Adaptation of Croatian Wine-growing Zones to Climate Changes

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Abstract: Most parts of Croatia are suitable for viticulture, but the choice of grape variety depends heavily on the temperature conditions of the areas and thus on the wine-growing regions and zones in which the areas are located. Since the last revision of the wine-growing zones, the temperature characteristics in Croatia have changed, making it necessary to revise the existing zones and regions. In this study, the changes of five biometeorological indices (Growing Degree-Days (GDD), Temperature Growing Season (TGS), Huglin Index (HI), Cool night Index (CI) and Dryness Index (DI)) were calculated at 80 stations of the Croatian Hydrometeorological Institute in the period 1961–2020 and in three CORDEX Regional Climate Models (RCMs) simulations for period 2041–2070. The observed and modelled data were spatially interpolated using regression kriging, assuming a linear relationship between the meteorological parameters and four predictors: Latitude, Longitude, Elevation and Distance from the Sea. The results show significant changes in the bioclimatic indices over the observed period, which were not always accompanied by administrative changes in the wine-growing regions and zones. As a result of climate change, there are also new areas suitable for viticulture, and climate model simulations indicate further changes and shifts in the regions and zones.

Keywords: viticulture; climate change; wine-growing zones; bioclimatic indices; regional climate models.

1 Introduction

Global climate data shows that air temperatures have risen in the last decades of the 20th century and are likely to continue to rise in the 21st century. Climate change is affecting the entire biosphere, including viticulture (Lalić et al. 2018). Recent changes in temperature and precipitation have led to changes in the growth and development of grapevines (Van Leeuwen et al. 2019), in the quantity and quality of the harvest (Bock et al. 2013) and in the concentration of sugars and acids in the must (Omazić et al. 2020). In addition, the areas suitable for viticulture in Europe have been moved further north of the continent or to higher elevations (Malherio et al. 2010). Wine-growing areas are divided into different zones. The wine-growing zone division differ according to climate and soil, but also according to other conditions that are important for the cultivation of vines. This division is directly related to the regulations defining protected designations of origin and application of certain viticultural and oenological techniques (Prša 2022). The division of Croatia into wine-growing zones was first made in the 1970s. The basis for division was the study by Winkler (Fazinić and Fazinić 1983). The aim of this study is to re-examine whether the administrative wine-growing zones correspond to the current climatic conditions and how fast the bioclimatic indices are changing in the current and future climate to determine the optimal time frame in which the zones should be revised again.

2 Materials and methods

The starting points for determining the suitability of a grapevine growing are bioclimatic indices. Four temperature indices have been calculated and are described in Table 1: the Temperature Growing Season (TGS), the Growing Degree-Days (GDD), the Huglin Index (HI) and the Cool night Index (CI), complemented by the Dryness Index (DI). Administratively, Croatia is divided into four wine-growing regions (Prša 2022) and had more than 18,000 ha of vineyards in 2020. To obtain indications of changes in the bioclimatic indices in Croatia, this study used data on the daily values of minimum, maximum and mean (Tmin, Tmax, T, °C) air temperature as well as daily precipitation (P, mm) and wind speed (v, m/s) from 80 meteorological stations throughout Croatia from 1961 to 2020. The spatial and temporal interpolation proposed by Perčec Tadić (2010) was performed due to missing measurements (instrument malfunction or missing

Table 1. Bioclimatic indices used in the study.

Index/ Reference	
Temperature Growing Season (TGS) (Jones 2006)	$TGS\ (°C) = \sum_{1.4.}^{31.10.} \left(\frac{T_{max} + T_{min}}{2}\right)$
Growing degree-days (GDD) (Winkler et al. 1974, Jones et al. 2012)	$GDD = \sum_{1.4.}^{31.10.} \left(\frac{T_{max} + T_{min}}{2} - 10\right)$
Huglin Heliothermal Index (HI) (Huglin 1978)	$HI = \sum_{1.4.}^{30.9.} \left(\frac{T + T_{max}}{2} - 10\right) \cdot k$ k- parameter dependent on the latitude of the location
Cool night Index (CI) (Tonietto 1999)	$CI\ (°C) = \frac{1}{30} \sum_{j=1.9.}^{30.9.} T_{min,j}$
Dryness Index (DI) (Riou et al. 1994, Tonietto and Carbonneau 2004)	$DI\ (mm) = W_0 + P - T_v + E_s$ W_0 – estimated initial water reserve P – mean monthly precipitation amount T_v – potential transpiration E_s – evaporation

