THE FUTURE OF WINE GRAPE GROWING REGIONS IN EUROPE

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Abstract

Recent warming trends in climatic patterns are now evident from observational studies. Nowadays, investigating the possible impacts of climate change on biological systems has a great importance in several fields of science.

We applied the MaxEnt modelling approach to predict the possible effect of climate change on wine grape distribution as a species at European scale using basic bioclim variables. Two climate models were developed for 2050 and 2080 by Hadley Centre Coupled Model and Commonwealth Scientific and Industrial Research Organization. The area loss is calculated for the main wine producing countries in Europe (Portugal, Spain, France, and Italy).

Based on the analysis of variable contribution we can conclude that annual mean temperature has great importance in model performance while precipitation variables show much less contribution. The prediction of the best model for the present fits well to the known wine growing regions. Future predictions show consistent changes based on various climate scenarios: wine growing regions are predicted to shift northwards. At the same time, additional problems might arise in the Mediterranean region, especially in the Iberian Peninsula where the most radical changes are predicted (30% losses in average). France and Italy are less affected. For 2080 the suitable areas continuously decrease except for France where only a small amount of area loss is predicted. The predicted stability until 2050 is dynamic implying adaptation such as change of grape varieties, selection or modification of cultivation technology could be necessary even in those regions which remains suitable in the future.

Keywords: Vitis vinifera, climate change, MaxEnt, bioclim, climate scenarios

1 INTRODUCTION (SECTION, CAPITAL TIMES NEW ROMAN, BOLD 12PT, LEFT ALIGNED)

Recent warming trends in climatic patterns is now evident from observational studies demonstrating increases in global average air and ocean temperatures, widespread melting of snow and ice as well as rising global average sea levels (IPCC 2007a).

Nowadays, investigating the possible impacts of climate change on biological systems has a great importance in several fields of science from nature conservation to agriculture. Species distribution modelling has become increasingly important as researchers and managers seek to understand current species distribution patterns and to predict future distributions in the face of climate change, human-assisted invasions and many other on-going environmental changes.

Plants are especially sensitive for changes in spatial and temporal patterns of climatic variability (Walther et al. 2002, Thuiller et al. 2005). Specifically, plant phenology has been shown by a number of investigations to advance as a result of increasing temperatures (Menzel et al. 2006). Similarly, distribution areas of plants have been demonstrated to shift northwards or to higher altitudes owing to warming climate (Kelly & Goulden 2008).

As climatic patterns also influence phenology and distribution patterns of plant species used in agricultural production, it might have significant economic impacts (Howden et al. 2007). This prediction has accelerated the need for studies on the effects of global change on agricultural production (reviewed in (Smith & Gregory 2013)). Indeed, as historical data on wine grape phenology constitute one of the longest ones in agricultural sciences , the effects of climatic variability on wine grape phenology is relatively well studied (e.g. Jones & Davis 2000, Webb et al. 2012).

Evidence is accumulating that temperature and precipitation are major environmental factors driving grape wine phenology, yield, and wine quality (Jackson 2008, Santos et al. 2012): wine grape growing areas are traditionally bordered by the 10 and 20 C° annual isotherms (Jackson 2008).

Recently, several studies aimed to estimate the possible effects of climate change on wine grape distribution, applying two types of methodological approach: (i) distribution areas are predicted by independent variables such as temperature or precipitation and (ii) using different Species Distribution Models (SDM) models.

For instance, Kenny & Harrison (1992) used Latitude-Temperature Index (LTI) in combination with a winter severity constraint to assess climate suitability for grapes. They pointed out that climate change could have a significant impact on the distribution of wine grapes in Europe. A further study published exploring the impact of the climate change on the Australian wine industry (Webb et al. 2007, 2008), analysing the likely effects of spatial patterns in climatic trends on wine grape phenology and wine industry in Australia predicted between 2030 and 2050.

