for climate viticultural zoning within the Rioja Appellation area in the north of Spain between 1950-2014 (60 years), and (2) to carry out a comprehensive sociological evaluation among grapegrowers and winemakers of this region, to better understand the impact of climate change on their activity, their degree of concern about it and the potential adaptation measures they would be willing to adopt to cope with it in future years.

Methods and Results: For the climatic evaluation, two high-resolution (5Km x 5Km) daily gridded temperature and precipitation datasets covering the years between 1950-2014 were used. Following the criterium of the World Meteorological Organization, two subperiods of 30 years were created. For the Winkler index (WI), the Huglin index (HI), the Growing Season average Temperature (GST) and the Growing Season Precipitation (GSP), the median for each subperiod was compared (at $p<0.01$ or $p<0.05$) using the Wilcolxon-Mann-Whitney test. A significant increase between 0.7 and 1.1°C of GST was found for most of the region between the two subperiods. This was reflected in changes in the WI and HI zoning within the region, with increased and predominant area in zones II and III for WI and H+1 and H-1 for HI. In terms of GSP, no significant changes were detected, but larger areas with GSP between 160 and 200 mm H_2O were observed. Regarding the sociological approach, 481 on-site surveys with 29 different questions were conducted among grapegrowers, winemakers, consultants and other wine-related stakeholders. Some of the main findings include that 64.3% of respondents have experienced some negative impact, including economical effects. The main actions taken in the last years to cope with climate change were installation of irrigation, increase of crop insurance adoption against hail and frost, and adaptation to new pests and diseases.

Conclusions: Global warming was significantly detected in a 60 year period in the Rioja Appellation area, which caused changes in the grapegrowing climate zoning within the region. At social level, climate change was highly perceived by viticulturists and winemakers, which had started to adopt different actions to cope with increased temperatures and strong climate events.

Significance and Impact of the Study: This work provides a unique, high-resolution diagnosis about climate change and viticultural zoning displacement within the Rioja Appellation, which is one of the top wine regions worldwide. Likewise, the sociological study is the first one carried out in this area, and offers valuable information for policy makers to drive mitigation and adaptation policies towards global warming in future years.

Keywords: Climate change, Rioja, bioclimatic indices, viticultural zoning

Introduction

The wine industry is a relevant socioeconomic sector in many regions worldwide. That is the case of the Rioja Wine Appellation located in the north of Spain, which accounts for more than 65,000 ha of planted vineyards, 14,800 grape growers and 600 wineries, producing around 336 million liters of wine, and contributing with the 12% of the gross domestic product of this region. As in most of wine regions worldwide, climate change is one of the main challenges that current viticulture and winemaking has to face in the Rioja area. Generally speaking, across many wine growing regions, climate change has mostly led to regional warming (Jones *et al.,* 2005), and overall greater variability in seasonal rainfall (Laget *et al.,* 2008). However, despite the global extent of climate change (IPCC, 2014), several works have pointed out the importance of the spatial scale to understand the challenges and the opportunities as well as to drive policies and decision making at administrative levels (Neethling *et al.,* 2019). Disregarding the regional level may lead to erroneous generalizations that can encourage adaptation and/or mitigation measures, which can only be successful if the specific features of a particular region are considered, with its technical, environmental and socio-economic implications (Shultz, 2017).

In viticulture, several bioclimatic indices have been developed to assess the suitability of any given region to successfully grapegrowing (Santos *et al.,* 2020) and, in some cases, Winkler (Amerine and Winkler, 1944; Winkler *et al.,* 1974) or Huglin Indices (Huglin, 1978) to classify the wine regions according to a defined scale. These indices are based on ratios, summation or relationships that involve climatic variables such as temperature, rainfall, insolation or frost frequency and timing.

The goals of the present work were to appraise the changes in some of the main bioclimatic indices used for climate viticultural zoning within the Rioja Appellation area in the north of Spain between 1950-2014 (60 years), and (2) to carry out a comprehensive sociological evaluation among grapegrowers and winemakers of this region, to better understand the impact of climate change on their activity, their degree of concern about it and the potential adaptation measures they would be willing to adopt to cope with it in future years.