observation). In addition, simulations of three regional climate models (CLMcom-CCLM4-8-17, SMHI-RCA4, CNRM-ALADIN5.3) from the EURO-CORDEX database with a grid spacing of 0.11° are used. The selected models proved to be good for predicting bioclimatic indices in the present climate (Omazić et al. 2020). The observed and modeled data were spatially interpolated using regression kriging, assuming a linear relationship between the meteorological parameters and four predictors: Latitude, Longitude, Elevation and Distance from the Sea. The predictors were derived from the digital 1-km elevation model.

3 Results

In the 30-year period from 1961 to 1990, the TGS in most of the Croatian mainland was between 15 and 17 °C (Figure 1a). This temperature favours the cultivation of vines, especially white varieties. In the coastal areas, the TGS was mostly between 17 and 24 °C over the same 30-year period. This air temperature favours the cultivation of almost all grape varieties. However, the sharp increase in air temperature in the period 1991-2020 compared to the period 1961-1990 is worrying (Figure 2a). The GDD indicates the suitability of most areas for viticulture and as expected, follows the characteristics of the spatial distribution of the TGS for the same periods. Most of continental Croatia has index values of 1389-1667 °C units for the period 1991-2020 (Figure 2b). These index values indicate good conditions for the cultivation of white grape varieties such as Graševina and Chardonnay, for which these areas are famous. In the coastal areas, the GDD values during the growing season are so high that the climate is suitable for the cultivation of almost all grape varieties and the high quality of the wine produced. However, as with temperature, the sharp increase in GDD compared to the period 1961–1990 is also worrying (Figure 1b, 2b). Similar to the previous two indices, the distribution of HI also shows further warming and changes in the categories by area (Figure 1c, 2c). The CI and divides the lowlands into two categories: "very cool nights" and "cool nights", while the coastal area is warmer and is mainly represented by the two warmest categories (Figure 1d, 2d). Certain differences can be seen in the spatial distribution of the DI (Figure 1e, 2e). These characteristics show a deviation in the southern part of Croatia, which is "moderately dry" (negative DI values) compared to the rest of the country, which is characterized by "humid" conditions. These relatively dry conditions contribute to the production of high-quality, mostly red wines in

