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Short Communication

Environmental Modelling of Climate Change Impact on Grapevines: Case Study from the Czech Republic

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Abstract

Predicted climate change can significantly affect ecosystem services in agricultural landscapes. Possibilities of predicting climate change effects on growing conditions of crops are therefore sought for practical reasons. The aim of the present study is to contribute to the current discussions about the impact of climate change on agriculture. The case study from the Czech Republic presents methods and results of environmental modelling of the impact of predicted climatic changes on future conditions for growing grapevines. The model is based on the ecological relationship between climate and vegetation zonation of the landscape and thus belongs to the group of process biogeographic models applicable on a regional scale. The results of the presented model show significant enlargement of areas climatically suitable for growing grapes within the studied area. The results of the model relevant to the Czech Republic are in line with the previous assumptions of trends in future impacts of climate change on viticulture in Europe. However, the data resulting from the presented model, which relate to the time horizon beyond 2050, should be regarded as indicative and fraught with a high degree of uncertainty linked with the uncertainty of the input climatological prediction for this time period.

Keywords: agricultural crops, biogeographical model, climate change, vegetation zones

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Introduction

Grapevine (*Vitis vinifera* L.) is one of the oldest crops in the world [1] and its cultivation is reflected in the regional identity of people from different geographical regions [2]. Vineyards have formed the structure of cultural landscapes of climatically suitable regions for centuries [3]. The growth and production of grapevines grown in vineyards is significantly affected by a number of environmental factors [4]. Individual cultivars respond to environmental factors differently in terms of the resulting wine quality [5], which is reflected in concrete and regional-specific characteristics of wines [6]. The specific effects of environmental factors on the quality of wine are called "terroir" [7] and known in many wine regions, e.g., France [8]. As regards climatic conditions, temperature is a crucial factor for the thermophilic grapevine [9]. This fact is important in the context of current discussions about global warming [10], which is likely to have an increasing effect on the possibilities of grapevine cultivation [11] as well as on the economy of vineyard production [12].

In Europe there is a very dense network of long-term measuring weather stations with a variety of complementary distance measurement systems and, therefore, the analyses of temperature trends are much more accurate in Europe than anywhere else in the world. The temperature of the European continent increased on average by 1.2ºC during the 20th century, the average number of summer days doubled, and the average number of tropical days tripled [13]. These changes obviously have important environmental implications for European agriculture and for the formulation of the priorities of agricultural policy in Europe [14].

Also, trends in long-term meteorological measurements taken in the Czech Republic show a significant increase in average air temperature and, additionally, a marked increase in the incidence of weather extremes – the numbers of tropical and summer days and nights increase and the numbers of frost days and ice days decrease [15]. Analysis of the stability and diversity of agricultural production in the Czech Republic (CR) in the last 75 years shows that the changes of climatic factors have had a positive effect on the production of certain agricultural crops (higher production) [16]. Linear trends in regional temperature and precipitation amounts in the Czech Republic (i.e., the modified values derived from data measured by station network, which take into account the position of individual meteorological stations) confirm the increase in average temperatures and decrease in the total precipitation amounts in all seasons of the year except winter, and at the same time dramatic increases in extreme weather events [17]. Such development of climate may be associated with adverse environmental consequences for agricultural production [18]. Also, the results of a broad-based questionnaire focused on the views of agro-climatic experts and agronomists from 26 countries of Europe showed a surprisingly high proportion of negative expectations concerning the impacts of climate change on agricultural crops and production throughout Europe [19].

Vegetation zones are a suitable environmental frame for the evaluation of possible climate change impacts on the growing conditions of agricultural crops in the Czech Republic [20], because the distribution of vegetation zones in the Czech landscape reflects the character of the orographically conditioned differences in climatic conditions and their gradients. In the Czech Republic, vegetation zones were originally defined using bioindication as a basic environmental framework for the creation of a national ecological network [21]. Based on the vegetation zonation, a model predicting shifts in climate conditions of vegetation zones according to climate change scenarios was developed in the Czech Republic. The model allows us to predict the impact of climate change on the environmental conditions of various agricultural crops on a regional scale [22].