Materials and Methods

Area Under Study

The wine region under study is the Rioja Wine Appellation. This is the oldest designation of origin in Spain (designated in 1925), and it is located in the north of Spain, on both sides of the Ebro river. With more than 65,000 ha of planted vineyards, it is divided into three zones: Rioja Alta, Rioja Alavesa and Rioja Oriental, and involves 144 municipalities. The two most separated villages are 100 km apart, while the maximum width of the valley area where grapes are grown is about 40 km. The vineyards are planted on successive terraces and some grow as high as 700 m above sea level. In terms of the climate and soil features, regarding the former, the whole area benefits from the confluence of two contrasting climates (Atlantic and Mediterranean) with an average annual rainfall slightly above 400 l/m^2 and mild temperatures. In terms of the soil, Rioja soils are diverse, ranging from clay-limestone, clay-ferrous and alluvial, slightly alkaline, poor in organic content and have moderate water availability during the summer (https://www.riojawine.com/es-en/rioja/).

Climatic Assessment

Two high-resolution (5Km x 5Km) daily gridded temperature (Serrano-Notivoli *et al.,* 2019) and precipitation (Serrano-Notivoli *et al.,* 2017) datasets covering the years between 1950-2014 were used. For the indices related to precipitation only the years between 1950 and 2012 were available. Following the criterium of the World Meteorological Organization, two subperiods of 30 years were created (1950-1982 and 1983-2014 for all temperature related indices; 1950-1981 and 1982-2012 for the precipitation related indices). For the Winkler Index (WI), the Huglin Index (HI) and the Growing Season average Temperature (GST) the median for each subperiod was significantly compared using the Wilcolxon-Mann-Whitney (Wilks, 2006) test at $p<0.01$, while for the Growing Season Precipitation (GSP) the level of significance was $p<0.05$. GSP was computed following the equation by Blanco-Ward et al. (2007) between 1st April and 30th September while GST was computed from the 1st April to the 31st of October, following the formula described by Jones (2006).

Daily data of temperature and precipitation were preliminary analysed with Phyton (Phyton 3.8.5.; www.phyton.org). This software was also used to compute the four bioclimatic indices under study. Ordinary kriging using QGIS 2.18 (QGis 2.18, Free Software Foundation, Boston, MA, USA) was applied to prepare the maps for the different indices and subperiods.

Sociological Assessment

Regarding the sociological approach, 481 on-site surveys with 29 different questions were conducted among grapegrowers, winemakers, consultants and other wine-related stakeholders across the whole DOCa Rioja. The survey included questions regarding the perception about climate change in their viticulture and wine related activities, the potential cost increase to adapt to climate events and the main measures or actions carried out to adapt to climate change. All data were statistically analysed using SPSS (IBM SPSS Statistics 19; IBM, New York, USA) at $p<0.05$.

Results and Discussion

Regarding the temperature-related bioclimatic indices, a significant increase between 0.7 and 1.1°C of GST was found for most of the region between the two subperiods (Figure 1), while in some areas of the Rioja Alta (north-west) and spotted zones of Rioja Oriental (south-east) the increase was more moderate, ranging from 0.3 to 0.7°C.