Webb et al (2013) used the climate-analogue approach using estimated future temperature and precipitation climatology of 23 global climate models centred on 2030 and 2070 for 23 winegrowing regions worldwide. They concluded that the climatic conditions for global winegrowing regions are predicted to shift with considerable regional differences.

Species Distribution Modelling (SDM) is an effective approach to predict climate suitability of plants with a wide range of subject-specific tools. For example, Random Forest modelling approach (Liaw & Wiener 2002) was applied to analyse the similarities between present and future climate of wine regions in Hungary (Gaál et al. 2012) and in Western Europe (Moriondo et al. 2013). Both studies predict substantial changes in distribution patterns of wine grape production due to climatic changes for 2020 and 2050.

Among a broad variety of distribution modelling tools, MaxEnt was successfully applied in a number of studies on predicting distribution patterns of plants (e.g. Sheppard 2013, Syfert et al. 2013). This approach is also known as one of the most commonly used methods for predicting species distributions and environmental tolerances from occurrence data (Warren & Seifert 2010). MaxEnt's predictive performance is consistently competitive with the highest performing methods (Elith et al. 2011). In contrast, only a single article has been published using MaxEnt investigating the distribution of wine growing regions and predict possible impacts of climate change on global scales (Hannah et al. 2013). However, this work has strongly been criticised in terms of methodological issues, especially the calculated indexes and the predicted dramatic decline of the present wine growing regions for 2050 (Leeuwen et al. 2013).

In this study we use MaxEnt modelling method to predict the possible effects of climate change on wine grape distribution at European scale using of the basic bioclim variables (Busby 1991). We also report correlations between the above Busby's bioclim variables and the most widely used climatic indexes used in viticulture such as the Winkler, Huglin-index (see: **Table 1**). Additionally, we applied a novel approach for calculating the percentage of potential area loss for the most important wine producing countries (Spain, Portugal, France and Italy).

2 MATERIALS AND METHODS

Vineyard distribution data was downloaded from CORINE land cover database (http://www.eea.europa.eu/). Based on this shape file 6047 random presence points were generated using the random point generator function of QGIS 1.8. These random points were used as presence points in the analyses.

Climate variables for the present were obtained from WorldClim database (http://www.worldclim.org) version 1.4 (Hijmans et al. 2005) with a resolution of 2.5 arc minutes.

For projections under future global warming scenarios, a set of different families of emission scenarios was formulated by the IPCC based on the future production of greenhouse gases and aerosol precursor emissions. Future climate scenarios were obtained from the CCAFS database (http://www.ccafs-climate.org). Two climate models were used for the years 2050 and 2080 developed by (1) the Hadley Centre Coupled Model v3 (HadCM3) and (2) Commonwealth Scientific and Industrial Research Organization (CSIRO). Each of these climate models provide three emission scenarios: (I) rapid economic growth (A1b), (ii) regionally oriented economic development (A2) and (iii) global environmental sustainability (B1) (IPCC 2007b). All climate models and the associated emission scenarios were analysed independently.

Based on the gridded climate data the most widely used climate indices in viticulture were calculated using the 'raster' (Hijmans 2013) package in the R statistical environment (R Core Team 2012). Calculations from monthly data were performed following Jones et al. (2010). BioClim variables (Busby 1991) were also used as variables which are generally used in distribution modelling.

Since the CORINE database does not include information on wine grape distribution from all European countries, it was necessary to control for sampling bias. To achieve this aim, we generated a mask grid where sampled countries are assigned a constant value while unsampled countries are marked as missing values. We trained our model using only regions covered by CORINE.

Although MaxEnt is more robust in controlling for correlations between variables than stepwise regression (Elith et al. 2011), strongly correlated variables ($r>0.75$) should have been excluded from the analysis (see: Elith et al. 2010, Stohlgren et al. 2010). To calculate the level of correlations, ENMtools 1.3 was used (Warren & Seifert 2010).To assess the importance of predictors we applied jackknife test (using MaxEnt). During variable selection we consider the results of jackknife test, physiological knowledge on wine grape and the results of correlation test between the used variables.