The aim of this paper is to follow the published analysis of the current state of viticulture in the Czech Republic [23] and predict the future development in the context of climate change, and thus contribute to the current discussions about climate change impacts on the biotic components of the landscape.

Methods and Materials

The biogeographical model of the shift in climate conditions of vegetation zones due to predicted climate change, which was used in this study, can be classified into the group of process biogeographic models that are used to predict the equilibrium vegetation responses to potential climate change on a regional or global scale [24]. These models identify ecological restrictions in relation to the distribution of plant formations (vegetation zones) under different equilibrium climatic conditions [25]. The model applied within this study is based on the ecological relationship between the current climate and the distribution of vegetation zones in the landscape [26]. It is based on the assumption that the general ecological relationship between vegetation zones and climatic conditions also will be maintained in the future [27]. The projected climate change may, therefore, be manifested by a shift in the climate conditions of vegetation zones on a regional scale [28].

The prediction climatic database of the Czech Hydrometeorological Institute (CHMI) was used as the source of climatological data for the model; data on annual precipitation, annual average relative humidity, and annual average daily sums of global radiation, annual average air temperature, and annual average wind speed were used. This database links climatic data to a set of 131 points regularly spaced throughout the Czech Republic in the form of a regular trapezoidal network, and contains a validated database of climatic elements calculated by the ALADIN-CLIMATE.CZ model for the period from 2010 to 2100 according to the SRES A1B scenario [29].

A biogeography register [30] was used as the source of geobiocoenological data for the model. It contains geobiocoenological classification of the landscape in the

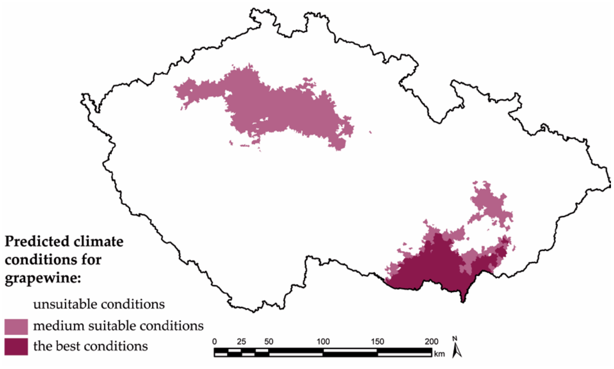

Fig. 1. Current areas suitable for growing grapevine in the Czech Republic according to vegetation zonation.

Czech Republic (vegetation zones, trophic, and hydric series) projected on the selected type of administrative spatial units of the Czech Republic's cadastral territories. The biogeography register contains descriptions of geobiocoenological properties of approximately 13,000 polygons (cadastres), fully covering the area of the Czech Republic. This database describes quite well the heterogeneity of natural conditions in the Czech Republic owing to the link to cadastral territories because the original cadastres were delimited in the 19th century according to natural boundaries such as streams, forest borders, and marked geomorphological features in the landscape [31].

The computer model of the shift in climate conditions of vegetation zones due to climate change is designed as a set of special programs (FORTRAN programming language) and Arc/Info GIS applications [32]. The definition points of the Biogeography register were assigned climatic characteristics using an analytic-geometric method designing a more detailed network of points in the area (250 m step), to which the values of climatic variables were recalculated by the gradient method using the values relevant to the four nearest neighbouring points of the original CHMI climatic database. Based on the analysis of the current environmental conditions in wine regions of the Czech Republic, the current conditions for growing grapes were algorithmized into vegetation zones and geobiocoenological characteristics of hydric and trophic series. Projected climatic characteristics of the definition points, the corresponding vegetation zones, and the characteristics of natural climatic conditions were determined using the method of space-time analogies, for which Lang's rain factor, which combines the average annual rainfall and average annual temperature into a single value, was employed as a relationship indicator [33].