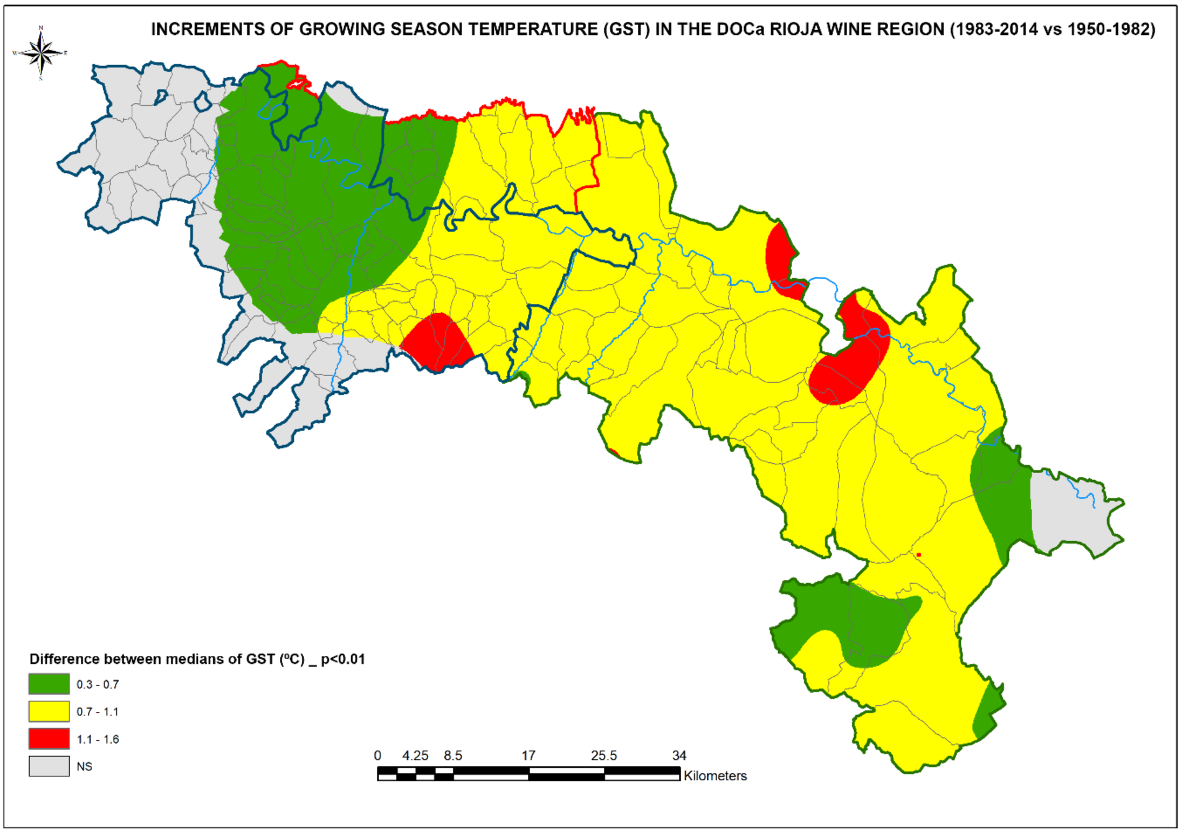
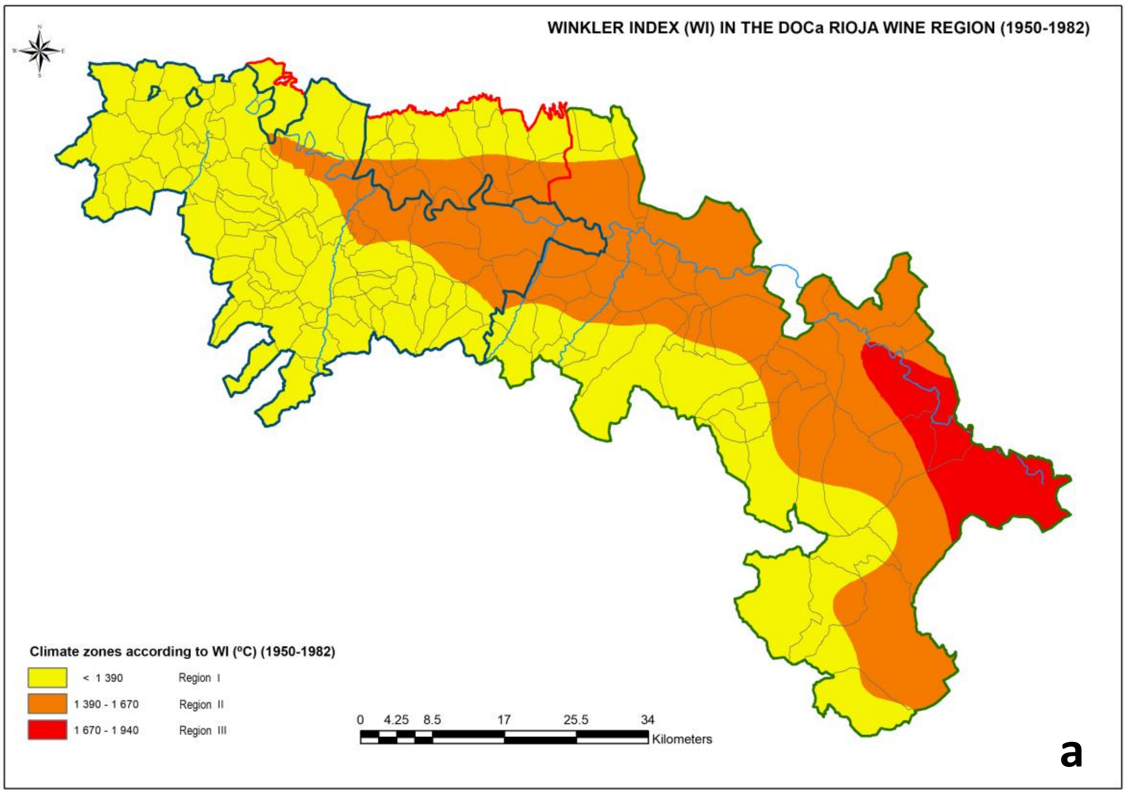