Since the calculated bioclimatic indices show strong correlations ($r>0.95$) with annual mean temperature and each other, we included to our model only annual mean temperature (bio1) and temperature seasonality (bio4) which controls for seasonal fluctuation of temperature.

Previously, it has been shown that annual precipitation and its seasonality are critical factors influencing viticulture, as water stress can lead to a wide range of effects (Austin & Bondari 1988) especially in certain phenological phases (see in discussion).

In contrast to previous studies using the precipitation of the growing season we favoured annual precipitation (bio12) since this variable also includes winter precipitation which is crucial for most of the southern regions of Europe where majority of their precipitation is received during winter. Moreover, if the depth of soil allows it, grapevines tend to root deeply thus avoiding water stress during periods of drought (Jackson 2008). To fine-tune the effects of bio12 the precipitation seasonality (bio15) and the mean temperature of the wettest quarter (bio8) also added to the preselected variables.

The discrimination ability of the model is evaluated by Area Under the Curve (AUC) metric. The value of AUC varies between 0.0 and 1.0 where 1.0 is considered perfect prediction and 0.5 or less is considered the prediction is not better than random (Fielding & Bell 1997, Franklin 2009).

The results were visualised on a logarithmic scale where MaxEnt gives an estimate between 0 and 1 of probability of presence and on a binary map where threshold rule (10 percentile training presence) were also applied to demonstrate the possible effects of climate change.

To evaluate the impacts of climate change on the distribution of wine grape we used the binary rasters (presence/absence) for present and the future climate scenarios. To provide future predictions, presence values have been changed from 1 to 2 followed by grid overlaying which results in four possible values for each cell: (i) high impact areas: areas where a species potentially occurs in the present climate but which will not be suitable any longer in the future (ii) areas outside of the realized niche: areas that are neither suitable under current conditions nor under future conditions (as modelled) (iii) low impact areas: areas where the species can potentially occur in both present and future climates (iv) new suitable areas: areas where a species could potentially occur in the future, but which are not suitable for natural occurrence under current conditions (for more details see: (Scheldeman & Zonneveld 2010).

We calculated the area change for the four biggest vine producing countries in Europe (France, Italy, Portugal, Spain) using the a pessimistic scenario (A1b) for 2050 and 2080. The predicted areas were cut with the CORINE wineyard shape. In this way we could get a more realistic picture on area loss, since the suitable area is much larger than the actually used.

For the area loss calculation we used the following equation: $An\% = An/Ap \times 100$, $Ad\% = Ad/ Ap \times 100$, $As\% = As/Ap \times 100$ where An is the new suitable areas, Ap is the suitable areas in the present, Ad is the area decrease and As is the stable areas.

3 RESULTS AND DISCUSSION

Based on the analysis of variable contribution bio1 has the highest importance in the model. The other variables shows much less percent contribution. This pattern seems relatively robust since the permutation importance shows the same trend.

The jackknife-regularized training indicate very similar pattern. bio1 appears the most useful (by itself) for predicting the potential distribution of wine grape. It is also remarkable that the performance of the model is the lowest without bio1, which also indicates its importance.

The models received substantial support (mean AUC = 0.918, standard deviation = 0.021) values following the definitions of Sweets (1988).

The prediction of the best model for the present is fit well to the known wine growing regions (**Fig. 1**). It is remarkable that the model shows realistic picture for those areas where the presence data are missing e. g. vineyards in Southern England not covered by CORINE database. In contrast, the model predicts suitable areas for these regions.

Future predictions show very consistent changes based on the different climate scenarios (**Fig. 2**). As in the case of several surveyed plant and animal species the wine growing regions shifting to North as it is visible from the new suitable areas. At the same time in the Mediterranean region more problems could arise especially in the Iberian Peninsula, North-Africa and the South-Eastern region of Anatolia.