Results

Fig. 1 shows the result of the algorithmization of the current climate conditions for growing grapevine into vegetation zones and geobiocoenological characteristics of hydric and trophic series. It is clear that the current area with optimal climate conditions for growing grapes in the first and second vegetation zone copies the area of the traditional wine-growing regions in the Czech Republic [34]. Areas with ecological conditions unsuitable for growing grapes include vegetation zones, and trophic and hydric series (e.g., waterlogged alluvial hydric series) that do not comply with the growth requirements of grapevine.

The graph in Fig. 2 shows the predicted trend in Lang's rain factor values in the regions climatically suitable for growing grapes in the Czech Republic in 10-year forecast

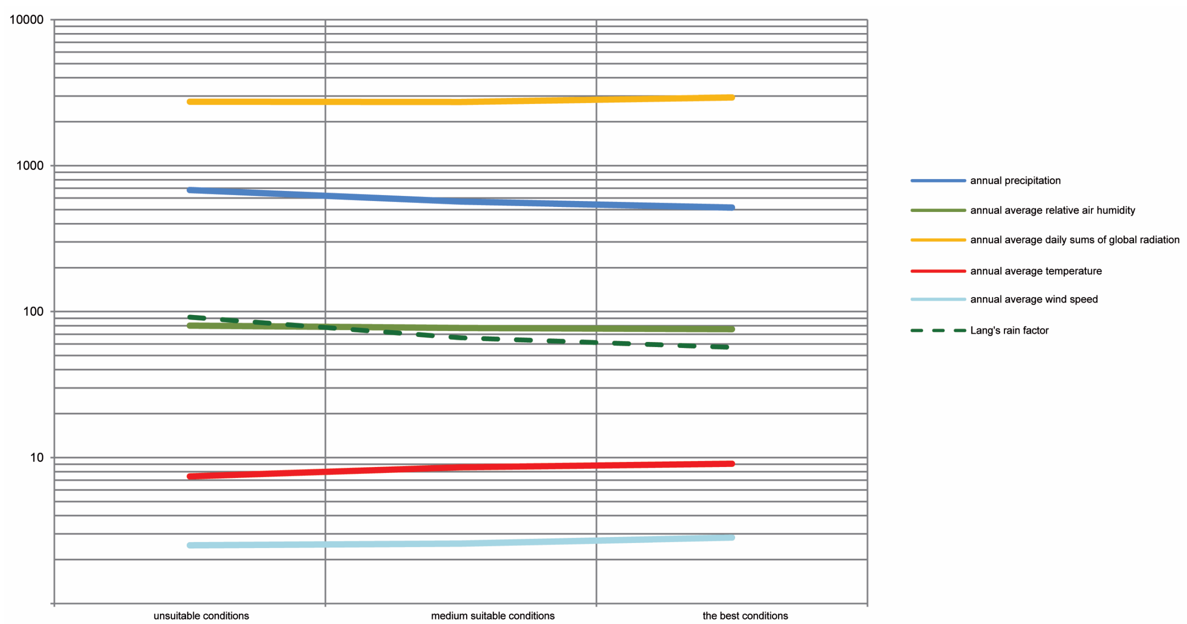

Fig. 2. Predicted trend in Lang's rain factor values in areas climatically suitable for growing grapevine in the Czech Republic in ten-year time horizons.

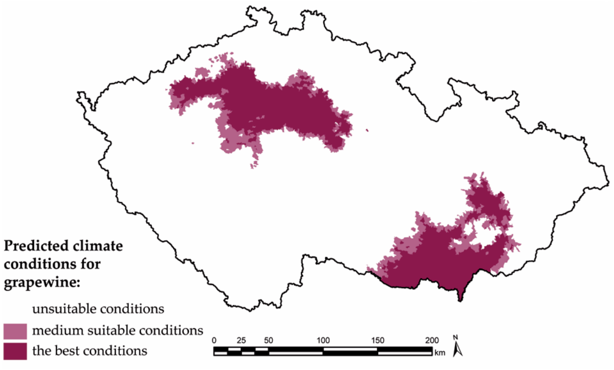

Fig. 3. Predicted delimitation of areas suitable for growing grapevine in the Czech Republic in 2050 time horizon.