Figure 1. Variation of the Growing Season Temperature (GST) in the Rioja Wine Region between the two 30-yr subperiods (1983-2014 vs 1950-1982). Growing season temperature was computed between the 1st April to 31st October.

This was reflected in changes in the WI (Figure 2) and HI (Figure 3) zoning within the region, with increased and predominant area in zones II and III for WI and H+1 and H-1 for HI. These results reveal a significant warming during the last 60 years, with important implications for the viticulture of the region, as the grapevine growth cycle has been advanced, leading to earlier phenological stages and changes in ripening dynamics (decoupling of technological vs phenolic ripening in red cultivars, which are predominantly planted in this region) as reported by Ramos and Martinez de Toda (2020). This could also impact some adaptation measures as changing the varieties of new plantings. In this regard, cultivars of longer ripening cycles, such as Graciano or Carignan could be preferred to widely planted Tempranillo in some areas. In this regard, it is worth remembering that strict regulations about the grapevine varieties that are allowed for planting and winemaking in the Rioja Wine Appellation, with restrictions in terms of yield and some viticultural practices, such as pruning, exist. This implies that any given modification or action to adapt to this observed warming has to meet all these regulations. Among other measures, some growers have started to explore plots at higher altitudes.



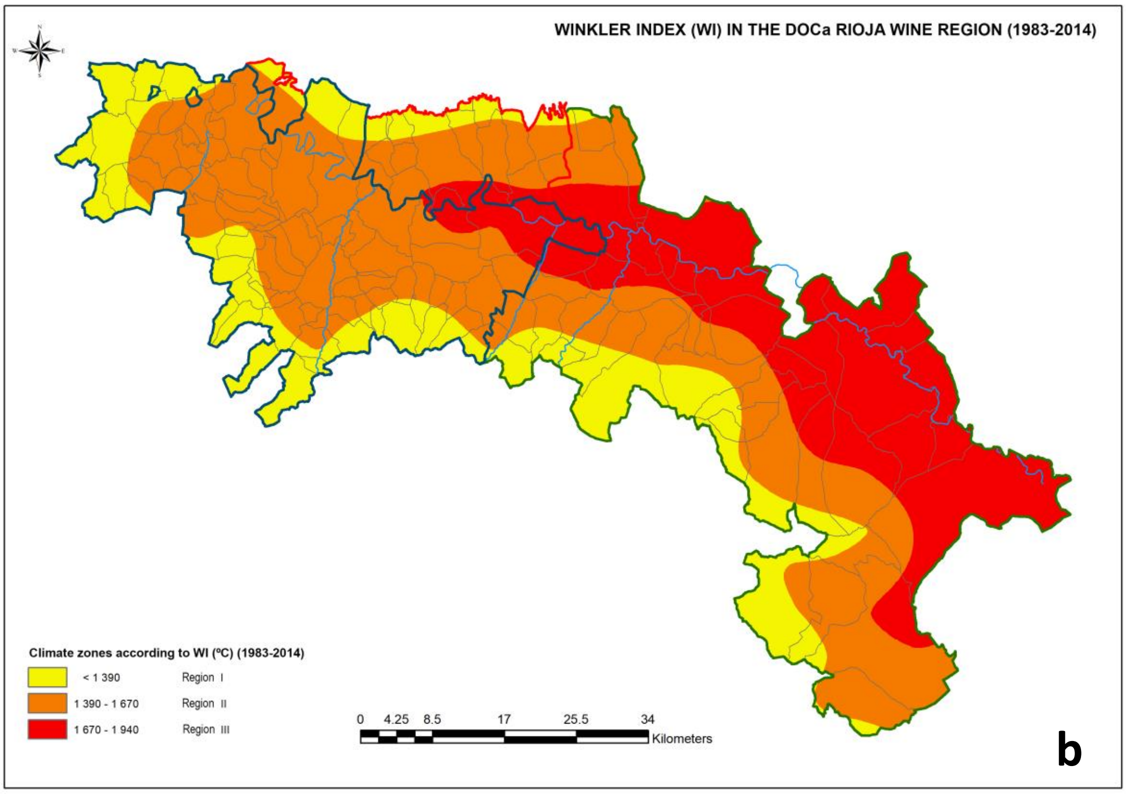


Figure 2. Winkler index (WI) in the Rioja Wine region for the two 30-yr subperiods. a) Period ranging from 1950-1982, and b) period ranging from 1983-2014.