We calculated the area change for the four most important vine producing countries in Europe using a pessimistic scenario (A1b) for 2050 and 2080. The difference between the predicted area changes in CSIRO and HadCM3 is less than 10% in all cases. The results show that the suitable area for wine growing will only slightly reduce for 2050. The most radical changes are predicted for the Iberian peninsula (30 percent loss in average) while France and Italy are less concerned. For 2080 the suitable areas continuously decrease except for France where only small amounts of area loss is predicted.

4 CONCLUSION

To our knowledge this is the first study to analyse the present distribution of wine grape (*Vitis vinifera*) for the present and to formulate medium- and long-term future in Europe using MaxEnt.

Our results provide realistic predictions for present distribution areas using basic variables. Although there are several complex indices for describing suitable temperatures for the different wine grape varieties such us Winkler, or Hugglin-index which are originally based on daily temperature data (Winkler et al. 1974, Huglin 1978), we chose the annual mean temperature completed with temperature seasonality information. The model contribution data validate the old practice where the temperature data was the main factor to determine suitability for vine grape and its varieties.

All precipitation predictors show only minor contribution to model performance. Jackson (2008) reviewed in detail the interaction between precipitation and grape quality pointing out that medium to low rainfall is the optimal for wine grape. In the Mediterranean vine growing regions the majority of precipitation falls during winter. Therefore sufficient moisture is available for wine grape in spring and early summer when it is the most important for plant development. On the other hand in summer the grape have to face serious water deficit what could improve fruit quality and advance ripening. Additionally, grapevines tend to root deeply which allows avoiding water stress in deep soil, even during dry periods.

It is notable that our predictions remained robust even outside of the training areas e.g. Ukraine. The best wine growing regions assigned high suitability values as shown by **Fig. 1**. Although the projections of the model predicts a decrease of suitable for some of the wine growing regions such as the Iberian Peninsula, the majority of the present vineyards remain suitable at 2050. *Vitis vinifera* is able to survive under very different climate conditions, but yield and wine quality are strongly connected to specific climate conditions (Santos et al. 2012). Moreover, optimal climate could be different for different grape varieties. Since in this study we considered the demands of *Vitis vinifera* as a species and did not differentiate between varieties, the predicted stability until 2050 is probably dynamic one since change in the composition of grape varieties or selection may be necessary in most of the cases.

Our predictions show less degrees of area contraction than in Hanah et al (2013) where predicted area decreases in areas suitable for viticulture of 25% to 73% in major wine producing regions by 2050. This value for the most important European vine producing countries amounts to 2-48% in our study. The source of this pronounced difference could arise from different causes. First, the applied climate variables were different although the predictions indicate the same trends. Second, we considered area loss for only those locations where viticulture is covered by the CORINE database providing more realistic picture, even if we know that the CORINE database is not perfectly cover all the vineyards (e.g. based on CORINE no vineyards in Great Britain). Evidently the suitable area for wine grape are much larger than the realised. Additionally, the total cover of vine growing region is decreasing across Europe, independently from the climate change (OIV 2012).

As we previously mentioned, during our analyses, we treat wine grape as a species and we did not consider the demand of different grape varieties. As different grape breeds might have different climatic sensitivity, this issue warrants further research which would need breed-specific and improved geographical coverage of grapevine distribution across Europe. The climate change and the related need for technological modifications have been discussed by several papers. Perhaps the most applicable technique appears to be the so-called 'climate-analogue technique' presented by Webb et al (2013). For future planning, wine grape cultivars better suited to the projected climate may then be selected from the range of breeds currently cultivated in identified analogue regions. Alternatively, climatically optimal sites can be identified for growing particular cultivars in future conditions.