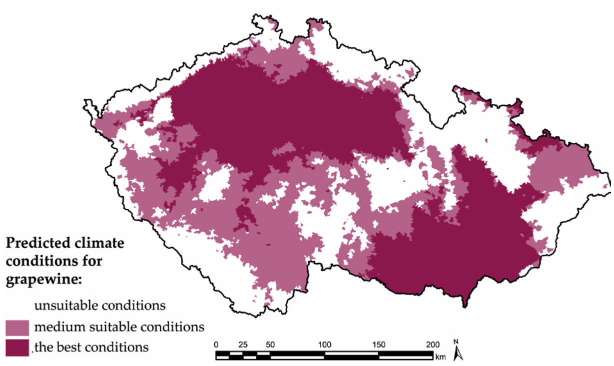

Fig. 4. Predicted delimitation of areas suitable for growing grapevine in the Czech Republic in 2070 time horizon.

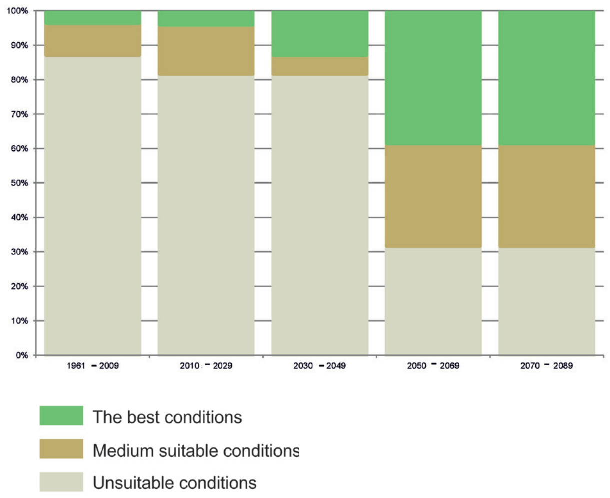

Fig. 5. Prediction of temporal and spatial trends in the development of areas suitable for growing grapevine in the Czech Republic in relation to the trend in the shifts in vegetation zonation in ten-year time horizons until 2091.

horizons. Graphical data in the prediction period up to 2090 refer to the initial trends of measured values of the average annual precipitation and average annual temperatures for the period 1961-2009.

The map in Fig. 3 illustrates the predicted delimitation of areas with suitable climate conditions for growing grapes for the forecast time horizon of 2050, and Fig. 4 for the forecast time horizon of 2070. Both figures show a clear trend toward the expansion of areas with suitable climate for growing grapes in the Czech Republic. The total area of regions with optimal climate conditions for growing grapes should increase by 10% in 2050 compared to the present situation. This finding suggests that the predicted changes in climate may have positive effects on agricultural production in the studied area as regards thermophilic crops such as grapes (enlargement of the total productive area). In 2070 the increase in the total area of regions with optimal climate conditions for growing grapes should reach 38% of the area of the Czech Republic, but the prediction for this time horizon provides only indicative data (in relation to the degree of uncertainty in the underlying climate prediction data for this time period).

The graph in Fig. 5 shows the detailed results of the model predicting the temporal and spatial trends in the development of the areas climatically suitable for growing grapes in the Czech Republic. The graph generally corresponds with the cartographic expression of the development trends in Figs 3 and 4 but presents the model prediction of the impact of climate change on the growing conditions of grapevines in detail – in 10-year time steps. The graph thus shows the possibilities of the employed model that reaches the time horizon of 2089, which is the limit for the prediction capability of the model in relation to the input climate prediction data. However, the figures in this graph, which relate to the time horizon beyond 2050, should be regarded as indicative data fraught with a high degree of uncertainty of the climatological prediction.

Discussion and Conclusions

The grapevine grown in vineyards probably originated from a wild grape subspecies *Vitis vinifera sylvestris* C. C. Gmelin [35], which can still be rarely found in the warmest lowland regions in the Czech Republic [36]. Viticulture in the Czech Republic, as well as the entire agricultural sector and the entire agricultural landscape, underwent fairly extensive organizational and economic changes in the 1990s due to political events [37]. Another major turning point in the development of viticulture is connected with the accession of the Czech Republic to the European Union. The issue of changes in viticulture in the Czech Republic has been a subject of much research [38].