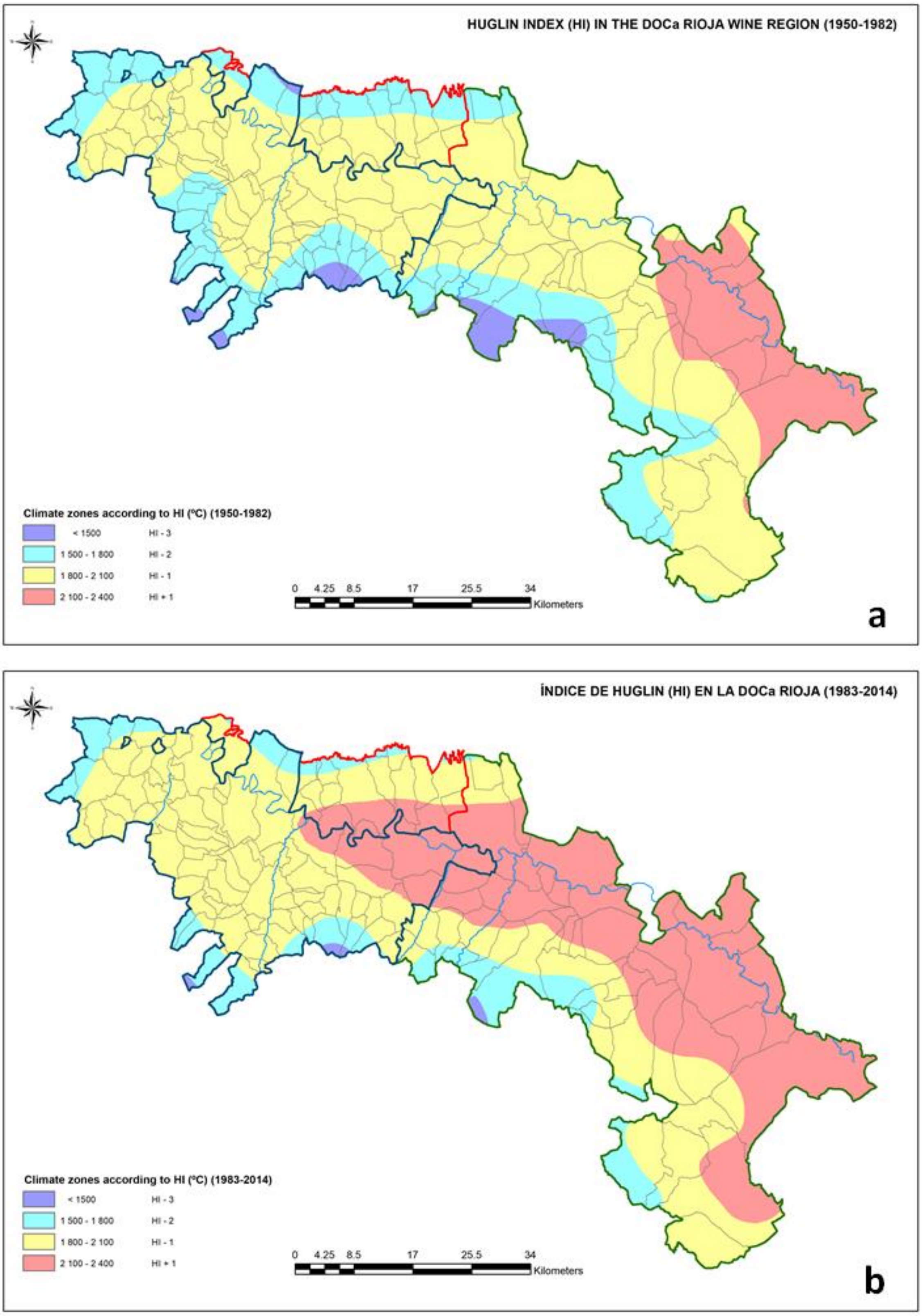


Figure 3. Huglin index (WI) in the Rioja Wine region for the two 30-yr subperiods. a) Period ranging from 1950-1982, and b) period ranging from 1983-2014.

In terms of GSP, no significant changes were detected, but larger areas with GSP between 160 and 200 mm H_2O were observed (Figure 4).