The adaptation for a tendentious climate change seems to be plausible with the optimisation of the growing system and varieties but the most dangerous side effect of the changing climate is the growing frequency of extreme events what has been detected in the last decades (Hanson et al. 2007). Additionally, changing climate could indirectly influence the distribution boundaries in several ways. Climate-related shifts in distribution could change the structure of trophic and parasitic interactions. For instance herbivores with southerly range could invade novel areas further to the North which is not only the source of increased level of herbivory but also introduces novel diseases. Besides climate change prevalence and virulence of native diseases could also modified. Although, several studies confirmed the northward shifts of the winegrowing regions, many open questions remained due to the complexity of the system.

Aknowledments

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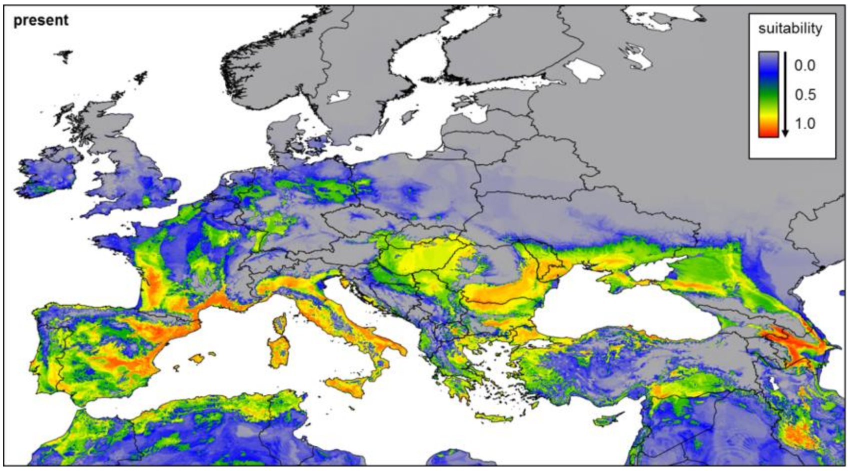

Fig. 1 Present climate suitability map of wine grape.

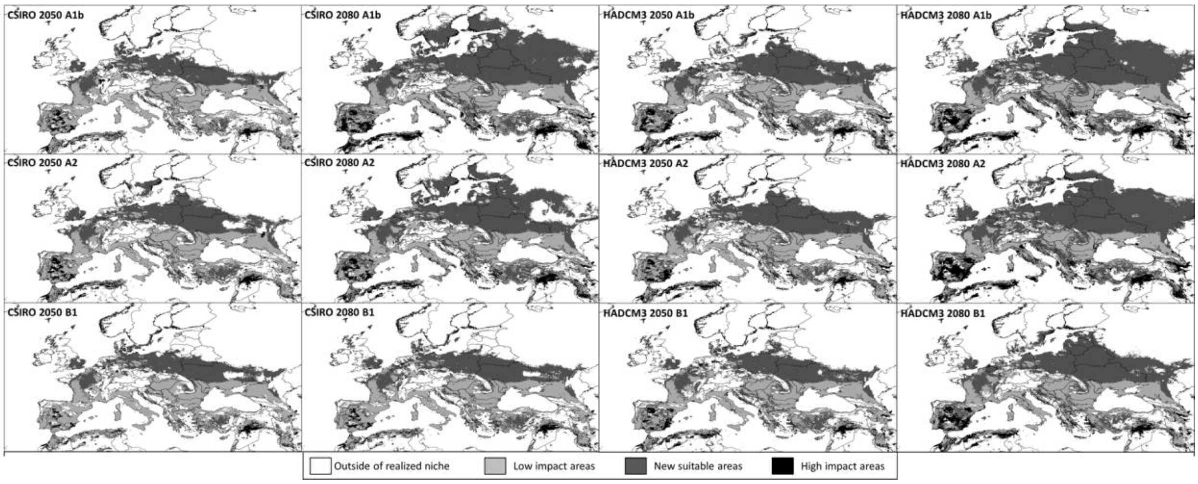

Fig. 2. Climate change impacts on wine growing regions based on CSIRO and HADCM3.