The current trend in viticulture in major wine production areas of the world is directed toward quality production instead of quantity [39]. The importance of research focused on environmental factors affecting the cultivation of grapevine increases in the context of increasing consumer interest in high-quality wines [40]. The cultivation of grapevine in the near future will be affected by climate change and, therefore, this issue has attracted the increasing attention of researchers [41].

Specialized experimental studies or mathematical modelling are often used to evaluate the potential impacts of ongoing and expected climate change on agricultural production. However, it must always be taken into account the fact that mathematical models do not represent predictions of future development. Models contribute to the predictions but their results must be carefully interpreted on the basis of knowledge of biology or ecology of organisms that are modelled [42].

The vast majority of the hitherto proposed models are correlation models that are based on the interdependence (a function or algorithm) between certain bioclimatic variables of the environment (usually average temperature and average rainfall) and the current range of a species or the characteristics of an ecological niche of a species [43]. When you predict future changes in climatic conditions on the basis of climate scenarios, you can assign relevant biological species or communities to the changed variables. This procedure is known as bioclimatic envelope modelling [44]. For example, the model predicting the effects of climate change on the growing conditions of sugar beet in the Slovak Republic was based on the evaluation of the current production potential of agricultural soils expressed by estimated pedologic-ecological units that were assigned environmental growth requirements and production parameters of sugar beets [45].

The biogeographic regional model used in this article uses the dependence of vegetation on the long-term effects of altitude and climate exposure, which is determined by the average and extreme air temperatures and the amount and distribution of precipitation (including horizontal precipitation). The current vegetation zones in the Czech Republic stabilized in the older subatlantic about 800-500 BC, and the shifts of vegetation zones in the landscape faithfully reflect the progress of climate change. The delimitation of the current vegetation zones in the Czech Republic was elaborated in great detail in the context of the creation of bio-geographical basis for the national ecological network of the landscape [46] and, therefore, the current vegetation zonation is a suitable basic initial framework for the modelling of the effects of climate on production and growing conditions of the vegetation in the Czech Republic.

The simulation of redistribution of climate conditions for vegetation zones within biogeographic models is essentially a static (equilibrium) perspective of the analysed problem as these models represent modelling of a certain level of carbon dioxide concentration at some time in the future (while ignoring the more realistic accumulation of carbon dioxide over time on a local scale). Static/equilibrium biogeographic models provide useful "images" of terrestrial ecosystems in equilibrium with certain climatic conditions [47]. The application of these models, however, has its limitations as they do not simulate internal factors of vegetation dynamics (competition, mortality, physiological factors, etc.). Dynamic global vegetation models [48] have been newly developed to overcome these limitations. These models integrate vegetation dynamics and ecosystem functions, but are not yet applicable in a regional scale [49].

The development of climate significantly affects the geographical distribution of organisms in ecosystems and human activities such as agriculture [50]. Possibilities of predicting the effects of climate change on growing conditions of agricultural crops are therefore sought for practical reasons. The study from the Czech Republic dealing with the impact of predicted climate change on the possibilities of grapevine cultivation as presented in this article aims to contribute to the current discussions about the effects of climate change on agriculture [51]. The results of the presented model of the shift in vegetation zones due to predicted climate change show significant enlargement of areas climatically suitable for growing grapes within the studied area. The results of the model relevant to the Czech Republic are in line with the previous assumptions of trends in future impacts of climate change on viticulture [52]. The data resulting from the model, which relate to the time horizon beyond 2050, should be regarded as indicative and fraught with a high degree of uncertainty linked with the uncertainty of the input climatological prediction for this time period.

Despite the attention which has been recently given to the research into the effects of climate change on various taxonomic groups of organisms, it is clear that our ability to predict changes in the abundance and distribution of both cultural and wild plant species due to climate change remains limited in the context of statistical and stochastic uncertainties in environmental data.

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