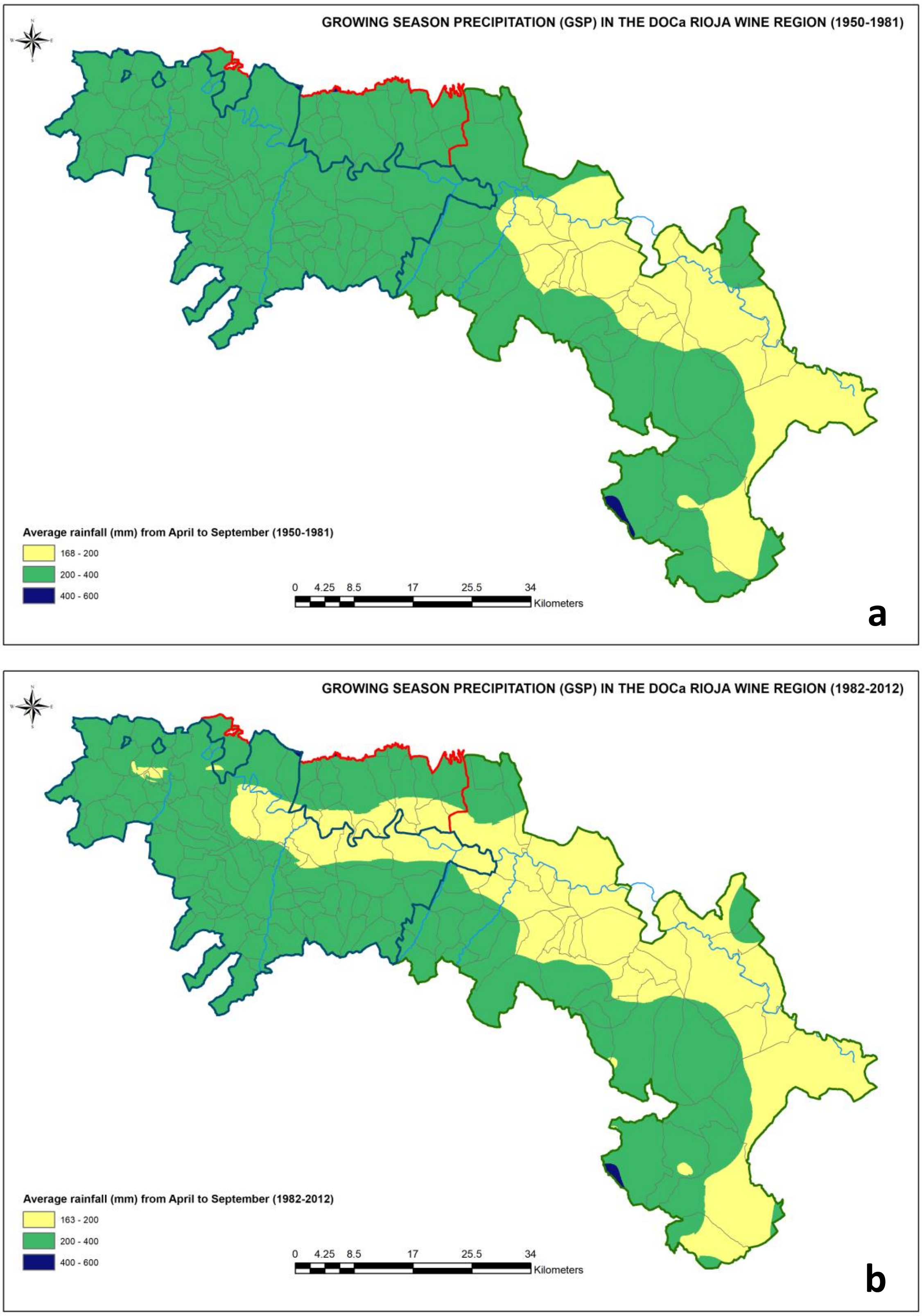


Figure 4. Growing season precipitation (GSP) in the Rioja Wine region for the two 30-yr subperiods. a) Period ranging from 1950-1981, and b) period ranging from 1982-2012.

Linked to these results are the answers of the surveyed growers in the sociological study. Some of the main findings include that 64.3% of respondents have experienced some negative impact, involving economic effects. Interestingly, the main actions taken in the last years to cope with climate change (55% of surveyed people reported that specific actions had to be taken in last years to adapt to climate change) were the installation of irrigation (63%), increase of crop insurance adoption against hail and frost (66.6%) and adaptation to new pests and diseases (80%). Moreover, 78.8% of the 481 surveys declared that the advancement of harvest was big or very big in the last ten years. When requested about future scenario of the viticulture and winemaking industry in the Rioja Wine Region in the next ten years, the main findings are summarized in Table 1.

Table 1. Future scenario and main actions foreseen (next decade) by the stakeholders of the Rioja Wine Region affected by climate change (in %). Number of responses: 481.

Action	Strongly agree	Agree	Neutral	Disagree	Strongly disagree	Not his/her activity	Don't know