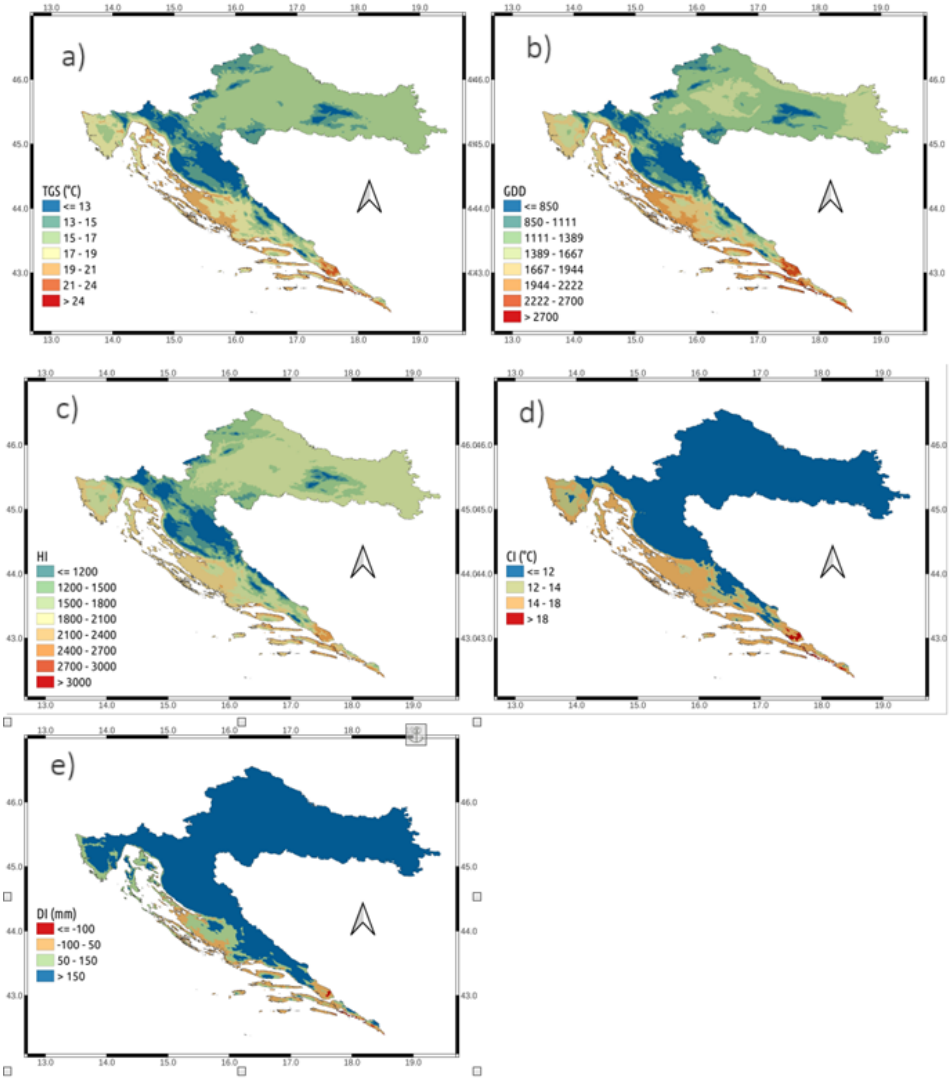

Figure 1. Spatial distribution of bioclimatic indices: a) TGS, b) GDD, c) HI, d) CI and e) DI in 1961–1990 period.