New irrigation systems	30.6	41.2	12.3	7.1	4.4	0.6	4.4
Changes in grapevine varieties	3.3	12.3	15.8	25.8	35.8	0.2	6.9
Changes in harvest dates	30.1	43.7	15.0	4.8	2.3	0.2	4.0
Changes in winemaking	4.8	11.4	11.6	12.1	7.3	44.3	8.5
Planting at higher altitudes	19.5	31.6	17.5	11.6	13.3	0.6	5.8
Some plots no longer suitable	6.4	10.4	20.4	25.6	29.9	0.4	6.9
Increased pressure of pests and diseases	39.7	31.4	14.8	7.3	2.1	0.2	4.6
Increased need of insurance	44.9	27.0	11.9	6.2	4.8	0.2	5.0
Increased need of information	38.9	43.0	9.4	3.1	1.2		4.4
Increased need of training	37.6	43.0	9.1	3.5	1.9		4.8
Increased need of subsidies	39.6	37.7	8.5	4.8	1.9		7.5

In agreement with the reported actions carried out during the last decade to adapt to climate change, the surveyed agents also mentioned the need for more training, subsidies and information about the main adaptation measures (around 80% agreed or strongly agreed), as relevant actions to be taken in the next years.

Conclusions

Global warming was significantly detected in a 60 year period in the Rioja Appellation area, which caused changes in the grapegrowing climate zoning within the region. At social level, climate change was highly perceived by viticulturists and winemakers, which had started to adopt different actions to cope with increased temperatures and strong climate events.

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