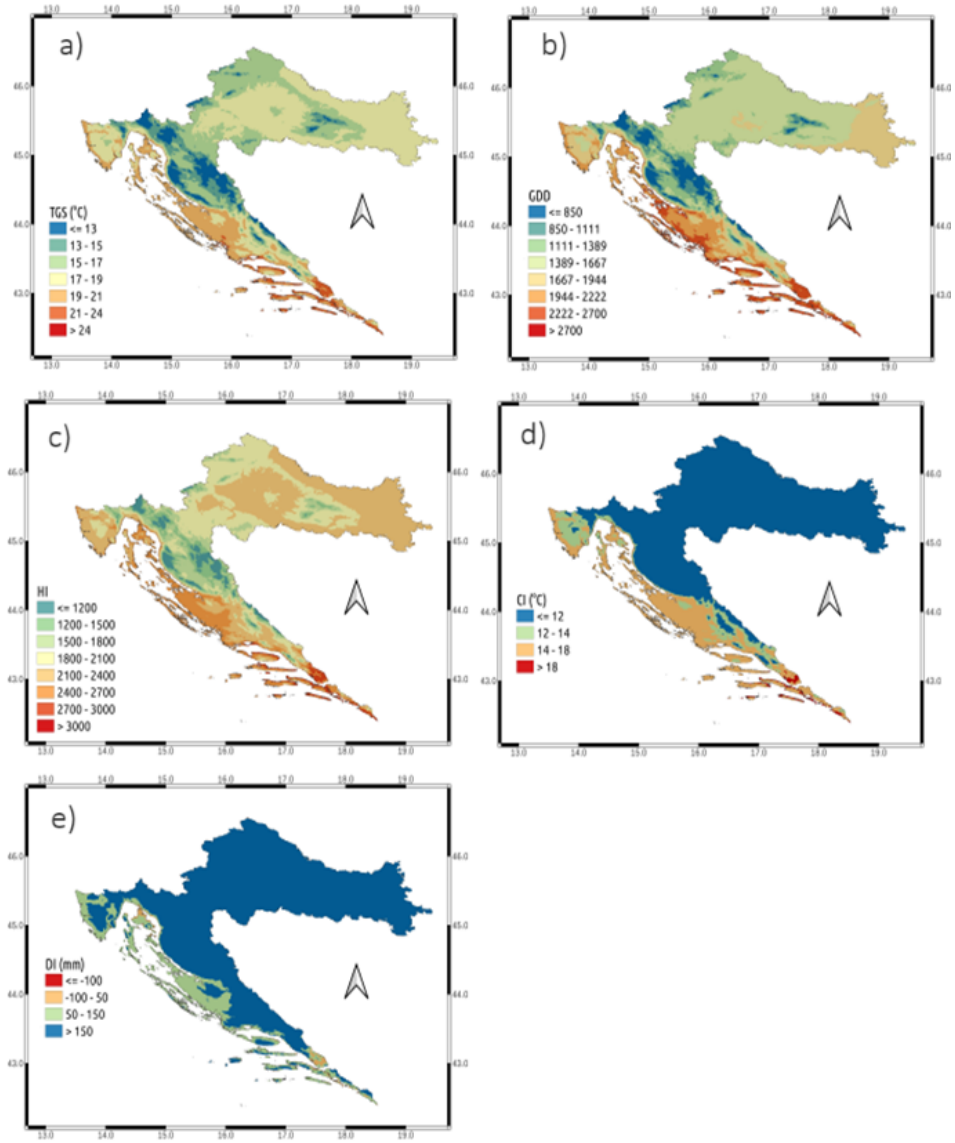

Figure 2. Spatial distribution of bioclimatic indices: a) TGS, b) GDD, c) HI, d) CI and e) DI in 1991–2020 period.

southern Croatia. The distribution of DI also shows the differences between the two climatic norms, which indicates a further drying out of the southern part of the Croatian territory. Climate models indicate a further increase in air temperature over the course of the year,

particularly during the growing season (Omazić et al. 2020). In the period 2041–2070, a further increase in air temperature of 2.25 °C to 2.75 °C is expected for the whole of Croatia compared to the period 1971–2000. In addition to the increase in air temperature, a further change in the precipitation regime is also expected, with increasingly frequent dry periods. The wine-growing area with reduced DI is increasing under climate change, which indicates a further water deficit on Croatian territory. and their ratio is to be expected in Croatia under future climatic conditions.

4 Discussion

The value of all indices clearly shows that almost all of Croatia is suitable for viticulture, but it can be seen that the temperature has risen by 2–3 °C throughout Croatia. A look at the GDD values shows that eastern Croatia itself has slightly higher values than the rest of continental Croatia, and this area offers the opportunity for the successful cultivation of more resistant black varieties such as Merlot. Similarly, the vines in certain mountainous areas can accumulate enough heat (more than 1111 °C units) and are thus suitable for growing vines in areas with lower elevation, because although we have enough heat during the growing season, the risk of frost is still much higher here than in continental areas. The production map is changing or will change very soon in the future, and they would have to be ready to adapt to new administrative and technological changes. All current evidence on climate change indicates that the atmosphere will continue to warm, increasing the likelihood of far-reaching and irreversible consequences for people and the ecosystem. Good and timely adaptation is key to maintaining tradition and quality in this agricultural and economic sector. The increase in TGS is particularly pronounced in the far south of Croatia, where we already have extremely high air temperatures, and such a further increase will only make production more difficult. Since the results shown here indicate a further warming of the climate, which could be accompanied by more frequent longer periods with air temperatures above 30 °C (especially an increase in TGS,

followed by GDD and HI) and more frequent droughts (a decrease in DI), a significant change in the characteristics of grapes (sugar, acidity and their ratio) is to be expected in Croatia under future climatic conditions. In addition to droughts, a further increase in the number and intensity of extreme events in the future climate (such as hail) is expected, which would further threaten the vineyards.

5 Conclusions

In this study, the bioclimatic indices for the wine-growing regions of Croatia were analyzed in detail. Data from measurements in the period from 1961 to 2020 and climate models with climate projections up to 2070 were used. On this basis, we can conclude that the current boundaries of climate zones can still be considered largely relevant based on average data for the period 1991–2020. However, if we look at the detailed data within this period, it becomes clear that there is significant warming and an increase in the value of temperature indices in the second and especially the third decade of this series. The largest and most rapid changes are observed in zone B, i.e. in the region of Central Hilly Croatia where it is already justified to recommend the correction of the boundaries of climate zones B and C I. This correction is supported by climate models for the period 2041–2070, which indicate further warming of the atmosphere. In the far east of Croatia, the bioclimatic indices tend to increase, and it is expected that these areas will, over time, have climatic conditions corresponding to zone C II. It is, therefore, crucial to establish a high-quality system for monitoring climate change and its impact on viticulture. In view of the observed trend of changes, it is necessary to carry out a regular review of the climatic zones every ten years.

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